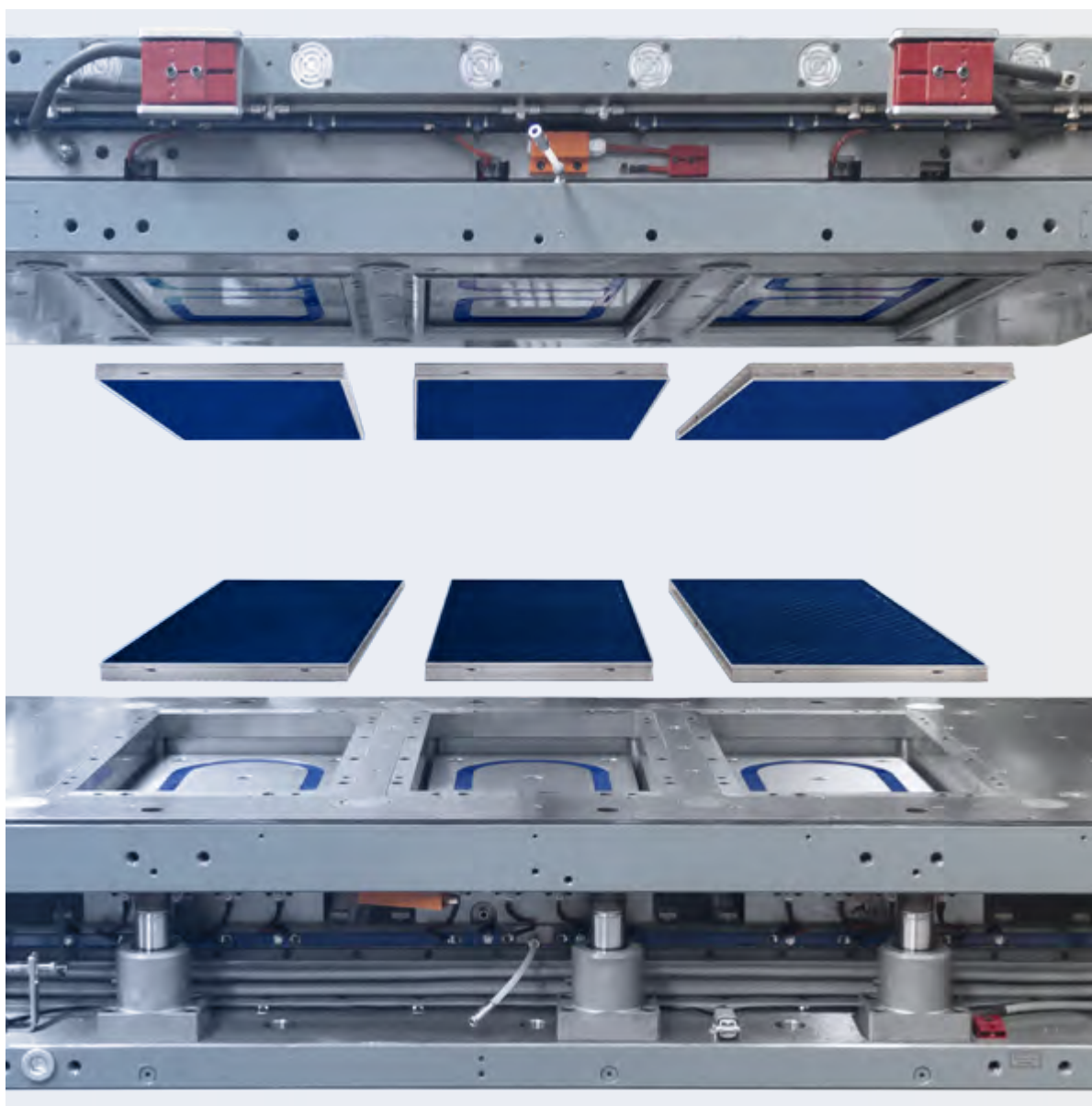


M O U L D S

FOR THE PRESSING OF CERAMIC TILES



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Rafael Galindo Renau
José Antonio Pérez Maximino

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I have been granted with the honour of presenting you a book by José Antonio Pérez and the professor Rafael Galindo dedicated to moulds for the pressing of ceramic tiles. It is a new publishing project from MACER which, like the two previous ones, focuses on the technical artifact that is fundamental for the competitiveness of the ceramic industry. Unlike the previous editions, this time Rafael Galindo has had the direct involvement of José Antonio Pérez, the current Technical Director of MACER, the company that edits the book.

The first thing I want to emphasize in this foreword refers to the author's solvency, which is widely known throughout the ceramic cluster in Castellón, and recognises the role that Professor Galindo played in the design and implementation of professional training dedicated to ceramics and his constant predisposition to participate in any training action aiming to improve the knowledge of technicians and workers in the ceramics industry. His extensive academic career and his broad knowledge of materials, equipment and ceramics processes are an endorsement for the publication that I introduce to you. The author reveals in a rigorous and entertaining way all the necessary knowledge that any ceramic technician needs to master the life cycle of a mould.

The previous works, show off the scientific and technical rigour the author always exhibits in presenting the selected contents and his ability to make explicit the extensive knowledge he had accumulated within the ceramics cluster. Throughout this edition these skills gain special relevance. The great involvement of the co-author of the book and the strong support given by all the management and technical staff of MACER has been critical, as they have always been willing to share all their knowledge and experience with us. Many of the innovations, concept solutions and designs that Macer has offered to the sector in the last thirty years, have passed through José A. Pérez's desk, especially during his long period as head of the Technical Department. A position of responsibility, in a company that has led the evolution of press and mould technology over the last five decades and has always incorporated the most advanced manufacturing technologies in its production plants, which guarantees the thoroughness of the contents of this work.

Well, as I have already mentioned above, inside the book you are holding right now, you will find all the information and knowledge you need to successfully manage most of the processes related to the different stages of the mould life cycle: design, manufacture, supply, use and support. A whole series of content structured in seven chapters, eight annexes and a final document where the reader can find answers to many of the questions that may be asked about the mould.

The contents regarding the design of the mould are presented in Chapters 2, 3, 4 and 5, after an opening chapter during a brief overview of the history of the mould is made. Chapter 2 describes a series of aspects that link the design of the tile with the design/technology of the mould cavity, establishing a series of rules that affect the thickness, reliefs and formats which can help the tile designer to define manufacturable products (tiles), following the principles that characterise the Design for Manufacture techniques. This view is enhanced during Chapter 7, where the types of product quality defects imputable to mould design/selection flaws are analysed. Chapter 3 describes the different elements which form a mould, regardless of its type. The moulds and the difference between them are presented in Chapter 5 – and the first section of Chapter 4, where the materials (steels and rubbers) and their functional characteristics are described.

The contents related to the central stages of the life cycle (manufacturing and transport) are presented in the second section of Chapter 5 and the last section of Chapter 6, while those related to the final stages (use and maintenance) are presented in the remaining sections of Chapter 6, focusing on the maintenance, changing and adjustment of the moulds.

To sum up, inside this publication you will find an extensive and well-structured compendium on the evolution and current reality of the mould, highlighted by large formats and high-capacity presses. Besides, if the readers wish to broaden their understanding of the ceramic process or require further information about the process variables that affect the pressing process and the technical characteristics of the installed presses inside the ceramic plants, they can consult the last edition of Rafael Galindo's previous book entitled "Presses, moulds and compaction in the manufacture of ceramic tiles".

To conclude this presentation, I would like to invite you to immerse yourself in the reading of the book and view the images and videos carefully selected by the authors and MACER, easily accessible through the QR codes that have been inserted. We hope that this journey will help you to complete your knowledge of the world of ceramics and, more importantly, encourage you to reflect and generate new knowledge.

Fernando Romero Subirón

Professor at the Engineering Department
of Industrial Systems and Design
at the Universitat Jaume I.

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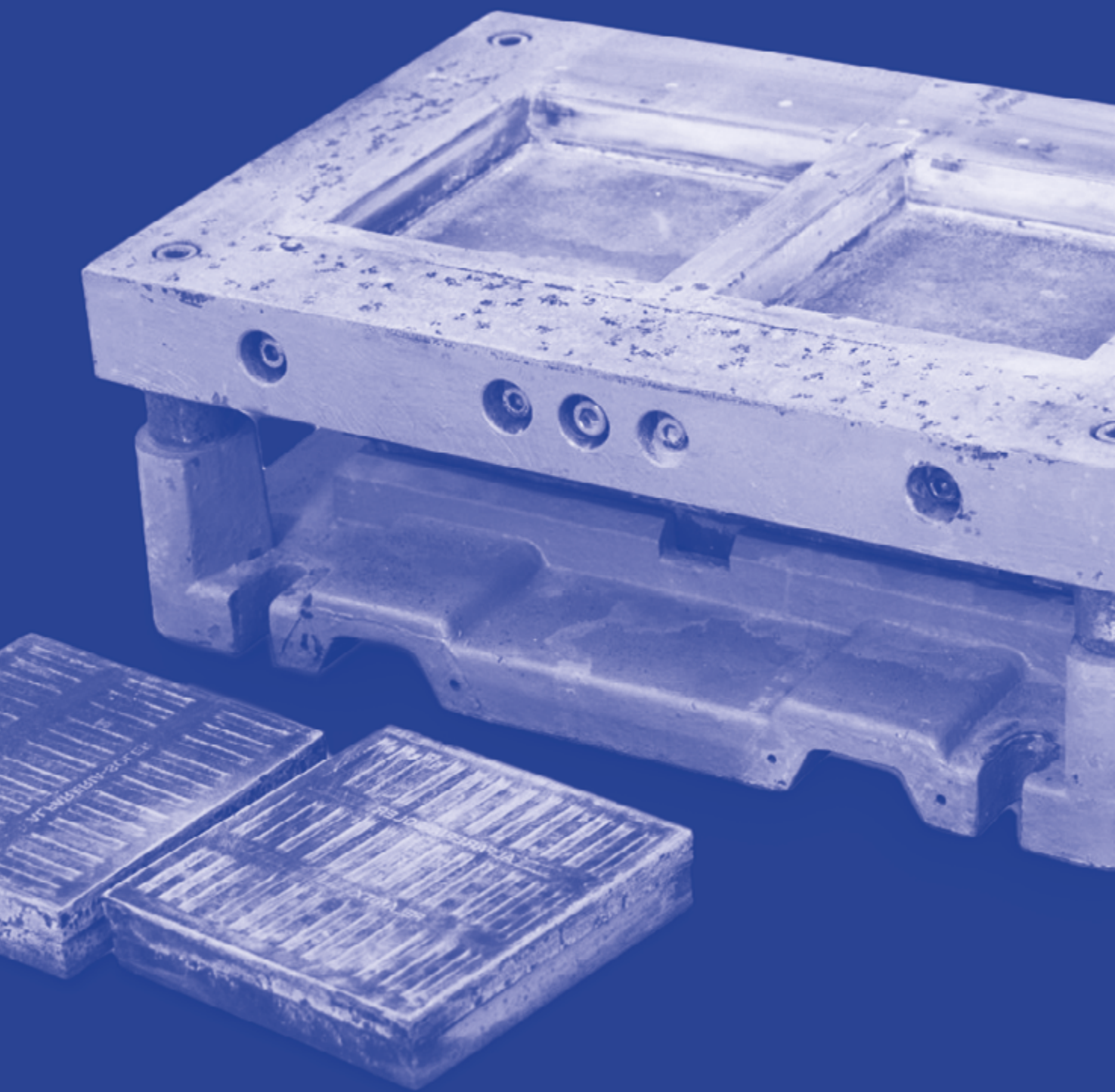
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Historical development of moulds.

Chapter 1



The industrial production of ceramic tiles is carried out by means of a modern, highly automated production line. Mainly by single firing, which includes stages as the preparing of the ceramic paste from raw materials, shaping, drying, enamelling-decoration, firing and frequently mechanical treatments on the fired pieces (Annex I). Naturally, all these stages have a strong influence on the quality characteristics of the final product, although the shaping/forming is a crucial stage, during which the product is shaped and is given the microstructure required for the correct development of the subsequent stages of the manufacturing process and for obtaining the required properties of the final product.

The forming of ceramic products can be carried out using different techniques, which are usually classified according to the moisture content. It can be classified in three main groups: semi-dry forming, plastic forming and suspension forming (Annex II). A series of parameters must be considered to choose the appropriate technique for the part-forming operation, such as the geometry and size of the tile, production (the number of parts per unit of time), duration of the process, available technology, etc.

The forming of ceramic tiles is mainly carried out by means of the **semi-dry unidirectional axial pressing** technique, which consists of the compaction of a wet powder (with humidities of less than 7%, with some exceptions) generally granulated, which is contained in a rigid mould, by applying pressure through the upper punches of the mould (Link 1.1). It is a very suitable technique for ceramic tile forming with small thicknesses, medium or large surfaces and simple geometries. This technique presents advantages of high productivity, associated with the ease of automation, and it makes possible to manufacture tiles in a wide range of formats, even with low dimensional tolerance products. The low humidity of the powder, which is necessary for the operation, facilitates drying, that can be performed in short cycles and with no or very low shrinkage values.



In this QR code there is a link to a video about pressing operations. Link 1.1

Therefore, pressing has a dual function: to shape ceramic tiles to the desired dimensions, without defects or unacceptable quality losses and to configure the microstructure for the requirements of the manufacturing stages, to achieve the required quality characteristics of the finished product.

Modern hydraulic presses of large tonnage where the **mould** is installed are used to apply the pressure during the pressing stage. In our previous publication ^[49] you can consult, among others, an extensive compilation of the process variables that affect the pressing stage and the description and technical characteristics of the presses currently used.

Thus, moulds perform their function in the pressing stage of the ceramic tile manufacturing process, giving them shape. Its function is, therefore, of great importance, as it directly influences the appearance and important quality characteristics of the finished product. The possible errors or non-conformities that may occur during this stage, arising from incorrect design, malfunctioning or incorrect maintenance will negatively affect the following operations of the manufacturing process and the quality of the finished product.

Current moulds (Figures 1.1 and 1.2) are the result of a technological development undergone by pressing, and their evolution has therefore been parallel to the technological evolution of the ceramic tile manufacturing process and, logically, closely linked to the evolution of the presses. As of the first manual presses, moulds have undergone many changes that will be described in this chapter. Among all of them, it is necessary to highlight those that have led to major functional and technological modifications.

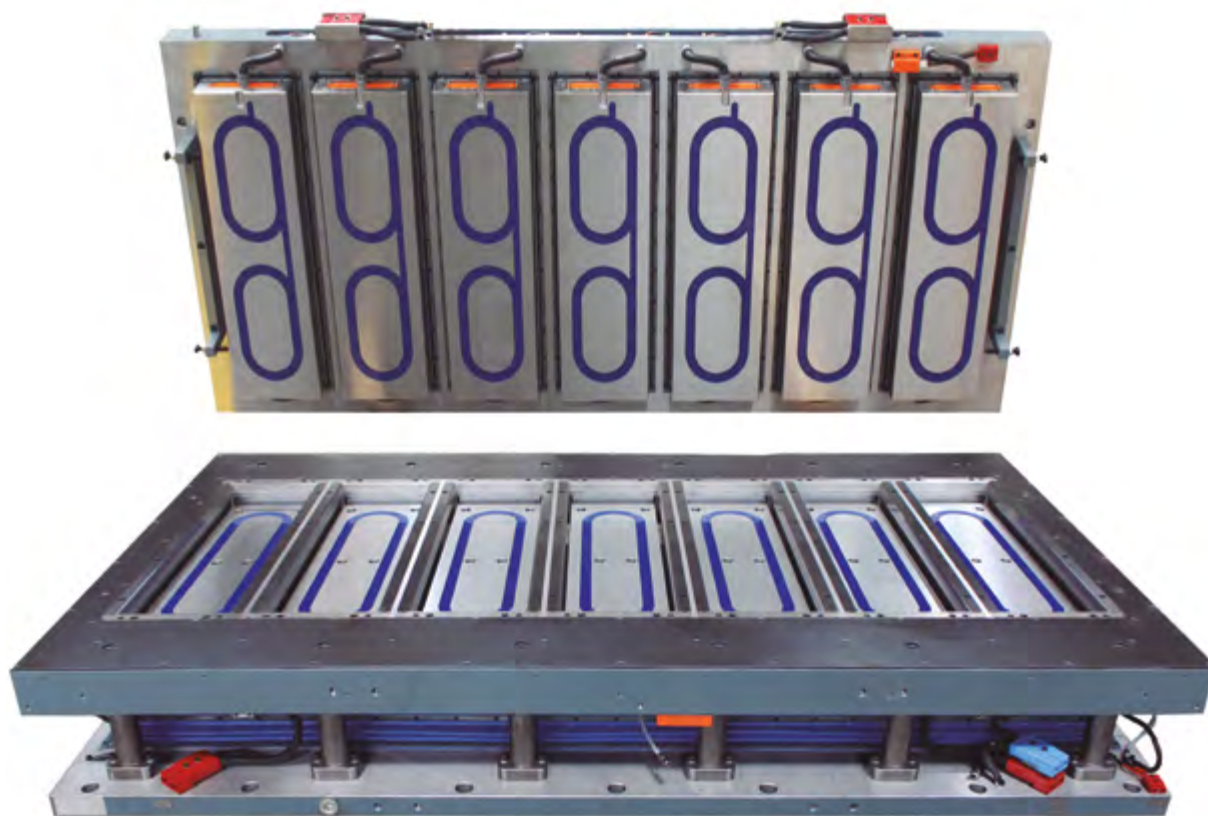


Figure 1.1. Seven outlets entry mould.

1.1. MANUAL LEVER AND SPINDLE PRESSES AND THEIR MOULDS.

The first manual presses used in the manufacture of tiles were lever and spindle presses, although other types of presses like the eccentric or reciprocating presses, are also cited by Gomis Martí in his book “Evolució històrica del taulellet” ^[51]. The forming technique initially used with **lever and spindle presses** was wet pressing, i.e. the application of deformation force to a plastic mass deposited in the mould. The use of these mechanical presses, that gradually replaced the manual forming of tiles by hand, which was done by breadding the clay in wooden or plaster moulds, has been known since the 18th century. One of these presses is exhibited in the ‘Museo del Azulejo Manolo Safont’ in Onda (Castellón).

In our sector, the use of **mechanical spindle presses** for forming by wet pressing has been documented from 1857 in the company “La Valenciana” in Onda, which produced tiles in square format and sizes close to 20 cm, with back side relief and the factory brand imprint, and from 1860 in the company of Vicente Peris Vidal, also in Onda ^[42]. Pickman (Cartuja de Santa María de las Cuevas, in Seville) began to manufacture tiles from 1860 onwards, automating some stages of the manufacturing process, including press-forming. All these companies used the pressing powder in a plastic state to produce tiles. Pressing the plastic mass allowed to obtain completely straight profiles and back reliefs.

Meanwhile, **semi-dry pressing** was patented as early as 1809 by Richard Potter, who pressed small porcelain tiles measuring 10x10 cm with a two-man spindle press equipped with an iron or copper mould ^[51]. The patent was purchased by the Minton company to introduce pressing in its tile factory. Subsequently, in 1834, M.P. Julien from Paris incorporated a patent on this pressing system. In 1840, a new patent to produce ceramic buttons from powdered clay, now by Richard Prosser, was again implemented by Minton and adapted to the manufacture of ceramic tiles. By the middle of the 19th century, Minton had already 60 mechanical presses producing tiles ^[51] ^[59]. Semi-dry pressing was first used for the production of encaustic tiles in 1863, according to a patent by Boulton and Worthington ^[67]. Until then, this type of tile was made in plaster moulds with masses in a plastic state, compacted by hand pressing and filled with different coloured slip filler in the low-relief areas after removal from the mould.

There is no verified data on the exact dates of the introduction of semi-dry pressing in Spain, although it seems that the first presses used were screw presses ^[51] ^[67] (Link 1.2), which are already found in the companies of San Carlos, of J. B. White y Boneli (Valencia) and Miguel Nolla (Meliana, Valencia). At the end of the 19th century it was introduced in tile companies in Onda ^[42], although until the beginning of the 20th century it coexisted with plastic forming ^[41]. Two types of spindle presses were used at this location: **wheel presses** and **balls presses**. In both presses, the pressure was transmitted to the powder by means of a helical spindle provided with a handwheel with four handles or a shaft with two manually operated spherical counterweights at the ends. It is precisely because of these counterweights that the second ones were called “balls presses”. Wheel presses were used to produce 15x15, 20x20 and 14x28 cm tiles, while balls presses were used for small complementary parts ¹. Balls presses were manned by a single person, while the wheel presses required two operators: one was in charge of manually filling the mould and extracting the piece, and the other turned the wheel to transmit the necessary pressing force, which logically was neither uniform nor very strong, which limited its use to the formats mentioned above. Moulds were periodically cleaned with a mixture of oil and petroleum to facilitate demoulding. There was no control over the operation other than the experience and good work of the operator, who occasionally broke some tiles with his hands to check their compaction.



In this QR code there is a link to images of spindle presses. Link 1.2

¹ Vicent Joan Estall i Polés ^[43] documents that in the Segarra factory in Onda (1906 to 1939): “Manual presses only had one box: 20x20, 14x12, 15x15, 11x11, 10x10 and a variety of add-on parts.”

1.1.1. The moulds.

The pieces obtained by semi-dry pressing with spindle presses, manufactured in the second half of the 19th century and the first decades of the 20th century, were mainly square-shaped, with a format of approximately 20x20 cm. Rectangular pieces were also produced in smaller formats, such as "cintetes" (4 - 6 cm x 13 - 16 cm), or handrails². The moulds of these presses had only one outlet and were very simple. They consisted of a frame, called "box", and two punches. The box consisted of two pieces of cast iron, "L" shaped for rectangular formats or "V" shaped for square formats, 9 cm high, bolted together and rigidly fastened to the press bench with four clamps. These pieces were commonly referred to as "collars". The punches were two iron plates, usually of lower quality, cut, machined by hand and sanded. Lateral wear of the punches, known as "plates", was compensated, as far as possible, by hammering and sanding the surfaces, and wear of the box was compensated by sanding the joining surfaces of the collars, which meant a reduction in the perimeter of the case. A mould with these characteristics could give an output of about 5,000 pieces.

Although, as indicated above, these moulds had only one outlet, it was also possible to make moulds with several outlets from separations of a 15x15 cm or 20x20 cm mould box with partitions bolted to it. Naturally, this meant that the upper and lower punches had to be changed, although the extraction mechanism remained the same.

Since the tiles produced had a straight edge, without a spacer, the tiles were pressed with the good side facing upwards, so the lower punch was reserved for the back side relief. (Link 1.3). This was intended to prevent the recompressed burr generated in the gap between the upper punch and the mould die box from falling on the smooth part of the mould, which would, undoubtedly, produce defects in the tile. A piston rod connected the punch to a pedal-operated slide elevator, which provided the up and down movement of the lower punch.

The most common back side relief for screw press moulds is the parallel bands and is the simplest, and probably the only, mechanical solution. It was obtained by manually brushing the bands on a punch. This relief can already be seen in catalogued pieces from the companies Peris, La Esperanza, La Primitiva and La Valenciana companies, dated between 1860 and 1880 ^[41].

A relief directly derived from the bands relief is obtained by a further brushing of transverse bands, resulting in a grid relief or square buttons. In the centre of the punch, the company's stamp was incorporated, which was made of brass by engraving or stamping, and was attached by nailing it into a cut-out made specifically for this purpose in the punch. The workshops that manufactured moulds also had what they called "the alphabet", which was a set of tempered steel punches letters, they used to engrave the name of the manufacturer or the legend of his choice, as a substitute for the much more expensive stamp option.

Some moulds were also slightly chamfered at each of the corners to make them more compact, which prevented blunting, especially when stacking.

² According to the testimony of Miguel Colera Durá, published by the "Museo del Azulejo Manolo Safont" in Onda ^[31]: "With the large wheel press, 20x20 tiles, 20x20 dovetailed tiles and 14x28 tiles called "collonots" and other large pieces were pressed. The small wheel press was used to press: 15x15 tiles, 7½x15 tiles, 14x14 tiles called 'alambrillas', 10x20 tiles, 7½x15 tiles, 10x20 and 7½x15 strips, 10x20, 8x20, 6x20, 4x20 and 2x20 handrails, as well as other small tiles."



In this QR code there is a link to images of back side reliefs and manufacturer's stamps of tiles pressed with manual spindle presses. Link 1.3

These moulds did not undergo major changes until the press equipment was fully automated and continued to be installed on both electric friction presses with manual loading and removal as well as manual screw presses.

1.2 FRICTION PRESSES AND ITS MOULDS.

Introduction of electricity in the ceramics industry in the 1920s allowed the introduction of machinery and the automation of some stages and phases of production. The old manual screw presses were gradually replaced by **electric friction presses**, (Link 1.4) which were of a similar mechanical design, the only difference being that the flywheel was driven by the friction of two discs joined by a shaft, the plan of which was perpendicular to that of the flywheel and they were driven by an electric motor. The pair of discs were alternatively moved from right to left by a cam actuated by a lever. This generated the contact between the flywheel and either the disc on the right or the left, thus transmitting a turn in one direction or the other, which resulted in an upwards or downwards movement of a triple-thread screw. Another foot-operated lever was used to operate the lower punch of the mould, which was used to fill, de-aerate and eject the tile. Compared to manual presses, these presses were a major breakthrough due to their high productivity, since they allowed the forming of about 2500 pieces of 15x15 cm for 8 hours, with only one operator in charge^[51].

Both types of presses, electric and manual, coexisted for a long time, as shown by the first census of the ceramic tile industry in the province of Castellón, which was conducted by the Industrial engineer Casimiro Meliá in 1946. This census accounted for 38 companies, in which 64 mechanical presses and 60 manual presses were reckoned, which were then called “stampers”, driving a total production of 155,760 m² per month ^{[51] [68]}.

In these presses, the powder for pressing was manually fed into the machine by an operator located at the back of the press, using a tool similar to a wooden sickle. To level the powder the operator used a strip of the same material. This loading system was replaced in some presses by a small feeder car, once again made of wood, which bears some similarity to the feeders later installed in automatic presses and which, with major changes, have survived to this day. As in spindle presses, moulds were periodically smeared with a mixture of oil and petroleum to prevent powder from sticking and facilitate demoulding.

These presses were progressively automated. The extraction system of the pressed tile was synchronized with the rise of the spindle, automating both. Subsequently, a feeder car was added to the press, the movements of which were also in sync with the rise of the spindle and the extraction of the tile, enabling the automatic feeding of the mould and the expulsion of the tile off the pressing area. This, without a doubt, was a great step towards the full automation of the manufacturing process and a clear improvement for operator safety. This line led to a new generation of presses called “**automatic friction presses**” (Enlace 1.4). These presses undoubtedly had its advantages, such as easy maintenance, high productivity and high “pressing force / weight of the machine” ratio. In essence, these were relatively simple and lightweight machines, highly productive and capable of developing, for its time, great pressing forces. However, the main limitation of automatic friction presses was its inability to guarantee a uniform and constant pressing force.

From 1962 onwards, the first automatic friction presses were built in Spain under Italian licence. These presses are the PF 145, with a maximum force of 145 tonnes, and the PF 175, capable of developing 175 tonnes, both from FATMI. In the late 1960s, FATMI built the PE 220, of 240 tonnes, which allowed the installation of moulds with 4 outlets 15x15 cm or three outlets 20x20 cm, which represents the introduction and mass production of this format; and in the early 1970s, the PE 500-V of 650 tonnes, the PE 501 and the PE 502, both of 500 tonnes of maximum force, were already manufactured in Italy.³ Also around this time, WELKO began to manufacture the Vulcano 175 400-tonne friction presses, the Ariete/s 280-tonne press, followed by the Ariete 2000 500-tonne press. All these presses had a clearance between columns of between 760 mm and 900 mm (Link 1.4). The FATMI presses operated with an entry mould, whereas the WELKO presses operated with a mirror mould ^[51]. However, until the mid-sixties of last century, most of the presses employed in the sector were still semiautomatic, and in them some operations were still manually operated. In Italy, fully automated presses were manufactured since the fifties, and in Germany they were known since the thirties.

With automatic friction presses, each pressing cycle consisted of the mould loading, first pressing, deaeration, second pressing and extraction of the tiles. In some cases a third pressing was necessary.

In some friction presses, SACMI introduced the first hydraulic component. These were two cylinder-piston groups located on both sides of the spindle, between the fixed plunger and the mobile plunger, with the aim of better distributing the pressing force and, therefore, improving the compactness of the obtained tiles. These units were operated by a hydraulic unit located outside the press structure (see press PE-220-V and press PE-500-V in Link 1.4). Hydraulic components were also incorporated in the loading, extraction system and in the feeder car. Welko has already incorporated hydraulic elements in the movement of the plunger and in the extraction of the tile in its Ariete presses.



In this QR code there is a link to images and technical information on semi-automatic and automatic friction presses. Link 1.4

³ According to the data of FATMI ^[45], in March of 1969 the company had already installed 14 presses in CEDOLESA (Manises), 12 presses in ZIRCONIO (Vila-real), 4 in ISIDORO SANSANO (Onda), 2 in AZULONDA (Onda), 2 in CERÁMICA HUERTA (Santa María de la Huerta), 7 en FABRESA (Llucena), 4 in AZULEJOS BECHÍ (Betxi) and 9 in NUEVA MENORA (Talavera de la Reina) and had installed entire plants in FARO (Ribesalbes), AZULEJERA ALCORENSE (Almassora), AZULEV (Onda), EUROCERÁMICA (Brihuega), IASSA (Sevilla), AVASA (Manises), AZULEJERA DEL SUR (no data), CICOSA (Onda), PERIS y CIA (Onda) and AZULEJOS SANCHIS (L'Alcora).

1.2.1. The evolution of the mould since the First Industrial Reconversion.

The first major change in the design of the press mould took place with the automation of most of the process steps and coincided in time with the **First Industrial Reconversion** that took place in the sector in the second half of the 1960s ⁴. This was perhaps the most significant transformation of tile moulds, as it affected its very conception and introduced greater mechanical and functional complexity, going from the old mould of the screw and electric presses, consisting of a box and punches, to the more complex mirror and entry moulds, which modern friction presses were equipped with. The structure of these moulds has remained largely unchanged until relatively recently.

The factor that determined this profound transformation was undoubtedly the automation of the extraction of the pressed tile, which until then had been carried out manually by means of a foot-operated mechanism that actuated over the lower punch. The introduction of spring-loaded extractors with hydraulic pistons for the first and second plate drop made it necessary to adapt the mould and also allowed the manufacture of moulds with several outlets, which, together with the high cycle speed that these presses were capable of developing and the reduction in the number of operators required to run them, led to a significant increase in the productivity of the plant.

This important change in the structure of the mould necessarily had to be accompanied by the logical transformation of its manufacturing process, which until then had been carried out in small mechanical workshops that diversified their service activities to industry and agricultural activities. Manufacturing new moulds led to the emergence of specialised workshops that required greater economic investment and more qualified personnel as, in parallel with the complexity of the mould, technical customer service functions developed in these companies.

Friction presses operated either with entry or mirror moulds. The structure of these moulds is similar and the main differences lie in the fact that in the mirror moulds, the upper punch has a larger surface area than the cavity and the die box is movable, so its downward movement, guided by hydraulic pistons, allows the application of the deformation force to the powder. However, both the mechanical design of these moulds and their manufacturing processes also evolved with the press technology and mechanical workshop technology then available.

1.2.2. Die-casting moulds.

The first moulds used in these presses were the so-called “**die-casting moulds**” which consisted of a base, the punch holder plate, the candle hook plates, the die box where the liners were installed and the upper and lower punches. Some of these components, such as the die box, punches and liners, have relatively simple geometrical shapes and the only difficulty in manufacturing them is that of achieving the required precision with the technology available during those years. However, the set of the base with pillars and the punch holder plate was more complex in form and therefore difficult to machine with the means of the time, so it had to be formed in one piece die-casting them. Once the format and number of outlets had been defined and the plan of the future mould had been drawn, a carpenter made the ejector and the wooden base. It was the die box for the mould, which was made

⁴ The First Industrial Reconversion of the Spanish ceramic tile sector which took place in the late 1960s and early 1970s was characterised by the profound technological transformations that modernised the ceramic tile manufacturing process of the previous decades. The main technological milestones were the introduction of the tunnel and the channels kilns, which replaced the old Arab kilns, automatic friction presses, tunnel dryers, mechanised clay grinding plants, automatic biscuit selection, glazing lines and the introduction of silk-screen printing in tile decoration ^[59].

by sand casting. These moulds, also known as “**black die-casting moulds**”⁵ because of their blackish colour, did not have today's bellows dust protection, and the task of protecting the ejecting plate from dust was carried out by an ejector profile or punch holder plate in the form of a flashing.

Since some of the first presses already developed pressing forces of 220 tonnes⁶, it was possible to produce moulds with 4 outlets 15x15 cm or 3 outlets 20x20 cm. Overall, at this time, moulds were produced for the formats 10x20 cm, 15x20 cm and primarily 15x15 cm. Occasionally, moulds for 15x22.5 cm, 15x25 cm and 20x20 cm formats were also produced by die-casting.

Lower punches were made from mechanised steel plates to which a special side weld facing was applied for surfaces subject to heavy wear. The clamping holes were drilled and machined, followed by side and surface grind using a tumbler grinding machine and finally a handmade grind was performed, where the nominal measurements were adjusted to an accuracy of +/- 0.01 mm. Subsequently, the punch surface was hollowed out by handmade grinding to achieve a bevel depth of 0.7 mm, which remained constant irrespective of the punch format. The interior was worked with a flat surface grinder and the finishing of corners and bevels was carried out with a high-speed head with a 30 mm grinding wheel. The corners were being hollowed by hand with a rotary manual tool with small grinding wheel diameters to obtain a better approximation to the measurements and also with high rotational speeds. Finally, the surfaces were sanded and polished to remove the traces of the grinding machine and the grinding wheel.

The upper punches were manufactured following a similar process. The dimensions of the punch should allow a clearance of 0.2 to 0.3 mm with respect to the liners of the die box, in order to facilitate the deaeration and movement of the punches. A 0.07 mm deep groove was made on the edges with a grinding machine to improve the compaction of the corners.

Press reliefs (Link 1.5.) involved a considerable increase in complexity in the process of making the moulds, as they had to be engraved in negative on the punches. In fact, this problem was already present in back side reliefs, which were limited to a few designs that were easy to machine and did not require the production of patterns.

On the other hand, in order to engrave the reliefs of the good face on the steel punch, a template, i.e. the positive of the relief had to be made beforehand, so that the steel punches with the negative of the drawing could be made from it. In the first relief moulds, the patterns were hand shaped in graphite from a drawing on paper. First, a rough down operation was carried out with a milling machine and then the contours were defined with a gouge. Once the relief was finished, the surfaces were smoothed through a patient hand sanding. The erosion process, however, wore down the graphite patterns to such a point that only two or three punches could be obtained from them.

This process, which can be considered almost semi-craft-like, could not completely guarantee the constancy of the dimensions of the reliefs on each punch.

Graphite patterns were replaced by copper patterns, which were much tougher and harder. This increased the number of the punches that could be obtained significantly. These patterns could not be modelled by hand, which meant that the reliefs had to be mechanised.

⁵ The first moulds of this type, manufactured by MACER in the 1970s for the old FATMI PF-145, PF-175 and PF-220 friction presses, were cast at the Vila-real company "Fundiciones Mijares".

⁶ We refer to the PF 220 press manufactured in Spain by FATMI from 1969 onwards.

Graphite has two important characteristics that are necessary in this manufacturing process: it is easily mouldable and, above all, it is electrically conductive. The latter is an indispensable property in this process, as the next step was the transfer of the relief to the punch (from positive to negative) by means of arc erosion.



In this QR code there is a link to images and technical information of semi-automatic and automatic friction presses. Link 1.5

The **back side relief** of the tiles and the maker's mark were made on the lower punches. These reliefs were limited to a few designs that were not too difficult to machine, such as buttons and back sides obtained by milling or rectifying (Link 1.6). However, its production was a very problematic aspect of the mould manufacturing process, as the design and execution of the back relief played an important role in the stacking of the tiles in the bogie, both for drying and for the first firing or “escaldat” which is the term used at the time in eastern Spain. Given that after pressing, the tiles were stacked in bogies. Any small differences in the measurements of the reliefs caused the instability of the pile and this could even lead to their collapse, which, although a major problem, had serious consequences if it occurred inside the kiln. The measurements of the back side relief also determined the section of air passage between pieces, allowing both the entry of the oxygen necessary to complete the oxidation reactions and the correct degassing of the powder. However, at the points of contact between the button or back side of one tile and the smooth side of one beneath it, “marking” defects may appear, probably due to incomplete firing of the tile at that point. This led to a change in the way of stacking, settling face to face, which did not prevent the regularity of the thickness of the relief, within the same punch and between punches of the same mould, from continuing to play a decisive role in the success of the tiles stacking.



In this QR code there is a link to images of back side reliefs on moulds for semi-automatic and automatic friction presses. Link 1.6

There were three procedures for the engraving of the back side reliefs on the upper punch of the die-casting moulds: grinding, milling with a toothed cutter tool. The button and imprint reliefs were obtained by milling with a vertical shaft milling machine.

The die box of the die-casting moulds was made from rolled steel plates on which the supplier had made, by oxy-fuel cutting, the cavities slightly smaller than the nominal size, in order to proceed, in the mould-making shop, to internal and external chip and burr removal, drilling of clamping holes and subsequent machining to nominal dimensions.

In the first moulds, in order to achieve a higher simplicity in its construction, the die box was made in a single cavity and the different outlets were achieved with the subsequent partitions to which the liners were screwed. This created major problems with the fit of the liners, which is why it was preferred to manufacture the die boxes with several oxy-cutting cavities.

The design of the **liners** of the die-casting entry moulds remained exactly the same until their partial replacement by interchangeable liners, but not their manufacturing process, which followed the general procedures of the mould-making workshop of the 1970s. Liners were made from rolled steel bars which were cut to the required dimensions with a bandsaw. The liners were machined by brushing and burr removal milling in the subsequent roughing process after which the clamping holes were drilled and the liners were tempered. After tempering, which was carried out in specialised workshops, the liners were returned to the workshop for grinding to nominal measurements and were mechanised the required radius and taper. An essential step after tempering was revise the threads and once finished, the laorious process of fitting them inside the die box could start.

These moulds were already equipped with 2 **heating elements** per outlet for heating and punches were screwed to the punch holder plate. A continuous blower could also be installed for the inner parts of the mould to prevent the accumulation of powder.

Moreover, each mould had its own **upper plate** which was screwed to the plunger. This made the process of mould manufacturing, element replacement and the mould change process more complex.

1.3. MOULD DEVELOPMENT WITH HYDRAULIC PRESSES.

Hydraulic presses (Link 1.7) are machines where the pressing action is performed by transforming hydraulic pressure into deformation force. The necessary pressure is supplied by a small hydraulic power unit consisting basically of a motor, pump, filters, cooler and regulation and control elements. The force required for pressing is obtained by means of a double-acting piston.



In this QR code there is a link to images of hydraulic presses and their development over time. Link 1.7

These presses completely replaced the friction presses in the Second Industrial Reconversion, which began at the end of the 1970s. From the technological point of view, this implied the predominance of tile production processes, both with red ceramic paste and later, with the white ceramic paste, by means of single firing in single-layer kilns and with wet preparation of the paste and drying the suspension obtained through atomisation process. Together with these important technological advances, the recovery of the "third fire" subsector and the development of an important auxiliary industry such as the manufacturers of atomised pastes, frits, glazes, pigments and machinery should also be highlighted. The arrival in 1980 of natural gas in the Valencian Community through the Tarragona-Valencia gas pipeline was a major boost for this important technological transformation ^[59] of a sector which is mainly concentrated in the area bounded by Castelló, Vila-real, Onda and L'Alcora.

This profound technological change implied a considerable increase in the productive capacity and productivity of companies. According to A. Brusa and A. Bresciani ^[28] productivity, expressed in m²/operator increased by 53% on average compared to a standard plant before the reconversion.

In large formats, homogeneity of the load is more difficult than in small formats, and in addition, products with low porosity after firing, which initially started to be manufactured, such as stoneware floor tiles, have a water absorption of less than 5% and a relatively high linear shrinkage after firing, with values between 5% and 7%, so that the dimensional problems derived from their manufacture are accentuated. Thus, the forming of new products, with the increasing quality requirements of the market, proved to be unfeasible with automatic friction presses, which were gradually replaced by Italian-made hydraulic presses⁷.

The production of increasingly diversified products in a wide range of formats, including single fast firing tiles, white paste and red paste stoneware floor tiles and finally, from 1988 onwards, both unglazed porcelain tiles, commonly known as "technical", and glazed, also led to more flexible production scheduling, with frequent changes of models and the production of shorter batches. At the same time, the quality requirements of the market were, and still are, translated, among other no less important factors, into the maintenance of the dimensional constancy of the tiles, which required the regularity of the forming process, especially in the loading and pressure distribution on the surface to be pressed.

Most of the first hydraulic presses that were installed for the manufacture of ceramic tiles generally developed quite moderate pressing forces, some of them being the result of modifications made to old friction presses where the entire mechanical pressing system was replaced by a piston-moving crossbar system and pressure circuit which in some cases lacked a multiplier device while maintaining the structure and essence of the feeding and loading systems⁸.

⁷Although it is well known that the first hydraulic presses installed in the sector at the beginning of the 1970s were Italian-made equipment (SACMI manufactured its first hydraulic press, the PH 330 in 1967^[81]), it should not be forgotten that between 1965 and 1966 there was a pioneering experience in the manufacture of hydraulic tile presses in the Onda workshop of Vicente Varella March, grandson of Vicente Varella Bastán and son of Vicente Varella Ibáñez, who had already been manufacturing spindle presses since the 1920s. This company, in collaboration with a Valencian printing house, produced some units of the MANCI press, known in the industry as "La Marilyn", presumably in reference to Herta Franckel's little dog popularised then by the emerging Spanish Television. It seems that some "Marilyn" were installed in companies in Onda, such as the factory of Fernando Moliner Navarro "El Clot", Cerámica Ondense, Azulesma and El Barco. Low production was the main problem with these presses, with very long pressing cycles, which made them uncompetitive and this was the reason for their short presence in the industry.

⁸Some of the first hydraulic presses to be installed in Spain were the MH 300, adapted by the company Consorcio Valenciano de Ingenieros from friction presses, capable of developing a pressing force of 300 tonnes. The first Italian-made presses introduced in the sector developed forces between 600 t and 800 t, although there were some of lower tonnage presses such as SACMI's PH 330-B with a maximum pressing force of 330 t and 900 mm column spacing. SITI, which had not manufactured friction presses until then, as it was specialised in the manufacture of kilns, entered the press market in the mid 1970s with the TAURUS and SUPERTAURUS, whose first units were installed in the companies Alcalagres de Madrid, Gres de Valls and Gres de Nules. These presses developed a pressing force of 800 t and 1000 t, which was quite high for the time, and could reach up to 12 cycles per minute. These SITI models could reach high outputs because they incorporated, given their high tonnage, moulds with two-row outlets.

Parallel to the modernisation of the technology used in the production system, there was a notable diversification in the range of products manufactured, with a significant increase in the production of floorings in increasingly larger formats. Thus, while in 1980, Spanish ceramic floor tile production represented only 10.4% of total tile production, only four years later this amount increased to 48.7%, while total production increased in this period from 105 to 145 million m²^[34] at the same time as market demands regarding the quality of the finished product increased.

The Second Industrial Reconversion brought a radical change in the production process of ceramic tiles, which, however, hardly affected the **mould**. The replacement of friction presses with hydraulic ones was carried out while maintaining the same type of mould, although the market's orientation towards large formats led to the manufacture of presses with an increasingly greater clearance between columns and capable of developing greater pressing forces. As a result, the moulds increased the number of outlets and the format of the cavities.

At this time, a series of **important mould transformations** began, which continued and evolved in the 1990s. The main ones were, firstly, the replacement, in 1980, of the screw clamping of the lower punches by magnetic fastening, which was completed in 1985 with the magnetic fastening of the upper punches, and in 1999 with the introduction of electro-permanent plates. Secondly, the introduction of rubber coated punches. The system was further improved in the 1990s with the introduction and development of isostatic upper punches⁹ ^[75] ^[76].

The second major change in the mould evolution took place when the Second Industrial Reconversion of the sector had already been fully consolidated, at the end of the 1980s, with the introduction, by press manufacturers, of **new loading and extraction systems** (Link 1.8). These introduced a hydraulic extraction pistons and the candles were replaced by new systems where the ejector mechanism and the mould form part of the same equipment. These changes were driven by the need to achieve a high degree of homogeneity in the mould load, derived from the high shrinkage after firing experienced by some products, such as porcelain body, especially in large formats. SACMI's SMU and SITI B&T's SYNCRO systems were introduced on the market and were well received by the industry. Subsequently, SACMI upgraded its extraction equipment with the development of the SPE system and SITI B&T introduced major improvements to its equipment with the E-SYNCHRO system. The mould underwent some changes and were integrated into these systems as a built-in part. Nowadays, these systems coexist with traditional piston and candle extraction systems.



In this QR code there is a link to images of the extraction systems and hydraulic presses. Link 1.8

⁹ Logically, in mirror and double mirror moulds, the isostatic punches are the lower ones.

The introduction of porcelain tiles in the late 1980s¹⁰ was the real catalyst for the development of pressing technology, and consequently led to new mould developments.

Porcelain tiles have a high compaction, and are practically free of open porosity and have a very low closed porosity¹¹. They may be glazed or unglazed and are made from white powder,¹² or are coloured by the addition of pigments inside the paste. It is mainly composed of kaolinitic clays, quartz, feldspars and talc. The main technical requirements for the product are whiteness, high colour development, high mechanical performance and high frost and stains resistance; properties which depend mainly on the vitreous and crystalline phases formed after firing and on the microstructure of the fired piece, especially low closed porosity and no or almost no open porosity.

The first porcelain body products to be marketed were medium-sized tiles, which quickly evolved into large-sized, unglazed, coloured and often polished tiles. The limited variety of models offered at the beginning of the 1990s, mainly single-colour and granite or “salt and pepper”¹³ polished or unpolished, was extended by decorations with soluble colours and decorations in the press, with the combination of different powder loading systems. Finally, the introduction of glazed porcelain tile in the nineties made it possible to definitively overcome the limited decorative repertoire which porcelain tiles had operated until then, enormously expanding the range of models offered.

At the same time, new systems of decoration were developed on the press, which became increasingly complex and richer in decoration. Naturally, these new systems forced a functional change in the feeder car, which went from powder feeding functions to equipment that took on increasingly complex loading and decorating functions. The manufacture of porcelain body tiles, with various fillings and decorations in presses, made it necessary for the smooth side of the tile to be shaped by the upper punch, i.e. the tiles are pressed with the good face upwards, as opposed to how they are made in the entry mould. This made possible to recover the mirror moulds, which had fallen into disuse. With this type of mould, however, it is not possible to manufacture tiles with spacers, so a much more technologically and functionally complex type of mould was finally developed: the top-forming or double mould^[47], which basically consists of a combination of an entry mould and a mirror mould, equipped with two dies boxes, one fixed and the other mobile, which allow forming in the upper part of the mould, which is also responsible for the tile extraction (see Chapter 5).

¹⁰ Porcelain body, as we know it today, began to be manufactured in some companies in the ceramic district of Sassuolo, Italy, in the late 1970s. In Spain, Pamesa presented the first Spanish-made porcelain body at CERSAIE '88, under the commercial name of "Compacto", and began production that same year. The company Porcelanatto followed in 1989. The following year, at Cevisama '90, only these companies, among the Spanish ones, offered porcelain body. The 1990s saw a gradual increase in the production of unglazed porcelain body, and from the middle years of the decade onwards, the manufacture of glazed porcelain body began, with many more decorative possibilities.

¹¹ According to the ISO standard for the classification of ceramic tiles, the water absorption of these products must be less than 0.5%.

¹² Some companies manufacture low porosity tiles from clays with high iron mineral content. Without detracting from their quality, which does not have to be inferior to those obtained from iron-free pastes, from a purely technical point of view it seems logical to maintain the traditional meaning of porcelain, i.e. “quality of porcelain”, for products obtained from white pastes, whether coloured or not.

¹³ The manufacture of the old granites and “salt and pepper” can be considered as the first decoration in presses in the sector after the industrial reconversion, although it should be remembered that the decoration in the forming operation was already known, it is enough to remember the typologies of hydraulic pavement.

Large formats have evolved into the current production of porcelain body tiles with thicknesses ranging from 3 to 30 mm [26] [27] [52] and long lengths.

Some of the tile formats currently produced are 60 x 120 (figure 1.2), 90 x 90 cm or 120 x 120 cm in traditional mould pressing and up to 360 x 160 cm in powder beds compaction deposited on a belt [52]. This has been made possible by the extraordinary development of presses, moulds and new technologies such as double compaction, pressing of powder deposited on a belt or compaction by continuous lamination. In addition, of course, all parameters affecting the manufacturing process are strictly controlled.

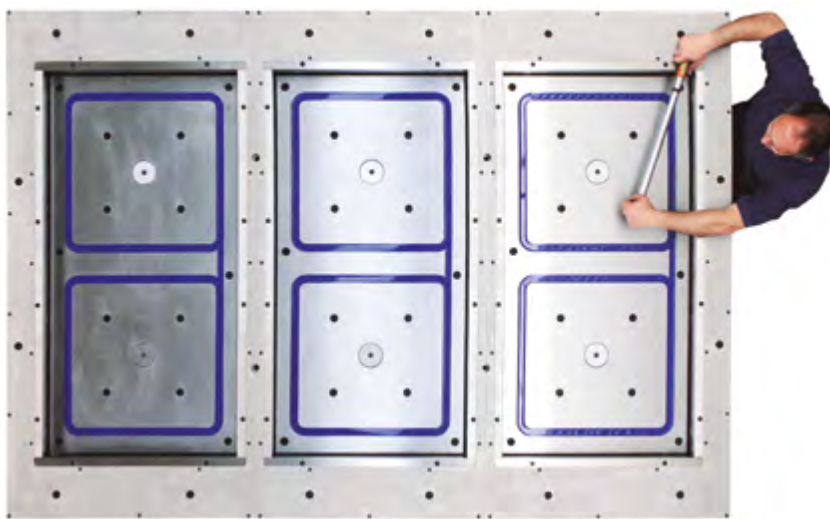


Figure 1.2. Mould of three outputs 60 x 120 cm

On the other hand, the mould manufacturing process has also evolved significantly with the incorporation of mechanical treatments controlled by numerical control (CNC) and new surface treatments of materials. Also with the diffusion of programmes for measuring and digitalising surfaces and with the improvement and innovation in used materials (see Chapter 4).

Finally, in recent years, the ceramic tile market trend has been moving towards increasingly larger formats and, in some products, towards the reduction of thicknesses, which required to redesign the pressing operation. This has led to important technological advances in the forming of large tiles and ceramic sheets. The first step in this direction was the appearance on the market of increasingly larger presses, which combined high pressing force with a large free span, such as the large tonnage presses EVO and STAR from SITI B&T and the IMOLA from SACMI, reaching pressing forces of up to 16,000 tonnes today, which has led to a significant increase in the complexity of the moulds used and, therefore, of their manufacturing process. Moreover, in the early 2000s, progress was made in the redesign of the forming operation with the appearance of SYSTEM's LAMINA technology and SACMI's double pressing with precompaction with lamination, which later evolved into the CONTINUA+ laminate compaction technology. In parallel, the belt-deposited powder bed pressing systems LAMGEA from SYSTEM and SUPERA from SITI B&T were developed. All these technologies incorporate in-line decorating stations and raw cutting equipment, both transversal and longitudinal, making it possible to obtain a wide range of subformats from the original plates.

Mould planning and design.

Chapter 2



Many of the projects for new ceramic products currently being developed in the ceramic tile manufacturing sub-sector involve the design of moulds, in terms of their dimensional, aesthetic and technical characteristics.

The process of creating a new product generally starts with the proposal of new technical and aesthetic solutions for the manufacture of ceramic tiles. This process includes the analysis and interpretation of information on market needs and expectations, consulting different sources of information (sectorial, trade fairs, specialised magazines, etc.); the conception of the new product; the identification of its technical, aesthetic, formal and economic conditioning factors and finally the preparation of the sketches and information necessary for the project realisation.



Figure 2.1. Prototype

These steps lead to the development of the prototype, which must be reviewed and accepted by the management and by the design and commercial departments, as well as by the technical departments of the tile manufacturing companies and the mould manufacturer, who must make the necessary corrections to guarantee the manufacture of the product under the required quality conditions. Therefore, there is a need for fluid communication between the technical departments of both companies. An outline of the information flow required in the mould design process [29] is shown in Figure 2.2.

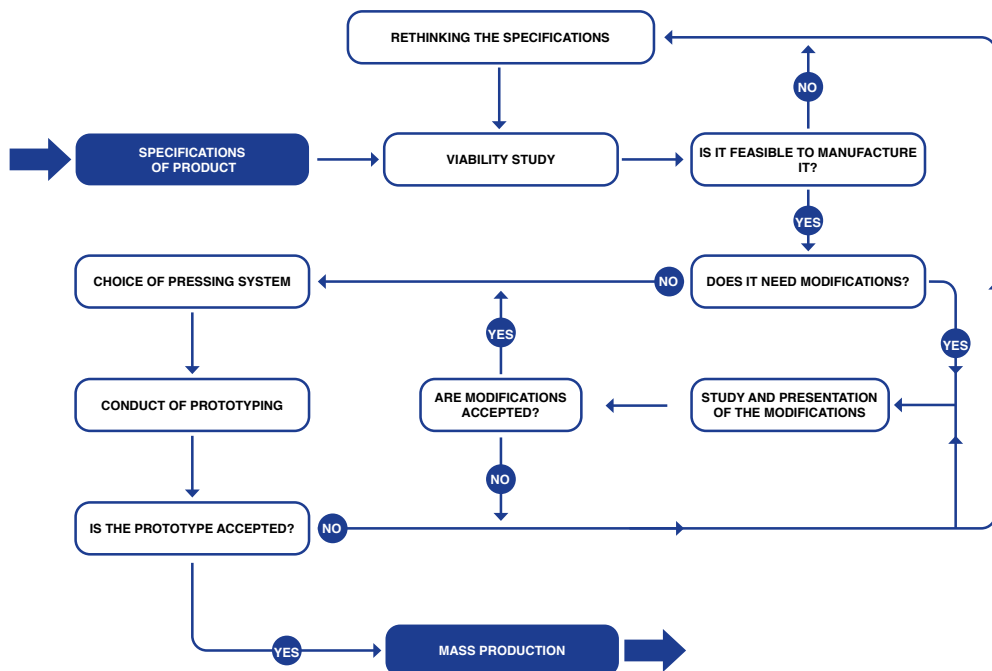


Figure 2.2. Diagram of information flow between technical departments and companies for a new manufacturing project

2.1. PRODUCT SPECIFICATIONS AND FEASIBILITY STUDY.

The mould design process must take into account both the product characteristics and those of the pressing operation. The characteristics of the product are powder types (and therefore its behaviour in the manufacturing process); properties of the finished product; formats; profiles; reliefs; decorations to be carried out in the pressing operation and dimensional characteristics of the tile. Consideration should also be given to the type of press to be used; the clearance for the installation of the mould; the distance between bed and plunger; whether the product is decorated in the cavities of the press; the type of feeder car and its dimensional characteristics and also the tile transport systems to be used in the manufacturing process (conveyor belts, spinners, roller boxes, etc.).

On the other hand, there may be requirements arising from specific production constraints of the tile manufacturer himself, such as the need to manufacture moulds of the same product for two different types of presses, with different clearance or pressing forces.

The feasibility study covers both the economic and technical constraints of the new product. In short, the aim is to answer the questions of whether it is possible to shape, decorate, extract the tile from the cavity, transport and store the tiles without unacceptable losses with the required quality characteristics, under economic conditions that make this feasible, and also whether the mould allows a pressing force capable of achieving a uniform microstructure that confers the desired properties on the tile during the manufacturing process and after firing.

2.1.1. Thickness and reliefs.

It is important that the tile has an average thickness that does not show a large variability, i.e. large changes in thickness caused by aggressive back side design or, more often, by uncompensated relief design leading to abrupt variations in compactness. On the basis of purely practical considerations, some technicians advise that tiles with relief should have at least 20% of the surface the same height, distributed in flat areas [29]. These areas of equal height should be those with the higher thickness (shallower depth).

There is also a trend towards thinner tiles and slabs, which has important advantages [37] such as reduced raw material, energy, storage and transport costs.

When reference to “relief” is made in the design of ceramic tiles, the focus should be on the good face, where aesthetic and technical quality characteristics are required, but it should not be forgotten that the design of the back face of the tile is also of great importance, since it should serve to compensate for the differences in thickness that may be caused by the relief projected on the good face and, among other things, to minimise the differences in compactness that this may cause.



Figure 2.3. Tile sections with different thicknesses

Therefore, the relief of the tiles must be carefully designed to avoid pronounced elevation differences affect the demoulding. On the other hand, very abrupt reliefs may originate stress concentrations between the angles formed by the joints of the planes that form the relief, causing cracks, especially in tiles formed with powders with high postpress expansion. To avoid this, and to compensate for the compactness differences the relief may produce, it is now common to design some products with compensated back side relief, so that the relief is reproduced on the back of the tiles keeping the thickness of the tiles approximately constant (Figure 2.4). This combined with a back side design that guarantees a stable support base and sufficient points of support to facilitate their movement by means of the conveyor belts during the manufacturing process. In addition, the back side relief must also allow transport over rollers (baskets, roller boxes and kiln) to be carried out without rocking or bumping, which must be taken into account in its design.



Figure 2.4. Deep reliefs with compensated back sides

On another hand, important technological advances in the manufacture of ceramic tiles developed since the 2000s allow greater freedom in the design of the reliefs. These advances are, for example, the generalisation of digital inkjet decoration, in which there is no physical contact with the tile during the decoration operation, or the decoration of the tile during the pressing operation itself. This can be carried out either in the press feeder car itself or in decoration stations located after the forming equipment (Figures 2. 4, 2.5 y 2.6.).

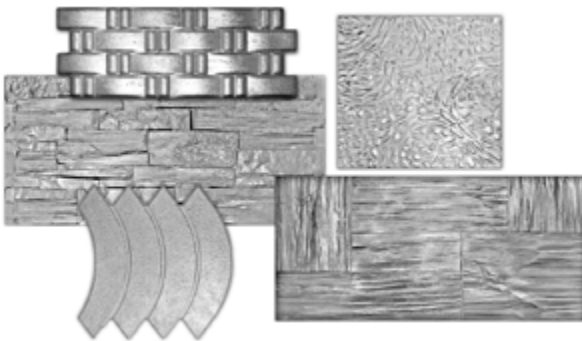


Figure 2.5. Pronounced relief design

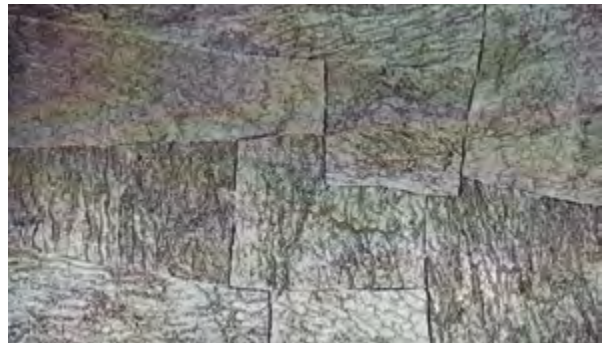


Figure 2.6. Designs with relief

Section 2.2 describes the process followed in the design of reliefs for mould punches from the customer's needs or the original idea to the construction of the patterns necessary for the manufacture of the punches (see Chapter 4).

2.1.2. Format.

The design process can often start from a pre-established format. The choice of format is generally based on commercial criteria, although in some cases it is defined during the actual design phase of the mould.



Figure 2.7. Format with stress accumulation points

Most ceramic tile formats are square or rectangular and not very thick, so these simple geometric shapes do not present problems of stress accumulation in singular points that could cause cracks in the manufacturing process. However, in some formats such as the one shown in Figure 2.7, or the so called “interlock” formats (Figure 2.8), which along their perimeter present angles that can act as stress concentration points. If the definition of the format is part of the design process, the problem can be minimised by slightly rounding the corners.



Figure 2.8. Pattern for “interlock” tile

2.1.3. Side profile: edges and spacer.

Many tiles are designed with a side profile (figure 2.9) consisting of the spacer, the bottom bevel (figure 2.10) and the bevel of the good face or top bevel. These three elements are of a technical nature, i.e. there are technical constraints related to the manufacturing process that make this design advisable.

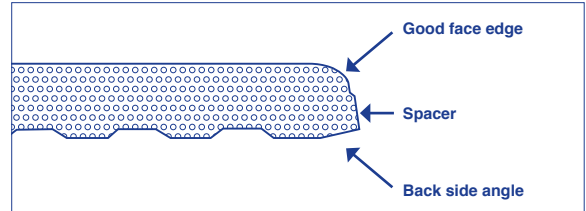


Figure 2.9. Side profile of a tile

The **spacer** is intended to prevent contact between the glazed edges of the raw tiles in an occasional impact between them during the manufacturing process. This spacer is necessary and conditions the extraction of the tile, which makes it necessary to place the good face of the tiles in the lower punch of the entry moulds, or to form the tile in the upper die box of the double moulds. Its technical role becomes less relevant after firing, so that some types of tiles are rectified, thus eliminating the spacer, significantly improving the aesthetic appearance of the product once it has been laid. As will be seen in chapter 3, the liners are the component of the mould that shapes the spacer.

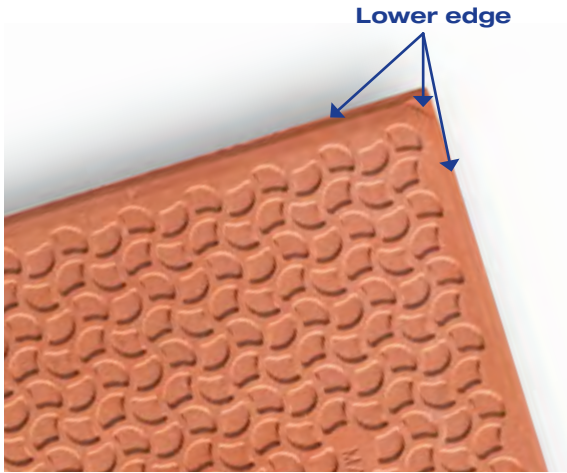


Figure 2.10. Lower edge of a non-rectified tile

The **upper and lower edges** are intended to improve the mechanical strength of the edges of the workpiece, to avoid blunting due to knocks during the manufacturing process. The bottom bevel protects the tile from minor impacts when accessing roller assembly, changing belts on conveyor lines or entering the roller boxes.

The top edge or chamfer of the glazed side can cause some major problems during the glazing process. If the tile is designed without a top edge, the glaze can form a ridge during application by means of a bell tongue or press-on edge. This problem can be minimised by acting from the perspective of enamel formulation, decreasing, as far as possible, the surface tension of the suspension. Another solution concerns the design of the edge, as the flange is smaller if the bevel profile is softened.

2.2. RELIEF DESIGN.

It should be taken into account that when mould design refers to reliefs, these can refer to both the so-called “press relief” that goes on the good face of the tile, and the “back side relief”, commonly known as “costillas” in Spanish. Depending on the mould type, these reliefs can go to the upper or lower punch and their manufacturing process is exactly the same.

The reliefs on the good face of the tile and the reliefs on the back side are part of the product design and condition the manufacture of the upper and lower punches. It is a long way from the initial idea to the punches with the negative of the projected relief or from the specifications of the tile manufacturer to the manufactured punches, which will be discussed in Chapter 4.

2.2.1. Back side relief.

Back side relief, is a general name for the relief on the underside of the tiles. This relief is commonly known as “**back side**” although in this text this generic name has been preferred, considering that the so-called “**ribs**” is a specific type of back relief ^[48].



Figure 2.11. Design Exhibition

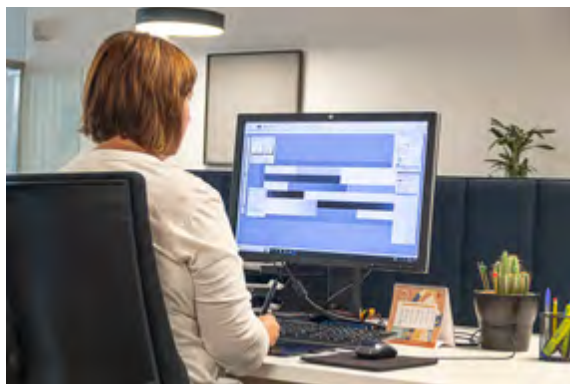


Figure 2.12. Design Department

The objective of this relief was initially to create a sufficient surface to facilitate the adhesion of the cement mortar applied in a thick layer. As the use of adhesive pastes, cementitious adhesives and resins for thin layer tile installation, both in floor and wall tiling, has become more widespread, the importance of the bonding surface function of the back relief has diminished. However, its design is still of great importance since it directly influences the distribution of compactness in the tile. A bad design may create heterogeneities in compactness that result in defects such as visible stains on the noble face, pinholes, etc. (see Chapter 7). On the other hand, the design of the back relief can compensate for variations in thickness, and therefore compactness, caused by very pronounced noble face reliefs as discussed above. Some types of back relief, especially very pronounced ones, can also influence the mechanical strength of the tile ^[35].

Many of today's tile back relief designs became widespread after the massive introduction of the single-firing ceramic tile manufacturing process in single-layer roller kilns in the late 1970s and early 1980s. These reliefs replaced the traditional button and rib reliefs, characteristic of friction presses, because these had a very pronounced relief that generated significant compaction differences, transparency or marks of the reliefs on the noble face of the tile and caused the tiles to swing inside the single-layer kiln, which resulted in scratches and deformation of the tiles. Initially, with the pressing by friction presses and even after the second industrial conversion in the 1980s, it was therefore the firing operation, and not the pressing, the main conditioning factor in the design of back reliefs. However, the popularisation of highly accentuated press reliefs, both in traditional pressing and in press decoration, influenced the need to compensate the compactness throughout the piece to avoid the defect known as “rib marking”, due to inappropriate designs of the back relief and other defects associated with heterogeneities in the distribution of compactness, and this conditioned in many cases the design of the back relief. Nowadays, other factors, often aesthetic, have been added to condition the design of the back relief, which, sometimes has even become part of the company's brand image.

The choice of the shape of the back relief, although it is not usually considered as part of the tile design, determine technical aspects of the process [36]. Its design has also become a potential field of optimisation. In this context, lightened back reliefs have been tested that allow a substantial reduction in the mass of the tile, which leads to savings in raw materials and energy [36] and a reduction in transport costs although, as indicated above, its design must consider and minimise the variations in compactness that it may cause.

The most widely used back reliefs in floor tiling during the early years of industrial conversion were those with a **ribbed surface** (Figure 2.13). The structural unit of this relief is small elongated ribs 1 cm long, 1 to 2 mm wide and only 0.5 to 1 mm high, which form a homogeneous-looking texture when grouped in rows and columns.

One group that encompasses many of the back reliefs of today's manufactured products is the **grid reliefs**. Grid reliefs are those formed by the ordered repetition of one or more modules. The repetition of hexagons, whether regular or irregular, generates the lattice known as a "**honeycomb**". This type of relief, generally in very small heights of less than 1 mm, has been frequently used in many stoneware and porcelain floor tiles. These include "**diagonal cross-linking**", as shown in Figure 2.14, which seeks uniform contact with the kiln rollers in the firing process, so that, combined with a suitable protective engobe, it minimises soiling of the rollers. Tiles are also produced with back reliefs obtained by the repetition of irregular shapes, or "**mixed reticulates**" (Figure 2.15).

In order to compensate the compactness throughout the tile volume and the differences that may be caused by the reliefs of the noble face, especially very pronounced reliefs, textured reliefs, (Figure 2.16) which offer a wide range of options, and the combination of deep reliefs with compensated back sides (Figure 2.4), have also become widespread. On the other hand, many manufacturers choose to design their own back reliefs like their own exclusive textures, which form part of the company's own brand image and they adapt to each type of product manufactured according to the thickness, press reliefs or composition of the paste (Figure 2.17).

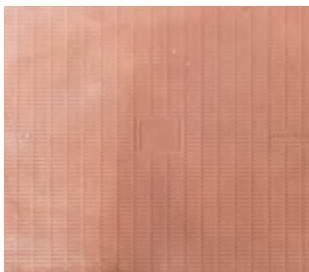


Figure 2.13. Back side relief on back side surface.

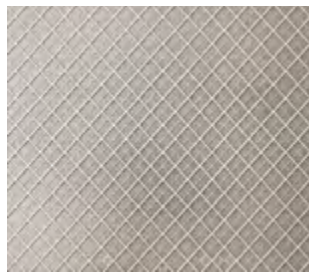


Figure 2.14. Cross-linked back side relief.



Figure 2.15. Mixed back side relief.



Figure 2.16. Textured back side relief.



Figure 2.17. Back side reliefs can also be exclusive to a brand.

2.2.2. Press relief.

Press reliefs have always been an important added value in ceramic tiles, and their use has been noted since practically the generalisation of semi-dry pressing with friction presses. However, the manufacture of moulds for this type of product was quite complex, since the reliefs had to be engraved in negative on steel punches, for which a template with the positive had to be made beforehand. In the first relief moulds, the patterns were hand shaped in graphite from a drawing on paper. First, a rough down operation was carried out with a milling machine and then the contours were defined with a gouge. Once the relief was finished, the surfaces were softened through a patient hand sanding. Graphite is electrically conductive, which allowed the transfer of the relief to the punch by arc erosion.

The erosion process, however, wore down the graphite patterns to such a point that they could only be used two or three times. Graphite patterns were replaced by copper patterns, which were more resistant and harder. This increased the number of the punches that could be obtained significantly. These patterns could not be modelled by hand, which meant that the reliefs had to be mechanised.

Nowadays, press reliefs have become widespread and floor and wall tiles are manufactured with relief imitations of natural materials such as wood, cement, stone, sand, slate, granite, etc. These include combinations of geometric reliefs that generate optical effects on walls, micro-reliefs that not only accompany natural wood or stone but have opened up possibilities for the reproduction of fabrics and textile patterns and the most abrupt textures of materials or combinations of reliefs that form walls with interesting volumetric variations (Figures 2.18 and 2.19).



Figure 2.18. Showroom with embossed tiles



Figure 2.19. Showroom with embossed tiles

To make the necessary moulds, the punches have a smooth and even surface and the relief is marked on the rubber coat during the hardening process, using aluminium or bakelite patterns. In the case of very pronounced reliefs, this process is complicated and it is choose to mill the relief on the surface of the punch, and to cover it with a rubber layer with constant thickness.

The design and manufacture of the patterns has now become a stage in a highly automated process involving the creation and digitisation of the prototype and the engraving of the patterns using a CNC milling machine or laser engraver.

2.2.2.1. Prototype realisation.

The initial idea for a new design may come from the mould maker's own initiative through his design department. In this case, the resulting prototype is one more option among those offered in the company's catalogue available to its customers. It can also be based on an express request from them, i.e. from a tile manufacturing customer, expressed in different degrees of concreteness, such as simple ideas, images or real samples of existing textures in natural or synthetic materials, etc. Finally, this initial design idea can also emerge from collaboration between the two.

Some projects can also start from ideas or images transformed into reliefs and textures by manually moulding a first sketch with clay, plaster or plasticine (Figures 2.20 and 2.21) when the aim is to obtain handmade designs with the imprint of manual work. The sketch is made following the traditional modelling techniques and procedures used in artistic ceramics and may undergo some minor adjustments to make it viable in a semi-dry press forming process¹⁴.



Figure 2.20. Manual pattern making



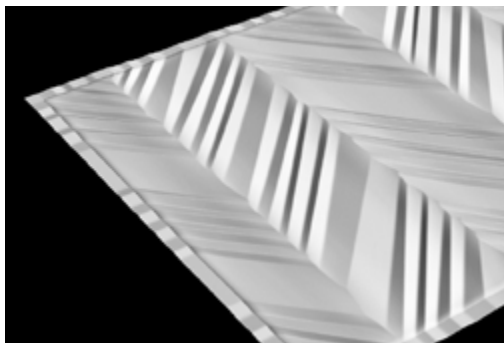
Figure 2.21. Manually made relief pattern

In any case, the designer can start from a physical object, whose texture is intended to be reproduced in an industrial process, or from images and ideas that must be transformed into a physical sketch, prior to its digitalisation.

When there is no physical object to be reproduced, the first step is to produce a 3D image (Figure 2.22) with 16-bit output, since, as will be seen, working in greyscale will provide greater definition, which is particularly necessary when a pronounced relief is intended.



Figure 2.22. 3D image of a pattern



¹⁴ Very pronounced reliefs (higher than 8.5 mm), stress accumulation points or closed relief profiles, which are incompatible with semi-dry pressing, should be avoided.

2.2.2.2. Digitalisation of the prototype.

Once the sketch has been made and approved, the prototype is digitally processed. Digitalising the prototype consists of obtaining a map of coordinates corresponding to each pixel, which is called a “point cloud”. This map can be obtained by means of a digital probe or a laser digitiser (Figure 2.23). This point cloud is then converted into a 16-bit¹⁵ “greyscale” relief (Figure 2.24) using a computer program.



Figure 2.23. Laser digitiser

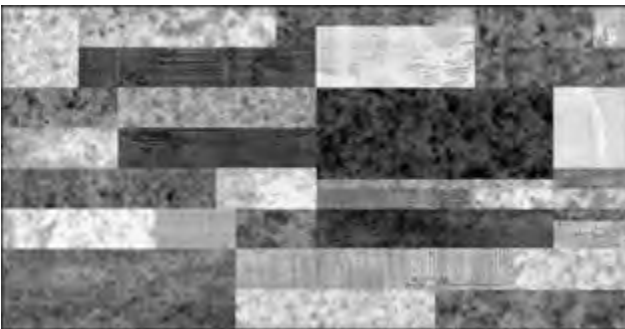


Figure 2.24. Relief representation of a tile using grey scales

The laser digitiser is equipped with a scanning head that recreates the read relief in a greyscale. A 16-bit greyscale contains thousands of shades of grey, which allows a perfect characterisation of the relief since each shade of grey, measured quantitatively and characterised by colour coordinates, is associated with a coordinate. The 0 level, or maximum height, is the white. The lighter areas indicate the highest elevations of the relief, and the darker areas the deepest. From this file, a machining programme is defined that can be understood by the milling machine, for the creation of a prototype in plaster, which will be used for a first revision of the prototype (Figure 2.25 and link 2.1). This programme was, until only a few years ago, introduced in the design department from the data generated by the reader, but

¹⁵ In the past, 8 bits were used. The difference between an 8-bit and a 16-bit image is the amount of information they can contain. With 8 bits, 256 shades of grey can be stored, while with 16 bits, 65536 shades can be stored"



Figure 2.25. CNC milling machine for plaster prototypes.

nowadays, modern milling machines work directly from the greyscale file itself and it is only necessary to load the file into the control system of the milling machine together with some data, such as the tool to be used and the depth references, in order to translate the greyscale tones into heights. Naturally this speeds up the work of the design department by transferring to the machines the work of converting the images into machine-understandable language, previously done by the designers.

From the greyscale map, it is also possible to build a rubber prototype, called "Teflon", which can be mounted on the punches of an industrial press for a short test trial.



In this QR code there is a link to a video where you can see a CNC milling machine for plaster prototypes working. Link 2.1

Figure 2.26 shows some prototypes of relief tiles made of plaster.



Figure 2.26. Prototypes made from plaster

2.2.2.3. Pattern making.

The patterns obtained are the positives of the punches (Figure 2.27). In other words, they are the "moulds" that will allow us to obtain the surface of the punches and their relief.

On both the upper and lower punch, we find the negative of the relief that will be transferred to the tile. On the upper punch of the entry moulds¹⁷, on the lower punch of the double mould and generally on the lower punch of the entry mirror mould¹⁶, the ribs, the manufacturer's logo and the references for the identification of the punch and the mould are engraved. On the other punch, we can find the reliefs and textures typical of the product design, known as "press reliefs", or a completely smooth texture if desired.

Once the plaster prototype has been examined, the grey map can be retouched at will using an image processing programme if necessary, and a template is produced with the positive of the relief machined on one of its faces. To carry out this machining step, the operator programs the work instructions (feed rate, feed depth, pitch, etc.) of the **milling machine** with tungsten carbide head or of the **laser engraver**.



Figure 2.27. Back side relief on the aluminum pattern (right) and the corresponding punch (left)

The patterns or master moulds, which are necessary for the manufacture of punches (see Chapter 4), can be made of **iron, aluminium or bakelite** (Figure 2.28). Table 2.1 shows some general characteristics of these types of punch patterns. As can be seen in the table, iron patterns are used exclusively for the production of smooth bevelled punches, coming from grinding, intended for the good face of the tiles. Aluminium is generally used for punches with very pronounced reliefs (greater than 1.0 mm), despite the milling machine is slower than the laser engraver and aluminium is more expensive than bakelite. The supplied aluminium sheets are tailored made, although the thickness may vary depending on the reliefs to be engraved. On the other hand, bakelite sheets are supplied in sheets of up to 300 x 200 cm, which

¹⁶ This statement should be qualified, since, although in most entry moulds the upper punch has the back side relief engraved (pressed with the good face down), it must be taken into account that this is not always the case and that some manufacturers use entry moulds with this inverted position (see section 5.3.4 in Chapter 5 regarding inverted entry moulds).

¹⁷ Although it can be reversed, with entry mirror moulds the tile is pressed with the good face upwards.

can be engraved entire in the laser engraver to obtain several punches, and cut after engraving. Both bakelite and aluminium allow the rubber to harden, as they can be easily heated, although aluminium conducts heat far better than bakelite.



Figure 2.28. Different types of patterns.

Bakelite (figure 2.29) is a polymer formed by reaction under heat and pressure between formaldehyde and phenol and is considered the first synthetic plastic to be produced¹⁸. Its use quickly became widespread due to its excellent properties as an electrical insulator, high heat resistance without deformation, chemical stability, mechanical strength and easy machinability. It is a thermostable plastic, i.e. once it has been cooled in the manufacturing process, it cannot be deformed again by heat.

Bakelite is served in 10 mm thick sheets that are engraved without prior treatment, in the laser engraver.



Figure 2.29. Bakelite sheets used for patterns.

¹⁸ It was patented by the Belgian-born chemist Leo Baekeland in 1909.

Pattern type	Manufactured punches	Type of engraving.
Iron patterns.	Flat	Without engraving
Aluminium patterns.	Good face with pronounced reliefs. Pronounced back side relief or compensating relief on the back side.	Milling machine
Bakelite patterns.	Good face with shallow reliefs, or back side relief.	Laser engraving machine

Table 2.1. Pattern types for punch making.

a) Milling machine engraving.

Milling machines are used for the engraving of aluminium templates (Figure 2.30 and link 2.2) sequences the operations automatically, in order to optimise the process performance while the operator has to deal only with the zeroing the device, i.e. the input of the reference coordinates, and the subsequent verification of the product with the established dimensional control. The lateral displacements per head pass range between 1 and 1.5 tenths of a millimetre to achieve a resolution that allows the tiles to be pressed under the required quality conditions.

The milling machine must be programmed to make the template with only one head because it is not possible to replace it once the operation has started, as the intense heating that the head undergoes during the work makes it very difficult to control its expansion. If the head is replaced without finishing the complete milling of the template, it is very difficult to find a starting point without losing continuity in the design.



Figure 2.30. Relief machining with milling machine on aluminium pattern



In this QR code there is a link to a video where you can see an engraver making a relief on an aluminium pattern. Link 2.247

The aluminium pattern is fixed to a smooth iron template, known as a measuring template, which is magnetically attached to the base of the milling machine. For the subsequent vulcanisation (see Chapter 4), the whole assembly is mounted in the press and the iron template heats the aluminium pattern.

b) Laser engraving.

The pattern (Figure 2.31) can also be obtained by **laser engraving** (see link 2.3) on bakelite templates, using engraving machines such as those shown in Figure 2.32, equipped with CO₂ laser nozzles (Figure 2.33).



Figure 2.31. Laser engraved back side bakelite pattern



In this QR code there is a link to a video where you can see a laser engraver making a relief on a bakelite pattern. Link 2.3



Figure 2.32. Laser engraving equipment.

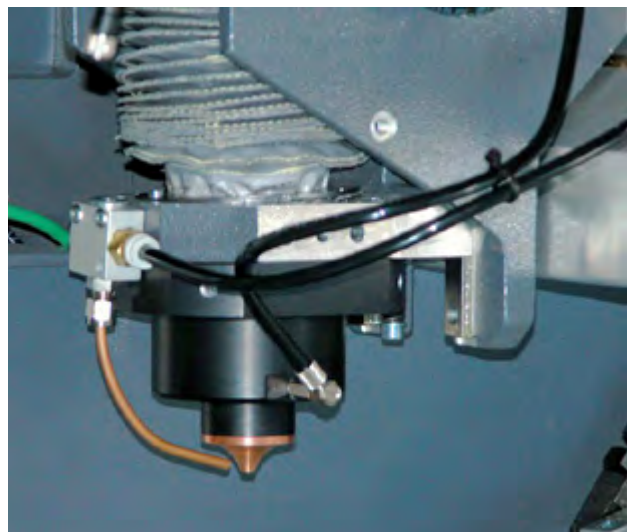


Figure 2.33. Laser engraver nozzle (photograph courtesy of CIELLE)

2.3. TECHNICAL AND MANUFACTURING CONSTRAINTS ON MOULD DESIGN.

The design of a mould is subject to a number of technical and manufacturing constraints that determine, among other things, the dimensions and materials of all its components.

Of course, the main design element to be considered is the **press** where it will be installed and the following features of the press should be given special consideration:

- Maximum pressing force.
- Clearance.
- Installed extration system.
- Dimensions of the feeder car grid.
- Sizes of the movable plunger and the bedplate

Presses used in the ceramic tiles industry can be classified according to **the maximum force** developed. This important parameter determines the maximum pressing area depending on the type of product to be produced and therefore has a direct impact on the **format** and the **number of outputs**. Today there is a wide range of traditional presses ranging from small tonnages (less than 1000 tonnes of maximum force), suitable for small formats and special parts, to presses capable of developing forces of up to 16000 tonnes¹⁹, suitable for the manufacture of large formats.

The **clearance** or "distance between columns" ²⁰ of a press is the useful distance for the installation of the mould, therefore it is the main factor that determine, together with the force the press can develop, the maximum number of outlets the mould could have and therefore its productivity. The higher the maximum force the press can develop, the wider the clearance will be.

All the presses are equipped with a **hydraulic extraction system** which has the task of performing a first plate drop to fill the cavities and a second one to place the mould in pressing position with the bench plate resting on the press structure²¹; and to perform the extraction of the pressed tiles with a punch lifting movement. The equipment responsible for these movements is called forming and extraction

¹⁹ Nowadays, other forming lines have been developed that deviate from the traditional pressing that requires the moulds described in this text, such as SUPERA technology from SITI B&T, which incorporates a compacting equipment fed by a belt up to 160 cm wide on which the powder is deposited by several dispensers. Forming is carried out by a discontinuous press capable of developing a force of up to 48000 t. This press is equipped with a moulding unit which, in practice, acts as a mould and is equipped with a system of mobile powder containment plates, driven by hydraulic pistons that delimit the powder area, making the longitudinal cutting of the plate unnecessary. The deaeration of the large amount of compacted dust is carried out through a semi-porous membrane.

²⁰ Although the term "column spacing" is still occasionally used to indicate the space available for the installation of the mould or "clearance", this concept has become obsolete as many presses have replaced the column structure with "closed ring" structures which allow better absorption of the stresses generated during pressing or are manufactured with a sheet structure.

²¹ In double charge decoration processes, the lower punches must perform three downward movements or "drops"; the first one is to receive the powder charge, the second one for the decoration charge (just a few mm) and the third one to rest the mould ejector plate on the bench plate for pressing.

equipment, or more frequently “**extraction equipment**”. The traditional extraction equipment is the piston and candle extraction system, which is still present in many operational presses in the sector, although each manufacturer equips its presses with its own patented equipment. SITI B&T presses are equipped with Syncro® and E-Syncro® extraction systems, while SACMI equips its presses with SPE® systems. A detailed description of this equipment can be found at ^[49]. Each extraction system also has different types of pistons, located in different positions and, of course, different anchoring systems, so the design of both, the bench plate and the ejector plate will be conditioned by the extraction system type installed in the press.



Figure 2.34. Floating honeycomb grill made by MACER

The presses are equipped with a **feeder car** which task is to collect and ration the powder from the press hopper and to fill the mould cavities quickly and homogeneously. The dimensions of the car grid (Figure 2.34 and 2.35) must allow the correct filling of the cavity, so the useful loading width of the cart must be slightly larger than the space occupied by the cavity and their separating partitions. Depending on products and pressing cycles, it is recommended that the payload width exceeds 5 to 15 mm on each side of the mould cavity space. This also determines the dimensions of the ejecting plate.

Another factor that influences the design of the mould is the size of the mobile plunger and the bedplate, as well as the arrangement of the fastening bolts on both.

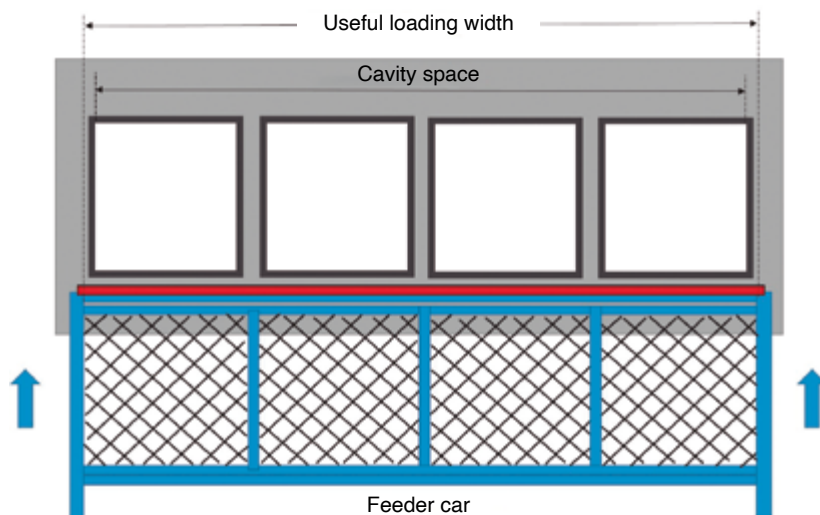


Figure 2.35. Floating honeycomb grid made by MACER

2.4. OUTLETS.

The number of outlets of a mould is its number of cavities, i.e. the tile number obtained in each pressing cycle. Therefore, this depends on the format, the maximum force that the press can generate and the clearance or distance between columns, in other words the maximum size the mould can be.

Cavities may be arranged in single or multiple rows. The considerable increase in tile sizes in recent years has led to an increase in the maximum force presses can develop, which is why manufacturers are concentrating their efforts on obtaining structures that allow high clearances for the installation of the mould.

2.4.1. Calculation of the cavity dimensions.

In order to correctly define the cavities dimensions and, subsequently, the number of outlets of a mould, it is necessary to consider the using conditions of the mould. In addition to the nominal sizes of the tiles to be obtained, it is also necessary to know the type of product and some of its technological characteristics, such as its post-pressing expansion or shrinkage after firing; and of course the technical characteristics of the press and the feeding system used.

To illustrate how to perform these calculations, let us assume in this section the most general case of tile manufacture, with square or rectangular formats.

The actual dimensions of the cavities depend on the nominal size (L_{F1} y L_{F2}) that we want to obtain after the manufacturing process. It should be regarded that tiles undergo an expansion after pressing (**EP**) which generally ranges around 0,5 %, although higher values may occur, and a shrinkage after firing (**CL**) which is small in claddings but important in stoneware products (table 2.2). The dimensional variations that the tiles may undergo in the drying stage are not considered in this section, since the pressing moisture content is below the shrinkage limit of the industrial pastes used.

Product	Compaction pressure (Kg/cm ²)	ρ_a (g/cc)	Firing temp. (°C)	EP (%)	CL (%)
Porcelanic – 1 standard.	400	1.998	1180	0.49	6.62
Porcelanic – 2 white.	400	1.948	1200	0.59	7.32
Porcelanic – 3 white.	400	1.980	1200	0.55	6.68
Porcelanic – 3 coloured.	400	2.026	1190	0.49	6.32
White ceramic wall tiling.	250	1.975	1140	0.45	0.17
Red ceramic tiles.	250	2.071	1135	0.41	5.33

Note: ρ_a : dry bulk density.

Table 2.2. Post-press expansion and linear shrinkage in the working conditions of some industrial pastes.

Therefore, if it is desired that the dimensions of the tiles after firing are those of their nominal format, they must be pressed with different dimensions to compensate for the resultant dimensional changes.

“Post-press expansion”(PE) is the widening experienced by the tiles after their extraction from the cavity and is expressed as:

$$EP = \frac{L_0 - L_A}{L_A} \cdot 100 \quad (\text{Equation 1})$$

in which:

- PE: Post-press expansion (%)
- L_0 : Length of the raw tile after extraction from the cavity (cm)
- L_A : Length of the raw tile inside the cavity (cm)

“Linear shrinkage” (LS) is the shrinkage experienced by ceramic products after firing and is expressed as:

$$CL = \frac{L_0 - L_F}{L_0} \cdot 100 \quad (\text{Equation 2})$$

where:

- LS: Linear shrinkage (%)
- L_0 : Length of the raw tile after extraction from the cavity (cm)
- L_F : Length of the fired tile (cm)

Figure 2.36 shows the dimensional variations that a tile undergoes throughout the manufacturing process.

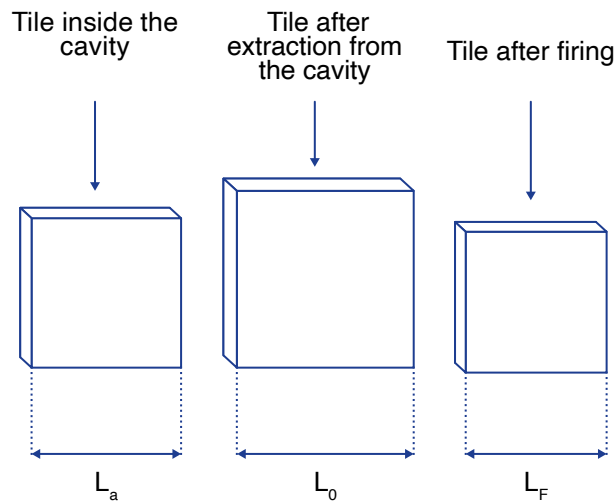


Figure 2.36. Dimensional variations (not to scale) that a tile undergoes throughout the manufacturing process.

Combining equations 1 and 2, the cavity length (L_A) and the length of the tile after firing, or nominal format (L_F) are linked:

$$L_A = \frac{L_F}{\left(1 - \frac{CL}{100}\right) \cdot \left(1 + \frac{EP}{100}\right)} \quad (\text{Equation 3})$$

2.4.2. Calculation of the maximum number of outlets.

Once the dimensions of the cavities have been determined, the next step is to define the number of mould exits. This depends on the dimensions of the cavity, which have already been calculated, the type of product to be manufactured, the maximum force the press can develop, the clearance of the press and the dimensional characteristics of the feed carriage used.

In order to achieve the pressure capable of giving the tile the required microstructure, the press must develop a certain pressing force (**F**) depending on the area (**S**) to be pressed. This area is equal to that of an alveolus (**S_A**) times the number of outlets (**N**).

The cavity area is:

$$S_A = L_{A1} \cdot L_{A2} \quad (\text{Equation 4})$$

y

$$F = P \cdot S = P \cdot S_A \cdot N \quad (\text{Equation 5})$$

It is convenient that the press should usually be operated below 80% of its power²², so if $F_{\max}$ is the maximum force (in tonnes) it can develop, the working force (F) will be equal to $0.8 F_{\max}$. The maximum force depends on the type of the press used.

Thus, **the theoretical maximum number of outlets** a mould can have is:

$$N = \frac{0.8 F_{\text{press}}}{P \cdot S_A} \cdot 1000 \quad (\text{Equation 6})$$

Where **P** is expressed in Kg/cm², **F_{max}** in t and **S_A** in cm²

²² This data, recommended by some press manufacturers, sometimes contrasts with the practice of tile manufacturers who can choose a higher or lower maximum pressing force. In fact, depending on the manufacturer, a ratio of 85 % or even higher may sometimes be used for the calculation of the maximum outlets number.

2.4.3. Conditioning factors of the outlets number.

Once we have calculated the theoretical outlets number that can be installed under the given conditions, we have to check that it is actually possible to build a mould with this outlets number and if it fits and perform flowlessly inside the press. There is a number of **conditioning factors**, which may cause the number of outlets to be lower than the maximum possible. These factors are:

- Press clearance.
- Feeder car usable width.
- Plunger dimensions.
- Depth of the press bench.
- Distance between cavities.
- Dryer mouth width.
- Compensator width(if available).

The first characteristic that conditions the useful distance for the installation of the mould is, logically, the clearance of the press. The clearance is the gap inside the press structure where the piston, the mobile plunger and the mould should be installed and therefore is the main factor that determines, together with the force the press can develop, the number of outlets that can be installed in the mould and therefore its productivity. The higher the maximum force the press can develop, the wider the clearance will be.

It should be noted that, as mentioned above, to ensure proper loading of the cavities, especially those at the ends of the mould, **the useful feeder car width** must be slightly greater than the space occupied by the cavities and their partition walls as defined in Figure 2.35, so these useful lengths are reduced by the useful width of the feed trolley installed in the press, as this limits the useful mould space where the cavities can be placed. In general terms, and for guidance purposes only, this reduction in usable length can be considered to be around 180 mm for the larger tonnage presses and 150 mm for the smaller ones. A reduction between 7 % and 9 % respectively.

Press	Clearance between columns (mm)	Maximum mould loading width (mm)
PH-1000	1550	1405
PH-1500	1600	1455
PH-1890	1750	1595
PH-2090	1750	1595
PH-2590	1750	1595
PH-2890	1750	1595
PH-3020	2250	2085
PH-3590	1750	1595
PH-3800	2450	2275
PH-4600	1750	1595
PH-4800	2250	2085
PH-4900	2450	2275
PH-6200	2450	2275

Table 2.3. Useful dimensions for the installation of the mould in SACMI presses.

Table 2.3 shows the values for the clearance between columns and the useful distance for mould mounting considering the carriage width, for some SACMI presses.

Although it is not frequent, the **the mobile plunger dimensions** may also become a limiting factor for the outlets number. The mobile plunger is connected to the piston and supports the punch holder plate where the upper mould punches are attached and therefore it must have sufficient dimensions for installation, although exceptionally, in entry moulds, punch holder plates exceeding no more than 75 mm per side may be installed. However, this is not advisable with the double mould and neither with the entry mirror mould.

It should always be checked that the **depth of the press bench** is sufficient to accommodate the type of mould designed, especially in large formats or when the cavities are placed in two or more rows.

The **minimum gap between cavities** to ensure adequate mechanical strength of a die made of DIN CK45 steel, 100 mm thick with traditional liners is between 40 mm to 50 mm, including the liners. In both traditional and removable liners, in small formats, there are exceptional cases where we can find 30 mm liners, although they are always combined with 50-55 mm partitions walls in order to gain space but not completely lose the strength of the die box.

There are other external factors that may condition the maximum outputs number, and even the production feasibility of a given format, such as **the dimensions of the compensators and the dryer**. Its definition concerns the design process of the plant and not the mould, so we will simply record its existence.

2.4.4. Example.

Let us suppose that we have a press capable of developing 4900 t of maximum force, and we want to press white porcelain tiles - 2 (table 2.2) with a nominal format of 45 x 45 cm, and we want to calculate the number of outlets of the mould.

Calculation of the cavity dimensions.

The paste to be pressed has a postpressing expansion of 0.59 %, under usual working conditions, which we define as 400 Kg/cm² of specific pressure and 6.3 % humidity on a dry basis. After firing at 1200 °C it experiences a linear shrinkage of 7.32 %. Therefore, the length of the alveolus to obtain tiles fired at this temperature with LF = 45 cm has to be:

$$L_A = \frac{45}{\left(1 - \frac{7,32}{100}\right) \cdot \left(1 + \frac{0,59}{100}\right)} = 48,27 \text{ cm.}$$

Outlets number calculation.

The maximum pressing force of this press is 4900 tonnes, so the recommended working force (80%) will be:

$$F = 0,8 \cdot 4900 = 3920 \text{ t}$$

Based on this data, the number of outlets that can be installed in the mould will be:

$$N = \frac{3920}{400 \cdot (48,27)^2} \cdot 1000 = 4,2 \rightarrow \mathbf{4 \text{ salidas}}$$

Theoretically, this press would be able to press porcelain tiles at 400 Kg/cm² with a 4 outlets mould with . However, the calculation has not been solved yet , since it is still necessary to analyse the conditions for the installation of a mould with these characteristics in the press, i.e. it is still necessary to evaluate whether the clearance of the press and the dimensions of the installed feeder car can condition the installation of this mould, as indicated above.

A 4900 tonnes operating press in the sector has a clearance of 2450 mm. Clearance, however, is not the dimensional characteristic that determines the width of the mould, but rather the useful loading feeder car width, which is obviously smaller. Logically, the dimensional characteristics of the feeding car depend on those of the press. The feeding car installed in this type of press has an effective loading width of 2275 mm (table 2.3) and therefore this is the new dimension conditioning the number of mould outlets.

In a first approximation, we can consider that the minimum width at the ends of the mould should not be less than 85 mm and that the distance between cavities should be equal to or greater than 60 mm ²³ including the liners (Figure 2.37). With these data the minimum width of the die box (A_m) with 4 outlets for 45 x 45 cm would be:

$$A_m = 4 \times 482,7 + 3 \times 60 + 2 \times 85 = 2280,8 \text{ mm}$$

Therefore, there is enough space for all 4 outlets.

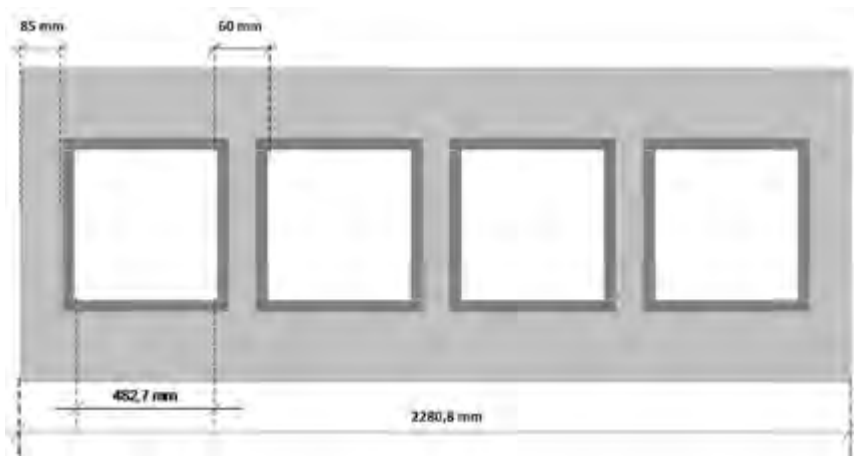


Figure 2.37. Drawing of a 4-outlet die box for porcelain tiles with the minimum dimensions of partition walls and frame.

²³ These minimum dimensions should not be taken as an absolute and standard value of the moulds. They depend on each format and, to a lesser extent, on the type of product.

At this point, once we have confirmed it is possible to manufacture a mould with 4 outlets of 45 x 45 cm for this press, we must take into account that the manufacturer of the press gives us a piece of information that conditions the design of the mould. This is the maximum loading width, which depends on the installed feeder car (Figure 2.35). This data is given in Table 2.3 and is 2275 mm which is compatible with the projected die box which can be larger by extending the lateral width of the die box.

The design of the honeycomb grid feeder shall take into account the space occupied by the alveoli and partition walls, plus 15 mm on each side given to ensure good alveoli loading.

The total length of a mould (bench plate) installed in this type of press is 2410 mm.

2.4.5. Tables.

Tables 2.4 to 2.16 show the maximum number of outlets, for different formats and products, that can be produced on some operational presses in the sector, considering a daily operation at 80 % of their maximum force. It should be noted that the calculations refer only to the **theoretical maximum number** of outlets that can be pressed under the given conditions²⁴. Thus, the number of outlets actually installed may be smaller, and in many cases is in fact smaller, as it also depends, as mentioned above, on the dimensions of the feeder car and other conditioning factors. In the boxes where the number of outlets is not indicated, it is considered that it is not usual to use the press in question to produce this format. It should also be noted that when it is necessary to place the outlets in two rows, the number of outlets should be an even number, so the maximum number of outlets according to this consideration should be indicated in brackets in the tables and it should be checked that it is possible to install them on the press bench.

CERAMIC TILES PPE = 0.4% LS = 6.0% (1135 °C) P = 250 Kg/cm ²				PH 1000	PH 1500	PH 1890	PH 2090	PH 2590	PH 2890	PH 3020	PH 3590
				F max (t).							
				Clearance (mm).							
Nominal format		Alveoli dimensions		Outlets maximum number.							
L (cm)	W (cm)	L _R (cm)	W _R (cm)								
15	22.5	15.94	23.90	8							
15	30	15.94	31.87	6	9 (8)						
20	20	21.25	21.25	7 (6)	10	12					
20	25	21.25	26.56	5	8	10					
20	30	21.25	31.87	4	7 (6)	8	9 (8)	11 (10)	12		
25	25	26.56	26.56	4	6	8	9 (8)	11 (10)	12		
30	30	31.87	31.87	3	4	5	6	7 (6)	8	9 (8)	
33.3	33.3	35.38	35.38	2	3	4	5	6	7 (6)	7 (6)	8
30	40	31.87	42.50	2	3	4	4	5	6	7 (6)	8
30	50	31.87	53.12	1	2	3	3	4	5	5	6
30	60	31.87	63.75	1	2	2	3	3	4	4	5
40	40	42.50	42.50	1	2	3	3	4	4	5	6
40	60	42.50	63.75	1	1	2	2	2	3	3	4
50	50	53.12	53.12	1	1	2	2	2	3	3	3
60	60	63.75	63.75	0	1	1	1	1	2	2	2
60	90	63.75	95.62	0	0	0	1	1	1	1	1

Table 2.4. PH 2000 press series from SACMI. (Stoneware flooring).

²⁴The post-pressing expansion and linear shrinkage values are for guidance only.

PORCELAIN TILES. PPE = 0.4% LS = 7.3% (1200 °C) P = 400 Kg/cm²				PH 1000	PH 1500	PH 1890	PH 2090	PH 2590	PH 2890	PH 3020	PH 3590	
				F max (t).	1000	1500	1800	2000	2500	2750	3000	3500
				Clearance (mm).	1550	1600	1750	1750	1750	1750	2250	1750
Nominal format		Alveoli dimensions		Outlets maximum number.								
L (cm)	W (cm)	L _R (cm)	W _R (cm)									
10	20	10.74	21.49	8	12							
15	22.5	16.12	24.18	5	7 (6)	9 (8)	10					
15	30	16.12	32.23	3	5	6	7 (6)	9 (8)				
20	20	21.49	21.49	4	6	7 (6) (6)	8	10				
20	25	21.49	26.86	3	5	6	6	8	9 (8)			
20	30	21.49	32.23	2	4	5	5	7 (6)	7 (6)	8		
25	25	26.86	26.86	2	4	4	5	6	7 (6)	8		
30	30	32.23	32.23	1	2	3	3	4	5	5	6	
33.3	33.3	35.78	35.78	1	2	2	3	4	4	4	5	
30	40	32.23	42.98	1	2	2	2	3	3	4	5	
30	50	32.23	53.72	1	1	2	2	2	3	3	4	
30	60	32.23	64.47	0	1	1	1	2	2	2	3	
40	40	42.98	42.98	1	1	1	2	2	2	3	3	
40	60	42.98	64.47	0	1	1	1	1	1	2	2	
50	50	53.72	53.72	0	1	1	1	1	1	2	2	
60	60	64.47	64.47	0	0	0	0	1	1	1	1	
60	90	64.47	96.70	0	0	0	0	0	0	0	1	

Table 2.5. PH 2000 press series from SACMI. (Porcelain tiles).

PORCELAIN TILES. PPE = 0.4% LS = 7.3% (1200 °C) P = 400 Kg/cm²				PH 3800	PH 4600	PH 4800	PH 4900	PH 6200	PH 7200	
				F max (t).	3800	4600	4800	4900	6200	7200
				Clearance (mm).	2450	1750	2250	2450	2450	1750
Nominal format		Alveoli dimensions		Outlets maximum number.						
L (cm)	W (cm)	L _R (cm)	W _R (cm)							
33.3	33.3	35.78	35.78	5	7 (6)	7 (6)	7 (6)	9 (8)		
30	40	32.23	42.98	5	6	6	7 (6)	8		
30	50	32.23	53.72	4	5	5	5	7 (6)	8	
30	60	32.23	64.47	3	4	4	4	5	6	
40	40	42.98	42.98	4	4	5	5	6	7 (6)	
40	60	42.98	64.47	2	3	3	3	4	5	
50	50	53.72	53.72	2	3	3	3	4	4	
60	60	64.47	64.47	1	2	2	2	2	3	
60	90	64.47	96.70	1	1	1	1	1	2	
60	120	64.47	128.93	0	1	1	1	1	1	

Table 2.6. PH POWER press series from SACMI. (Porcelain tiles).

PORCELAIN TILES. PPE = 0.4% LS = 7.3% (1200 °C) P = 400 Kg/cm²				PH 3800	PH 5000L	PH 5000XL	PH 5000XXL	PH 6500	PH 7500	PH 10000	
				F max (t).	3800	4600	4800	4900	6200	7500	10000
				Clearance (mm).	2450	1750	2450	2450	2450	2450	2450
Nominal format		Alveoli dimensions		Outlets maximum number.							
L (cm)	W (cm)	L _R (cm)	W _R (cm)								
30	60	32.23	64.47	3	4	4	4	6	7 (6)	9 (8)	
45	45	48.35	48.35	3	4	4	4	5 (4)	6	8	
40	60	42.98	64.47	2	3	3	3	4	5 (4)	7 (6)	
60	60	64.47	64.47	1	2	2	2	3	3	4	
60	90	64.47	96.70	1	1	1	1	2	2	3	
60	120	64.47	128.93	0	1	1	1	1	1	2	

Table 2.7. PH IMOLA press series from SACMI. (Porcelain tiles).

PORCELAIN TILES. PPE = 0.4% LS = 7.3% (1200 °C) P = 400 Kg/cm²				2500 / 1750	2800 / 1750	3000 / 2250	3500 / 1750	4600 / 1750	4600 / 2250	4800 / 2450	
				F max (t).	2500	2800	3000	3500	4600	4600	4800
				Clearance (mm).	1750	1750	2250	1750	1750	2250	2450
Nominal format		Cavities dimensions		Outlets maximum number.							
L (cm)	W (cm)	L _R (cm)	W _R (cm)								
33.3	33.3	35.78	35.78	3	4	4	5	7 (6)	7 (6)	7 (6)	
30	40	32.23	42.98	3	4	4	5	6	6	6	
30	50	32.23	53.72	2	3	3	4	5	5	5	
30	60	32.23	64.47	2	2	2	3	4	4	4	
40	40	42.98	42.98	2	3	3	3	4	4	5	
40	60	42.98	64.47	1	2	2	2	3	3	3	
50	50	53.72	53.72	1	1	2	2	3	3	3	
60	60	64.47	64.47	1	1	1	1	2	2	2	
60	90	64.47	96.70	0	0	0	1	1	1	1	
60	120	64.47	128.93	0	0	0	0	1	1	1	

Table 2.8. CLOCK press series from BARBIERI TAROZZI. (Porcelain tiles).

PORCELAIN TILES. PPE = 0.4% LS = 7.3% (1200 °C) P = 400 Kg/cm ²				EVO 2808/2180	EVO 3208/2150	EVO 3608/2400	EVO 4208/2400	EVO 4608/2280	EVO 5008/2450	EVO 6208/2450	EVO 7208/2400
				F max (t).	2800	3200	3600	4200	4600	5000	7200
				Clearance (mm).	2180	2150	2400	2400	2280	2450	2400
Nominal format		Cavities dimensions		Outlets maximum number.							
L (cm)	W (cm)	L _R (cm)	W _R (cm)								
33.3	33.3	35.78	35.78	4	4	5	6	7 (6)	7 (6)		
30	40	32.23	42.98	4	4	5	6	6	7 (6)	8	
30	50	32.23	53.72	3	3	4	4	5	5	7 (6)	8
30	60	32.23	64.47	2	3	3	4	4	4	5	6
40	40	42.98	42.98	3	3	3	4	4	5	6	7 (6)
40	60	42.98	64.47	2	2	2	3	3	3	4	5
50	50	53.72	53.72	1	2	2	2	3	3	4	4
60	60	64.47	64.47	1	1	1	2	2	2	2	3
60	90	64.47	96.70	0	1	1	1	1	1	1	2
60	120	64.47	128.93	0	0	0	1	1	1	1	1

Table 2.9. EVO press series from SITI B&T. (Porcelain tiles).

POROUS CERAMIC WALL TILING. PPE = 0.4% LS = 0.8% (1140 °C) P = 250 Kg/cm²				Magnum 801	Magnum 1201	Magnum 1501	Magnum 1701	Magnum 1705XL	Magnum 2101	Magnum 2501	Magnum 2501XL	
				F max (t).	800	1200	1500	1700	1700	2100	2500	2500
				Clearance (mm).	1150	1450	1450	1450	1750	1560	1260	1750
Nominal format		Cavities dimensions		Outlets maximum number.								
L (cm)	W (cm)	L _R (cm)	W _R (cm)									
15	30	15.06	30.12	5	8	10						
20	20	20.08	20.08	6	9	11 (10)						
20	25	20.08	25.10	5	7 (6)	9 (8)						
20	30	20.08	30.12	4	6	7 (6)	8	8				
25	25	25.10	25.10	4	6	7 (6)	8	8				
30	30	30.12	30.12	2	4	5	5	5	7 (6)	8	8	
33.3	33.3	33.43	33.43	2	3	4	4	4	6	7 (6)	7 (6)	
30	40	30.12	40.16	2	3	3	4	4	5	6	6	
30	50	30.12	50.20	1	2	3	3	3	4	5	5	
30	60	30.12	60.24	1	2	2	2	2	3	4	4	
40	40	40.16	40.16	1	2	2	3	3	4	4	4	

Table 2.10. Magnum press series from SITI B&T. (Porous ceramic wall tiles).

STONEWARE FLOORING PPE = 0.4% LS = 6.0% (1135 °C) P = 250 Kg/cm²				Magnum 801	Magnum 1201	Magnum 1501	Magnum 1701	Magnum 2101	Magnum 2501	
				F max (t).	800	1200	1500	1700	2100	2500
				Clearance (mm).	1150	1450	1450	1450	1560	1560
Nominal format		Cavities dimensions		Outlets maximum number.						
L (cm)	W (cm)	L _R (cm)	W _R (cm)							
15	22.5	15.89	23.84	6	10					
15	30	15.89	31.79	5	7 (6)	9	10			
20	20	21.19	21.19	5	8	10	12			
20	25	21.19	26.49	4	6	8	9 (8)			
20	30	21.19	31.79	3	5	7 (6)	8	9 (8)		
25	25	26.49	26.49	3	5	6	7 (6)	9 (8)		
30	30	31.79	31.79	2	3	4	5	6	7 (6)	
33.3	33.3	35.28	35.28	2	3	3	4	5	6	
30	40	31.79	42.38	1	2	3	4	4	5	
30	50	31.79	52.98	1	2	2	3	3	4	
30	60	31.79	63.58	1	1	2	2	3	3	
40	40	42.38	42.38	1	2	2	3	3	4	
40	60	42.38	63.58	0	1	1	2	2	2	
50	50	52.98	52.98	0	1	1	1	2	2	
60	60	63.58	63.58	0	0	1	1	1	1	
60	90	63.58	95.36	0	0	0	0	1	1	

Table 2.11. Magnum press series from SITI B&T. (Stoneware flooring).

PORCELAIN TILES PPE = 0.4% LS = 7.3% (1200 °C) P = 400 Kg/cm²				WK 1500	WK 2000	WK 2500	WK 2800	WK 3500	WK 4200	WK 5000	WK 5500	WK 7500	
				F max (t).	1500	2000	2500	2800	3500	4200	5000	5500	7500
				Clearance (mm).	1600	1750	1750	1750	1750	1750		1750	
Nominal format		Cavities dimensions		Outlets maximum number.									
L (cm)	W (cm)	L _R (cm)	W _R (cm)										
33.3	33.3	35.78	35.78	2	3	3	4	5	6	7 (6)	8	11 (10)	
30	40	32.23	42.98	2	2	3	4	5	6	7 (6)	7 (6)	10	
30	50	32.23	53.72	1	2	2	3	4	4	5	6	8	
30	60	32.23	64.47	1	1	2	2	3	4	4	5	7 (6)	
40	40	42.98	42.98	1	2	2	3	3	4	5	5	8	
40	60	42.98	64.47	1	1	1	2	2	3	3	3	5	
50	50	53.72	53.72	1	1	1	1	2	2	3	3	5	
60	60	64.47	64.47	0	0	1	1	1	2	2	2	3	
60	90	64.47	96.70	0	0	0	0	1	1	1	1	2	
60	120	64.47	128.93	0	0	0	0	0	1	1	1	1	

Table 2.12. WK press series from WELKO. (Porcelain tiles).

PORCELAIN TILES. PPE = 0.4% LS = 7.3% (1200 °C) P = 400 Kg/cm²				WK2 3500	WK2 4600	WK2 6200	WK2 12000	
				F max (t).	3500	4600	6200	12000
				Clearance (mm).	2250	2250	2500	1770 x 2800
Nominal format		Cavities dimensions		Outlets maximum number.				
L (cm)	W (cm)	L _R (cm)	W _R (cm)					
33.3	33.3	35.78	35.78	5	7 (6)	9 (8)		
30	40	32.23	42.98	5	6	8		
30	50	32.23	53.72	4	5	7 (6)		
30	60	32.23	64.47	3	4	5		
40	40	42.98	42.98	3	4	6		
40	60	42.98	64.47	2	3	4	8	
50	50	53.72	53.72	2	3	4	8	
60	60	64.47	64.47	1	2	2	5	
60	90	64.47	96.70	1	1	1	3	
60	120	64.47	128.93	0	1	1	2	

Table 2.13. WK2 press series from WELKO. (Porcelain tiles).

POROUS CERAMIC WALL TILING. PPE= 0.4% LS = 0.8% (1200 °C) P = 250 Kg/cm²				VIS 400	VIS 401	VIS 801	VIS 1000	VIS 1200	VIS 1500	VIS 2000	
				F max (t).	350	400	800	1000	1200	1500	2000
				Clearance (mm).	720	920	1120	1450	1600	1600	1600
Nominal format		Cavities dimensions		Outlets maximum number.							
L (cm)	W (cm)	L _R (cm)	W _R (cm)								
10	20	10.04	20.08	5	6	12					
15	22.5	15.06	22.59	3	3	7 (6)	9	11 (10)			
15	30	15.06	30.12	2	2	5	7 (6)	8	10		
20	20	20.08	20.08	2	3	6	7 (6)	9	11 (10)		
20	25	20.08	25.10	2	2	5	6	7 (6)	9 (8)	12	
20	30	20.08	30.12	1	2	4	5	6	7 (6)	10	
25	25	25.10	25.10	1	2	4	5	6	7 (6)	10	
30	30	30.12	30.12	1	1	2	3	4	5	7 (6)	
33.3	33.3	33.43	33.43	1	1	2	2	3	4	5	
30	40	30.12	40.16	0	1	2	2	3	3	5	
30	50	30.12	50.20	0	0	1	2	2	3	4	
30	60	30.12	60.24	0	0	1	1	2	2	3	
40	40	40.16	40.16	0	0	1	1	2	2	3	

Table 2.14. VIS press series from NASSETTI. (Porous ceramic wall tiles).

STONEWARE FLOORING PPE= 0.4% LS = 6.0% (1200 °C) P = 250 Kg/cm²				VIS 400	VIS 401	VIS 801	VIS 1000	VIS 1200	VIS 1500	VIS 2000	
				F max (t).	350	400	800	1000	1200	1500	2000
				Clearance (mm).	720	920	1120	1450	1600	1600	1600
Nominal format		Cavities dimensions		Outlets maximum number.							
L (cm)	W (cm)	L _R (cm)	W _R (cm)								
10	20	10.60	21.19	4	5	11					
15	22.5	15.89	23.84	2	3	6	8	10	12		
15	30	15.89	31.79	2	2	5	6	7 (6)	9 (8)	12	
20	20	21.19	21.19	2	2	5	7 (6)	8	10		
20	25	21.19	26.49	1	2	4	5	6	8	11 (10)	
20	30	21.19	31.79	1	1	3	4	5	7 (6)	9 (8)	
25	25	26.49	26.49	1	1	3	4	5	6	9	
30	30	31.79	31.79	1	1	2	3	3	4	6	
33.3	33.3	35.28	35.28	0	1	2	2	3	3	5	
30	40	31.79	42.38	0	0	1	2	2	3	4	
30	50	31.79	52.98	0	0	1	1	2	2	3	
30	60	31.79	63.58	0	0	1	1	1	2	3	
40	40	42.38	42.38	0	0	1	1	2	2	3	

Table 2.15. VIS press series from NASSETTI. (Porcelain floor tiles).

PORCELAIN TILES. PPE = 0.4% LS = 7.3% (1200 °C) P = 400 Kg/cm²				VIS 1500	VIS 2000	VIS 2500	VIS 3200	VIS 5000	
				F max (t).	1500	2000	2500	3200	5000
				Clearance (mm).	1600	1600	1600	1600	1750
Nominal format		Cavities dimensions		Outlets maximum number.					
L (cm)	W (cm)	L _R (cm)	W _R (cm)						
33.3	33.3	35.78	35.78	2	3	3	4	7 (6)	
30	40	32.23	42.98	2	2	3	4	7 (6)	
30	50	32.23	53.72	1	2	2	3	5	
30	60	32.23	64.47	1	1	2	3	4	
40	40	42.98	42.98	1	2	2	3	5	
40	60	42.98	64.47	1	1	1	2	3	
50	50	53.72	53.72	1	1	1	2	3	
60	60	64.47	64.47	0	0	1	1	2	
60	90	64.47	96.70	0	0	0	1	1	
60	120	64.47	128.93	0	0	0	0	1	

Table 2.16. VIS press series from NASSETTI. (Porcelain tiles).

Mould components.

Chapter 3



All mould types described in Chapter 5 have common components with a similar function, regardless of their mechanical design, structure and mould operation. This chapter will describe each of these components, their main characteristics and their structure. The necessary indications will also be provided to understand how they work in each typology. For this purpose, it is quite useful to start from different types of moulds where all these components are reflected as schematically as possible and their real look can be appreciated in each type of mould (Figures 3.1 and 3.2). The manufacturing processes of these components and the physical properties of the materials they are made of will be explained in the next chapter.

Table 3.1 describes the main components of a mould as shown in Figures 3.1 and 3.2, together with a brief description of their function and the materials used in their manufacture.

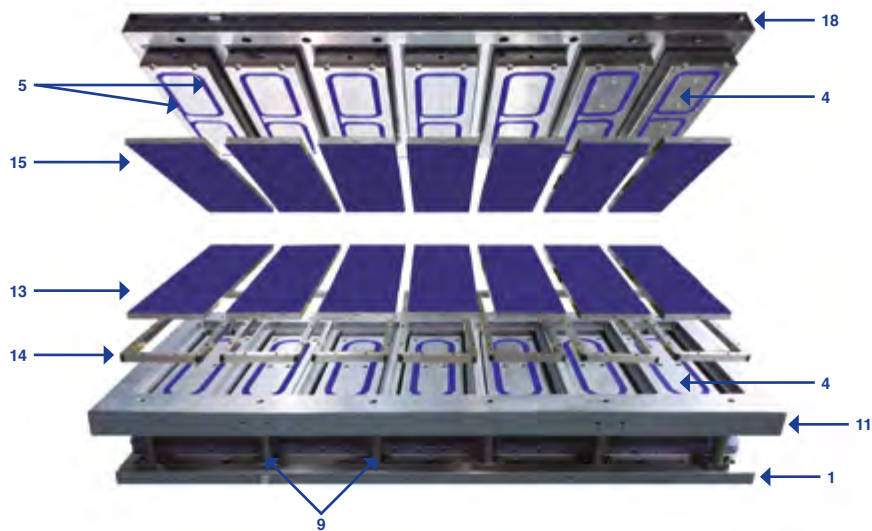


Figure 3.1. Mould components (of an entry mould)

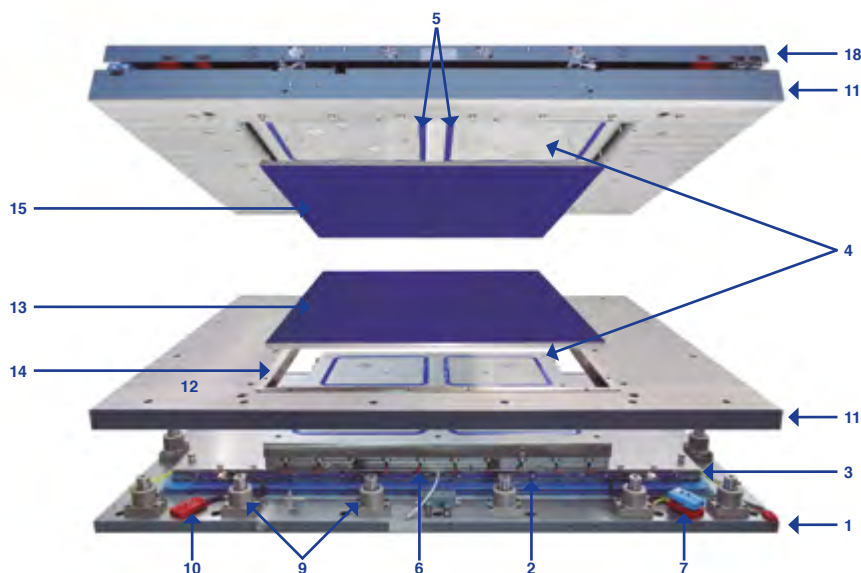


Figure 3.2. Mould components (of a double mould)

COMPONENT	No. (FIGURES 3.1 AND 3.2)	FUNCTION	MATERIAL
Bench plate.	1	It is the base of the mould that is bolted to the press bed. The die box supporting pillars in the entry moulds and the pistons for the movement of the die box in the double moulds and mirror moulds are located here. It withstands the compacting pressure.	DIN CK45 steel ²⁵ .
Bellows.	2	Synthetic protection with pleats which is clamped between the bench plate and the ejecting plate. It prevents powder entry between them. In some old moulds or some brick moulds the bellows may be made of leather.	Leather (old bellows). Elastomers
Ejecting plate.	3	This is the holder punch plate, i.e. the plate where the magnetic blocks and punches are attached, forming the ejector assembly of the mould.	DIN CK45 steel.
Blocks	4	These are steel blocks attached to the ejecting plate and where the lower punches are magnetically attached. This connection can be mechanical for small formats.	DIN CK45 steel, or higher strength steels, depending on their size ²⁶ .
Magnetic coils.	5	They are located inside machined slots inside the blocks and the upper punch holder plate. They have the function of magnetising them to hold the punches.	
Magnetic blocks heating resistances.	6	These are tubular heaters used to heat the punches in order to prevent the moulds from sticking and to adjust, if necessary, the clearance between the punches and the liners.	
Fast plugs.	7 to 10	Depending on the number of power transformers of the press, one or two connection boxes are used for heating and magnetisation of the mould.	
Standard heating systems.	8	Set of heating elements, supported by steel plates, with power and design according to the characteristics of the die box to be heated and the press.	
Fixed pillars	9	They keep the die box of the entry mould fixed and leveled. They are supported by the bench plate.	
Lower die box holding and movement pistons (double die and mirror die).	9'	These are the pistons that guide the lower die box of double moulds and mirror moulds during the pressing operation.	
Die boxes.	11	This is the plate where the cavities are located, delimited by the liners. Entry moulds have a single fixed die box. Mirror and semi-mirror moulds have a single movable die box and double moulds have two die boxes, the lower one, which is movable, and the upper one, which is fixed.	According to types. DIN CK45 steel.

²⁵ Carbon steel for products with a strength between 65 and 75 Kg/mm². Quenched steel is suitable for surface hardening equivalent to steel F1140 UNE 36011-12 standard ^[60].

²⁶ In small formats, quenched steels are used.

COMPONENT	No. (FIGURES 3.1 AND 3.2)	FUNCTION	MATERIAL
Wear resistant plate.	12	It is a stainless steel plate screwed on top of the die box. It has the function of supporting the wear caused by the feeder car when it slides over the die box, protecting it.	Stainless steels.
Lower punches.	13	They form the face of the back reliefs in double moulds and mirror moulds and the good face in entry moulds (*).	According to types. • Rubber coated DIN CK45 steel. • Tempered DIN 1.2080²⁷ steel.
Liners.	14	Components that are installed inside the cavities of the die box, delimiting the perimeter of one cavity. They give the final shape and side profile of the pressed tile. They withstand the lateral stresses generated in the pressing operation and the wear caused by the abrasive materials in the pressed powder.	According to the type: • Tempered DIN 1.2080 steel. • DIN 1.2080 steel with WC HVOF injection - Co • DIN 1.2080 steel with tungsten carbide plates.
Upper punches.	15	They transmit the pressure to the dust contained inside the cavity. In entry moulds (*): - They form the underside of the tiles. They print the manufacturer's brand name and the punch number. - With hydraulic compensation. In mirror and double moulds. - They form the good face of the tile. - Without hydraulic compensation.	According to the type: • Rubber coated DIN CK45 steel (with or without hydraulic compensation). • Tempered DIN 1.2080 steel.
Thermoprobe.	16	Allows temperature control of the lower punches.	
Blowers	17	Located between the magnetic blocks. They emit air pulses every press stroke in order to prevent dust accumulation.	
Candle hook plates or ring candles.	-	Candle hook plates are hardened steel plates which, in moulds with piston and candle extraction systems, are located in housings at the base of each magnetic block and are used to fix the candles. Ring candles are the anchoring systems of the mould to the SPE extractor system.	• Tempered DIN 1.2080 steel. • Others.
Magnetic upper plate.	18	Screwed plate to the mobile plunger of the press where the upper punches are magnetically attached.	DIN CK45 steel.

(*) These configurations described for the upper and lower punches are the usual ones for the vast majority of these moulds. Exceptionally, however, they can differ and some entry moulds can be adapted to form tiles with the good face upwards, thus reversing the configuration of the punches.

Table 3.1. Mould components and materials.

²⁷ High chromium alloy steel with high wear resistance, abrasion resistance and high dimensional stability after tempering. It is suitable for the manufacture of cold working tools with high wear and abrasion resistance.

3.1. BENCH PLATE.

Bench, bottom or bed plates (Figure 3.3) are the base of the mould that is bolted to the press bench. The die box supporting pillars, in entry moulds, or the pistons for supporting and movement of the die box, in double moulds, mirror moulds and entry mirror moulds, are located here.

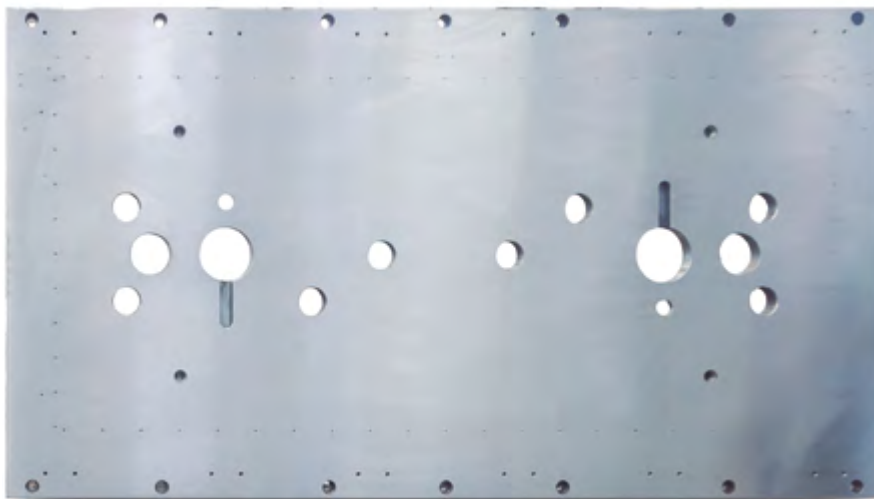


Figure 3.3. Bench plate

During the first and second pressings, the ejecting plate rests on the bench plate. Initially, this plate was machined with deaeration channels for the evacuation of the air sheet located between the bench plate and the ejecting plate, which allows the latter to quickly rest on the bottom plate during the pressing operation. Nowadays, these channels are no longer machined on the bottom plate and have been replaced by machining on the ejecting plate.

Table 3.2 shows the dimensions of bench plates used in some presses and their relation to the press clearance.

Press	Manufacturer	Clearance (mm)	Dimensions of the bottom plate (mm)		
			Length	Width	Height
PH 1400.	SACMI	1550	1350	700	48
PH 1500.	SACMI	1600	1500	900	55
PH 2590.	SACMI	1750	1710	860	55
V-3000.	NASSETTI	1600	1590	950	48
Magnum 2805.	SITI B&T	1750	1710	860	55
Alpha 800.	LAEIS BUCHER	1300	1230	600	48
PH 6500	SACMI	2450	2430	1700	55
EVO 7608	SITI B&T	2450	2430	1500	65
WK2 4800	WELKO	2250	2100	960	55
PH 5000 XXL	SACMI	2450	2430	1300	55
EVO 7208	SITI B&T	2400	2350	1450	65
PH 8200	SACMI	2450	2430	1700	55
PH 10000	SACMI	2450	2430	1700	55

Tabla 3.2. Dimensions of some bench plates.

3.2. EJECTING PLATE, CANDLE HOOK PLATES AND ANCHORING SYSTEMS.

The ejecting plate is the one where the magnetic blocks and punches are attached, thus forming the mould ejecting assembly. It is also the base for holding the extractor pistons of the forming and extraction system. They move the assembly formed by the ejecting plate, the magnetic blocks and the lower punches. If necessary, venting channels can be machined on the bottom side in order to evacuate the air trapped between the bench plate and the ejecting plate.

The size of the ejecting plate is conditioned by the size of the bench plate, and to determine its exact size for each mould, during the design stage, some structural characteristics of the mould and the press extraction system must be considered. Some examples are the type of bellows installed and its anchoring system or the position of the die box feet or pistons.



Figure 3.4. Ejecting and candle hook plates (back view)

In presses equipped with pistons and candle extractors, the ejecting plate (Figure 3.4.) is connected to the latter through candle hook plates (Figures 3.4. and 3.5.), where the blocks (Figure 3.4.) are mechanically fastened.



Figure 3.5. Candle hook plates.

The attachment of the ejecting plate to the extraction systems depends on the system the press is equipped and differs according to the press manufacturer. For example, in SACMI presses (SPE system, Figure 3.6), this is done using ring candles (Figure 3.7), which are lockable clamps. They are supported on a set spring washers to allow them to open and close. Quick changeover moulds have a threaded cam and screws with spring washers. This allows the mould to be removed without having to exert pressure over the plate. SITI B&T presses (SYNCRO® and E-SYNCHRO® system, Figure 3.8) use ball joint bearings (Figure 3.9), which have a hemispherical cavity that support the pistons that follow the downward movement of the central piston. The extraction systems of the SITI B&T presses consist

of a central piston that moves the punch holder downwards, and four hydraulic pistons positioned at the corners of the ejecting plate for moving it upwards. These cylinders are fitted using the ball joint bearings described above.

The anchorage in WELKO presses is carried out through the candle hook plates described above.



Figure 3.6. Detail of the SACMI SPE 2+2® forming and extraction system. Photo courtesy of SACMI.



Figure 3.7 Anchoring ring candles for the SACMI SPE forming and extraction system.

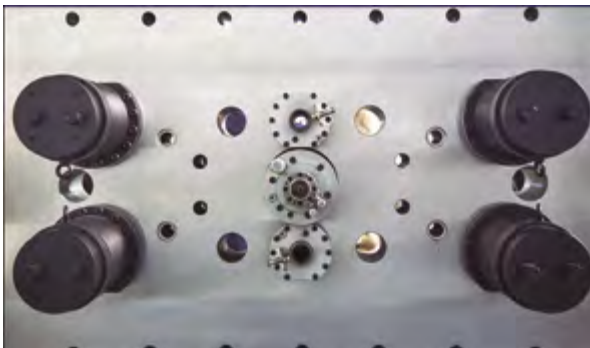


Figure 3.8. SYNCRO forming and extraction system® Photo courtesy of SITI B&T.



Figure 3.9. Anchorage for central piston and ball joint bearing for the SYNCRO® forming and extraction system.

3.3. MAGNETIC BLOCKS.

The magnetic blocks (Figures 3.10 and 3.11) are steel blocks attached to the ejecting plate, which hold the lower punches and they are part of the mould ejector system. Inside them there are machined slots where the magnetic coil is located²⁸. The coils housed in the magnetic blocks may be electromagnets or permanent magnets.



Figure 3.10. “Blocks” with magnetic coil.

The thickness, or height, of the magnetic block is the last thing to be decided in the design phase of the mould, as it depends on different parameters that usually have predetermined values, such as the thickness of the bench plate, ejecting plate, the thickness of the lower punch, the possible use of supplements and the value of the powder loading height. These dimensions, together with the mobile plunger stroke of the press, determine the thickness of the magnetic block.

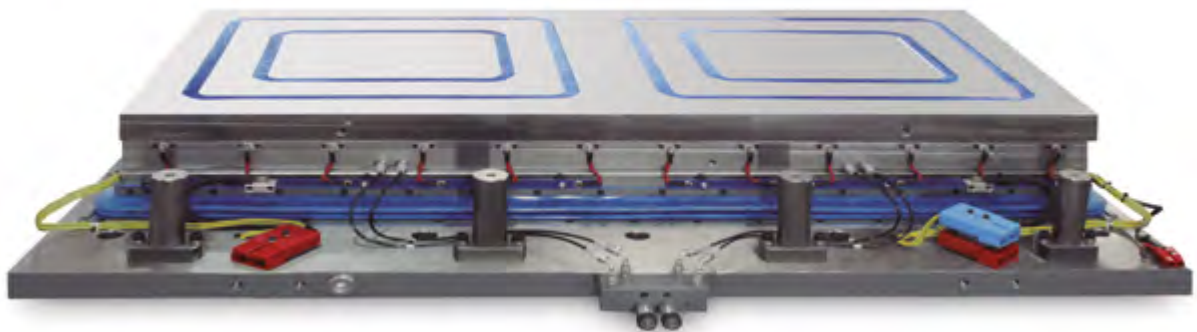


Figure 3.11. “Block” for 60 x 120 cm mould, with magnetic coil and the extraction system pistons.

²⁸ Initially, the lower punches were attached to the blocks with screws, although after the Second Industrial Reconversion of the sector, improvements were made to the moulds and one of them was the magnetic fastening of the punches. However, in small formats, where it is not possible to house a magnetic coil inside, the blocks are still mechanically held in place.

The magnetic block must be slightly smaller than the area of the lower punch, at least 4 to 5 mm less per side, to avoid powder accumulation between the block walls and the liners, and to facilitate its attachment to the ejecting plate by bolts. The difference between the area of the lower punch and the area of the magnetic block depends on the format, since in large formats there may be a greater difference; and it also depends on some pressing variables such as pressure, paste composition, etc. On some products, an excessive difference between the two areas can lead to a magnetic block marking, visible on the tile, or even a deformation of the lower punch. To avoid this, when the difference is excessive, the magnetic block can be supplemented along the perimeter with a sleeve, which is a metal insert that encloses it, assembled and screwed to the ejecting plate or to an insert of the magnetic block itself, thus increasing its area and reducing the overhang of the lower punch (Figure 3.12).

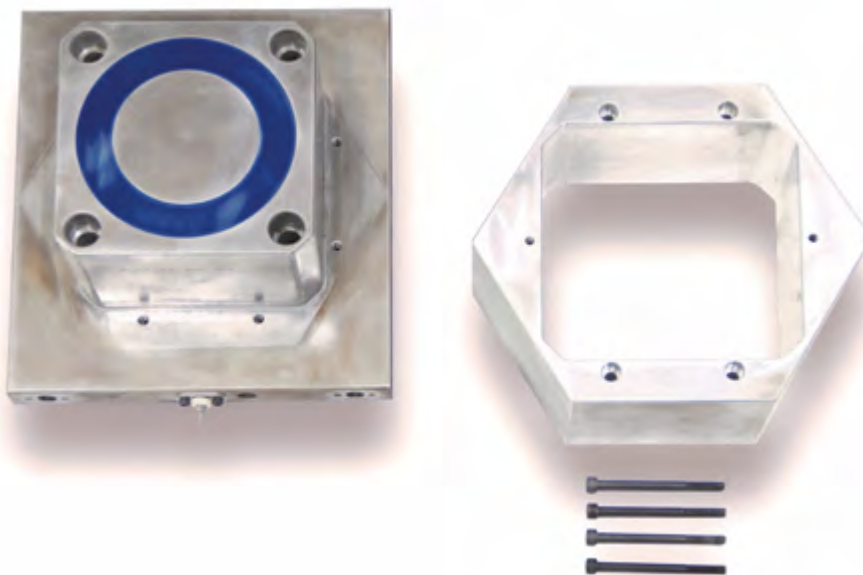


Figure 3.12. “Block” and coupling supplement, or “block” sleeve to reduce the overhang of the lower punch.

To facilitate the replacement of large-format punches (Figure 3.11), some magnetic blocks are equipped with anchored pistons to raise the punch (Figures 3.11 and 3.13) to a height above the level of the die box so that it can be moved out of the mould by means of sliding guides. Depending on the type of mould and punches, the same sliding system can be used for both upper or lower punches.

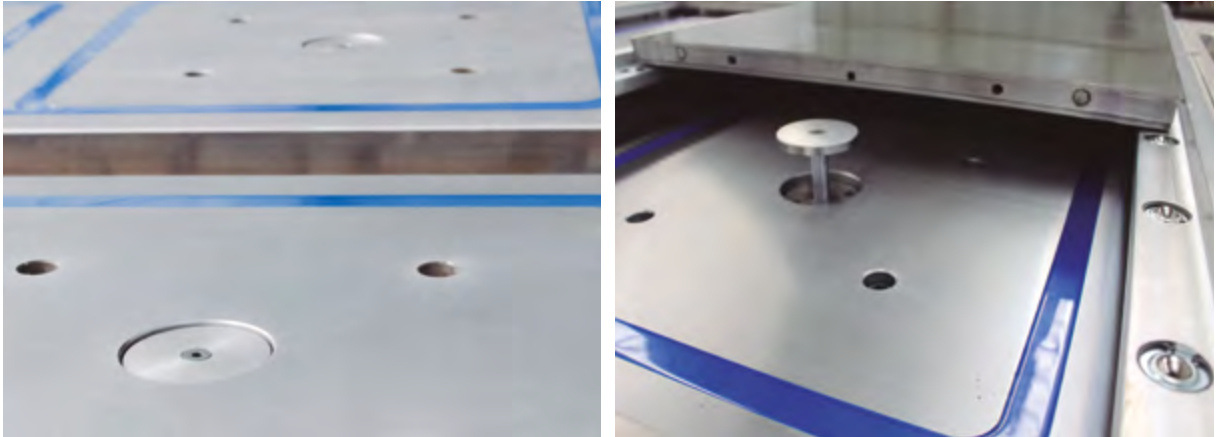


Figure 3.13. Punch extraction system.

One of the areas of the mould where a high accumulation of powder occurs is between the magnetic blocks. This space is difficult to access and therefore hard to clean. Excessive powder accumulation here can lead to deterioration of the mould and even breakage of the die box wall partitions. To avoid this, MACER incorporated an internal pneumatic circuit inside the ejecting plate to blow the powder that accumulates between the magnetic blocks. This system works releasing an air pulse each pressing stroke, displacing any powder that may be deposited during the pressing cycle and thus avoiding the formation of large accumulations. Figure 3.14 shows the nozzles used; figure 3.15 shows their arrangement in a mould between the magnetic blocks and figure 3.16 shows their arrangement on the sides of the bottom plate. The powder is sucked up by the mould's internal suction system.



Figure 3.14. Blower for mould cleaning.



Figure 3.15. Blowers located between the magnetic blocks.



Figure 3.16. Blowers located on the perimeter of the bottom plate.

3.4. BELLOWS.

Bellows (Figure 3.17) are a folded elastomeric ²⁹ material protection, installed between the bottom plate and the ejecting plate, which is intended to prevent the accumulation of powder between the two plates. If powder enters the space between these plates, it can cause the loss of parallelism between them and a slight inclination of the lower punches, which leads to increased wear, rectangularity defects and wedging of the pressed tiles. Bellows ruptures in integrated extraction systems can also lead to the deterioration of the hydraulic components of these systems.

The bellows must be complemented by an efficient de-aeration system capable of rapidly depressing the area between the ejecting plate and the bench plate when the first one starts the downward movement for the plate drop, otherwise the life of the bellows would be drastically reduced. To prevent the bellows from being damaged by the air driven out by the ejecting plate in its downward movement, MACER has installed an inner perimetral frame in its moulds (Figure 3.17). The bellows is attached to the ejecting plate with steel platens (Figure 3.18). The same type of platens are also used to hold in place both the bellows and the frame beneath it. The frame is made from an aluminium magnesium alloy 5083 (Figure 3.18). Deaeration is achieved through holes located in the bench plate connected to air extraction channels of the ejecting plate³⁰.

These bellows have two folds topped by a flat canopy, or tilted in a 10° angle, which prevents the accumulation of dirt, and two end sections for fastening to the ejector plate and together with the aluminium frame screwed to the bench plate. They consist of four straight and four curved sections joined by chemical bonding or welded with the same material, at a temperature of 170 °C.

The natural colour of the elastomer is whitish-yellowish, but the used formulations incorporate colourants to give the bellows the colours they are marketed with.

As they are made of synthetic material, the composition and thickness of the sections or parts of the bellows may vary depending on the specific requirements.



Figure 3.17. Elastomeric bellows with protective frame.



Figure 3.18. Silicone bellows assembly.

²⁹ Initially, bellows for moulds were made exclusively from a single piece of leather, with some complementary elements, such as stiffening rods located in correspondence with the folding areas on the inner side of the leather material, which allowed good resistance to folding without breaking. Leather bellows has now been replaced by silicone bellows. Elastomeric bellows, with a 55/60 Shore hardness, offer better stretchability, better protection in critical areas, ease of assembly and a far lower cost than leather bellows, which is why they have been progressively replacing them.

³⁰ Although this is the ideal solution to achieve correct deaeration and extend the life of the bellows and it is the solution adopted by MACER, not all manufacturers opt for this solution, so it is possible to find moulds on the market without these deaeration channels.

3.5. DIE BOX.

The die box (Figures 3.19 and 3.20) is the plate where the cavities are located. On entry moulds, the die box is fixed and attached to the bottom plate by means of fixed screwed pillasters. On mirror moulds and entry mirror moulds, the die box is movable due to a set of pistons anchored to the bench plate. Double moulds have two die boxes: one fixed, attached to the upper plate, which can be equipped with pushers or stops; and the other equipped with pistons able to perform upward and downward movements.

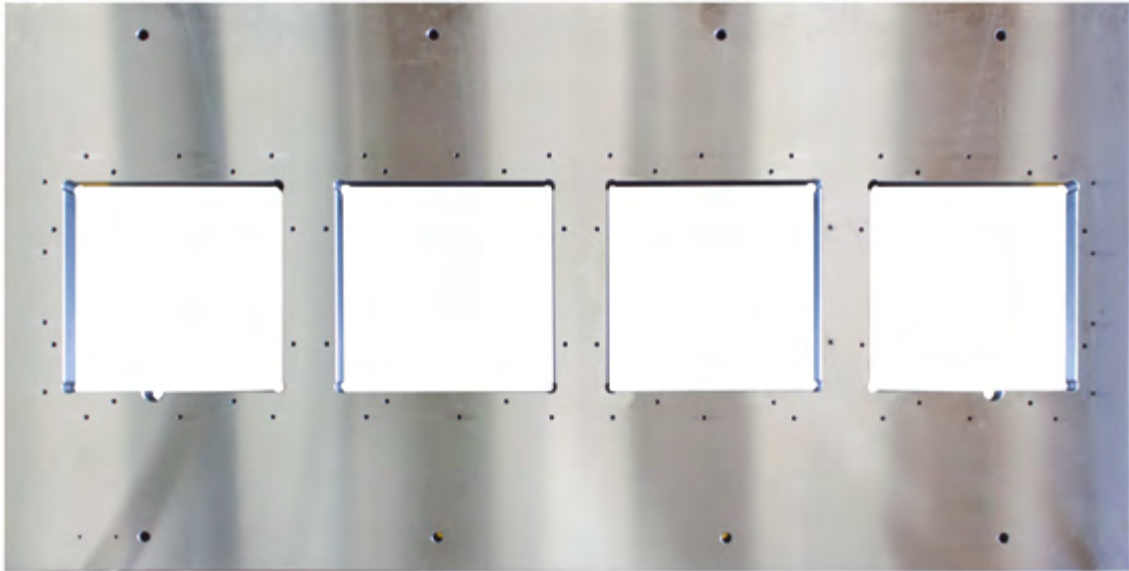


Figure 3.19. Die box (without liners).

Table 3.3 shows the most common dimensions of bottom plates, ejecting plates and die boxes.

Press	Manufacturer	Clearance (mm)	Format (cm)	Bench plate (mm)	Ejecting plate (mm)	Die box ^o (mm)
PH-1890 PH-2090 PH-2590 PH-2890	SACMI	1750	≤ 50 x 50	1710 x 860 x 55	1580 x 485 x 108	1740 x 860 x 98 1740 x 800 x 98 1740 x 960 x 98 1740 x 1000 x 98
PH-3590 PH-4600	SACMI	1750	60 x 60	1710 x 960 x 55 1710 x 1000x 55	1580 x 685 x 108 1580 x 590 x 108	1740 x 860 x 98 1740 x 800 x 98 1740 x 960 x 98 1740 x 1000 x 98
PH-3800 PH-4900 PH-5000 PH-6200	SACMI	2450	≥ 60 x 60	2390 x 900 x 55 2430 x 900 x 55 2390 x 1000 x 55 2430 x 1000 x 55	2200 x 540 x 108 2280 x 540 x 108 2200 x 685 x 108 2280 x 685 x 108	2440 x 900 x 98 2440 x 1000 x 98 2430 x 900 x 98 2430 x 1000 x 98

Source: MACER

Table 3.3. Dimensions of some bench plates.

In order to increase the life time of the mould and its efficiency, MACER can equip the die box with a **wear resistant plate** made of stainless steel which is screwed on its outer side in order to protect the die box from the abrasion produced by the feeder car. These plates are not reversible, as reversing their position can cause powder to accumulate inside the grooves caused by the press feeder car on the face already used, slightly deforming the profile of the plate and causing problems in the cavities loading.

Figure 3.20 shows the die box of an entry mould with 3 outlets and the corresponding wear resistant plate.



Figure 3.20. Wear resistant plate ready to be screwed onto the die box.

3.6. LINERS.

Liners (figure 3.21) are the mould components that are installed inside the die box cavities, delimiting the perimeter of the cavity. They have a quadruple function: to provide the final shape and side profile of the pressed tile; to facilitate its extraction; to withstand the stresses generated during the pressing operation and to withstand the wear caused by the abrasive and hardness of the materials used in the composition of the pressed paste. Therefore, they must have a higher mechanical performance than the die box where they are screwed and it is essential to have a high wear resistance, since, for example, a loss of only 0.2 mm in the liners of an entry mould is sufficient for the clearance between the liners and the upper punch to cause powder losses after the impact of the punches and, in addition, the tiles pressed this way present an unacceptable quality loss. For this reason, liners are made of tempered steel, surface-tempered steel or reinforced with tungsten carbide inserts. Despite this, liners are subject to continuous wear caused by abrasive particles of powders, which means that they have to be replaced after a certain number of strokes (see Table 3.6).

The liners of the upper die box of the double mould or entry moulds must be manufactured with a certain exit angle (α), which is known as **conicity**, or **angle** (Figure 3.22) that facilitates the tile extraction and allows the elastic force accumulated by the tile during pressing to be released gradually. This angle of inclination is determined empirically depending on the format and the used powder and, if

necessary, it is modified if there are drops due to post-pressing expansion, although there is a tendency to unify the angle values depending on the type of product and the manufactured format ³¹ (Table 3.4).



Figure 3.21. Different types of liners

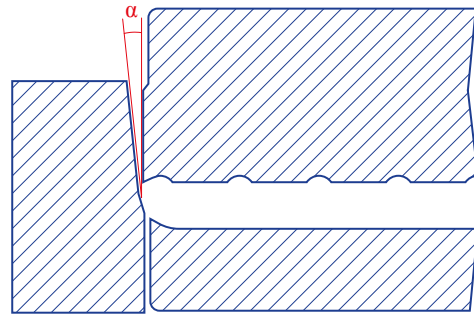


Figure 3.22. Conicity or liner angle.

In the entry moulds, chamfers, or radii, are also machined on the liners to prevent damage from the edges of the liner on the side to be glazed during tile ejection. Small cut-outs are also usually made to the liners of the upper forming moulds or "double moulds"; the lower part of the double mould, on the other hand, is equipped with a die box with liners without angles or radii, as this part acts as a mere container for the load and the forming is carried out in the upper part of the mould.

Product	Side (cm)	Loading height (mm)	Thickness (mm)	Compression ratio	Real angle (°)
White body single-fired tiles	33	18	8.5	2.12	2.26
	40	19	9.5	2.00	2.10
	44.5	19	9.5	2.00	2.14
	60	22	10.5	2.10	2.37
Red body single-fired tiles	25	15	8	1.88	2.29
	25	17	8	2.13	2.33
	33	16	9	1.78	2.18
	45	21	10	2.10	2.03
	44.5	19	9.5	2.00	2.14
	60	22	10	2.20	1.84
Red body stoneware tiles	9.8	14	7	2.00	2.09
	33	22	10.5	2.10	2.03
	45	21	9	2.33	2.21
	50	23	10	2.30	2.27
Porcelain tile	33.3	19	8.2	2.32	2.14
	45	21	9	2.33	2.21
	67.5	22	9.5	2.32	2.37
	111.7	27	13	2.08	3.00

Source: MACER.

Table 3.4. Actual angle values of moulds used in the ceramic industry.

³¹ It is also possible to estimate the minimum exit angle depending on the parameters described above, based on purely geometrical considerations, resulting in:

$$\operatorname{tg} \alpha = \frac{L_A \cdot EP}{200 \cdot h}$$

being **LA** the length of the liner, **h** the loading height and **EP** the post-pressing expansion. The obtained values are slightly different from those actually used for small format moulds, but are very different as the format increases, so this calculated value is only useful as a guide.

Table 3.4 shows the conicity angles practised in some moulds depending on the format, type of manufactured product and some characteristics of the pressing operation. It should be noted that in large formats, the increase in dimensions by expansion is so large that it will always exceed the value of the angle, therefore, extraction, in these formats³², must always be done as a sandwich.

3.6.1. Types of liners.

According to their assembly system, one can identify two groups of liners: **fixed liners** which are independent liners screwed to the die box; and **removable** or **interchangeable** liners, formed by a single body, responsible for shaping the tiles, and screwed to the die box by horizontal drilling. The latter liners (figure 3.21 and 3.23) were developed and patented by MACER in 2003 [71].

As for the removable liners, they can be **rectified** and/or **rip cut**, offering a wide range of shapes and forms.

Both types of liners, fixed and removable, are made of tempered DIN 1.2080 steel and may be reinforced to increase their lifespan. A few years ago MACER patented a thermal spraying reinforcement system (high velocity oxy-fuel or HVOF) of a metal-ceramic coating comprised of tungsten carbide and cobalt. Nowadays, however, tungsten carbide sheet reinforcements are preferred.



Figure 3.23. Removable liners

Table 3.5 shows a classification of liners used in the manufacture of moulds, according to the criteria earlier described, and table 11.6 describes some of the main technical specifications of the liners.

Type of liner				MACER reference	
Based on installation	Conventional or fixed	Single face. 1. Short. 2. Long.	Single face.		
			Symmetrical		
			Reinforced by welding		
		Double. 1. Short. 2. Long. 3. Central.	Single face.		
			Symmetrical		
	Removable	Rectified			MRCM
		Rectified – rip cut			MRCMH
		Rip cut (MHI)			MHI
Wear resistant (Can be fixed or removable)		Wear resistant with HVOF projection		MMD	
		Wear resistant made of tungsten carbide			

Table 3.5. Classification of liners.

³² Generally, it is advisable to perform sandwich extraction when the formats have at least one side equal to or greater than 60 cm.

Liner type	Material	No. of pressings (approx)	Rockwell C hardness (HRC)
Conventional	Tempered DIN 1.2080 steel	500,000 – 600,000	60-62
Rectified (MRCMH)		500,000 – 600,000	60-62
Rip cut (MHI)		500,000	58-60
Rectified and rip cut (MRCMH)		500,000 – 600,000	58-60
Wear resistant (MMD)	DIN 1.2080 steel with HVOF projection of WC - Co	2,200,000	91 – 91.5
	DIN 1.2080 steel with tungsten carbide inserts.	3,000,000 – 4,500,000	75-85

The hardness tests used to characterise steels are summarised in Annex III.

(*) Depends on the characteristics of the paste (composition and percentage of abrasive materials).

Table 3.6. Technical characteristics of liners.

3.6.1.1. Fixed liners.

Fixed liners (figure 3.24) are a set of tempered steel parts that form the side profile of the pressed tile, and are manufactured and mounted separately in each of the cavities of the die box. Depending on the format of the tiles to be obtained, it is possible to differentiate between up to three types of fixed liners: **long** and **short** side liners and, in some moulds, **central** liners. The first two are used to cover simple cavities in the die box. With the central liners it is possible to split a cavity in two or to convert a single die box cavity into several cavities. Long liners are adjusted to the size of the die box by means of vertical threaded holes that prevent them from moving vertically, and the short liners are adjusted to the long ones. The length of the short liners therefore matches exactly with the length of one side of the tile to be formed.



Figure 3.24. Fixed liners with tungsten carbide insert.

The liners are fixed to the machined housing in the die box with screws in horizontal threaded bores, and/or³³ at the tops of the long liners, and even of the short ones, depending on the format. These liners are assembled at once, adjusted by hand, in an extremely slow process that requires great precision and cannot be carried out on site at the press, which means, the mould has to be changed or at least the die box has to be removed and taken to the manufacturer's workshop. The procedure becomes extremely complicated in formats with irregular edges, due to the difficulty in defining measurement points.

To allow the liners to be removed from the die box where they are anchored, there are socket set screws into horizontal threaded holes. When tightened, they bump into the die box and start to push the liner out of its housing. When this type of liner wears out, the mould must be taken to the manufacturer's workshop for grinding. This operation involves the removal of material, and it is therefore necessary to place shims, usually thin sheets of brass, between the liner and the die box to restore the original dimensions of the cavity. However, when a certain limit is exceeded, which, depending on the liners and formats, can be up to 3 mm, this operation can no longer be carried out as the deformation experienced

³³ Vertical retaining washers may also be used occasionally

by the shim, which is made of a softer material than the steel of the liners and the frame, puts the integrity of the anchor bolts at risk. In this case, the liners must be removed and replaced with new ones.

Despite of these disadvantages, which make assembly and disassembly a tedious task, this type of liner is still used when the space for installing the mould limits the number of outlets excessively and makes it necessary to manufacture the liner with a reduced thickness or, in occasions, at the customer's own request.

3.6.1.2. Reversible symmetrical liners.

A variant of this type of liners are **reversible symmetrical liners** [70]. They are shaped in a way that was novel at the time, since, unlike the previous ones, they have two angle bevels (figure 3.25). This allows the lower cutting flange to be used when the upper one is worn out, simply by flipping the die box over. Experience with this type of liner has shown that, although they increase the service life of the liners, they do not double it, as the no working part of the liner is also subject to stress and wear, and when the die box is turned over, the life of the second liner is shorter than the first one. It should also be taken into account that the die box must be removed and reassembled in the factory itself, which means this type of liners is used only in small formats. In large moulds installed in high tonnage presses, this change cannot be carried out in the factory itself, so for these large presses and formats, this type of liners are pretty much useless.

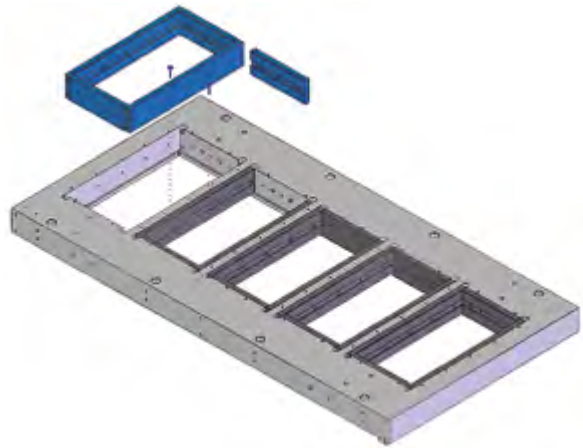


Figure 3.25. Arrangement of the reversible symmetrical liners in the die box

Figures 3.25 and 3.26 show a schematic of the assembly and arrangement of these liners in the mould and figure 3.27 shows a detail of these liners.

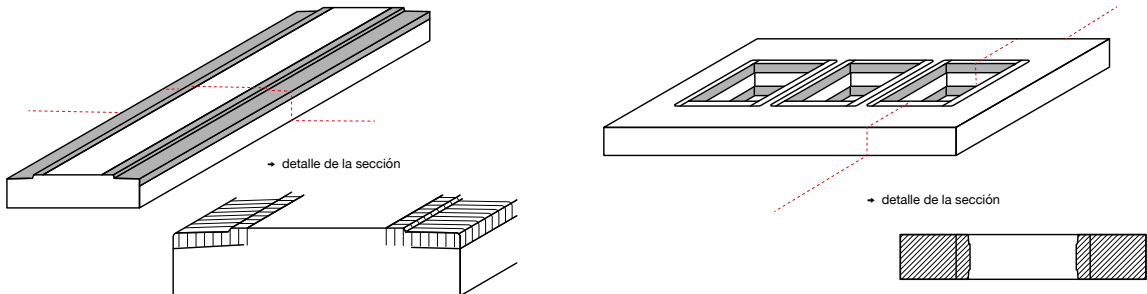


Figure 3.26. Arrangement of the reversible symmetrical liners in the die box according to reference [70].



Figure 3.27. Reversible symmetrical liners (detail).

3.6.1.3. Removable liners.

These are removable die box liners, which are mounted on the die box as a single body, making them easy to assemble and disassemble. Removable liners allow the same die box to be adapted to different formats, by means of simple mechanical operations. They also allow for quick and easy format changes, which reduces the number of moulds a company needs. Naturally, these changes can be combined with multi-format magnetic blocks and their sleeves, although this is not always necessary, as it is also possible to install removable liners in single-format moulds. On the other hand, these liners eliminate the need for manual adjustment procedure and improve the flexibility of the mould manufacturing process. Moreover, it is possible to replace the liners on site at the press, inside the tile manufacturer's own factory, which saves both time and money.

Depending on their manufacturing process, or their technical characteristics, there are different types of removable liners (table 3.5). A significant advantage of all of them is, as mentioned above, the flexibility in the design of the mould. With a simple change of liners, it can be quickly adapted to different formats, although it is preferable to do so in small and medium formats. Some examples of these mould adaptations are shown in table 3.7.

Mould of...		Can be adapted to...	
Format (cm)	Number of outlets	Format (cm)	Number of outlets
33x67	2	33x33	4
30x30	4	30x60	2
12x24	8	24x24	4
40x40	3	45x45	3
30x30	2	33x33	2

Table 3.7. Mould flexibility examples through the use of interchangeable liners.

Likewise, and also as an example, it is possible to adapt a 40 x 40 cm mould with three outlets to a 45 x 45 cm octagonal, hexagonal, rounded corner, irregular, etc.

3.6.1.4. Rectified removable liners.

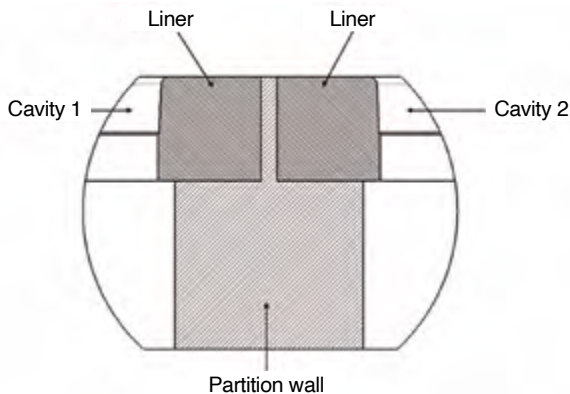
Removable liners can be manufactured separately, like fixed liners, and assembled by dovetail jointing (figure 3.28). These are then referred to as rectified liners [71]. In some cases it is necessary to manufacture them in one piece from rip cut steel plates.



Figure 3.28. Rectified removable liners with dovetail joint.

Each cavity of the rectangular and square moulds, equipped with this type of liners, consists of a set of four liners: 2 long and 2 short, just as we have seen with the fixed liners. Thus, these liners are essentially fixed and manufactured separately, but they incorporate two important new features: on the one hand, they can be assembled in a single body by means of dovetail joints, which make them easily removable, and on the other hand, they can be fastened to the die box by means of vertical boreholes. Double outlet or even triple outlet rectified removable liners can also be manufactured, although in this case there is no central wall partition between two consecutive cavities, as the liners themselves are the separation, so, for maintenance purposes, it is advisable to produce them with only one outlet. Figure 3.29 shows a diagram of a partition wall with two liners between two consecutive cavities **(a)** and only with one liner in the case of removable multi-outlet rectified liners **(b)**.

b) Sectional view of the separation of two cavities with a wall partition and liners.



a) Sectional view of the separation of two cavities with a liner without a wall partition.

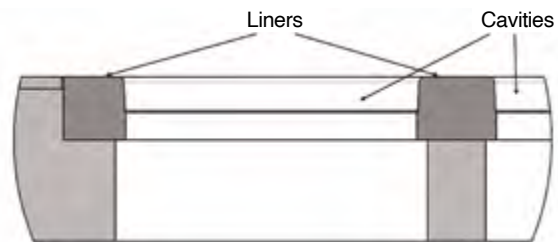


Figure 3.29. Separations between cavities with wall partition and with liners only.

With this type of liners, characterised by their high ease of assembly and disassembly, it is also possible to divide the cavities by means of a central piece, thus obtaining different formats for the same die box (multiformat moulds), as well as making similar formats (rounded corners, interlock profile, etc.) with the same number of outlets.

3.6.1.5. Rip cut rectified liners.

These are liners with a similar structure to the rectified liners, manufactured separately and then assembled into a single body by means of dovetail joints. This type of liners, MACER's MRCMH reference, incorporates the rip cutting technology to create the inner shape once the whole set has been assembled, in order to obtain interlock profiles which cannot be achieved with a grinding machine (figure 3.30).



Figure 3.30. Rectified and rip cut interlock liners (MRCMH)

3.6.1.6. Rip cut liners.

When irregular liner profiles are required (figure 3.31) which cannot be obtained by conventional abrasive grinding, rip cutting is used, as we have seen with MRCMH type liners. If, on the other hand, they are made from a single steel plate, and therefore form a single piece, they are called rip cut liners (MHI or MACER). These are removable liners consisting of a single metal piece that delimits each of the mould cavities. These liners are manufactured separately and assembled.



Figure 3.31. Irregularly shaped liner cut from a single steel plate.

3.6.1.7. Wear resistant liners.

Liners, both fixed and removable, are made of tempered steel, as they are subject to the abrasion of the pressed ceramic powder and withstand the transverse the pressing force. The resulting continuous wear of the liners increases the clearance with the upper punches and makes it necessary to replace them approximately every 600,000 strokes. This wear starts at the surface and depends on the composition of the pressed powder, especially its content of abrasive defatting materials. On the other hand, it is noticeable that the amount of tempered steel used in the manufacture of liners is very high compared to the small amount of wear (0.2 mm) which can make them unacceptable for the quality tiles production.

In order to improve wear resistance, in many industrial sectors, metal coatings are used together with other materials, metallic or non-metallic, of higher hardness. From the coating of untempered steel substrates with different techniques, two types of liners are obtained, which we will refer to generically as “wear resistant liners”:

- HVOF-coated liners.
- Liners with tungsten carbide insert.

a) Wear resistant liners with HVOF coatings.

One of the coating procedures on metals is thermal spraying, which consists of adding harder metals over the base metal or substrate by spraying at high temperatures. This process is used to protect parts against wear and tear, or for other applications such as improving resistance to atmospheric corrosion, acid attack, etc. Therefore, it is widely used in many industrial sectors, such as the steel industry, the textile industry, the automotive industry, etc. However, in the manufacture of moulds for ceramic tiles, the coating of the die box is the tempered steel liner itself, which has the task of withstanding the mechanical stresses and abrasion of the powder during the pressing operation.

In 2004, the company MACER, in collaboration with the Institute of Ceramics and Glass (CSIC) presented wear resistant liners³⁴ at CEVISAMA. These are removable liners of the MRC type, without tempering heat treatment, where a coating of metal-ceramic material, consisting of tungsten carbide (WC) in its dispersed ceramic phase and cobalt (Co) as mould, in the ratio 80:20, is applied by thermal spraying on the face in contact with the ceramic powder [72] [73]. The tempering stage, which aim the improving the mechanical properties of the steel, is replaced by the deposition of a steel coating by thermal spraying of particles at very high speeds.

The coating method used is a variant of thermal spraying, called “hypervelocity spraying” HVOF (Hyper Velocity Oxi Fuel Spraying). The material that will form the anti-wear coating is sprayed at high speeds (between 700 and 1100 m/s) after being heated to temperatures between 1500°C and 2000°C using a conventional hydrogen, acetylene or natural gas flame, which is produced inside a spray gun where the WC - Co powder is fed and sprayed with high kinetic energy. This allows obtaining high-density coatings with thicknesses between 0.1 and 0.3 mm and a porosity of less than 1 %.

³⁴ This project was awarded an honourable mention by the jury of the Alfa de Oro Awards given annually by the Spanish Ceramics and Glass Society.

The coating is applied by a SULZER METCO DJ2700 equipment to the area subject to wear of the liners and consists of WC ceramic particles embedded in the Co mould.

The process allows good adhesion to the substrate, which in this case is DIN 1.2080 steel with 12 % Cr without quenching heat treatment.

This type of liners are also removable, so the manufacturing process is similar to those described in this section, incorporating the stage of applying a layer of anti-wear coating by means of hypervelocity spraying.

These liners can withstand a higher number of pressings (2,200,000 compared to 600,000 for tempered steel liners), which reduces the cost of the die box per pressing cycle and allows the use of cheaper steels in their manufacture.

The steel used, as we mentioned, does not undergo the energy-intensive heat treatment of tempering, which requires high energy consumption and that usually causes a high number of rejections, so it can be machined, removing the remains of the coating applied previously. After degreasing and sand blasting, a new spraying process can be performed and the liner can be reused.

b) Wear resistant liners with tungsten carbide (WC) strips.

Tungsten carbide is a high hardness material consisting of tungsten and carbon, which is used, among other applications, in the manufacture of tools³⁵ for working steel and other hard materials.

Tungsten carbide materials are obtained by pressing or extruding WC powders and between 6 and 10 % cobalt, which acts as a binder, and subsequently firing them at very high pressures to form a "cermet"³⁶. The obtained pieces can only be machined using abrasive methods or electro-erosion. The most commonly used binder in tungsten carbide is cobalt, although some specifications use nickel or mixtures of Ni-Co or Ni-Cr, especially for applications requiring anti-corrosion material.



Figure 3.32. Tungsten carbide strips.

Tungsten carbide parts for wear resistant liners are supplied in the form of strips (figure 3.32), as it is advisable, and much cheaper, to bond tungsten carbide strips to steel. The rigid union of two metals to produce a component subjected to high stress and friction can be problematic. There are different joining techniques ^[50] between steel and tungsten carbide, such as brazing³⁷, the use of powerful

³⁵ This material is also known as "widia". The name comes from the German "wie diamant", which means "diamond-like".

³⁶ A "cermet" is a composite material consisting of a metal and a ceramic material.

³⁷ Brazing is a thermal joining process using a filler metal that is heated until it melts, flowing by capillarity between the two metals to be welded. The filler material has a melting point higher than 450 °C and lower than the two metals to be joined. If it is lower, the process is known as "soft welding" (soldering).

industrial adhesives³⁸ or mechanical anchors. However, conventional acetylene or arc welding is not recommended for joining steel and WC.

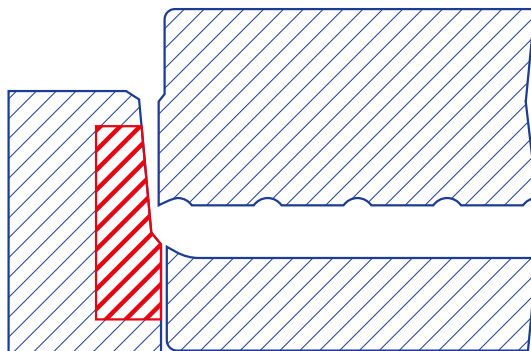


Figure 3.33. Tungsten carbide strip inserted in a liner.

Wear resistant liners with a tungsten carbide insert (MACER reference MMD), consist of a tempered steel support³⁹ with a tungsten carbide strip glued to it. They have replaced the HVOF coated liners due to their lower cost. These are fixed or removable liners (Figures 3.24, 3.34 and 3.35) made of the same steel as the rest of the liners to which WC strips are bonded and subsequently machined. These liners have a Rockwell hardness, in their pressing area, between 75 and 85 HRC and are capable of withstanding between 3 and 4.5 million strokes, which means multiply the span life of the liners by 4.



Figure 3.34. Drawing of tungsten carbide strip inserted into a liner and reinforced liners assembly



Figure 3.35. Removable reinforced liner with tungsten carbide strip insert.

³⁸ Acrylic adhesives or epoxy resins, such as cyanoacrylates, are commonly used .

³⁹ Although it is possible to find non-tempered steel supports for the reinforced liners with tungsten carbide inserts on the market, MACER prefers to use tempered steel for the support as it is subjected to permanent friction with the feeder car of the press.

3.7. PUNCHES.

The mould punches (figures 3.36 and 3.37) shape the upper and lower faces of the tiles, and together with the liners are the components that are subject to the greatest wear. They are made of steel and the exposed areas to abrasion are reinforced by welding beads of high-strength steels. Next they are rectified and machined to the established dimensions. Generally, the surface of the punches is usually coated with vulcanised rubber to prevent the sticking of wet powder.

The punches are responsible for forming the faces of the tiles. Depending on their position inside the mould, two types of punches are distinguished: the **upper** ones, which together with the punch holder plate are anchored to the plunger and are responsible for transmitting the force developed by the press to the powder, and the **lower** ones, which are rigidly attached to the magnetic blocks of the mould and are part of its ejector system.



Figure 3.36. Punch for large format tiles (60 x 120 cm) with relief.

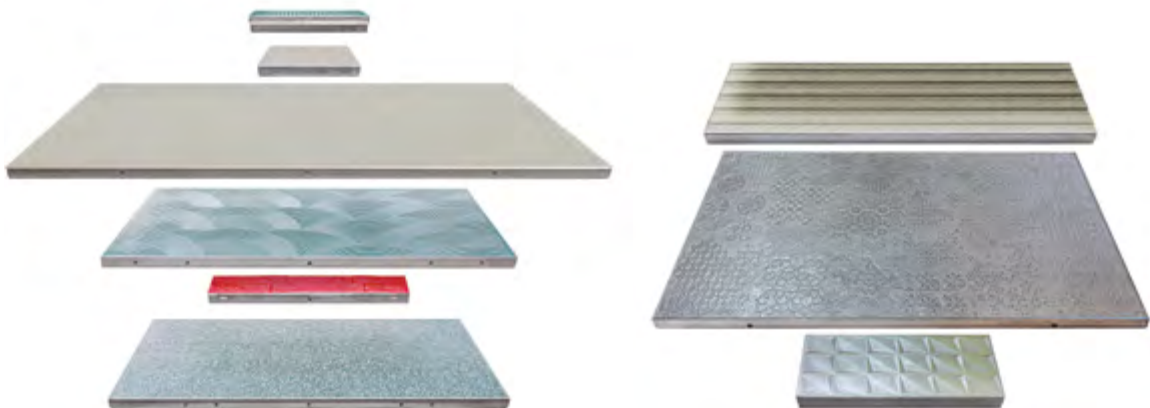


Figure 3.37. Different types of punches.

The upper punch, in entry moulds, or the lower punch in double die box moulds, shapes the back side of the tile, generally referred to as “back sides”, and is often provided with a hydraulic compensation system to compensate for possible load differences in the cavity. Such hydraulically compensated punches are called **isostatic punches** and are classified according to the compensation system used. The other punch forms the good face of the tile and, although, generally it is not isostatic, for some types of tile it can also be isostatically compensated. Table 3.8 gives a **classification of punches** for pressing tiles.

Type				Description	MACER reference	Most frequent use
Rubber free	Tempered.			Tempered steel punches.		Good face and back sides of early hydraulic press moulds. Disused.
	Tempered and polished.			Tempered and polished steel punches.		Good face Unglazed porcelain tiles.
With rubber	Isostatic	Single cavity	With groove fastening.	Rubber fastened by perimeter groove.		First isostatic punch solution. Early 1990s. Currently only in minority use.
			Single cavity.	A single gap in each cavity to contain the oil. Without metal plate.	MGPV	Back sides. Small and medium-sized formats.
			Single cavity with free plate.	Variant of the previous one. A thin swinging plate is placed inside the cavity.	MGPVT	
			Single cavity with fixed perforated plate.	The plate inside the cavity is attached to the rubber, which in turn is attached to the punch by the perimeter bevelled edge.	MGV-1M MGV-2M	
		Interconnected cavities	Mixed.	Interconnected compartments and rubber bonded to a system of perimetral grooves and holes or spacers.		Back sides. Widespread use. Good results in medium and large-sized formats.
			Grid.	In the oil cavity, a system of small interconnected cavities is machined and filled with oil.	MRPV	
	Without oil compensation.			Steel punches coated with rubber or synthetic resins.		In back sides for medium and small formats (occasionally also in large formats if they do not allow isostatic compensation) (*). On the good face: widespread use.

(*) Large format polished tiles cannot be pressed with isostatic punches, as these generate small differences in thickness that can cause visible stains after polishing.

Table 3.8. Classification of punches.

It can be seen from the table that on a first level, punches can be classified according to whether they are rubber coated or not. Rubber coated punches can be equipped with oil compensation systems or without them. The table also gives a short description of each type of punch, which will be expanded in subsequent subsections along with the MACER references for each type of punch and the most frequent use given to them.

3.7.1. Rubber free punches.

In these punches, the powder comes into direct contact with the steel, which has to be tempered due to the greater wear to which it is subjected. This type of punch was used in the friction presses and the first hydraulic presses in the early 1980s. Also, nowadays, some punches are manufactured without rubber, with a polished surface to obtain a very smooth, high quality texture in certain products, for example when micronised or flakes are used.

3.7.1.1. Rubber free tempered punches.

The punches used in the moulds of the old friction presses and in the first hydraulic presses were made entirely of steel, therefore, the surface in contact with the powder being made of this material. These punches were subject to continuous wear due to the direct contact with the abrasive elements of the powder and the pressures they were subjected. Wet powder easily adheres to the steel, which means that, apart from possible quality losses due to adhesion, the press had to be stopped frequently to clean the punches, which meant a reduction in production. This problem is greater in the pressing of atomised powders than in the pressing of dry milled powders, and therefore would be more important today than it was with friction presses pressing dry milled powders, due to the longer contact time of the punches with the powder in hydraulic presses [9]. The problem increases when pressing models with some kind of press relief.

Mould sticking can be significantly reduced by heating them. As mentioned above, the moulds are equipped with a heating system using electrical heating elements, described in section 3.11.

Some press manufacturers provided solutions, or at least minimising the problem of mould sticking by using spatulas or cleaning rollers [32] [86]. This solution was only applicable to smooth moulds. A more effective solution was to coat them with synthetic rubber, with low rubber-clay adhesion, bonded to the metal by a vulcanising process, which is the solution that has survived to this day.

3.7.1.2. Rubber free, tempered and polished punches.

Nowadays, punches without rubber coating are given a polishing finish by grinding (figure 3.38), which gives the pressed tiles a high quality surface texture, superior to that obtained with high hardness rubber coatings. To improve their strength, they are also subjected to a thermal tempering process. This type of punch is highly recommended for pressing unglazed porcelain body, due to its high finish quality of the tile.

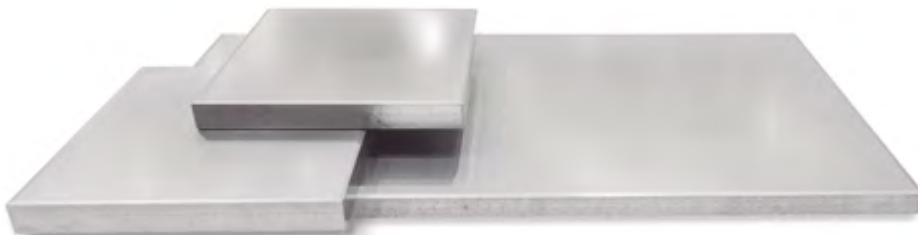


Figure 3.38. Rubber free, tempered and polished punches.

3.7.2. Rubber coated punches.

Rubber coating (Figures 3.39) of the punches prevents the sticking of wet powder, thus eliminating the sticking defects from the pressing process and allowing a continued operation of the press, minimizing cleaning stops, and increasing production. These punches became widespread from the 1980s onwards and, although they required the technology then available for their manufacture to be adapted, they facilitated the dissemination of press reliefs, as they simplified the process for obtaining embossed punches.



Figure 3.39. Rubber coated punches.

3.7.2.1. Isostatic punches.

Isostatic punches (figure 3.40) incorporate an oil chamber between the body of the punch and the rubber coating to compensate for possible heterogeneities in the load distribution of the cavities, in order to distribute the pressure equally, maintaining a constant compactness throughout the tile, at the cost of compensating the load differences with slight thickness differences.



Figure 3.40 Isostatic punch with threaded hole for oil filling valve

Obtaining homogeneous loads in the cavities is necessary for the manufacture of tiles, especially in highly densified products, such as stoneware and porcelain body for large formats. Irregularities in loading lead to variations in compaction that result in differences in linear shrinkage of the tile after firing, which may cause defects such as rectangularity defects, crescents and even thickness differences ^[9].

A good flow of the atomized powder facilitates the loading of the mould ^{[8] [15]} although there may be situations where the charge may present certain irregularities which, depending on their magnitude, are likely to generate defects. These load differences can be minimised by adjustments in the press, such as

regulation of the feeder car's speed, the drop of the lower punch during loading and its synchronisation with the position of the feeder car, rearranging the strips using multiple regulation flushing strip systems and even modifications in the moulds such as surface correction or placing additional thickness layers [79].

There have been also attempts of monitoring bulk density in real time through sensors placed inside the punches [24] [69]. On the other hand, MACER developed a system to determine significant variations in bulk density in real time by on-line measurement the weight and thickness of the tiles, in order to establish corrective actions in the press, based on variations in compactness, although this system is now obsolete.

However, the problem of poor load distribution, especially within the same cavity, is difficult to solve automatically with the current press adjustment mechanisms. The use of isostatic punches, is an attempt of automated solution for the load compensation and therefore the compaction differences of the tile. This technique derives from the cold isostatic pressing inside a sealed container, or dry-bag method^[23], known and used in the forming of some ceramic products such as tableware, advanced ceramics, etc. This method consists in the application of pressure to an elastomeric mould, which is part of the press, via an incompressible liquid, which transmits this force equally in all directions. As a consequence, any possible loading differences result in differences in thickness in the pressed piece, but not compactness.

Basically, isostatic punches are punches where a bed of oil has been inserted between the rubber and the metal, so that the rubber, being deformable and the oil incompressible, absorbs the differences in load. In some isostatic punch models, the oil may be distributed in small cavities which are interconnected with each other (Figures 3.51, 3.52 and 3.53), so that if during pressing, the punch encounters an unevenly distributed load, it is equalised in all cavities when pressure is applied, according to the principle of communicating vessels. Thus, the oil pressure in the different cavities of the isostatic punch acquires the same value, and therefore the specific pressure applied to the irregularly loaded areas of the tile is the same. Consequently, **the tile will tend to maintain the same compactness in areas where the load is not equal, at the cost of a varying thickness** (Figure 3.41).

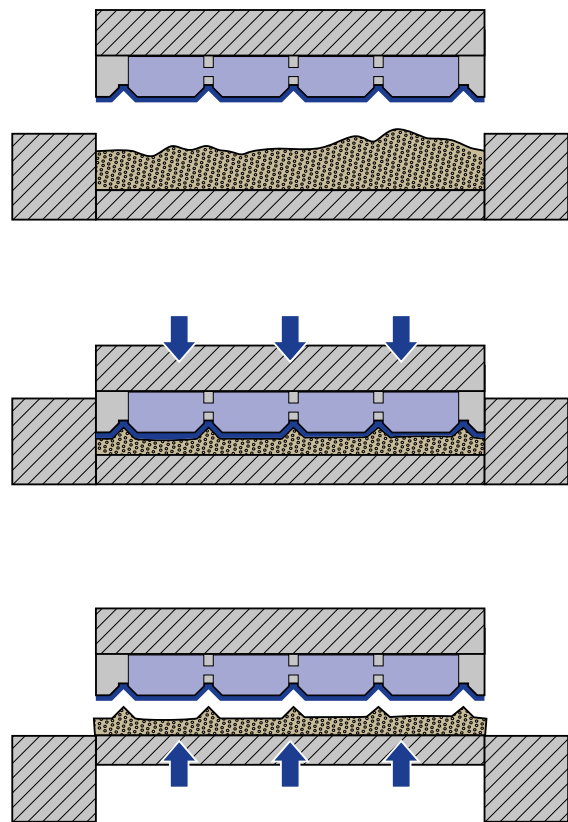


Figure 3.41. Pressing process with isostatic punches

In order to prevent small deformations due to differences in thickness from being visible on the “good

face” of the tile, this effect is almost always used on the punches of the “back side face”⁴⁰ although it is now also used on the good face for the forming of some models with a stone effect or with very pronounced reliefs. In entry moulds, the back relief is usually formed by the upper punches, so these are the isostatic ones. However, in double die box moulds, used for the manufacture of unglazed porcelain tiles, the back side face corresponds to the lower punch, which in this case is the one with the isostatic effect.

Figure 3.42 shows the effect of isostatic compensation on the bulk density distribution in comparison with the distribution obtained when pressing the same powder under the same conditions with solid punches, i.e. without isostatic compensation. The maps of bulk density shown were obtained with a DENSEXPLORER x-ray absorption measuring device ^[56] (see Annex IV).

The maps obtained show the great heterogeneity in the distribution of compactness in the tiles pressed with punches without isostatic compensation compared to those obtained with isostatic punches. On the other hand, these differences are reversed with respect to thickness, as shown in figure 3.43, since, as has been said, bulk density offsets in isostatic punches are achieved at the cost of thickness differences.

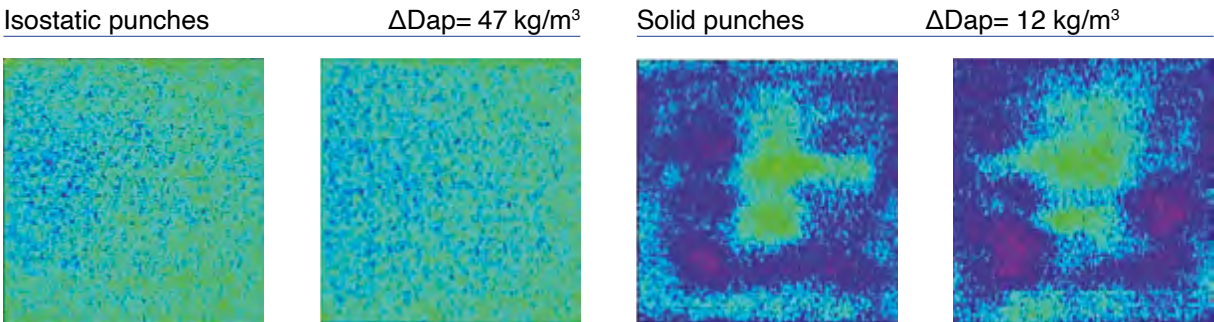


Figure 3.42. Bulk density distributions in tiles pressed with isostatic and solid punches according to reference ^[56].
Image: ITC-MACER

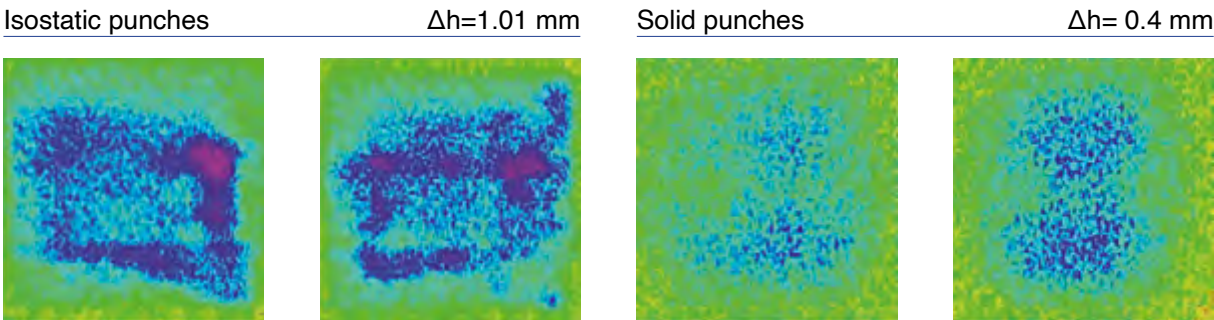


Figure 3.43. Thickness distributions in tiles pressed with isostatic and solid punches according to reference ^[56].
Image: ITC-MACER

⁴⁰ Although it is true that the thickness variations are manifested on the back side relief face, large differences may cause clearly visible deformations in the tile, which means that it is sometimes preferable to obtain small compaction differences while keeping the thickness constant, as opposed to a constant compaction obtained at the expense of thickness differences that appear on the good face of the tile.

It should be noted that in some types of isostatic punches, excessively fast pressing cycles may reduce the isostatic compensation, since in order for the oil to circulate from one cell of the same punch to another, a pressure difference must exist between them. The oil flow rate depends on this pressure difference and can therefore, in excessively fast cycles, be too high to compensate for the pressure differences. Naturally, the design of the connections between these cells then plays an important role.

In isostatic punches, the design of the back sides is very important, and it must be ensured that the effect of the compensation, i.e. the variation in thickness, never exceeds the height of the back sides, as this would result in a loss of stability of the tiles on the support. Some authors ^[1] recommend that the minimum height of the back sides should not be less than 0,5 or 0,6 mm.

The main advantages of using isostatic punches in pressing are the drastic reduction of dimensional defects attributable to the pressing operation, the reduction of sizes and the increase in press performance ^[23].

There are many types of isostatic punches currently available on the market. The main differences between them lie in the arrangement of the oil chamber(s), and in the rubber fixing systems, which are related to the design of the punch itself. The rubber attachment to the punch is an important technical aspect, since it is possible that partial detachments of the rubber to cause bulging defects in the tile.

Moreover, it should be noted that the rubber used in isostatic punches generally has a lower hardness than the one used for the good face punches.

a) Single cavity isostatic punches.

These are the isostatic punches with the simplest structure. On the surface of the punch, a cavity is made, limited by a perimetral frame (figure 3.44) where the rubber is fixed. A narrow chamber is delimited between the rubber coat and the punch, which is filled with oil. The different rubber fixing techniques give rise to the different typologies of single cavity punches. This fixing can be done in a simple way, using a strong adhesive, or mechanical fastening elements such as threaded holes, slots or crossheads can be used.

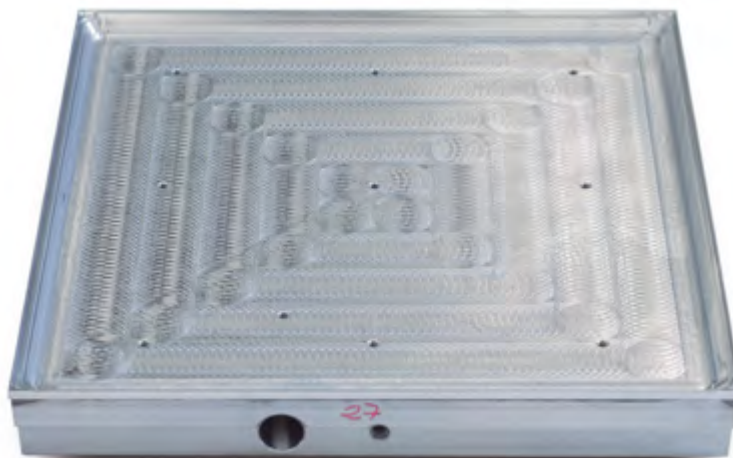


Figure 3.44. Single cavity isostatic punch.

A variant of special interest is the free or floating metal sheet punch, which consists of a single cavity punch where a metal sheet is inserted to minimise the ripples caused by the oil, which can become visible on the glazed side of large tiles, especially when bright and clear glazes are used.

MGPV type punches⁴¹.

Similar in concept, but with a significantly improved bonding of the rubber, single cavity isostatic punches of the MGPV type are manufactured, where the rubber is bonded to the bevels machined inside the cavity of the punch. The oil is loaded into each punch by injecting it through the filling valve. The filling valves are non-return valves and can be either threaded or quick-connecting (Figure 3.54).

When the thickness of the punch is so small that it cannot accommodate a filling valve (generally those under 40 mm), they are manufactured without a valve and are filled with oil through the back side plugs⁴².

Slot punches.

Slot punches were the first isostatic punches to appear on the market between 1992 and 1993. They had a very simple design, which basically consisted of sandwiching a layer of oil between the rubber and the metal in a watertight enclosure. The rubber was held by a perimetral slot. The amount of oil in each punch was therefore constant.

This type of punch, however, did not manage to completely solve the problem of unbalanced loads, as the rubber has a small bonding surface and if the load differences are very pronounced, deformations can become perceptible on the good face of the tile ^[74].

Punches with threaded hole fasteners.

It is a type of isostatic punch similar to the previous one, with a single cavity, which is no longer in use. In this type of punches, the rubber was attached to the punch by means of an adhesive on the perimetral bevelled edges and by small threaded holes on the surface of the punch, after a heat pressing operation ^[77].

Rubber filled the holes drilled inside the hydraulic cavity so once solidified, the part embedded into the threaded holes acted as a mechanical retainer with the body of the punch, while generating a grid of small interconnected chambers.

As in all isostatic punches, the oil was introduced through a non-return valve, and was distributed through internal channels to all the small chambers generated by the fastening system of rubber coating.

⁴¹ Trade name of this type of punches of the company MACER S.L.

⁴² In reality, any isostatic punch can be manufactured without a valve and fill the oil through the back side plugs, although this is not advisable, as it is a cumbersome operation, so, if the thickness of the punch allows it, they are made with a valve

Single cavity punches with floating metal sheet (MGPVT TYPE BY MACER).

In large formats, single cavity isostatic punches have a tendency to transfer a certain waviness to the glazed face, which is particularly visible when using clear and glossy enamels. One way to minimise this problem is to insert a floating metal sheet inside the oil cavity (Figure 3.45) so that the tilting of the sheet reduces the ripple effect caused by the oil in the large cavities.

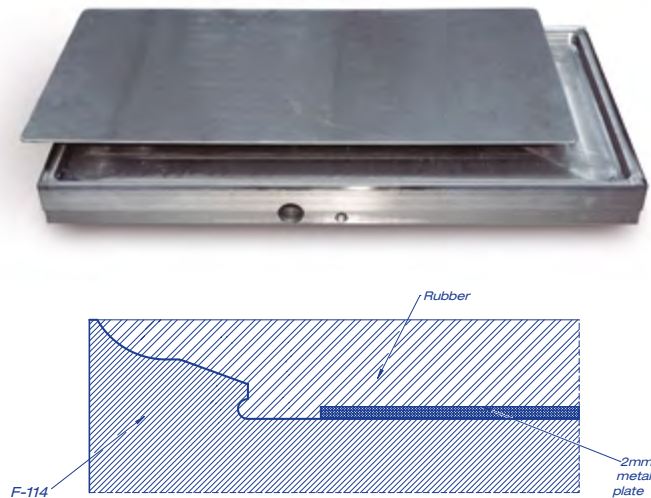


Figure 3.45. Single cavity isostatic punches with metal sheet.

Single cavity punches with fixed perforated plate.

In this type of punch, a perforated metal sheet is fitted inside the oil cavity (Figure 3.46). The rubber is fixed to the body of the punch at the perimeter bevelled edge, on one hand, and to the perforated plate which faces the bottom of the cavity at the base, on the other. The oil is lodged between the metal sheet and the bottom of the cavity.

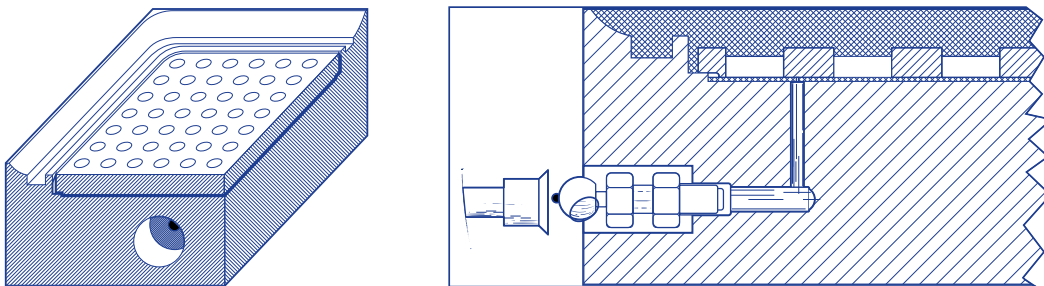


Figure 3.46. Single cavity isostatic punches with fixed perforated metal sheet.

Depending on the type of sheet metal used, MACER manufactures two different types: MGV-1M punches (Figures 3.47 and 3.48) and MGV-2M punches (Figures 3.49 and 3.50).

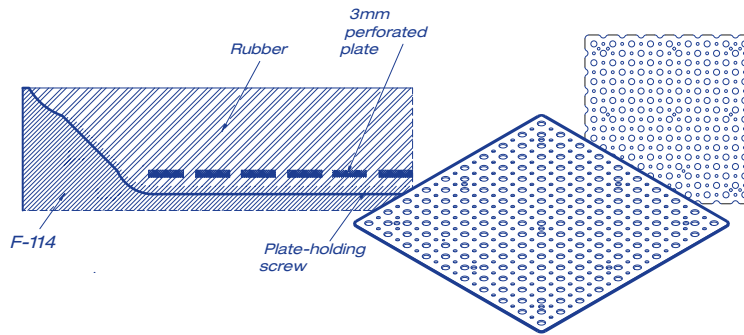


Figure 3.47. Isostatic punches with fixed metal sheet MGV-1M (schematic).



Figure 3.48. Isostatic punches with fixed metal sheet MGV-1M

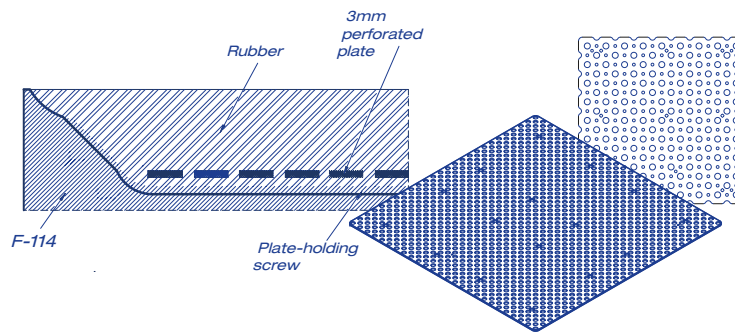


Figure 3.49. Isostatic punches with fixed metal sheet MGV-2M (diagram).



Figure 3.50. Isostatic punches with fixed metal sheet MGV-2M.

b) Isostatic interconnected cavity punches.

Single cavity isostatic punches are limited by the format, as it is difficult to prevent oil ripples from appearing on the glazed surface on large surfaces. Although floating sheet metal punches can be a good solution, it is not good enough for large formats, which is why new types of isostatic punches have been developed that transform the oil cavity into a system of small interconnected cells.

A wide variety of such punches can be found on the market. The differences between them lie in the solution used to build the structure of the interconnected cells where the oil is located.

Mixed punches.

These are an improvement on the previous types of punches, with a mixed design that inherits the way of rubber fastening from the previous ones and integrates it into a system of interconnected cavities.

The rubber is attached to the side groove and to threaded holes or crossheads. During the heat treatment to which the rubber is subjected (hardened), it is firmly fixed to the groove and bores, or to the crossheads, and not to the cavities, as this is prevented by the application of release agents in these areas, creating a sufficiently rigid structure which nevertheless allows the isostatic effect, since all the compartments are, as indicated above, interconnected with each other.

Isostatic grid punches (MACER type MRPV).

Grid punches (Figures 3.51, 3.52 and 3.53) are provided with a mechanised grid in the punch that defines a system of cavities that can have different shapes, although the most frequent due to its constructive simplicity and effectiveness is the square shape. The small chambers that form the grid of cavities are interconnected with each other by different procedures: channels, drilled holes at different angles, etc.

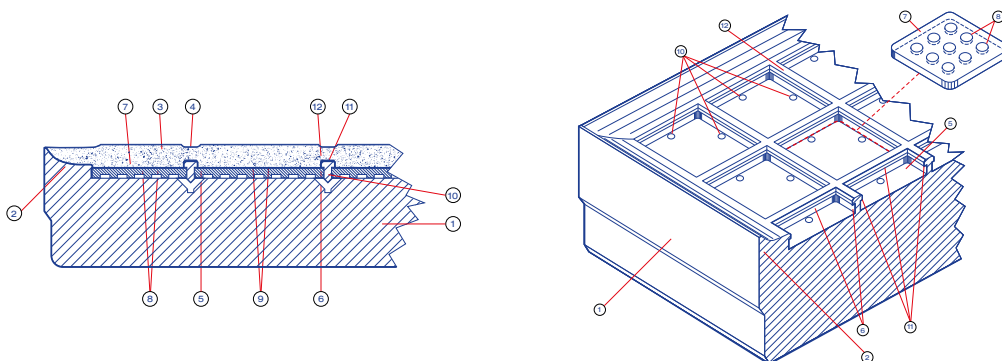


Figure 3.51. Isostatic punch structure with grid cavities.

1. Punch body.
2. Perimetral frame.
3. Rubber.
4. Back sides.
5. Bottom of the cavities.
6. Partition walls of the cavities.

7. Elastic modular pieces.
8. Buttons of the elastic pieces.
9. Oil filled holes.
10. Holes for oil filling.
11. Staggered attachment of the stops.
12. Upper sections of the partitions.

The design of the grid is made in such a way that the cells formed are smaller than the back side to be used and that the partition walls coincide with those of the original back side (Figure 3.52), without offsetting them and forming a perfect plane with the piece. This is important because the tile must have a perfect support plane during storage and handling in the raw state, and especially during firing. Consequently, the design of the cavities can reduce the isostatic effect of the punch to maintain a perfect support of the tiles ^[1].

Blinded cavities with elastic stops

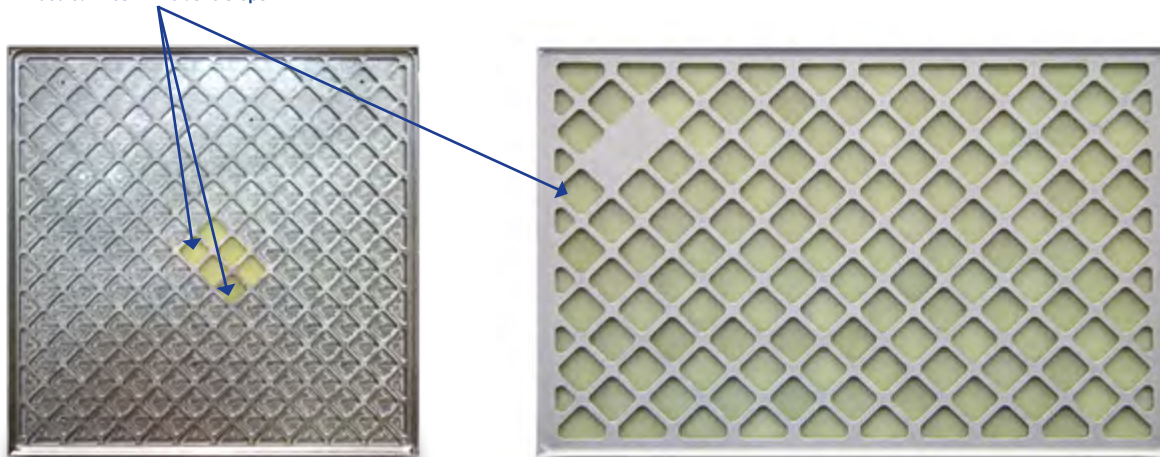


Figure 3.52. Grid cavities structure and elastic closing stops.

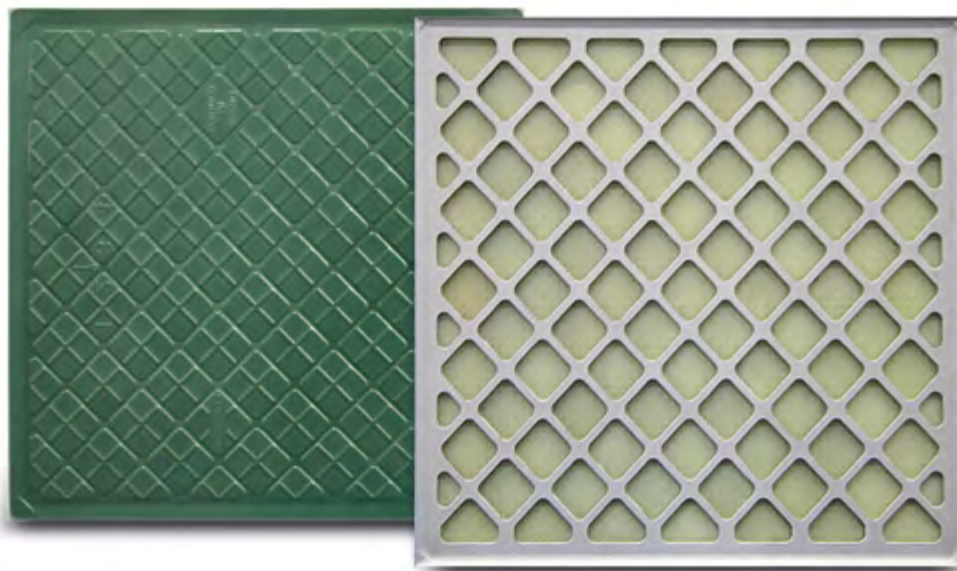


Figure 3.53. Isostatic punches with grid structure.

The oil is introduced through the piloted non-return filling valve and fills the cavities. The valves (Figure 3.54) can be either quick-connect or screw-in valves. This operation is facilitated by small venting ducts made in the grid. The oil is never in contact with the rubber of the punch, as the cavities are closed by means of elastic modular pieces that have buttons or projections on their lower bases that sit on the bottom of the cavity and fit perfectly into each of the cavities [77]. Some projections or perimeter steps made in the cavities partitions prevent their movement. The upper faces of these stops are in contact with the rubber of the punch, so the stops transmit the oil pressure and therefore allow the isostatic effect to be maintained as all the pockets are interconnected, and the oil can circulate freely between the lower projections of the modular pieces.



Figure 3.54. Types of valves for isostatic punches.

In this type of punch, the amount of oil required is greatly reduced and, furthermore, it is not necessary to apply additional pressure to the fluid. They also have the advantage that, due to their design, they perform the hydraulic compensation while keeping the thickness practically constant, with differences of only ± 0.1 mm.

When tiles are glazed with glossy glazes, such as clear ones, these punches may give the defect known as “back side marking”, i.e. the ribs can become visible on the glaze surface in reflected light. To avoid this, it is advisable to design the mould back sides with a low thickness, although it is preferable to use this hydraulic compensation system on matt and very thick tiles.

There are systems available to control the charging circuit. It consists of a loading tube or hose where all the punches are connected in series to a block with a valve, a logic element and finally a pressure transducer connected to a display which indicates the maximum and minimum working pressure of the circuit. This device allows the detection of circuit discharges.

On the other hand, it is possible to know the pressure in the oil chambers during the pressing operation if a pressure transducer is connected either directly to the body of the punch or by means of a hose.

Measuring the pressure in each of the punches allows balancing the pressing operation by equalising the compaction in all punches. For example, when pressing large formats, or medium-sized formats with a high number of outlets, large moulds are used, which require presses with a large clearance between columns. In these cases, the pressure is distributed unevenly, so the tiles in the central cavities are more compacted than those at the ends. This means that the volume of oil in each punch does not always have to be the same, as it varies according to the load in the cavity, and this can be variable. The equipment described can detect these differences, which allows us to modify the pressures in the chamber of each punch by injecting or extracting oil.

A direct variant of this device consists of a device to independently regulate the filling of the cavity of each of the punches from a hydraulic control unit with an injector, connected to each punch by means of independent control hoses and valves, so that when the pressing regulation is started, the punches are emptied and the real values of bulk density are obtained, without hydraulic compensation. Subsequently, the bulk density in each plate is adjusted by injecting the necessary amount of oil in each punch through pulses in order to unify the compactations in all the outlets. In each pulse, 2 ml of oil are injected. The system is operated by the press operator himself since it is part of the press regulation system that incorporates it. The amount of oil in each punch is therefore automatically adjustable by means of a microprocessor where the bulk density control data is loaded.

c) Interconnected isostatic punches.

Until now we have always referred to watertight punches, in which a quantity of oil is injected, which can be different depending on the position of the punch. It is possible, however, to interconnect the mould punches by means of a hose system, which allows some compensation of the oil load of each punch, but is not useful to compensate for differences in load between punches^[1].

For proper functioning of the punches, oil transfers between one punch to another must be kept to a minimum. If this is excessive, the balancing effect of the pressure inside the small cavities of a punch may be cancelled and the punch will therefore behave like a traditional punch without hydraulic compensation.

3.8. UPPER PLATES.

These are the plates (figure 3.55), which are used to hold the upper punches, which is why they are bolted to the mobile plunger of the press. Although electromagnetic coils can be used for the magnetisation system, current moulds tend to be equipped with a permanent magnetisation system that holds the upper punches in place and prevents them from falling in the event of an accidental power outage. These plates are made of DIN CK45 steel.

MACER sells a universal permanently magnetised top supplementary plate (figure 3.56) which has the same dimensions as the press plunger and is attached to it. This plate has centring and safety systems that allow a wide variety of plates to be mounted on it, both isostatic and traditional, thereby enabling quick format changes.

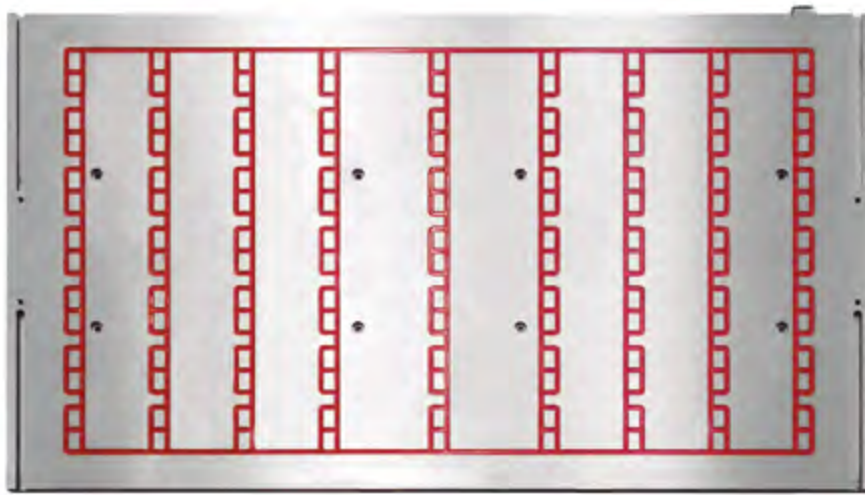


Figure 3.55. Permanent magnetised universal top supplement plate

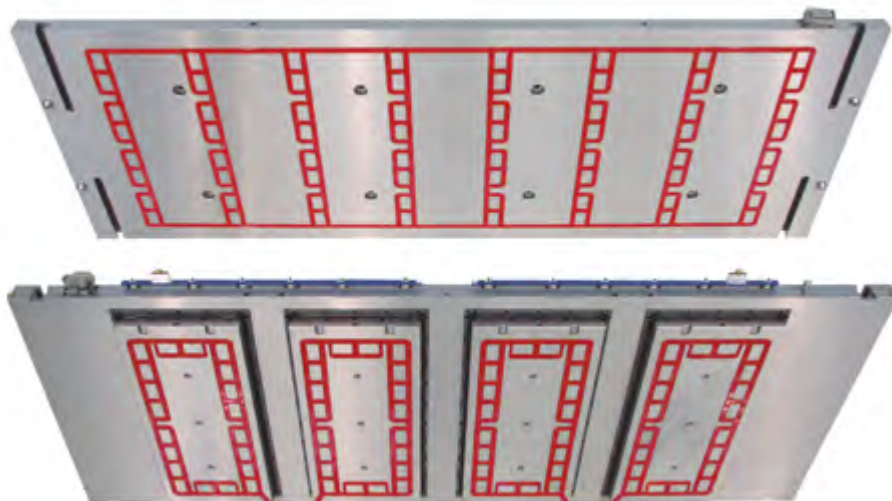


Figure 3.56. Isostatic upper plate mounted over a permanent magnetised universal supplement plate.

3.9. ISOSTATIC PUNCH HOLDER PLATES.

Some moulds are equipped with an isostatic punch holder plate. These plates have an internal hydraulic system that connects all the punches, thus achieving hydraulic compensation. This system is derived from isostatic compensation and is used when a minimisation of the number of sizes produced is required.

The isostatic punch holder plate can be installed in any type of mould. In the entry moulds, isostatic compensation is installed in the upper punches, and in the upper forming moulds, or double moulds it was initially installed in the lower part (figure 3.57). Although nowadays, due to the problems of decompensation of the cavity load detected in moulds with hydraulically compensated punch holder plates, it is preferred to install it in the upper plate (figure 3.58), despite the fact that this is a much more complex technical solution.



Figure 3.57. Low forming mould (double mould)

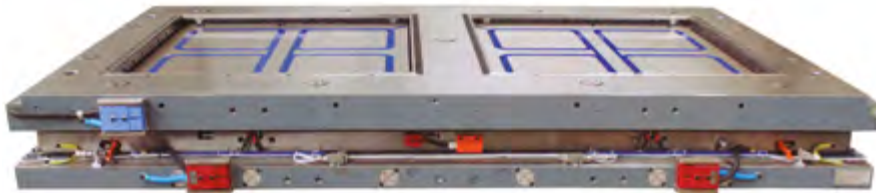


Figure 3.58. Low forming mould (double mould) with an upper isostatic plate.

The effect on the bulk density of an upper punch holder plate installed in a three-outlet penetration mould is shown in Figure 3.59 [25].

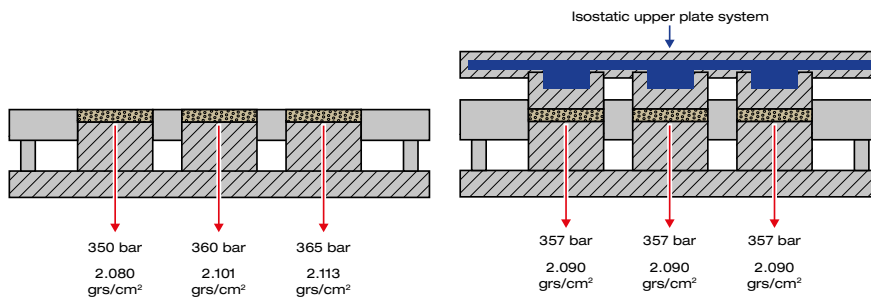


Figure 3.59.

3.10. MAGNETISATION SYSTEMS.

As early as the 1980s, magnetic fastening was used instead of screws to hold the punches in place. This type of clamping has significant advantages over the previous one, as it allows better centring and faster assembly of the punches.

Magnetic fastening can be carried out by permanent magnets or electromagnets. **Permanent magnets** are used to hold the upper punches to the upper punch holder plate (Figure 3.60). This system consists of three types of magnets: neodymium magnets with fixed polarity on one side and AlNiCo magnets with alternating polarity on the other, around which an electric coil is placed. The magnetic field is reversed by a short alternating current pulse, which orients the molecules of the AlNiCo magnets differently. In the magnetic phase (MAG), the magnetic field is doubly concentrated at the top of the magnet.

The coils are supplied with mains voltage via an electrical panel that transforms the voltage into positive or negative pulses. In one case, a polarity is induced into the magnets that cause magnetisation, holding the punches; and in the other case, the polarity is reversed to demagnetise and allow them to be changed. It is not necessary to maintain the electric current in the coil to maintain the state of the magnet; it is only necessary to provide the necessary current for a period of time to cause the change of state.

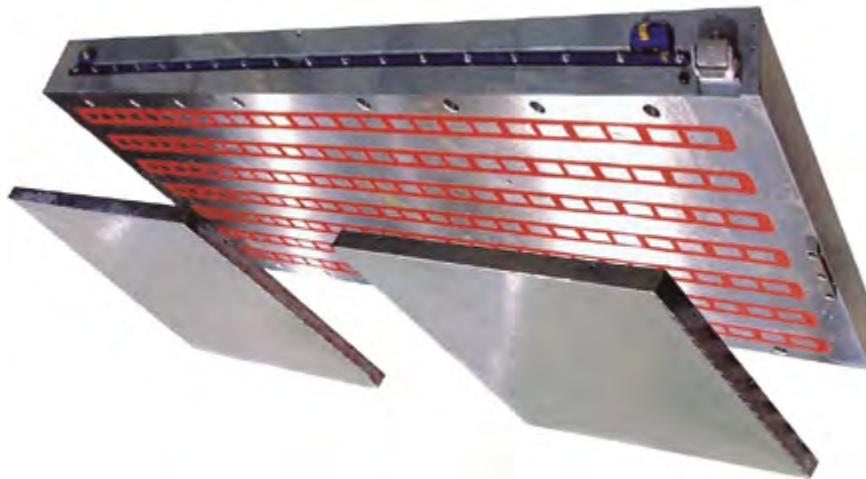


Figure 3.60. Magnetic clamping of upper punches in a mirror mould

The electromagnets are used to clamp the punches to the magnetic blocks (Figure 3.61) and also to hold the upper punches.

This system is made up of coils (solenoids) which must be continuously supplied with 24 or 48 Volts in direct voltage. The current flowing through the coils generates a magnetic field that keeps the punches attached to the magnetic blocks or to the punch holder plate.

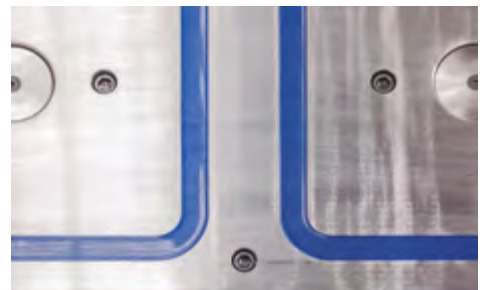


Figure 3.61. Electromagnet inside the block (detail).

3.11. HEATING SYSTEMS.

Moulds are equipped with a heating system whose objective is to heat the components that come into direct contact with the powder during pressing, i.e. liners and punches, in order to reduce the powder sticking to the mould and to avoid stopping for cleaning. The heating of all these components also allows acting on the clearances between liners and punches by controlling their expansion.

The intensity of electric current through the heating elements generates a heat energy (Q) equal to:

$$Q = I^2 \cdot R \cdot t$$

Being,

Q: heat energy (J)

I: intensity (A)

R: resistance (Ω)

t: time (s)

This heat energy generated in the core of the heating element is transmitted by conduction through the metal parts to the desired areas of the mould (inside the liner and rubber or punch faces in contact with the powder), raising their temperature to the working values, which is generally between 35 and 55 °C.

Two heating systems are currently used, depending on the type or component of the mould:

- **Tubular heating elements.** This type of heating elements (figure 3.62) is mounted inside holes practiced in the die box and in other the parts of the mould that are in contact with the punches (magnetic blocks and punch holder plates).
- **L-shaped perimeter heating elements** (figure 3.63). They are mounted at the corners and along the length of the die box, following its entire perimeter. They are best suited for distributing heat evenly in large moulds.

Apart from these two types of heating elements, it is also possible to find **flat heating elements** (figure 3.64), although their use is very limited due to their low efficiency.

In small moulds, generally less than 1750 mm long, the heating elements for heating the die box have usually been installed on the back side, in contact with it. Since the die box is not very thick in this type of mould, the heat is distributed with a certain homogeneity if the choice of heating elements and their distribution are appropriate. However, in large moulds used for pressing large tiles, the die box is very large and has a high thickness, so this arrangement of the heating elements is insufficient to achieve a homogeneous distribution of heat. MACER equips its moulds with long L-shaped heating elements that are installed perimetrically, as shown in Figure 3.63.



Figure 3.62. Tubular heating elements.



Figure 3.63. L-shaped perimeter heating elements.



Figure 3.64. Flat heating elements.

Table 3.9 shows the heating elements used depending on the type of mould.

Some mould models use three-phase current at 380 V - 440 V, which allows the use of smaller cross-section cables and fast plugs that facilitate the quick and safe replacement of the moulds. Depending on the number of heating zones of the press, one or two junction boxes are used for heating and magnetisation of the mould. In this type of mould, all installed heating elements are tubular. Each heating zone is controlled by a thermocouple, and presses with up to 16 zones have been manufactured, allowing each cavity to be controlled independently in moulds with up to 6 outlets.

Mould type	Component	Commonly used heating element
Small entry (*)	Upper punch	Tubular resistors
	Magnetic block – lower punch	Tubular resistors
	Die box	Simple L-shaped heating elements
Large entry	Upper punch	Tubular resistors
	Magnetic block – lower punch	Tubular resistors
	Die box	Double L-shaped heating elements
Double mould	Upper die box	Tubular resistors
	Lower die box	Simple L-shaped heating elements
Moulds 380 – 440 V		Tubular resistors

(*) Length less than 1750 mm

Source: MACER

Table 3.9. Heating elements used depending on the mould type.

3.12. ELECTRICAL CIRCUIT AND FAST PLUGS.

For the electrical circuits of moulds, the current trend is to arrange in covered inner mould cavities, all electrically live components i.e. wiring, heating elements and coils, so they could not be easily (or accidentally) accessible. This facilitates the protection of wiring and other components, it isolates them from humidity and dust, and makes equipment maintenance easier. The location of these components is clearly indicated by pictograms and colour codes.

MACER is currently equipping all its moulds with fast plugs, such as those shown in figures 3.65 and 3.66. These plugs increase the safety of the mould, avoid errors, facilitate assembly and reduce the time spent changing moulds.



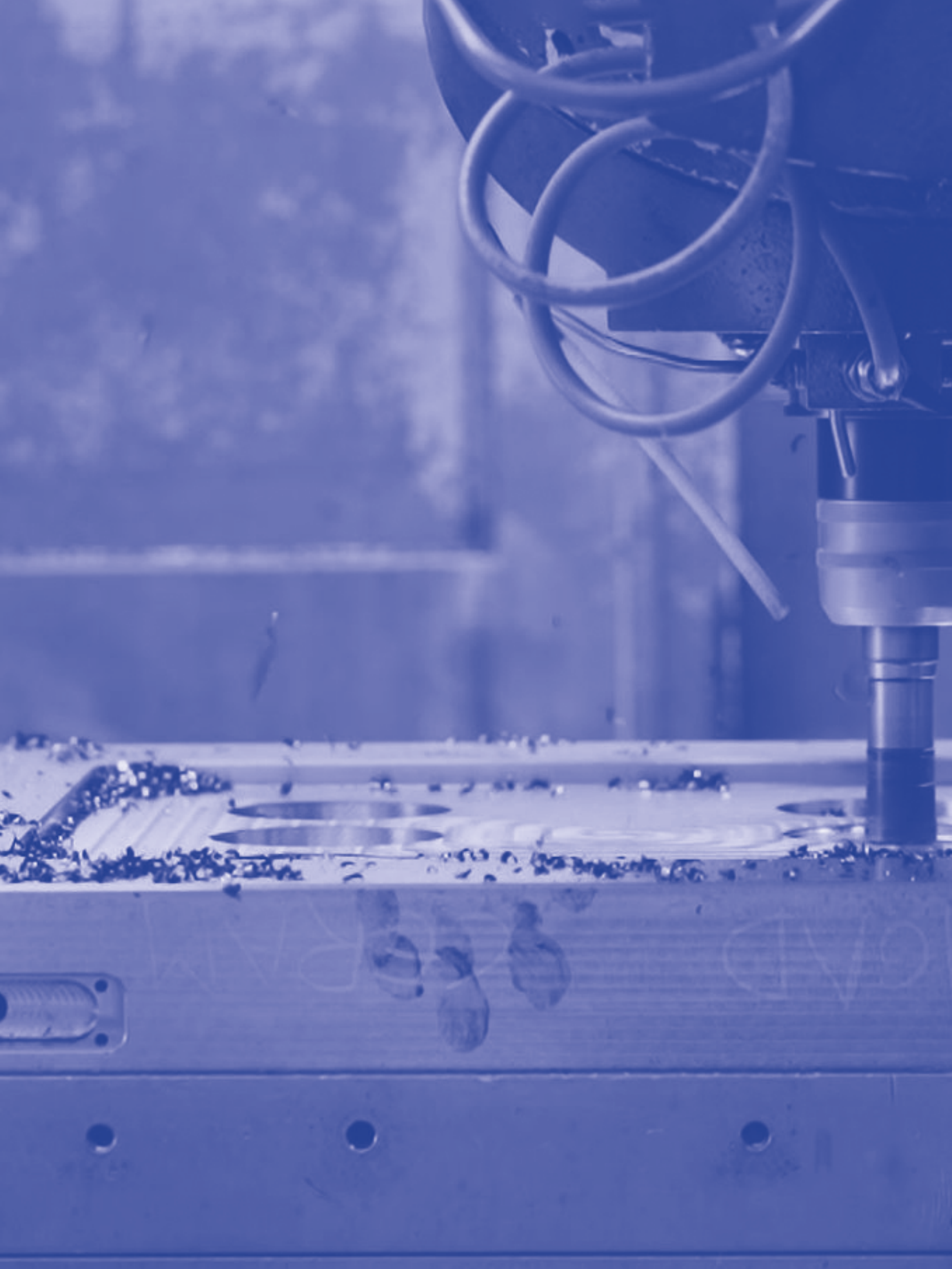
Figure 3.65. Fast plugs on the lower side of the mould.



Figure 3.66. Fast plugs on an upper plate.

Manufacturing processes.

Chapter 4



4.1. MATERIALS USED IN THE MOULDS MANUFACTURE.

The previous chapter has described the components of the mould and Table 3.1 shows information on the materials used in its manufacturing process. As seen in this table, most of the structural elements of the mould are made of steel (figure 4.1) and most punches, except for tempered and tempered-polished punches, are coated with rubber. These two materials are essential in the manufacture of moulds, to which must be added other materials used to a lesser extent for other components, such as elastomers used in bellows, etc.

4.1.1. Steels.

Steel is any alloy of iron and carbon where the carbon content in solid solution in the iron is below 2.1%. In general, an increase in the carbon content of steel increases its tensile strength, but also increases its cold brittleness and decreases its toughness and ductility. Apart from iron and carbon, steel may contain other alloying elements, including manganese, chromium, nickel, silicon, molybdenum and vanadium, which modify its properties.

Thus, the different chemical compositions of steels, together with the different thermo-mechanical treatments and the great variety of existing surface treatments, result in a huge number of steels with different properties and uses.



Figure 4.1. Raw steel plates.

4.1.1.1. Classification.

There is a wide variety of criteria for the classification and designation of steels. Industrially used steels are classified according to established national and international standards. For example, in Spain, steels are classified according to the **Standard UNE-EN 10020:2001**, which replaces the previous standard UNE-36010, although for structural steels, the European standards EN 10025-2 are followed: 2004 and EN-10025-4: 2004.

UNE-EN 10020:2001 standard classifies them according to chemical composition, quality and intended use:

a) Classification according to chemical composition.

According to their chemical composition, steels can be classified as follows:

- **Carbon steels.** These are the majority of steels. They contain varying amounts of carbon, less than 1%, and less than 1.65% manganese, 0.60% silicon and 0.60% copper.

Carbon steels are commonly used, among other things, in the construction of structures and machine components.

Depending on the amount of carbon, they can be divided into **low-carbon steels** (below 0,25 %); **medium-carbon steels** (between 0,25 % and 0,55 %) and **high-carbon steels** (above 0,55 %). Also depending on the carbon content they can be classified into **mild, semi-mild, semi-hardened and hardened steel**. Table 4.1 shows the characteristics of these types of steels and the link between the two classification criteria.

Their mechanical properties can be modified by heat treatments such as annealing, quenching and tempering (Annex V).

Type of steel		% C	Mechanical resistance (Kg/mm ²)	Mechanical resistance after hardening (Kg/mm ²)	Brinell (HB)	Brinell hardness after tempering (HB)	Uses
Low carbon	Mild steel	< 0.25	48 to 55		135 to 160		• It can be welded. • Medium-strength parts with good toughness, cold forming, drawing, bending, fittings. • Structural sections, wires, nails, bolts, screws, bars, rods.
Medium-carbon steels	Semi-mild steel	0.35	55 to 62	Up to 80	150 to 170	215 to 245	• Machine elements, bolts, screws, fittings, etc.
	Semi-hardened steel	0.45	62 to 70	Up to 90	180		• Shafts and machine elements, heavy-duty parts, combustion engine cylinders, transmissions, etc.
High-carbon steels	Hardened steel	0.55	70 to 75	Up to 100	200 to 220	276 to 300	• Shafts, transmissions, tensioners and regularly loaded parts of low thickness.

Table 4.1 Characteristics of steels according to carbon content [54].

- **Alloy steels.** They contain vanadium, molybdenum and other elements, as well as higher amounts of manganese, silicon and copper than carbon steels. This group can be further subdivided into **low alloy steels**, if the content of alloying elements is less than 5 %, and **high alloy steels** if it is higher than 5 %.

b) Classification according to quality.

According to this criteria, the standard classifies steels into three groups:

- **Non-alloy steels.** They are divided into **non-alloy quality steels**, with special mechanical performance and **non-alloy special steels**, which are characterised by good behaviour in quenching and tempering operations.

- **Alloy steels.** They are further subdivided into two groups, alloy quality steels and special alloy steels.
- **Stainless steels.** They are subdivided according to the nickel content, either above or below 2,5% and according to their physical characteristics, into corrosion resistant, hot oxidation resistant and good creep performance.

c) Classification according to use.

According to this classification criteria, steels are divided into:

- **Construction steels**, characterised by good welding behaviour.
- **Case-hardened steels.** These are steels that undergo a thermochemical process whereby carbon is added to the surface by diffusion. This treatment makes them harder, but also less resistant to breakage due to impact.
- **Steels for quenching and tempering.** The tempering⁴³ treatment (see Annex V) hardens and increases the strength of the steels. Hardened steels can be tempered⁴⁴ in order to remove the stresses created during tempering, bringing them to the desired hardness and strength.
- **Stainless steels for special uses.** They feature an iron alloy with a minimum of 10 % chromium by mass.
- **Steels for cutting and machining tools.** They have high hardness and high wear resistance.
- **High-speed steels.** They are used for cutting machinery, and are generally alloy with tungsten, molybdenum and molybdenum-cobalt alloys.

4.1.1.2. Steel designations.

Due to the enormous variety of steels mentioned above, there are a large number of standards and regulations for their designation, which vary from one country to another. In Spain, the designation of steels is governed by the **UNE-EN 10027:2001** standards, although structural steels are designated according to the European standards EN 10025-2: 2004 and EN-10025-4: 2004⁴⁵. The American **AISI** (American Iron and Steel Institute) and **ASTM** (American Society for Testing and Materials), the German **DIN**, the Japanese **JIS** (Japanese Industrial Standards) and the **ISO 3506** are also of interest due to their frequent application at international level. Special reference should also be made to the **CENIM** (Centro Nacional de Investigaciones Metalúrgicas) naming system, frequently used in Spanish industry.

In general, the identification of steels uses codes or designations established in the regulations, which can be of two types, symbolic or numerical.

⁴³The quenching treatment consists of heating the material to a temperature slightly higher than the critical temperature and then quenching it in a liquid, usually oil.

⁴⁴Tempering is a treatment similar to quenching, although it is carried out at about 50 °C less than quenching and with air cooling.

⁴⁵ It should be noted that an increasing number of national European standards (DIN, AFNOR, UNE, UNI, etc.) have been replaced by European standards (EN). This task is carried out by the European Committee for Standardization

Symbolic designation refers to the physical, chemical and technological properties of the material and, in some cases, to other significant properties or characteristics which enable it to be identified more precisely.

Numeric designation is an alphanumeric coding that allows the identification and classification of the material, but does not provide information on its characteristics.

In this text, special reference is made to the **UNE-EN 10027:2001** standard used in the ceramic press mould manufacturing industry, although, due to the great proliferation of standards mentioned, it will also be necessary to know the equivalences between the different designation systems of the steels referred to, such as those shown in tables 4.9 and 4.12, or those generally found in annex VII.

Designation of steels according to UNE-EN 10027:2001 standard

This standard provides for two types of designation:

- Numerical designation according to UNE-EN 10027-1:2001.
- Symbolic designation according to UNE-EN 10027-2:2001.

Numeric designations

The standard uses the following general numerical reference to designate any type of steel:

1. YY XX(XX)

In this reference:

- 1 corresponds to the type of material (steel). For other materials, numbers from 2 to 9 are used and are tabulated in the standard.
- YY indicates the group number of the steel according to a table in the standard.

Table 4.2 shows the groups of steels described according to the YY numbering of the standard and annex VI shows the complete table.

YY	Application
00 and 90	Non-alloy base steels
01 to 07	Non-alloy quality steels.
91 to 97	
10 to 13	
15 to 18	Non-alloy quality steels.
08 and 09	Alloy quality steels.
98 and 99	
20 to 28	Alloy tool steels
32 to 39	Alloy steels of various groups.
40 to 49	Stainless and refractory steels.
50 to 89	Prestressing steels.

Table 4.2. Types of steel according to the numbering of the UNE-EN 10027-1:2001 standard.

- XX(XX) represents the order number within the group. The digits in brackets correspond to extensions for future numbering needs.

For example, 1.1191 is a special non-alloy steel and 1.2080 is an alloy tool steel. Further information can be found at ^[44].

- **Symbolic designation.**

According to the symbolic designation followed by the UNE-EN 10027-2:2001 standard, steels can be identified according to two criteria:

- Depending on their use and their mechanical or physical characteristics.
- Depending on their chemical composition.

According to their purpose of use and their mechanical or physical characteristics are designated by a letter (**X**) indicating their application (Table 4. 3) followed by a number (**YYY**) giving the value of a characteristic mechanical property (generally the guaranteed minimum yield strength, expressed in N/mm²), and additional symbols (**ZZZ**), optional and tabulated in the standard, which are used, if necessary, to identify the steel.

General designation: **X YYY ZZZ**

Examples:

- According to this standard **S250** steel is a steel for metallic construction with a guaranteed minimum yield strength of 250 N/mm², equivalent in the numerical system to 1.0715 steel (see Table “Free machining steels” in Annex VII).
- **S235JRH** steel is a steel for metallic construction with a guaranteed minimum yield strength of 235 N/mm², for ordinary (JR) and hollow section (H) construction.

In general, this type of designation is generally used for steels of not very high quality in which the chemical composition is not strictly controlled.

X	Application
B	Reinforced concrete steels.
D	Flat products for cold deformation.
E	Mechanical construction steels.
H	Cold-rolled flat products of high-strength steel.
L	Pipe steels.
M	Electrical applications steels.
P	Pressure vessels steels.
R	Rail steels.
S	Metallic construction steels.
T	Packaging products.
Y	Prestressing steels.

Table 4.3. Applications of steels according to standard UNE-EN 10027-2:2001.

According to its chemical composition, the designation starts with a letter or type code, which indicates what type of chemical composition defines this steel (Table 4.4) followed by the percentage of carbon multiplied by 100 and the alloying elements. This is followed by element symbols and numerical values expressing their percentage in the composition.

If no type code appears at the beginning of the designation, it is interpreted as describing a non-alloy steel with more than 1 % manganese or an alloy steel with less than 5 % of all alloying elements.

Alloying elements are arranged according to their concentration.

Symbol	Type of steel composition
C	Non-alloy steels with an average Mn content of less than 1%.
X	High alloy steels with a weight content of alloying elements equal to or greater than 5%.
HS	High-speed steels.
S (+chemical symbol for alloy elements)	Cold-rolled flat products of high-strength steel.

Table 4.4. Type of chemical composition of steels according to UNE-EN 10027-2:2001 standard.

4.1.1.3. Mechanical properties of steels.

For calculation and structural design purposes, some average values of steel properties are taken from Table 4.5.

Physical property		Average value
Density.		7.85 t/m ³
Heat capacity.		0.11 kcal/kg °C
Coefficient of linear expansion.		120 x 10 ⁻⁷ °C ⁻¹
Melting temperature.	Low carbon steels.	1510 °C
	Medium carbon steels.	1430 °C
	High carbon steels.	1370 °C
Boiling temperature.		2500 °C
Poisson Index.		0.3
Elasticity modulus.		210.000 N/mm ²

Table 4.5 Average properties of steels for calculation and design purposes (common to all steels).

a) The “stress – strain” curve for steel.

This is the graphical representation of the “tensile stress – strain” curve obtained when a standard steel specimen is subjected to a continuous and increasing tensile stress (F/S) until it breaks. This test, standardised in UNE-EN 10002-1, allows some material properties to be calculated.

The “tensile stress – strain” curve of steels (figure 4.2) is an excellent representation of their behaviour when subjected to tensile stresses. The following sections and points can be identified in it:

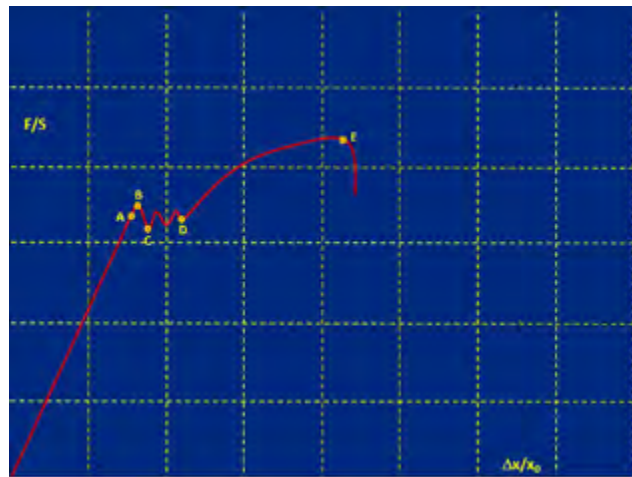


Figure 4.2. General appearance of the “stress – strain” curve of steel.

- Up to **point A**, known as the limit of proportionality, the steel behaves elastically according to Hooke's law, if the elongation ($\Delta x/x_0$) is proportional to the applied tensile stress per unit area (F/S) and is reversible, so that when the deforming force ceases, the material returns to its initial dimensions.
- Point B is the upper yield strength.** Before reaching this point (between points A and B) the material still has an elastic behaviour, although when the deforming stress ceases, it does not completely recover its initial shape. From this point on, increases in stress translate into irreversible deformation, that is, the material does not return to its original dimensions and a residual deformation remains. If this value is exceeded, components or structures can no longer be used safely.
- Point C is the lower yield strength.** It is the minimum stress in the yield zone of the material following the upper yield strength.
- In the **section between B and D**, called the creep state, or elastoplastic zone, the deformation increases rapidly while the stress fluctuates. This section is characteristic of mild steels, and does not occur in other types of steels.
- The **section between D and E** is called the material hardening zone.
- If tension continues to be applied **from point D onwards**, the deformation increases rapidly until reaching point E where the material breaks. The required stress (force per unit area) is referred to as the “**breaking load**”.

The shape of the stress – strain curve of steels depends on their composition, ductility and fragility. The more deformable steels have a much lower slope of the elastic zone (Young's modulus) and the more brittle steels have a smaller hardening zone. Mild steels have, as mentioned above, an elastoplastic zone and a high deformation before rupture.

This test allows us to determine different mechanical characteristics of materials in general and of steels in particular, such as:

- **Elasticity modulus.** Quantifies the proportionality between deforming stress and deformation. It is the slope of the stress-strain line in the phase of elastic behaviour of the material.
- **Poisson's ratio.** Describes the relationship between the longitudinal elongation experienced by the material and the decrease in cross-section of the material.
- **Yield strength.** It is also called the apparent yield strength and is the value of the stress that the material withstands at the moment when it reaches the yield state. This phenomenon occurs in the transition zone between elastic and plastic deformation and is characterised by a rapid increase in deformation without an appreciable increase of the applied load.
- **Elastic limit.** The maximum stress that can be applied without permanent deformation of the material.
- **Breaking load.** This is the maximum load the material can withstand without breaking. For its calculation, the initial section of the specimen is considered.
- **Tensile strength.** Length increase, expressed as a percentage, which the specimen has undergone until breakage.
- **Striction.** The decrease in cross-section, also expressed as a percentage, experienced by the specimen until it breaks. b) Physical characterisation.

b) Physical characterisation.

The physical characterisation of steels depends on their intended use, but generally comprises the physical properties given in tables 4.5 and 4.6.

⁴⁶ Hooke's Law states that, as long as the deformations produced do not exceed a certain limit, there is a proportionality between the stress σ or force applied per unit area, and the deformation produced ($\Delta x/x_0$):

$$\sigma = E \cdot (\Delta x/x_0)$$

where E is a proportionality factor characteristic of each material, known as **modulus of elasticity** or **Young's modulus**.

⁴⁷ The shear modulus (G) is related to Young's modulus (E) and Poisson's ratio (v) by means of the equation:

$$G = \frac{E}{2 \cdot (1 + \nu)}$$

⁴⁸ The Carbon Equivalent Value (CEV) is calculated using the following expression where [X] is the percentage present in the steel of element X

$$CEV = [C] + \frac{[Mn]}{6} + \frac{[Cr] + [Mo] + [V]}{5} + \frac{[Ni] + [Cu]}{15}$$

Physical property	Measurement units	Test	Description of the property
Elastic limit.	Kg/mm ² Kg/cm ² N/mm ² MPa	"Stress – strain" curve UNE-EN 10002-1 Standard ISO 6892-1 Standard (room temperature test) ASTM E8 Standard.	This is the point in the "stress – strain" curve where the steel ceases to behave as an elastic solid where the deformation is therefore proportional to the applied stress and is reversible (no longer following Hooke's Law ⁴⁶). From this point onwards, increases in stress lead to permanent deformations (plastic behaviour).
Tensile strength.			Breaking load per unit area after being subjected to tensile stress.
Modulus of longitudinal elasticity (Young's modulus).			Slope of the stress – strain straight line in the phase of elastic behaviour of the steel. Intrinsic property of the material that gives an idea of its structural rigidity.
Shear modulus. ⁴⁷			It measures the deformation the material undergoes when it is subjected to a shear stress, i.e. applied in a tangent direction to the surface where it acts. It is also known as transverse modulus of elasticity.
Poisson's ratio.	Dimensionless		Ratio of the decrease in cross-section of an isotropic, linear elastic material with respect to the increase in length of the material when stretched. It remains constant within the range of elastic behaviour.
Resilience.	J/mm ²	UNE EN ISO 148-1:2017 Impact bending test on a notched specimen of standard dimensions.	Resilience measures the degree of toughness or ductility of the steel at a given temperature (usually room temperature, at 0°C, or at -20°C).
Tenacity.	MPa.m ^{1/2}	ASTM E399-81.	Toughness defines the measure of a material's resistance to crack propagation. The fracture of the material is initiated at the location where the stress concentration is the greatest possible, and this location may be the tip of a pre-existing micro-crack.
Brinell hardness.	(HB)	EN ISO 6506-1:2005. Standard ASTM E10-08. Indentation test using a 10 mm diameter sphere of steel or tungsten carbide. (Annex III)	Hardness is a measure of the resistance of one material to penetration by another.
Rockwell hardness.	(HR)	EN ISO 6508-1:2017 ASTM E10-08 Indentation test using three types of indenters: a diamond cone; a 1/16" diameter steel sphere or a 1/8" diameter steel sphere (Annex III).	
Weldability.			Evaluates the weldability of the steel. Weldability depends on both the characteristics of the base metal and the characteristics of the filler. One parameter that provides information on weldability is the Carbon Equivalent Value (CEV) ⁴⁸ which equates the relative weldability of different steel alloys and compares them with the properties of a plain carbon steel.
Ductility index.		UNE-EN ISO 7438:2021 standard	It provides information on the ability to bend, i.e. on the presence or absence of cracks and fissures after steel bending.

Table 4.6. Physical characterisation of steels.

4.1.1.4. Properties of steels used in the manufacture of mould components.

The most frequently used steels in the manufacture of moulds are:

- 1.2080 steel.
- 1.1191 steel (CK45)

1.2080 steel.		
Classification.	Alloy tool steels.	
Manufactured mould components.	Upper and lower punches. Liners. Candle hook plates.	
Chemical composition.	C 1,9 % to 2,2 %. Si 0,1 % to 0,6 %. Mn 0,2 % to 0,6 %. Cr 11,0 % to 13,0 %.	
Brinell hardness (in supply).	250 HB	
Tensile strength (N/mm ²).	850	
Density (g/cc).	7.70	
Specific heat at 20 °C (J/Kg °K).	460	
Electrical resistivity at 20 °C (Ω.mm ² /m).	0.65	
Young's modulus at 20 °C (GPa).	215	
Thermal conductivity (W/m.°K).	Temperature	Conductivity
	20	16.7
	350	20.5
	700	24,2
Expansion coefficient (106 °C ⁻¹).	Temperature range	Expansion coeff.
	20 – 100 °C	11.7
	20 – 200 °C	12.0
	20 – 300 °C	12.4
	20 – 400 °C	12.9
	20 – 500 °C	13.3
	20 – 600 °C	13.6
	20 – 700 °C	14
Applications	Heavy duty cutting tools, punching tools, punches, scissor blades, knife jaws & head punches, brushes, stretching tools, stretching moulds, rollers and wood routers.	

Table 4.7. Physical properties of DIN 1.2080 steel.

a) 1.2080 steel.

1.2080 is a high carbon/chromium tempered tool steel with very high wear resistance. It hardens by oil quenching with low dimensional change. It has a very high compressive strength.

Table 4.7 shows the main physical properties of DIN 1.2080 steel and Table 4.8 shows the equivalences in different steel designation and identification systems. The following sections and points are identified:

Treatment	Temperature	Cooling
Soft annealing.	800 to 840 °C.	Kiln (slow cooling)
Annealed to release tensions.	650 to 700 °C.	Kiln
Quenching.	930 to 960 °C.	Oil
	950 to 980 °C.	Air (*)
Tempering.	Temperature	Rockwell hardness (HRC)
	180 °C	61 - 63
	200 °C	61 - 63
	250 °C	60 - 62
	300 °C	59 - 61
	350 °C	58 - 60
	400 °C	57 - 59
	500 °C	53 - 55

(*) Up to 30 mm thick

Table 4.8. Heat treatments of 1.2080 steel.

Spain.	UNE 36011-12	F5212
Europe.	EN 10083	X210Cr12
Germany.	DIN 17200	X210Cr12
	STAND N°	1.2080
France.	NF A35-552-86	X200Cr12
Italy.	UNI 7846	UX210Cr13KU
USA.	AISI/SAE	A681(D3)ASTM
Japan.	JIS	SKD-1

Table 4.9. International equivalents of 1.2080 steel.

a) 1.1191 steel.

In this text we refer to this steel as **CK45**, because this is the name commonly used in our industrial environment. It is a hardened, unalloy steel often used in general mechanical engineering. It is suitable for structural use in machines.

Table 4.10 shows the main physical properties of this steel, Table 4.11 shows its heat treatments and Table 4.12 shows the equivalences in different steel designation and identification systems.

1.1191 steel (CK45)	
Classification.	Special quality steel, unalloy.
Manufactured mould components.	Bottom plate. Ejecting plate. Blocks Die boxes. Rubber coated lower punches. Rubber coated upper punches. Magnetic upper plate.
Chemical composition.	C 0,40 % to 0,50 %. Si 0,15 to 0,40 %. Mn 0,5 % to 0,8 %. P $\leq$ 0,035 %. S $\leq$ 0,035 %. C equiv. 0,4 %. Cr $\leq$ 0,4 %.
Brinell hardness (in supply).	172/242 HB
Vickers hardness.	180/ 290 HV
Density (g/cc).	7.85
Specific heat (J/Kg °K).	460
Young's modulus at 20 °C (GPa).	215
Thermal conductivity at 400 °C (W/m.°K).	41.0
Tensile strength (MPa).	640
Expansion coefficient from 20 to 500 °C. (10^6 °C ⁻¹).	14.2
Welding.	Basic electrode or CO ₂ wire. Preheating between 200 and 250 °C and slow cooling are recommended.
Folded.	Deficient. Forming can be improved by applying softening or globular annealing. Hot forming is always recommended.
Mechanisation.	It requires annealing or stabilising treatment after oxy-fuel cutting to remove the resulting surface hardness.
Tempered.	It tempers well.
Applications.	Machine elements of good resistance. Hydraulic blocks. Moulds and mould-holders. It can be used for induction hardened parts requiring surface hardnesses of 55 HRC.

Table 4.10. Physical properties of DIN 1.1191 steel.

Treatment	Temperature	Cooling
Softening annealing.	670 - 710 °C.	air
Globular annealing.	710 °C 6 hours and	10 °C/hour up to 650 °C
	670 °C 8 hours.	
Standardised.	840 to 870 °C.	air
Quenching.	830 to 850 °C.	water
	840 to 860 °C.	oil
Tempering.	500 – 650 °C.	air

Table 4.11 Heat treatments of steel 1.1191.

Spain.	UNE 36011-12	F1140
Europe.	EN 10083	C45E
Germany.	DIN 17200	CK45
	STAND N°	1.1191
France.	NF A35-552-86	XC45
Italy.	UNI 7846	C45
USA.	AISI/SAE	SAE 1045
Japan.	JIS	S45C

Table 4.12. International equivalents of 1.1191 steel.

4.1.2. Rubbers used for punches.

Today, the use of vulcanised rubber coatings are widely used for all types of punches, both those that form the good face of the tile and those that form the back sides, which often have oil compensation. This type of punch is called “isostatic”.

The rubbers used in the coating of punches are urethane elastomers with high tensile strength, high abrasion resistance and high compressive modulus, which undergo a hardening process. The current trend is to perform this process at 100°C for liquid rubber applications, regardless of the type of punch, and at 120°C for rubber sheets. In both cases, a similar amount of time, around 20 minutes, is usually spent. The rubbers used are classified according to their SHORE hardness, scale A⁴⁹, in accordance with ISO 868; UNE 53130 and ASTM D 2240 measured with a Shore hardness tester (Annex VIII). Liquid rubbers usually have a glossy appearance, whereas rubbers sheets have a matte appearance after curing.

The rubbers used in the coating of punches (Figure 4.3) have Shore A hardnesses between 85 and 100. High hardness values give behaviors similar to metal in the pressing process, that means, high quality textures are obtained, but the punch becomes dirty more easily, which makes demoulding more difficult. As you go down hardness scale, a rougher texture is seen, with a more marked grain in the pressed powder, but nevertheless the press powder adherence decreases. This texture is very visible when using rubbers with a hardness less than 90 on the Shore A scale.

On the other hand, the lower the hardness, the greater the elasticity, so when pressing tiles with pronounced reliefs, it is advisable to use softer, more elastic and therefore better demoulding rubbers.

Some types of rubbers can be applied to the punch in very reduced thicknesses, which considerably increases rigidity and makes possible to achieve better textures on smooth pieces. This type of rubbers tend to displace polished punches, as it is possible to achieve the high quality finish of polished punches by reducing the adherence of the powder.

As an example, Table 4.13 shows the rubbers that can be used in the production of punches, their Shore A hardness and their most frequent use. These rubbers can be applied in sheets or in liquid form (Figure 4.4).

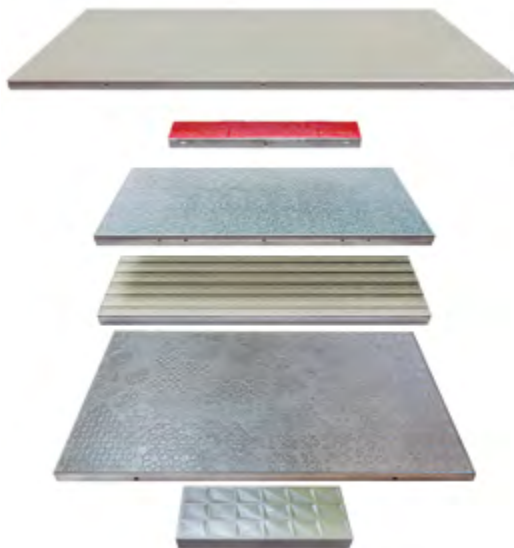


Figure 4.3. Punches with rubber coating of different hardnesses.

⁴⁹ Shore hardness is a rebound hardness. The test is carried out using a Shore hardness tester type PB at a temperature of 20 ± 2 °C on freshly vulcanised specimens and three days after hardening. Three tests are carried out on each probe at different points at least 5 mm apart from each other and from the edges, applying a constant weight of 1 kg for three seconds.

Presentation		Colour	Shore A hardness	Most frequent uses	
Sheet ^[30]		Blue.	95	Non-isostatic, smooth or embossed punches and special parts.	
		Red.	90		
		Green.	95		
		Red.	85	Isostatic punches.	
		Grey.	85		
		Green.	85		
Liquid.	Polymer (thermosetting).	Colourless (*).	95	Good face punches (smooth or embossed).	
			92		
			90		
			92		
	Elastomer (thermoplastic)	Green.	88	Back side punches (hydraulic compensation).	MGP. Rigid, MGPV; MGPVT; MRPV. MGV-1M; MGV-2M.

(*) Depending on the hardener used, colourless rubbers may show, after vulcanisation, a very strong or faint (champagne) yellow shade.

Table 4.13. Hardnesses and colours of punch rubbers.

In general, two types of rubbers are used, **polymers and elastomers**. The polymers used are thermosetting and are used on the good face of the tiles, both smooth and embossed. They are not susceptible to oil attack. Elastomers are used on the back side face. They are thermoplastics and are received in different hardnesses, but are mixed to obtain a SHORE A hardness of 88⁵⁰ which is used on the back side relief face.



Figure 4.4 Different types of rubber for punch coating.

⁵⁰ Generally, two rubbers of hardness 90 and 83 are mixed to obtain the rubber of hardness 88.

4.1.2.1. Rubber sheets.

Some manufacturers supply the rubber **in sheets** (Figure 4.5) with different colours depending on their Shore hardness. These sheets are served in rectangular formats, 40 x 90 cm and 2 mm thick, and are stored in freezer cabinets at temperatures between -10 and -15 °C, as they quickly lose their properties at room temperature. For their application, they must first be thawed naturally. It must be taken into account that this process depends greatly on the ambient temperature, so that the times must be adapted to this in order to avoid defects in the rubber during hardening, such as folds, blisters, orange peel, etc.



Figure 4.5 Rubber sheeting for punches.

4.1.2.2. Rubbers for liquid application.

Rubbers can also be applied **in liquid form**. These are mixtures of cast synthetic resins, with the dosage of which it allows the exact adjustment of the rubber properties. This type of rubber is most frequently applied in moulds, especially in medium and large format punches.

Liquid-applied rubbers are supplied solid in 200 kg or 25 kg drums, and they are stored at room temperature (Figure 4.6).



Figure 4.6 Storage drums for liquid application rubbers.

4.2. MANUFACTURING PROCESS OF THE BOTTOM PLATE AND EJECTING PLATE.

Both the bench plate and the ejecting plate are manufactured (figure 4.7) from DIN CK 45 steel sheets of 48, 55 and 65 mm thickness, as most common production values, which are received with the required dimensions. These plates are subjected to rough machining on the upper and lower surfaces; longitudinal and lateral, with the CNC milling machine (figure 4.8) from where they pass to the drilling division (figure 4.9). Here, the necessary holes are made, which are, among others, those required for the seating of the extraction pistons, the bellows, deaeration and fastening of the pillars and the pockets, etc. The final machining to exact dimensions is done with a CNC surface grinding machine, and is aimed at finishing the surface to the required thickness and flatness.

It should be noted that the plates can be received rectified, which simplifies the process, making all the rectifying operations (links 4.1 and 4.2) in the dotted line box in figure 4.7 unnecessary.

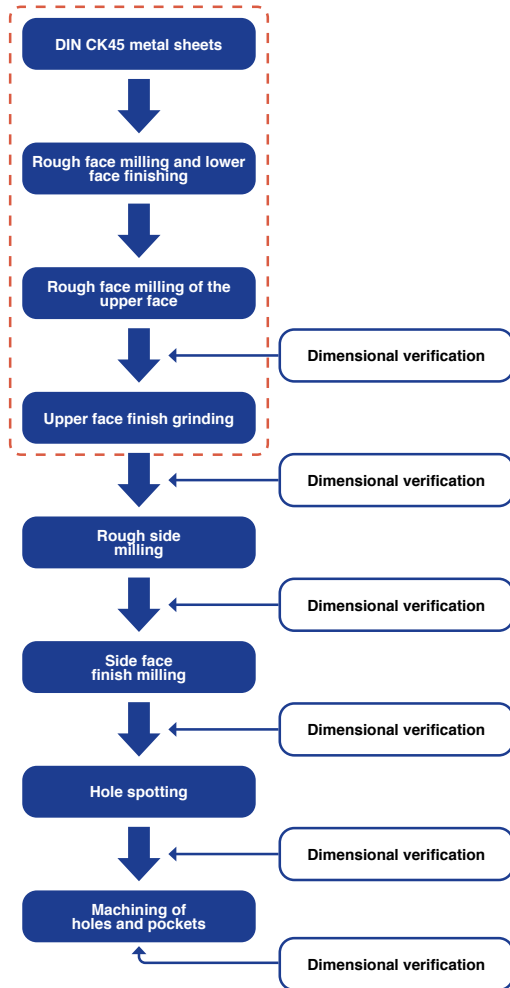


Figure 4.7 Manufacturing process of the bench and ejecting plate.



Figure 4.8. Rough milling of a bottom plate.



Figure 4.9. Drilling of the bench plate with a CNC drilling machine.



In the attached QR code you have a link to a video showing a bridge milling machine machining a bench plate. Link 4.1



In the attached QR code you have a link to a video showing the rectifying of a plate. Link 4.2



Figure 4.10. Barrel drill.

In today's moulds, all the hydraulic and pneumatic and lines for cleaning the moulds, such as the extraction circuit for the double moulds, which is located in the upper part of the mould, are drilled into the mould plates. This operation is carried out with special drilling machines, called barrel drills as shown in Figure 4.10. The main difference between this type of drilling machine and a conventional one lies in the drilling depth that can be reached, for which special deep-hole drills are used.

4.3. MANUFACTURING PROCESS OF MAGNETIC BLOCKS.

The manufacturing process of magnetic blocks (figure 4.11) includes the operations described for the bench and ejecting plates and, in addition, the machining of the slots for the seat of the magnetic coils and the drilling of the seats of the heating elements.

4.4. MANUFACTURING PROCESS OF BELLOWS FRAMES.

The bellows frame (Figure 4.13) is fabricated from angles which are welded and drilled, according to the process described in Figure 4.12.

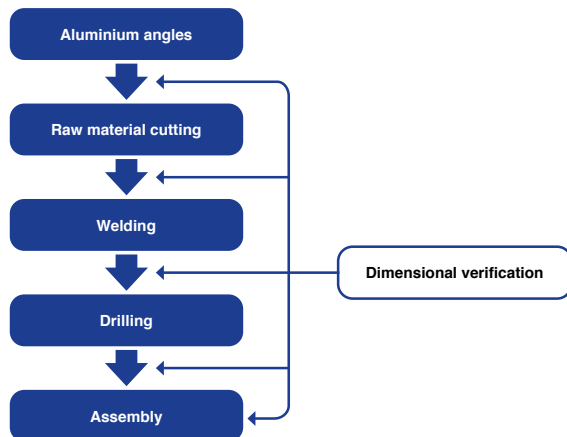


Figure 4.12. Manufacturing process of the bellows frame.

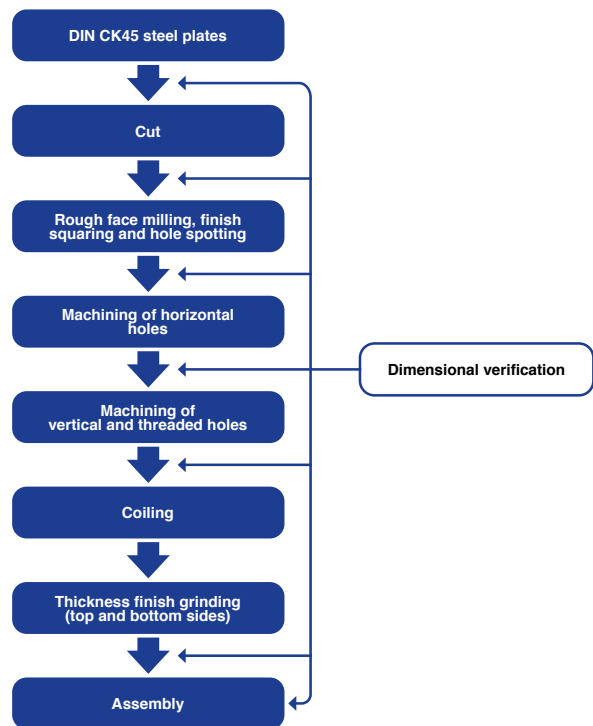


Figure 4.11. Manufacturing process of magnetic blocks.



Figure 4.13. Assembly of bellows.

4.5. MANUFACTURING PROCESS OF DIE BOXES.

Most of them are manufactured according to the scheme shown in figure 4.14 from DIN CK45 steel sheets of different thicknesses, depending on format. They are received with the required dimensions, and the cavities have already been made by oxy-fuel cutting. These plates are also subjected to surface, longitudinal and lateral machining on the CNC milling machine (figure 4.15); drilling and machining to exact dimensions, again with the CNC surface grinding machine (figure 4.16). The last step in the die box manufacturing process is the adjustment of the liners, which differs between the traditional fixed liners and the MACER system of removable liners.

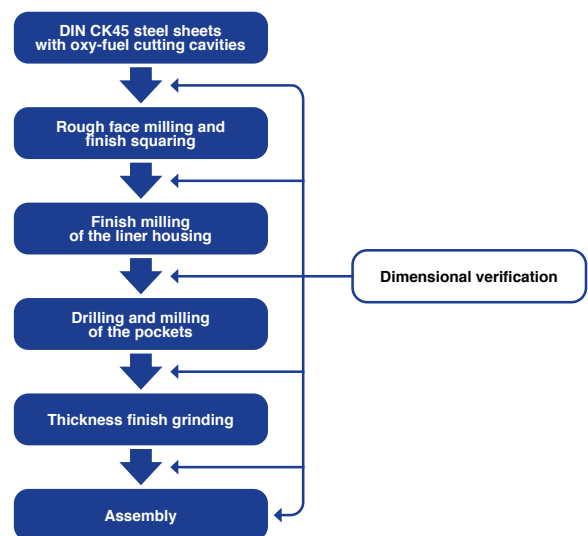


Figure 4.14. Manufacturing process of die boxes.



Figure 4.15. Milling of the die box.

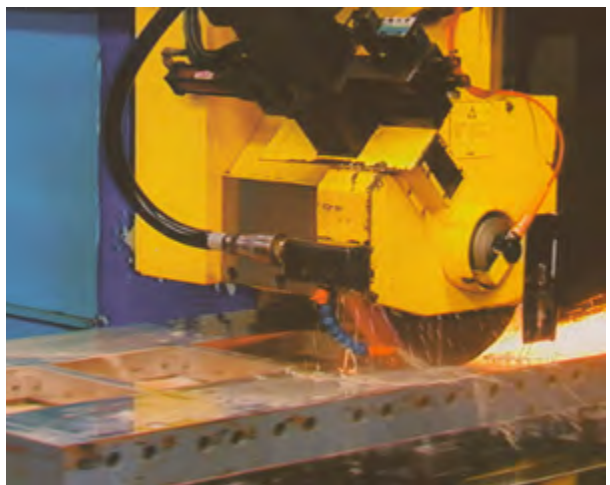


Figure 4.16. Surface abrasive grinding machine.

4.6. MANUFACTURING PROCESS OF LINERS.

In the previous chapter, different types of liners were described and classified. You can consult this classification in Table 3.5. In this chapter, we will describe the manufacturing processes of each of these types of liners.

4.6.1. Manufacturing process of fixed liners.

Figure 4.18 shows the flow chart of the manufacturing and assembly process of the fixed liners.

Liners are manufactured from raw DIN 1.2080 rolled steel bars or plates, which are cut to the required dimensions with the automatic sawing equipment. The cuts are made with CNC machining equipment. Then the drilling of the fastening holes is performed. This is followed by tempering.

It should be noted that during the tempering operation, variations in the liner geometry can occur, resulting in a certain number of rejections, given the strict dimensional accuracy required for these mould components.



Figure 4.17. Liners for one 31 x 90° outlet

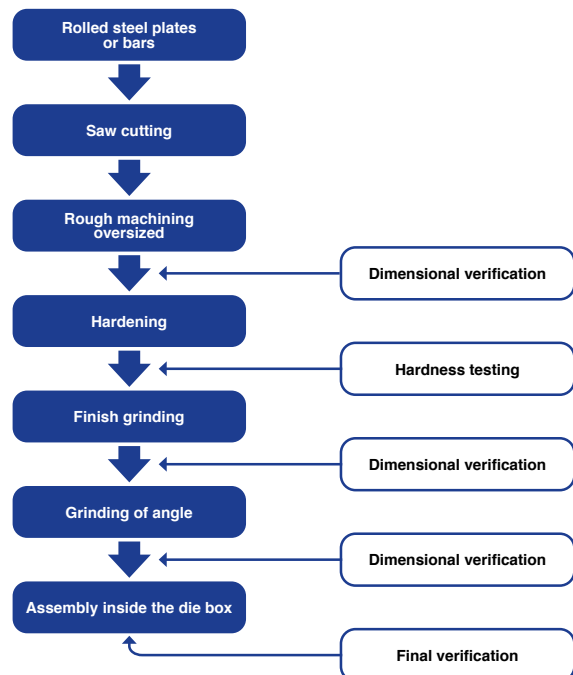
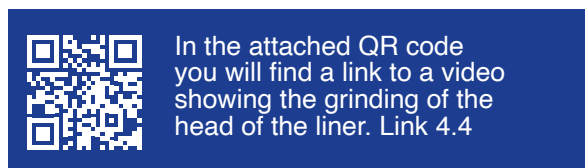
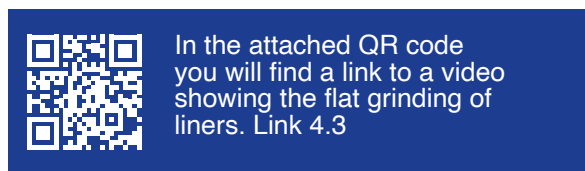


Figure 4.18. Manufacturing process of fixed liners.

After tempering, which is aimed to improve the mechanical properties of the metal, the liners are rectified to nominal dimensions and given the required angle (in Spanish also known as “tirada”) and radius, the threads are necessary reworked and only then, the laboriously work of screwing them into the die box can begin. Of course, it is essential that the internal machining of the cavities and the liners housing to be carry out with extreme precision.

After each operation, it is necessary to carry out the dimensional verification with the precision required in the procedures, to ensure that the dimensions of the semi-finished pieces conform to the dimensional requirements established in the designs. Verification is usually performed using precision measuring equipment such as micrometers, calipers and digital touch probes (Link 4.5.). After tempering, a hardness control is carried out.



In the attached QR code you will find a link to a video showing a centring process using digital touch probe. Link 4.5

4.6.2. Manufacturing process of rectified interchangeable liners.

These liners are manufactured, according to the diagram shown in figure 4.19, from rolled steel bars which are cut from raw stock. The preform with the holes is obtained by machining – milling. This machining stage is carried out with a slight increase of the measurements to compensate for the dimensional variation that will occur during tempering. After machining, the liners are dimensionally checked and the hardening proces is done in order to achieve a hardness of 60-62 HRC. Afterwards, the liners are rectified to reach the nominal thickness +0,1mm and also the width is also rectified to its nominal size. The dovetail joints are ripp-cut and the angle is machined. Once done the liners are assembled and the thickness corrected to its nominal value. Dovetail jointing is only used for removable liners.

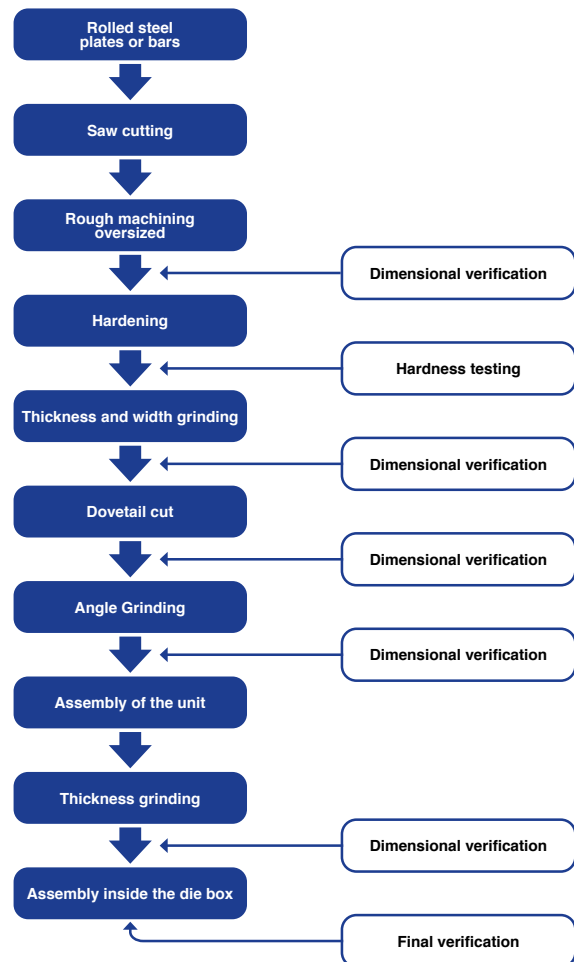


Figure 4.19. Manufacturing process of rectified interchangeable liners.

Figures 4.20; 4.21; 4.22 and 4.23 show graphically the process of mounting these liners into the die box.

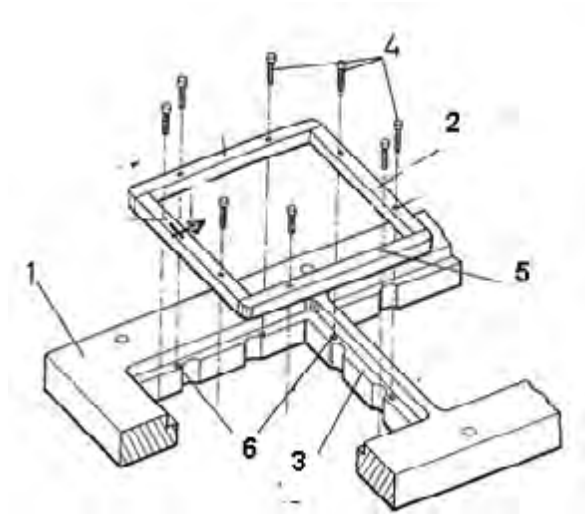


Figure 4.20. Removable liner set up into the die box.

- 1 Die box
- 2 Liner
- 3 The liner housing
- 4 Fixing screws
- 5 and 6 Threaded holes

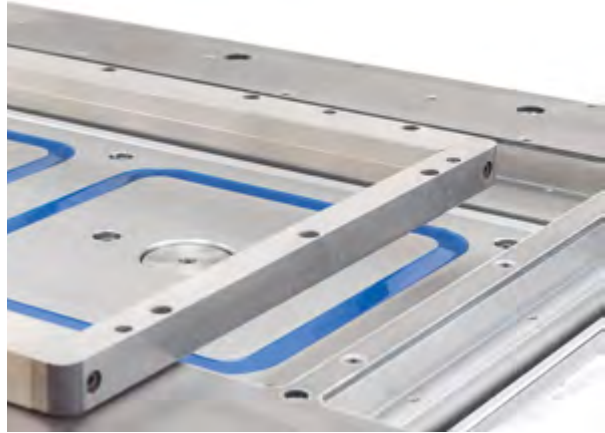


Figure 4.21. Set up process of the rectified interchangeable liners (1).

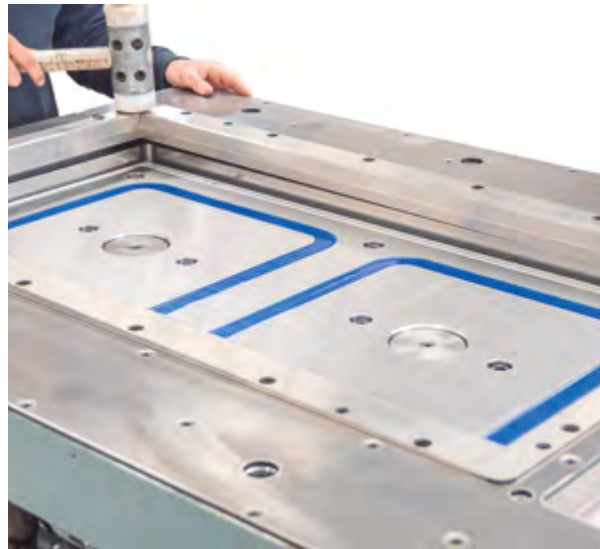


Figure 4.22. Set up process of the rectified interchangeable liners (2).



Figure 4.23. Set up process of the rectified interchangeable liners (3).

4.6.3. Rip cut rectified liners manufacturing process.

The manufacturing process (Figure 4.24) is similar to that of rectified liners. Rolled steel plates or bars are cut and machined to produce the preform with increased dimensions and then hardened. After subsequent grinding, they are assembled and the assembly is rectified again to adjust the thickness to the established measurements. The next rip-cutting step (Figure 4.25, 4.27 and link 4.6) produces the irregular inner profiles. The angle is obtained by electroerosion (figure 4.26) or by milling. Finally the assembly is sand-blasted and mounted into the die box. Sand blasting is a surface cleaning technique by the impact of abrasive particles projected at high speeds (between 65 and 110 m/s) on a metal surface. With this process it is possible to achieve an excellent surface finish.

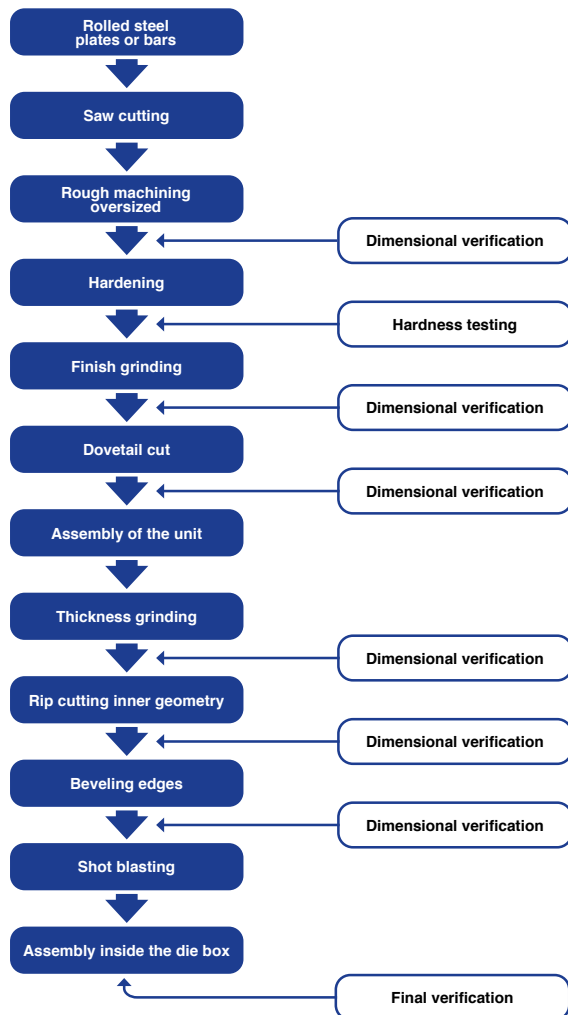


Figure 4.24. Manufacturing process of the MRCMH detachable – removable liners.



In the attached QR code you have a link to a video showing a process of rip-cutting removable liners. Link 4.6



Figure 4.25. Rip cut.

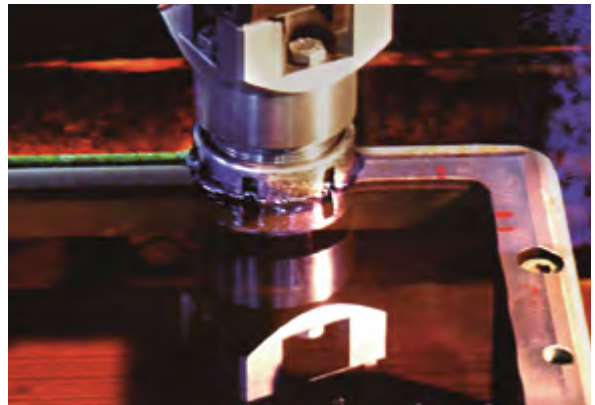


Figure 4.26. Electroerosion.



Figure 4.27. Rip cut machine.

4.6.4. Manufacturing process of rip cut liners.

The so-called "rip cut liners" are removable liners consisting of a single piece that limits each of the mould cavities. These liners are made from a sheet that has been rip cut on the inside.

Figure 4.28 shows the process flow diagram of the manufacturing process of this type of liners.

Rolled DIN 1.2080 steel sheets are used, which are cut with the sawing machine and machined with a CNC milling machine to the required dimensions. The liner is then drilled according to the drawing, as it will be far more difficult after hardening, as well known.

After the hardening treatment of these liners, a Rockwell hardness of 58-60 HRC is achieved, which is slightly lower than the hardness obtained with the MRC liners, in order to avoid their breakage during the rip cut process. After hardening, grinding is carried out to the established dimensions of thickness, dimension and squareness, with an accuracy of $\pm 0,01$ mm.

The inside of the liner is made in two stages. The inner surface is first formed by means of the wire erosion equipment, and then the separator with penetration erosion if required, since, remember, not all liners have a separator.

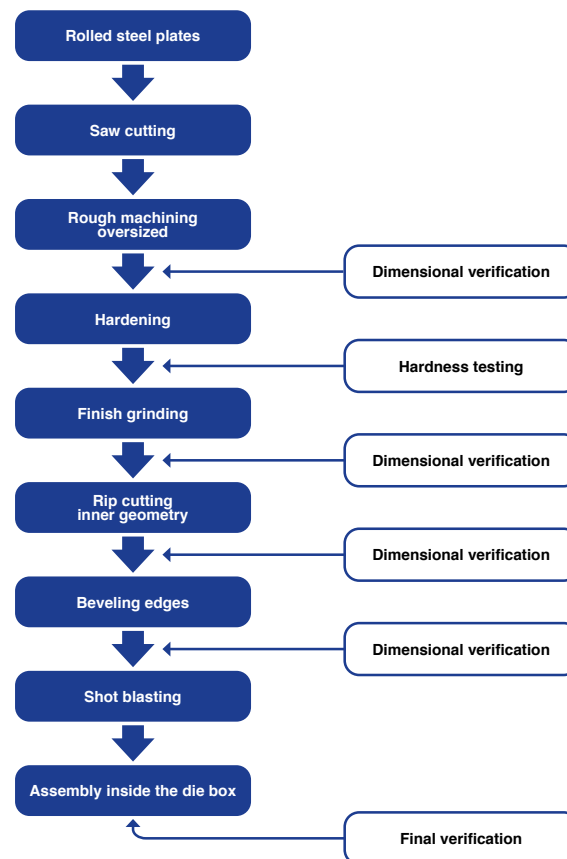


Figure 4.28. Manufacturing process of rip cut liners (MHI).

4.6.5. Manufacturing process of wear resistant liners.

As described in Chapter 3, the generic so-called "wear resistant" liners are obtained from the coating of untempered steel substrates. Thus, there are two types of liners: "HVOF coated liners" and "tungsten carbide insert liners".

HVOF coated liners are also removable, so the manufacturing process is similar to those described in that section, incorporating the stage of applying a wear resistant coating layer by hypervelocity spraying described in Chapter 3. In this process, the raw rolled steel plates or bars are cut and machined as described above, with a cut-out in the areas subject to friction, of a depth equal to or greater than the maximum admissible wear.

Wear resistant liners with tungsten carbide (WC) inserts can be produced in both **fixed** and **removable blades**. The basic operations of the process are the same except for the joining of the liners. The removable liners, as mentioned above, are joined by dovetailing, and the fixed ones are assembled by hand in the housing machined inside the die box by means of screws in horizontal holes and/or holes at the ends of the long liners, depending on the format. In both processes (Figure 4.29 and 4.30), raw rolled steel plates or bars are cut, machined and hardened as described above, making a housing where the tungsten strip will be inserted. The surface is then treated to improve the adhesion between the two parts and the rectified tungsten carbide insert is rigidly bonded to the liner. After the tungsten carbide strip has been bonded, the dovetail joint is cut on the removable liners, the dimensions are ground to the values specified in the drawing including the bevel, the liner is set up into the die box.

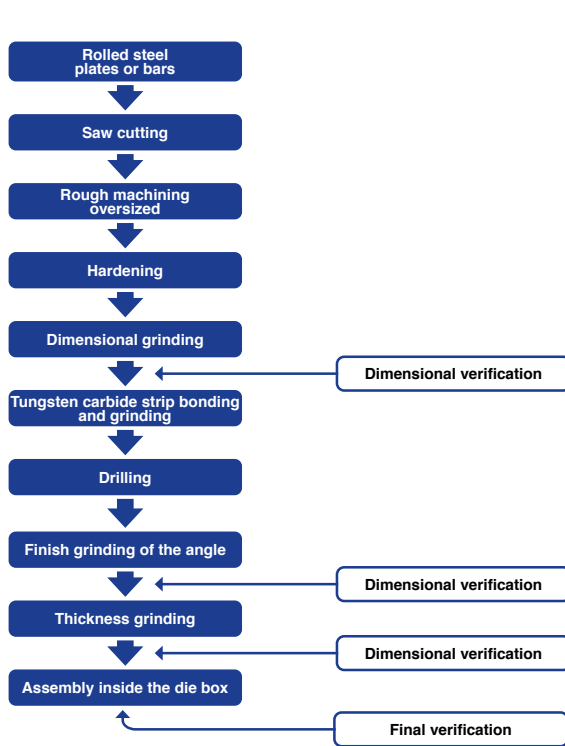


Figure 4.29. Manufacturing process of wear resistant fixed liners with tungsten carbide inserts.

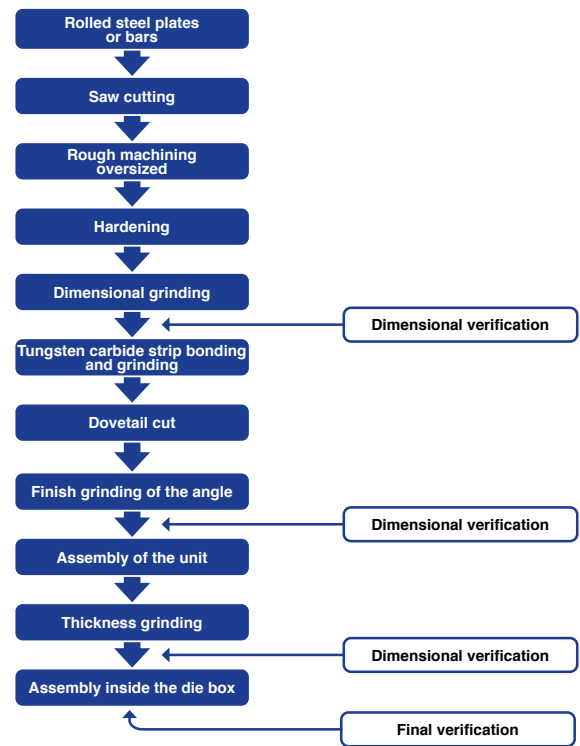


Figure 4.30. Manufacturing process of removable wear resistant liners with tungsten carbide inserts

4.7. PUNCHES MANUFACTURING PROCESS.

The punches (Figure 4.31 and 4.32) are made from raw DIN CK45 or DIN 1.2080 steel plates which are cut by oxy-fuel or sawing (Figure 4.33 and Link 4.7) to the nominal dimensions of the punch plus 4 to 5 mm thickness and 10 mm on the sides.



Figure 4.31. Punches in process.



Figure 4.32. Interlock punches

The sheets are supplied in standard thicknesses. For the manufacture of the punches, the ones indicated in Table 4.14 are used, choosing the thicker ones for large format punches.

Type of mould.	Punch.	Plate thickness (mm).
Entry.	Upper.	55
	Lower.	30 - 35
Double mould.	Upper.	30 - 35
	Lower.	40 - 45
Entry mirror.	Upper.	40 - 45
	Lower.	40 - 45

Table 4.14. Thicknesses of raw steel plates.



Figure 4.33. Cutting of the raw steel plates with a saw.



In the attached QR code you have a link to a video showing a process of cutting steel plates by sawing. Link 4.7

The cut sheets are milled to the required shape of the punch. The operation is called rough machining, as it does not reach the final dimensions of the punch, which is left oversized, and is carried out with a numerically controlled milling machine. The threaded and handling holes are then drilled. In addition, the holes for the filling and venting valve must be drilled in the isostatic punches.

The three operations described above are common to all punches. From this point onwards, the operations of the manufacturing process are different according to the type of punch and they will be described separately.

4.7.1. Tempered and polished punches manufacturing process.

The process is shown schematically in Figure 4.34. These punches are manufactured from DIN 1.2080 steel plate. After the cutting, rough machining and drilling operations of the steel plates, the punch is hollowed out and rough bevelled by milling on the side facing the tile. The punch is then hardened. This operation consists of a controlled heating up to 940 - 970 °C, followed by an abrupt cooling in oil or in a salt bath, whereby the metal reaches a hardness between 56 and 58 HRC.

After hardening, this is followed by thickness finishing operations by grinding with abrasive wheels and finishing of the side dimensions, i.e. quadrature finishing, with contour milling. The final inner profile of the punch is given its final shape by milling and chamfering. Finally, the surface of the punch is polished with the CNC grinding machine.

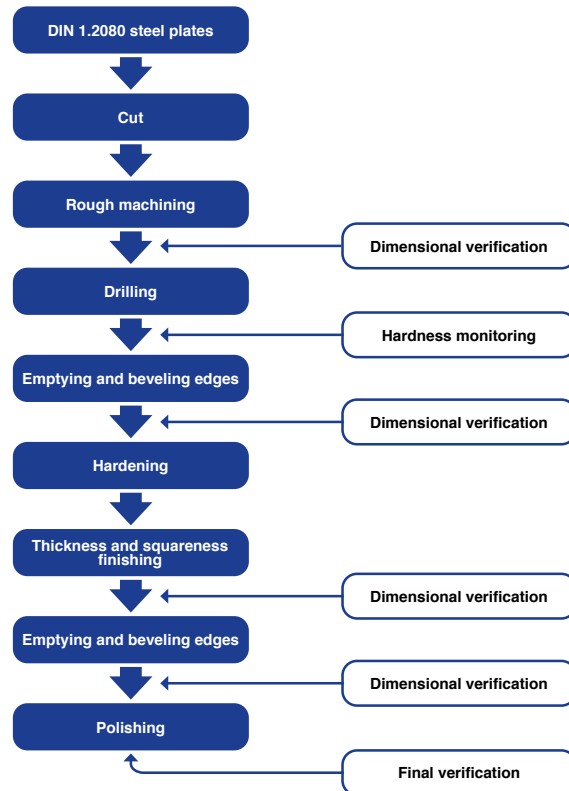


Figure 4.34. Tempered and polished punches manufacturing process.

4.7.2. Manufacturing process of rubber coated punches.

The manufacturing process of rubber coated punches (Figure 4.35) has a number of stages common to all the different types described above, although there are significant differences if the punches are equipped with a compensation system (isostatic punches) or not, therefore they are described separately.

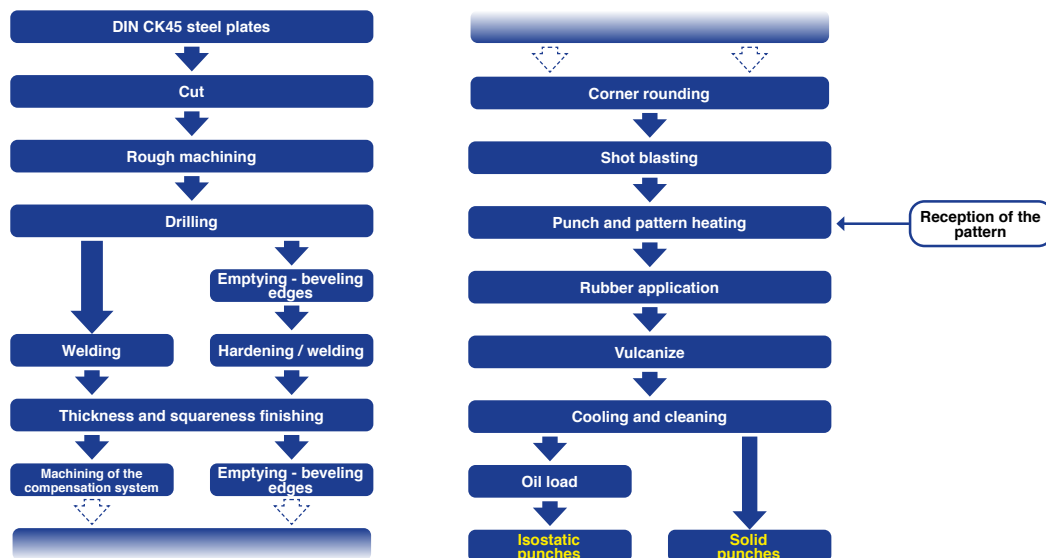


Figure 4.35. Manufacturing process of rubber coated punches.

4.7.2.1. Rubber coated solid punches.

Rubber coated punches without oil compensation, which we will call "solid punches", are mostly used⁵¹ for the noble face of the tile and also for back side punches for wall cladding or small formats, where the isostatic effect is not considered necessary, or is not advisable⁵².



Figure 4.36. Perimeter weld bead.

⁵¹ Nowadays, however, there is a tendency to install isostatic punches also on the noble face of moulds for tiles with a stone effect or with very pronounced reliefs.

⁵² It is not always advisable to use isostatic punches if the tiles are to receive a lapping treatment after firing, as the small differences in thickness caused by the isostatic compensation will become visible after the treatment.

They are manufactured from DIN CK45 steel plates which are cut, milled and drilled as described above. After these operations, the roughing and chamfering is carried out.

There are two procedures for reinforcing the areas of these punches exposed to increased wear, depending on the type of steel used in their manufacture. Punches made of DIN 1.1191 steel (i.e. F-114 or CK45) can be provided with a perimeteral weld bead (Figure 4.36) of a harder material and they are never hardened. In the case of punches made of DIN 1.2080 steel, the punch can be hardened according to the procedure described above, but the weld bead is never added.

The type of welding used for perimeteral hardening of DIN 1.1191 steel punches is MAG welding (Metal Active Gas). This type of welding, with gas shielding and consumable electrode, is almost exclusively applied to carbon and low alloy steels. The most commonly used gas is argon with a CO₂ percentage varying from 15 to 25 %.

Regardless of the strengthening process used, the punch shall be rectified to nominal dimensions by thickness finishing, quadrature finishing and final chamfering. The punch shall, after these operations, have the dimensions specified in the drawing, with a tolerance of $\pm 0,02$ mm. All that remains is to finish the bevelled corners, where it has not been possible to gain access with the tools used during these operations. This is done with very small grinding wheels. After these operations the punch is ready to receive the rubber coating.

4.7.2.2. Isostatic punches.

Isostatic punches have a similar manufacturing process up to the point described in the previous section, but they are not hardened, as they are made of DIN 1.1191 steel. Thus, the improvement of the mechanical characteristics of the areas exposed to friction is made in these punches by the addition of a weld bead. It should be noted that after hardening, machining of the compensation system is not possible.

After the thickness and quadrature finishing operations described above, the compensation system is machined using the CNC milling machine (Figure 4.37). In the case of MRPV grid type punches, the interconnecting ducts of the chambers must also be drilled. The corners are then finished with smaller grinding wheels.



Figure 4.37. Machining of the oil compensation system in isostatic grid punches type MRPV.

The surface to which the rubber is to be applied is subjected to an abrasive cleaning known as “shot or sand blasting”. The negative relief is made on the rubber during the hardening or curing process in the press. It is therefore necessary to use a metal, aluminium or bakelite patterns, with the positive of the relief, to transfer the shape to the rubber, which in the same process will be vulcanised and adhered to the punch. The process of developing these patterns has already been discussed in Chapter 2.

After the preparation operations, the punch and the pattern are heated to temperatures close to 100°C on a hot plate prior to the application of the rubber.

4.7.2.3. Rubber preparation and application.

It has already been mentioned that there are two types of rubber coatings: the **sheet application** and the **liquid application** of cast synthetic resins, which is generally used for isostatic punches, large format punches and punches with relief, regardless of the format, and has an excellent adhesion to the metal. The liquid rubber dosing machine (Figure 4.38) is fed with a limited number of standard rubbers, which are stored in tanks heated to 85 °C, with a capacity between 50 and 200 litres, equipped with a vacuum pump to avoid the presence of air bubbles occluded in the rubber and with independent circuits. A programme allows the dosing of different rubber recipes, pre-programmed from mixtures of the standard compositions, so that it is possible to establish exactly the properties of the mixture from the individual properties of each of the gums that form the mixture.

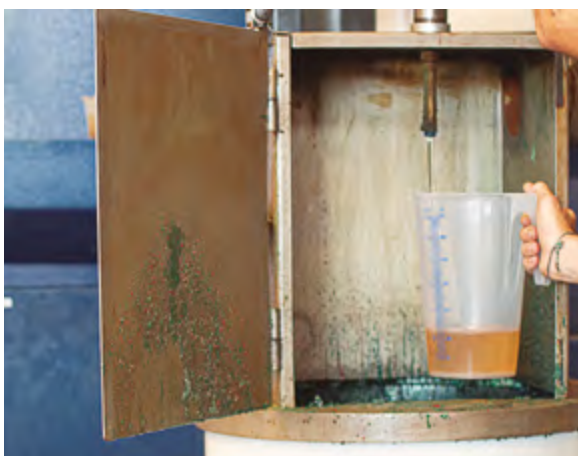


Figure 4.38. Dosage of liquid rubber for punches.

a) Hardeners for liquid-applied rubbers.

Liquid-applied rubbers are dosed with the addition of a hardening agent, also called a "curative" or "curing agent", which acts as an expander of the polymer or elastomer chains. The agents used are MOCA® and ETHACURE 300®. Table 4.15 shows some of the physicochemical properties of both curing agents.

Properties	MOCA	ETHACURE 300
Chemical formula.	$C_{13}H_{12}N_2Cl_2$	$C_9H_{14}N_2S_2$
Molecular weight.	267.16	214.36
Equivalent weight.	133.5	107
Business presentation.	Yellow pellets.	Light yellowish liquid.
Density (g/cc - 20 °C).	1.44 (solid)	1.208 (liquid)
Density (g/cc - 107 °C).	1.26 (liquid)	-
Melting range (°C).	98 to 102	-
Boiling temperature (°C).	-	200 °C

Table 4.15. Properties of some hardeners used for liquid rubbers.

The MOCA® hardener is currently being fully replaced by ETHACURE 300® [4] (dimethylthiotoluene diamine) which is a low-toxic, easy-to-handle liquid aromatic diamine, well known and widely used in the polyurethanes industry. This material, in the right proportions, acts as an effective hardener. Polymers cured with ETHACURE 300® show high mechanical strength and toughness as well as good chemical resistance. During the curing process, it has working times compatible with the punch manufacturing process.

Both hardeners require different working parameters (temperature, waiting and pressing times and pressure) and have different effects on the vulcanised rubber. ETHACURE 300® allows working at lower temperatures and requires different curing times, and therefore must be adjusted for each case. It has a better definition of the details, so it is more suitable for punches with reliefs, especially when they are very accentuated. On the other hand, MOCA® allows faster demoulding and colours colourless gums yellow (see Table 4.14).

Rubbers that are applied in liquid form are supplied in solid form, stored in drums. For their use, they are heated for 8 hours, between 80 and 90 °C in an oven, and then transferred to the dosing machine (Figure 4.38) by means of a vacuum pump, where the dosing of the mixture of hardener and rubber composition, or several rubbers, is programmed to achieve a specific hardness and properties. These machines are different for each type of hardener used, in fact MOCA® must be dissolved at 120 °C and then mixed with the pre-polymer in the mixing chamber of the dosing machine, while ETHACURE 300® is worked at room temperature. The total quantity of mixture dosed for each punch logically depends on its format, the depth of the cavity machined inside, and the reliefs, if any, so it must be calculated for each punch taking into account that the rubber is deposited inside it with a small surplus to facilitate the elimination of gases occluded during pressing.

The suppliers of the hardener provide a parameter, called NCO, which is used to calculate the proportion of hardener in the rubber. This information is provided by the manufacturer and can be found on the product label, although it may vary from one batch to another and should therefore be adjusted for each batch. As an example, [33] shows a data sheet for different MOCA® -hardened prepolymers where, among their properties, the average NCO and their range of oscillation according to batches can be seen for each one of them.

The calculation can be done with a simple formula and is different for each hardener. The general formula for calculating the proportion of a hardener or curing agent in a prepolymer is:

$$PPC(\%) = \frac{PE \times NCO \times RE}{42,02}$$

In this formula:

PPC (%) The percentage of curing agent per 100 parts of rubber.

PE This is the equivalent weight of the hardener. It is 133.5 for MOCA® and 107 for ETHACURE 300®.

NCO Data provided by the manufacturer.

RE Stoichiometric ratio expressed in percent per one. It is usually 0.95.

This formula is usually transformed into a simpler one by substituting known data for commonly used hardeners. In our case:

For MOCA® (PE=133,5)

$$PPC(\%) = \frac{133,5 \times NCO \times RE}{42,02} = 3,18 \times NCO \times RE$$

For ETHACURE 300® (PE=107)

$$PPC(\%) = \frac{107 \times NCO \times RE}{42,02} = 2,55 \times NCO \times RE$$

Table 4.16 shows the NCO values of some commonly used rubbers, as well as some of their properties [33].

Type of prepolymer	Shore A hardness	NCO range	Hardening (80-90 °C) in min.
TDI – PTMEG	85	3.10 to 3.50	25 to 30
	90	4.00 to 4.40	
TDI – PPG	90	4.00 to 4.40	12 to 16
	95	5.30 to 5.70	8 to 10
TDI – Polyester	80	2.90 to 3.30	7 to 8
	95	5.40 to 5.80	3 to 4

Note:

- TDI stands for toluene diisocyanate.
- PTMEG stands for polytetrahydrofuran.
- PPG is an acronym for propylene glycol.

Table 4.16. Properties of some prepolymers used for liquid rubbers.

All these prepolymers have a low free TDI content (less than 0,1 %). Very low free TDI prepolymers reduce operator exposure to TDI vapours, have a lower application viscosity (85°C) and increase the time required for curing.

b) Hardening pressing.

Before applying the rubber, the punch is sandblasted and carefully cleaned until it is completely free of particles and dust. An adhesive or glue is then applied to the surface of the punch by hand airbrushing, left to air dry and the pattern and punch are heated for about 15 - 20 minutes at about 100 °C if the liquid rubber is to be applied or 120 °C if a rubber sheet is applied. Although initially only one type of glue was used for each punch, today two different types of glues are used depending on whether they are used for sheet or liquid applications.

To prevent liquid rubber from sticking to the sides of the punch after pressing, a brush-on release agent is also applied to them (Figure 4.39).



Figure 4.39. Application of release agent on the sides of the punch.

As shown in Figure 4.40 and as can be seen in Link 4.8, **application of the liquid rubber** is done by pouring it onto the clean punch at a temperature of 100 °C. It can be seen in the video that after pouring the rubber, heat is applied in order to remove air bubbles occluded inside the rubber.

Subsequently, in order to ensure that the rubber does not stick to the pattern, a plastic film of release agent is also applied between the pattern and the rubber.

Once cooled, the rubber remains under tension, as it shrinks, but is retained on the punch, covering its entire surface homogeneously.

Although the hardening pressing process has a standard procedure for all punches, there are some differences depending on whether the punches are smooth, smooth relief or pronounced relief (abrasive or very pronounced). There are also differences between liquid and sheet applied rubbers, and even depending on the type of hardener used with liquid rubbers. As a reference for the latter, ^[33] shows a data sheet where these data can be found for a number of commercial pre-polymers toughened with MOCA®.

It should also be taken into account that aluminium and iron have good thermal conductivity, but bakelite, on the other hand, acts practically as an insulator and therefore behaves differently, which means that different process parameters must be used depending on the type of pattern used.

If the pattern is made of bakelite, it is centred manually with the help of centring devices incorporated in the pattern itself and if it is made of iron or aluminium, it is fixed by means of anchorages called "legs" (Figure 3.43 and link 4. 9) and then the 'pattern - rubber - punch' assembly, rigidly joined by means of the 'legs', is placed on the press bed and the dimensions are checked by means of depth gauges or 'probes' to determine the height of the stops, known as 'parallels', necessary for pressing (Figures 4.41, 4.42 and 4.43 and link 4.10). Generally, the height of the stops is one tenth of the thickness of the pattern plus punch.



Figure 4.40. Liquid rubber pouring into a punch.



In the attached QR code you have a link to a video showing a process of applying the rubber to a punch. Link 4.8



In the attached QR code you will find a link to a video showing the process of centring the pattern for rubber press forming. Link 4.9



Figure 4.41. Six-piston press for applying the rubber coat to large-format punches.

The automatic presses used in the operation develop forces ranging from 40 to 800 t depending on the punch format, with mould opening forces ranging from 6.5 to 35 tonnes. The appropriate press is chosen for each punch, taking into account, above all, the press clearance and the punch format. The maximum force that each press is capable of developing does not play an important role in its choice, as it is not very high. During the operating cycle, the operating parameters must be defined: punch temperature, time, speed, pressure, positions of the moving elements and cycle time, depending on the type of punch and relief.

At the end of the pressing operation, and after cooling, the punch is cleaned and retouched by hand, ready for assembly.



Figure 4.42. Sheet pressing.

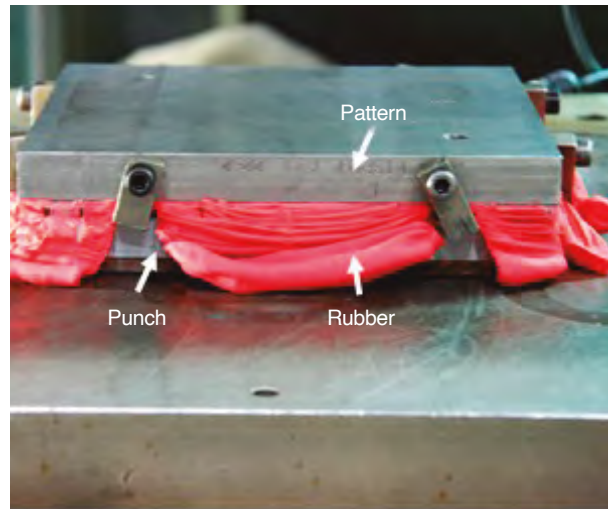


Figure 4.43. Process of applying a rubber sheet to a punch (sheet pressing).



In the attached QR code you have a link to a video showing the pressing process of the pattern-rubber-punch assembly. Link 4.10

Figure 4.44 shows an isostatic fixed metal sheet punch without the application of rubber and next to it another one with the same characteristics where the process of pouring the rubber and hardening has already been carried out.

Sometimes it is necessary to make back side relief punches with some identification cell (mark, plate number, etc.) free (Figure 4.45), so that the required stamps can be attached to it, as required. These seals are manufactured in different colours and are fitted into the gap provided, as shown in Figure 4.46.

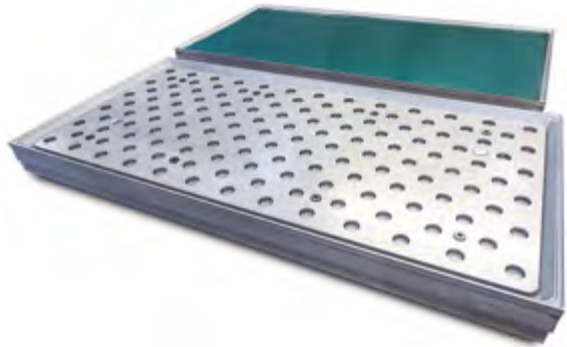


Figure 4.44. Isostatic fixed metal sheet punch before and after rubber application and hardening.



Figure 4.45. Punch (and pattern) with anagram hole.



Figure 4.46. Interchangeable anagram.

c) Stops.

During the pressing process, the liquid rubber does not offer a high resistance to the press and deforms into the shape of the punch. In order to regulate the operation, there are four (or more) metal stops located on the press bed (Figures 4.47, 4.48 and 4.49), which have a height slightly higher than the sum of the heights of the punch and the pattern, so that the deformation of the rubber stops at this point. The height of these stops depends on the type of punch, the pattern and the hardener used, and must be carefully chosen as excessive pressing due to low stops height could "pin" the pattern, i.e. cause the pattern to penetrate the rubber and even damage it. On the other hand, excessive height, and therefore insufficient pressing, would have an impact on the quality of the rubber and its bonding. The available parallels are available in different thicknesses starting from 0.05 mm (Figure 4.47) and are added until the desired height is reached (Figures 4.48 and 4.49). It should be noted that these supplements lose thickness with use and should be replaced from time to time.

The height of these stops can be defined using the information provided by the encoder of the press, which locates the position of the plunger, or by manual measurement using a depth gauge.

In large formats, for example 60 x 120 cm with bakelite patterns, this can become unbalanced during pressing, due to its large size, and present slight differences in flatness that can also be compensated with the parallels, adjusting the height of each stop to guarantee a perfect fit between pattern, rubber and punch and, if necessary, arranging two more parallels in the central part of the punch. In order to guarantee a correct distribution of pressure, it is preferable to press these large format punches with 6-piston presses, such as the one shown in Figure 4.41, which guarantee a perfect horizontality of the mobile plunger.

Examples.

- If the sum of the punch and the pattern is 54 mm, four stops can be installed in the press at a height of 54.8 mm, giving 0.8 mm of rubber that will be offering resistance to the press as it hardens.
- On smooth moulds with iron pattern, the stops are usually left about 0.3 mm above the sum of the heights of the punch and the pattern.



Figure 4.47. Stops.



Figure 4.48. Arrangement of the stops in the press (detail).

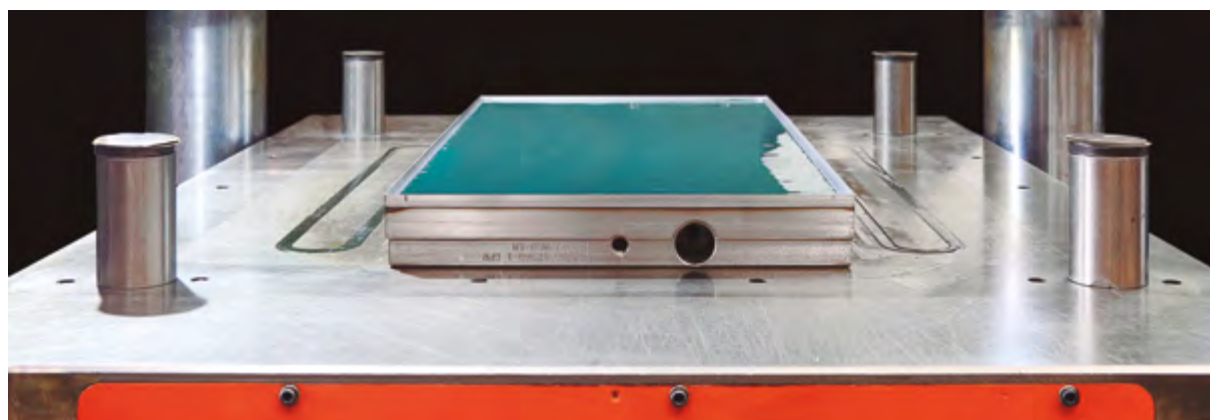


Figure 4.49. Arrangement of the stops in the press.

4.7.2.4. Variables in the hardening press operation.

From what has been described so far, the main variables of the hardening press process can be easily recognised and will be described. The large number of factors that influence the process, many derived from the enormous variety of existing punches in terms of format, relief and depth; the types of patterns; the physical state of the rubber applied, whether liquid or sheets, etc., makes it very difficult to standardise the process, which often relies on the experience and expertise of the operator.

The **temperature of the punch** strongly influences the viscosity of the rubber when it is deposited on the punch, and thus the way it coats the punch before pressing. Insufficient temperature causes a deficient cover of the the punch, generating occluded air bubbles that can cause the rubber to tear when the punch is in use. The viscosity at punch temperature, on the other hand, depends on the **composition of the liquid rubber** applied. Viscosities at working temperatures of some MOCA® cured rubbers are shown in ^[33].

It is important to establish the exact amount of **time** between the deposition of the gum on the punch and pressing, as this determines the viscosity of the liquid rubber and directly affects its quality after curing. If the time is not adequate, defects may appear in the rubber such as orange peel with rounded and poorly defined relief, or even excessive hardening that makes it difficult, or even impossible, to press.

The **pressing temperature** and the **pressing time** are two important process variables, although they are easily standardised. Until less than a decade ago, back side relief punches were pressed at 120°C and the rest at 90°C. Nowadays there is a tendency to press all types of punches at the same temperature: 100 °C in liquid applications and 120 °C for sheets; with a similar pressing time of about 20 minutes, although this parameter is conditioned by the type of hardener used.

In large formats it can be difficult to homogenise the temperature of the punches, as their size tends to show temperature differences from one point to another. To avoid this, large presses intended for these formats have heating plates divided into independently regulated zones, which compensate for temperature gradients that may occur in the same punch.

During the process of pressing punches with liquid rubber, it is important to control the **speeds of plunger lowering**. Once it comes into contact with the "insole-rubber-punch" package, it must stop descending for a few seconds to facilitate deaeration, i.e. the elimination of gases occluded in the rubber, and continue with a gentle descent until it reaches the stops. Deaeration should not be carried out by raising the crossbar, as this would cause the rubber to deform. It has already been mentioned when discussing the dosage of the liquid rubber, that a small excess should be used to facilitate deaeration.

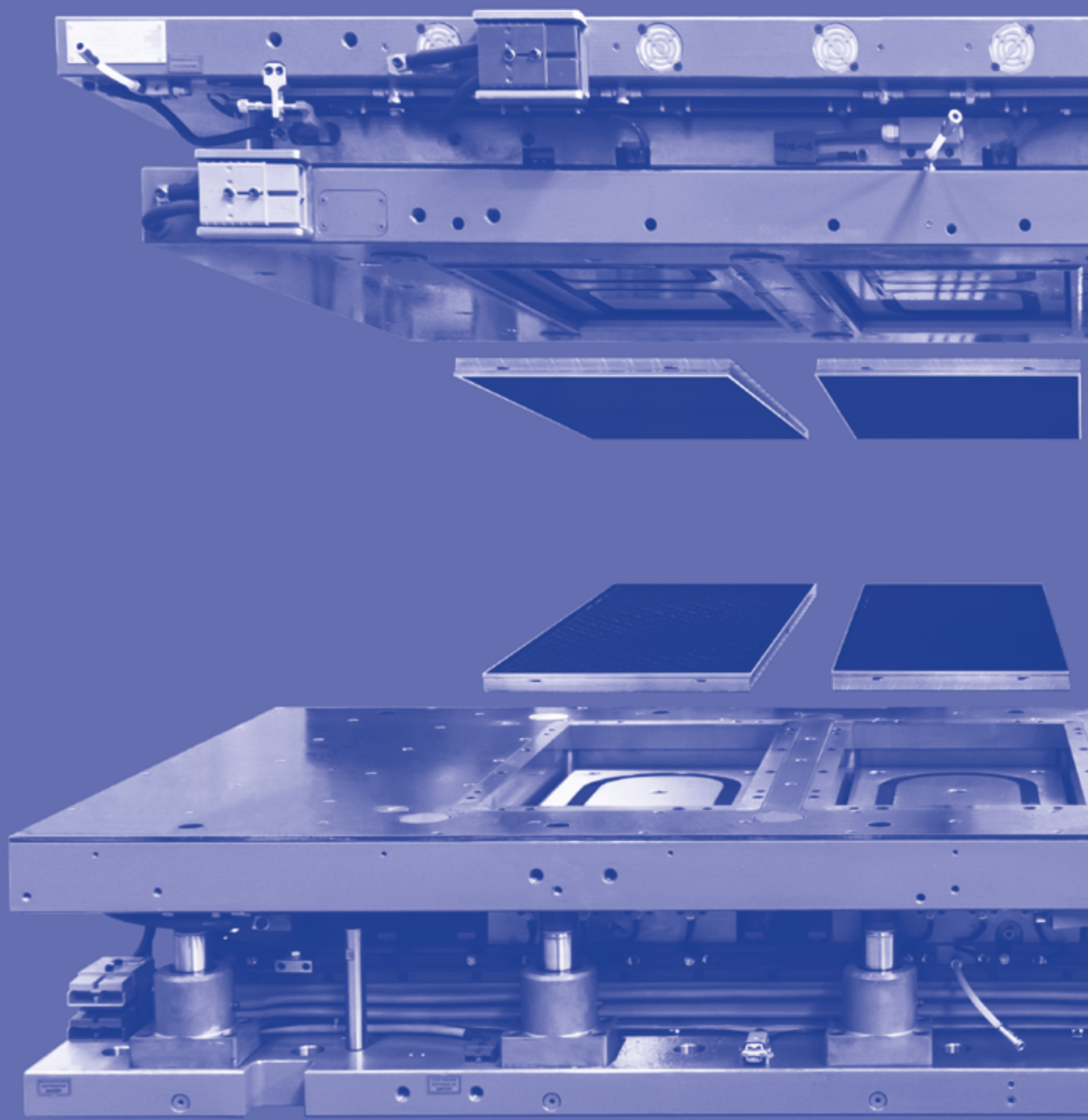
In the case of rubber sheets, this is cut somewhat smaller than the punch and as expands from the centre towards the borders during pressing, eliminates the air. When pressing sheets, the plunger can be lowered at the same speed until the set pressing pressure is reached.

Another parameter influencing the curing process is the **depth of the punch cavity**. On smooth plates, with a depth of 0.3 mm, the rubber is in direct contact with the hot punch and it is easy to obtain a homogeneous hardening, on the other hand, at higher thicknesses for embossed punches, for example above 4 mm, there may be a temperature gradient between the layer of the rubber in contact with the hot punch surface and the upper part in contact with the pattern, which will make it difficult to achieve a homogeneous hardening.

Some designs require very pronounced reliefs, especially in large format pieces, and thicknesses of more than 11 mm. In this case, the construction of the rubber relief according to the process described above is very problematic, as it requires high rubber thicknesses, which can lead to deformations of the relief ("strapping") during pressing. This problem can be solved by machining the relief on the surface of the punch, which in previous typologies has always been smooth, and covering it with a rubber of constant thickness. To do this, it is necessary to define the greyscale and invert it, i.e. to construct its negative, and from this, to elaborate the machining programme. Remember that in deep reliefs, if the design permits, the back side is compensated so the thickness remains approximately constant.

Types of moulds and how they work.

Chapter 5



5.1. TYPOLOGIES OF MOULDS FOR PRESSING.

The typologies of moulds for pressing have evolved over time according to the technological, structural, functional and economic conditions linked to the evolution of the sector. Some typologies, such as the entry mould, have remained almost unchanged, while others, such as the mirror mould, have been reduced to an almost testimonial use. Others have appeared, such as the entry mirror mould, which combines the characteristics and advantages of other typologies.

Moulds for unidirectional semi-dry pressing of ceramic tiles can be classified into four types:

- Entry moulds.
- Mirror moulds.
- Double mould.
- Entry mirror moulds.

These general typologies admit some variants as a result of modifications affecting both their components and their operation, but which, in essence, do not alter the general characteristics described for each one. Within these variations, the **quick changeover moulds (CSR)** and **380 - 440 V** moulds are currently on the market.

Table 5.1 shows the most relevant characteristics and the products preferably pressed with each of these typologies.

Typology	Characteristics	Main products	Variants
Entry.	The upper punch penetrates the cavity. Good face downwards: needs turner. With spacer.	White body stoneware. Red body stoneware. Single-fired white body. Single-fired red body. Double-fired wall tiles. Glazed porcelain stoneware. Large formats (with good face on top).	Inverted entry: The back sides are formed by the lower punch and the face to be glazed by the upper punch. Tiles with the good face upwards. Without spacer or with inverted spacer.
Mirror.	Upper punch with a larger surface area than the cavity. Pressing happens when the die box is lowered. Good face upwards. Without spacer. No turner required.	Low usage: mosaic.	Inverted mirror: The back sides are formed by the upper punch and the face to be glazed by the lower punch. Tiles with the good face downwards. With or without spacer. No turner required.
Double mould.	Double die box. Formed in the upper part. Good face upwards. With or without spacer. No turner required.	Porous ceramic wall tiling. Press-decorated porcelain tiles. Unglazed porcelain tiles. Double compaction porcelain tiles. Glazed porcelain tiles.	
Entry mirror	It has intermediate characteristics between the entry mould and the mirror mould. Upper punches with a size comparable to those of the entry mould and penetrate only up to a pre-established level. Rod bars move the die box downwards. The upper punch penetrates the die box. The stroke of the upper piston is controlled by stops located on the plate. Good face upwards. It may or may not have a separator. Movable die box controlled by hydraulic pistons.	Large formats (with subsequent rectification) of porcelain tiles.	

Table 5.1. Typologies of moulds.

5.2. THE PRESSING CYCLE.

In order to explain the characteristics and operation of the different types of pressing moulds currently used in the manufacture of ceramic tiles, it is necessary to introduce and describe the concept of pressing cycle. The **pressing cycle** is a set of operations and synchronised movements carried out by the press and the mould, which allow the forming and ejection of a part in each of the cavities.

A **standard cycle** includes the following stages:

- First plate drop.
- Loading of the cavities.
- Second plate drop.
- Lowering of the mobile plunger.
- First pressing.
- Deaeration.
- Second pressing.
- Pressed tile extraction.



Figure 5.1. Press outlet.

Depending on the type of product or the type of mould, the pressing cycle may change slightly. For example, the double mould has an extraction of the pressed tile divided into two different phases or some cycles include three pressings with another intermediate deaeration between the second and third pressing⁵³.

In a standard cycle there are two plate drops. The first drop is made to a certain level, which is called the “first drop level”. This level regulates the powder load and therefore influences the thickness of the pressed tile. The second drop allows the ejector plate to rest on the bench plate when receiving the

⁵³ A third pressing (and therefore two intermediate deaeration operations) is usually carried out on parts with deaeration problems and/or with very pronounced reliefs.

pressings, so the pressure is absorbed by the press bed and not by the pistons of the extraction system. Moreover, this second drop prevents the loss of powder after contact with the upper punches.

The filling of the mould cavity can be done in one or more loads, if decorations are desired in the pressing operation, which may require more than two plate drops.

On the other hand, in the double mould, extraction is carried out in two stages, as mentioned above. In the first stage, the entire assembly formed by the lower punches, the lower die box and the upper die box is lifted and the tiles are separated from the cavities of the upper die by the action of a hydraulic extraction system located in the upper part of the mould. In the second phase of the extraction, the upper punches and the lower die box regain their position, allowing the tiles to be ejected towards the roller assembly and the start of a new pressing cycle.

5.2.1. Duration of the pressing cycle.

This is the time taken by the press to complete a full cycle and has great importance as it defines the output of the press. In industrial practice, the term used to indicate the number of cycles per minute of a press is typically referred to as "strokes per minute". In each "stroke" the press forms as many pieces as cavities or "outputs" the mould has. The relationship between these parameters and the production is:

Being:
$$P = G \cdot N \cdot S_F \cdot t$$

P Production of the press (m²/day).

G Number of cycles per minute.

N Number of outlets per mould (tiles produced in each cycle).

S_F Tile surface defined by format⁵⁴ (m²).

t Actual time worked per day (min/day).

The production of the press therefore depends on the duration of the pressing cycle which, as mentioned above, comprises a set of movements that may be simultaneous or conditioned by the establishment of synchronisms. The duration of each of these operations depends on limiting factors related to the technical characteristics of the press, the product, e.g. the format or type of product (double loading, press decoration, etc.) or factors affecting the quality characteristics of the pressed product, e.g. the deaeration time, the beginning of the plate drop, etc., which determine the operating cycle. It can be seen from Table 5.2 that the cavity loading and deaeration stages are the ones that consume most of the pressing cycle time (67% between them) ^[55], so they are two key stages in the production values achieved and, of course, in the quality of the product obtained.

All operations in the pressing cycle can be described by reference to the position in relation to time of the moving parts of the press ^{[49] [69]}, i.e., the mobile plunger; the feeder car and the extraction equipment; and the value of the specific pressure inside the cavities or inside the circuit in relation to time.

⁵⁴ It should be noted that this is the commercial format. This data does not include the actual dimensions of the cavity or any dimensional variations of the tiles during the manufacturing process. Therefore, the value of production, expressed in m²/day, although very useful, does not express with absolute accuracy the value of the area produced.

Stage of the pressing cycle	Time (%)
First plate drop and cavity loading	39
Lowering of the plunger, second plate drop and first pressing	21
Deaeration	28
Second pressing	8
Extraction and positioning of the plunger	4

Table 5.2. Time taken (%) for each stage of the pressing cycle with an entry mould.

5.3. ENTRY MOULDS.

In order to explain the structure and operation of each type of mould, it is very useful to start with the entry mould (Figure 5.2), as it has a very simple design and most of its components can be found, in one way or another, in the other types. All of these components were discussed in detail in Chapter 3 and their manufacturing processes were covered in Chapter 4.

In the entry mould, the upper punches penetrate the cavities where the powder is pured and transmit the pressing force to the powder. The cavities are formed by the lower punches installed on the blocks and delimited by the liners which are mounted on the side walls of the die box, rigidly fixed to the bench plate with screwed pillars. The extractor system of the press is responsible for making the necessary plate drops for loading and pressing, and for ejecting the tiles from the cavities through an upward movement of the lower punches.

This type of moulds press the tiles in an inverted position (Figure 5.3), i.e. with the noble face downwards, due to the need to provide the non-rectified tiles with a spacer, which has the task of protecting the glazed side from possible lateral impacts during the manufacturing process. It is, therefore, understood, that the extraction of the tile would not be possible if the back sides would be formed by the bottom punch. Thus, in this type of mould, the lower punches form the noble face of the tiles, while the back sides are formed by the upper punches, so the hydraulic compensation must be carried out by these punches (isostatic punches).

The tiles are, therefore, removed in an inverted position and they must be turned over on the roller assembly by a mechanical device called a turner. When the tiles are placed outside the pressing area, pushed by the elastic stop of the feeder car, the side that will receive the glaze is exposed to the friction caused by the upper edge of the liners and the die box. These scratches may be visible after firing and, in addition, if decorative press reliefs have been done, they may be damaged by friction. These possible defects may condition the use of this type of mould for some types of products.

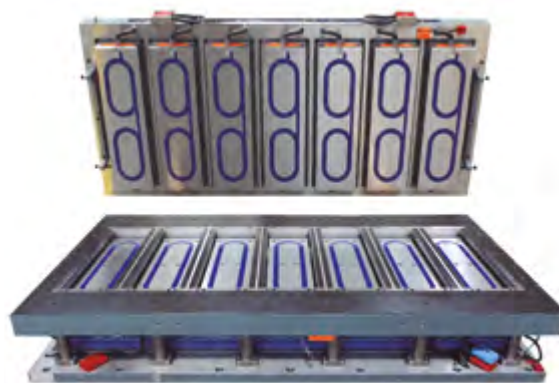
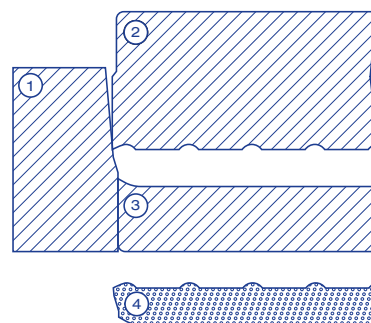


Figure 5.2. Entry mould with 7 outlets of 25 cm x 75 cm.



1. Liner
2. Upper punch
3. Lower punch
4. Resulting piece

Figure 5.3. Entry mould: tiles are pressed with spacers and with the good face downwards.

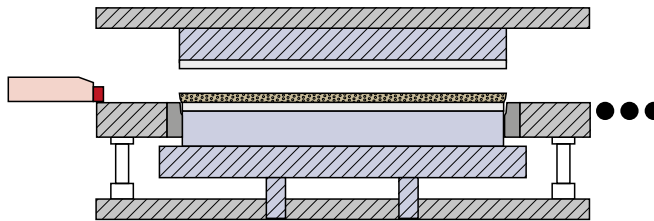
5.3.1. Stages of the pressing cycle with entry moulds.

0. Start of the cycle.

For a better understanding, it has been considered that the pressing cycle, in all typologies, starts when the plunger is in its highest position, which we call "**level 0 of the plunger**" and the lower punch is also in its highest position, and therefore perfectly aligned with the die box level. The feeder car then starts a small approaching movement to the mould cavities.



In the attached QR code you have a link to an animation of the pressing cycle with a entry mould. Link 5.1



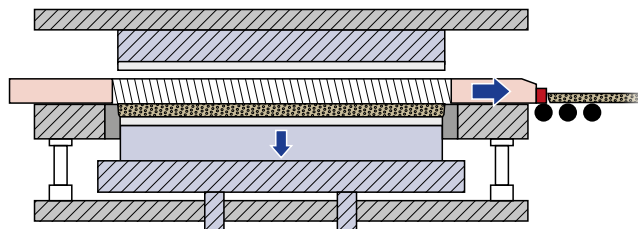
1. Ejection of the tile, first plate drop and cavity loading.

The feeder car starts the approaching movement to the mould cavities, pushes the tiles pressed in the previous cycle and places them on the roller assembly and the lower punches descend to the "**first drop level**" (first plate drop).

The grid of the feeder car is positioned over the cavities and unload the powder inside them. At a point in the feeder car movement, the first plate drop starts up to the "first plate drop level", which is the same distance in mm the ejector plate is located from the bench plate. The setting of this distance determines the height of the powder charge, which, combined with the pressing pressure, will determine the thickness of the tile.

The position of the feeder cart at the moment when the first drop starts is regulated from the control panel of the press and it is of great importance to achieve a good loading of the cavities.

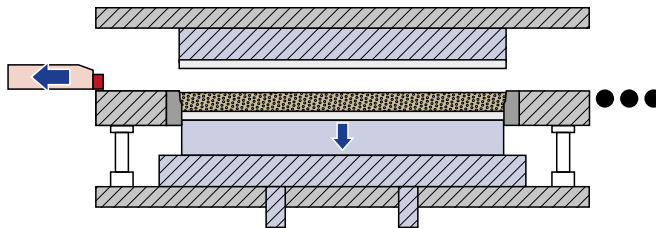
The function of the cavity filling operation is to obtain a homogeneous distribution of the load throughout the mould and to keep it constant over time. Correct filling depends on the technological characteristics of the powder, such as its fluidity and particle size distribution, the characteristics of the feeding system and its control parameters, i.e. displacements, plate drop times and speeds, the speed of the feeder car, etc.



2. Second plate drop.

In order to start the pressing process, the mould should be in rest position and on top of the press bed, so the plates make a second fall to that position, which allows the assembly formed by the punches, the "blocks" and the ejecting plate to rest on the bench plate, and the pressure exerted in the first and second press is supported by the press bed and not by the hydraulic equipment responsible for the movements of the punches.

During this operation, the feeder car moves back to its starting position and during this movement the levelling ruler levels the load. The leveling of the load is an important operation because if it is carried out at an excessive speed, it can cause ripples on the surface which result in differences in compactness that in some models, such as crystalline coatings, can be clearly visible.



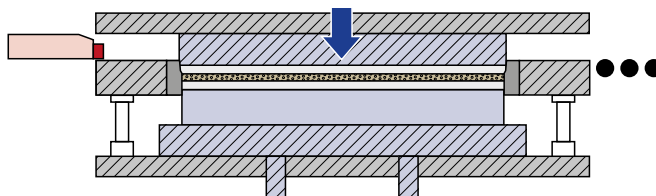
3. First pressing.

The plunger is lowered and slow down at a short distance from the load to prevent excessive impact causing powder loss.

The first pressing is the first application of pressure to the load deposited in the cavities and should remove as much of the air contained inside the powder as possible by densification through the application of moderate pressure (between 20 and 50 bar), compared to the compaction pressure.

This first contact between the upper punches and the powder is very important, as the deaeration and the first compaction depend on it. It should therefore be as gentle as possible to allow time for the air to be properly ejected.

In order for the plunger to start lowering, the punches must be in the "low mould" position (bench plate and ejecting plate in contact) and the feeder car must be in rest position ("feeder car back").



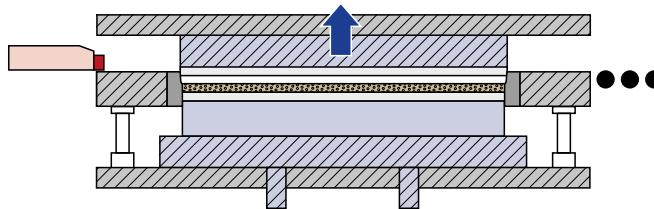
4. Deaeration.

The aim of the first pressing and deaeration operations is to remove as much air as possible from the powder in the compaction process, in order to avoid the appearance of laminations.

At this stage, the air occluded inside the cavity, which is compressed by the pressure exerted by the upper punches, is evacuated, so that the pressure on the paste must be reduced and the piston must rise slightly a few millimetres. In the entry mould, the air is mainly expelled through the clearance between the punches and the liners (approximately 80 % of the evacuated air is removed upwards and the remaining 20 % downwards).

The time taken for this operation will depend on the amount of air to be expelled, and therefore on the bulk density of the powder in the cavity (bulk density per free fall) and the dimensions of the tile. Long deaeration times ensure complete air evacuation but lengthen the pressing cycle, reducing production. Too short a time can lead to laminations of the pressed tiles.

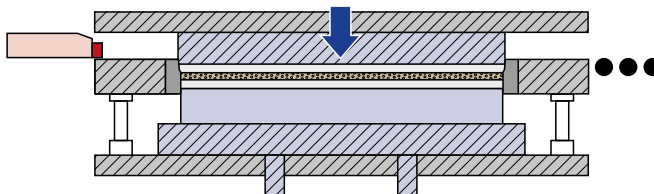
It should be noted that some cycles are carried out with three pressings, which implies a second deaeration, which is regulated in exactly the same way as the first one.



5. Second pressing.

The plunger is lowered again and the maximum cycle pressure or pressing pressure is developed. This is the stage that shapes the raw microstructure of the tile ^[13] and consequently gives the tile its raw properties and influences its behaviour in the following stages of the manufacturing process and, therefore, the properties of the finished product.

The upper punch has the task of transmitting the pressure to the powder bed, so that the distribution of the pressure inside the cavity and the homogeneity of the compaction of the tile depend to a large extent on its constructive characteristics.

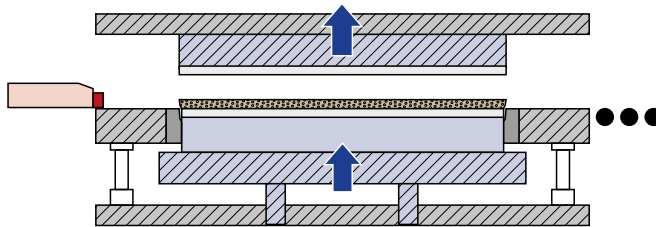


6. Extraction.

After the second pressing, the plunger starts to rise to level 0, while the lower punches start a rapid upward movement in order to extract the pressed tiles from their respective cavities without unacceptable quality losses, such as cracks or blunting.

The pressed tiles are placed on the roller assembly as they are pushed by the elastic stop of the feeder car during the loading phase of the cavities, which starts the new cycle. As pressing takes place in an inverted position, it is necessary to install a turner at the press outlet.

As the deforming force ceases, elastic energy is progressively released, so the longer the time the pressed tile remains inside the cavity, i.e. the time between the beginning of the ascent of the upper punches and the complete extraction of the tile, the lower the frictional stress will be. The frictional stress increases slightly as the rate of ascent of the punches increases, whereas the load application speed during the second pressing does not influence the friction ^[12]. In order to gradually release the elastic stresses accumulated by the powder during pressing and to facilitate the extraction of the tile, the liners of the entry moulds are manufactured with a small exit angle or “conicity”.



5.3.2. Extraction types.

Depending on the relative position of the lower punches and the plunger, it is possible to extract the tile in two different ways: free extraction (also called "delayed" extraction) and packed or sandwich extraction.

- The **free extraction** is carried out by slightly delaying the ascent of the lower punches in relation to the ascent of the plunger, so that punches and plunger rise separately. For this type of extraction, the delay is activated between 0 and 4000 ms⁵⁵, so the plunger starts the upward movement before the punches.
- The **sandwich extraction** (Figure 5.4.) is carried out by synchronising the speed and time of the upward movements of the lower punches and the plunger, so the tile is raised packed between the two punches. For “packed” extraction, also known as “sandwich” extraction the delay must be deactivated or set to 50 ms, initiating the ascent of the plunger and the punches at the same time. To ensure the extraction is carried out synchronously, a high the speed ascent

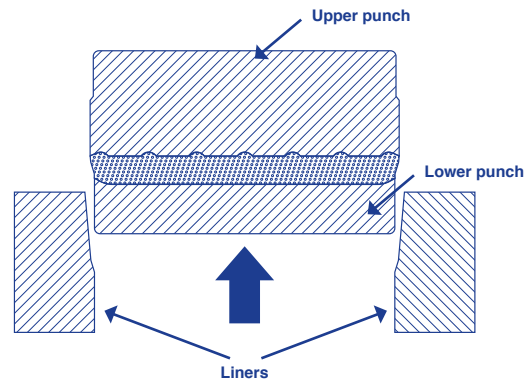


Figure 5.4. Sandwich extraction with an entry mould.

⁵⁵ For SACMI presses

of the lower punches must be set (60 to 100%) so the slower movement of the plunger will force the extraction with the tile packed between the two punches.

This extraction is recommended for large formats and also for any format if pressing powders with excessive post-pressing expansion that may cause small expansion cracks.

5.3.3. Problems associated with entry moulds.

The entry mould has the advantage of simplicity, low cost and high production, but it has some disadvantages that have led to the development of other types of moulds:

1. Recompressed. Because the good face is formed on the lower punches, it can cause defects if small recompressed burrs, from the powder trapped in the clearances between the upper punches and the liners, fall to the bottom of the cavity, carried by the downward movement of the lower punches during the first plate drop. This clearance must be at least 0,1 mm to allow for movement of the pressings and deaeration after the first pressing.

2. Wear of liners and upper punches. Both the upper punches and the liners are subject to the intense abrasive action of the particles that form the pressing powder and are therefore subjected to intense wear. This wear increases the clearance which, if not compensated for by heating the die box, can lead to powder leakage, recompressed and sticking. The lower punches are also subject to wear due to the dragging of the tiles during extraction.

3. Scrapes, stripes and drag marks. Another major disadvantage of pressing in an inverted position in this type of moulds is the fact that the tiles are pushed over the roller by sliding on their smooth or embossed face, rubbing against the edge of the liners and the die cast surface, which can obviously cause defects such as scratches and drag marks. This makes these moulds unsuitable for forming tiles with very pronounced reliefs.

Depending on the type of pressed relief with an entry mould, it may even happen that the tile could chafe against the lower punches when it is pushed onto the roller assembly, scratching the relief of the punch.

Table 5.3 summarises the main characteristics of this type of moulds.

Characteristics	
The back sides are formed in the upper punch.	Hydraulic compensation: isostatic punches.
The face to be glazed is formed by the upper punch.	• Possibility of scuffs and scratches on the good face. • Wear of the reliefs. • The installation of a turner on the roller assembly is required. • Possibility of recompressing.
The pressing force is applied by the upper punches that penetrate the cavity.	• The upper punch penetrates the cavity. • Possible dust ejection during deaeration.
Fixed die box.	
Liners always have angle, although they may or may not have a spacer.	

Table 5.3. Main characteristics of entry moulds.

5.3.4. Inverted entry moulds.

This is a variant of entry moulds, used to manufacture some types of tiles, or pieces with very pronounced reliefs. They are entry moulds where the punches are reversed so the back sides are formed by the lower punch and the good face or side to be glazed by the upper punch.

The liners of the inverted entry moulds are kept in the same position as they were in the entry mould, i.e. with angle and spacer, so when pressing in this mould variant with the good face upwards, the spacer is placed in a lower position, in other words close to the back sides.

A clear advantage of this type of mould is its simplicity, which allows an easy assembly and adjustment, in addition to the high production of the entry mould, already mentioned. Also noteworthy are their optimal productivity and low manufacturing costs, compared to more complex types that press with the good face upwards, such as double moulds. On the other hand, these moulds usually guarantee a good lateral finish of the tiles⁵⁶.

This variant of the entry mould is currently experiencing a boom due to the production of large formats, which are almost always rectified and therefore the finish of the profile is no longer important in the choice of mould type.

5.3.5. Interchangeable die box entry moulds.

This variation of entry moulds (Figure 5.5) has a double die box that allows the replacement of all liners of the cavities by exchanging the die box for another one where the new liners are already incorporated, thus allowing a considerable time saving in the changeover of moulds with a large number of outlets.

Removable die box entry moulds are not recommended for pressing large formats at high pressures (porcelain tiles), due to the deformation of the cavities, as the partitions are thinner. Its use, therefore, should be restricted to medium and small single fast firing tiles or stoneware tiles formats, although it is noted that in some cases it has been used for multi-format moulds, although this application can generate some problems in the management of the necessary die boxes because with use they may need to be rectified and this eventually means that all used die boxes may not have exactly the same thickness.

Although the variant referred to entry moulds has been discussed here, in reality the removable die box can be adapted to any type of mould and the conditions for its use remain the same.



Figure 5.5. Interchangeable die box entry mould.

⁵⁶ The best lateral finish of the tile is achieved with the double mould. With an entry mould, a good lateral finish is achieved by performing sandwich extraction. However, in delayed extractions there is, in general, a poorer lateral finish.

5.4. MIRROR MOULDS.

Mirror moulds (Figure 5.6) are now practically in disuse, being limited to the production of mosaic, although it was originally used for pressing tiles with the good face upwards, which made possible to obtain an excellent pressing quality, due to the absence of upper burrs, scratches and grooves caused by friction during extraction. Mirror moulds have gradually been replaced by double moulds and nowadays also by entry mirror moulds.

It differs from the entry mould in two points: the die box is mobile and the upper punches, which form the good face of the tile, are larger⁵⁷ than the corresponding cavities. Consequently, during pressing they are placed on top of the die box, which starts a downward movement followed by the upper punch while the lower punch remains fixed. The die box can perform this movement because, as shown in Figure 5.8, it is supported by a set of hydraulic pistons that allow this movement downwards. Occasionally this movement can be aided by the use of stops or rod bars on the holder punch plate.

The mirror mould allows the good face to be pressed upwards (Figure 5.7.) which improves production quality. This is therefore an advantage over the entry mould, which is, however, minimised as it is not possible to produce the tiles with spacers, and the edges of the raw glaze layer, after application, are exposed to the knocks and chafing between tiles or with fixed elements of the glazing line or the kiln, which considerably increases the losses.

The upper punches of mirror moulds are subject to less wear than those of entry moulds, and therefore last longer. However, nowadays, this type of moulds, which became a valid alternative for the manufacture of unglazed porcelain tiles and were capable of withstanding 2,000,000 cycles, have a minority use in Spain and their use is limited to the manufacture of mosaic.

The liners of this mould do not have radii, i.e., the characteristic ridge or chamfer of the liners of the entry moulds and, although in small and mosaic formats they may lack conicity, in large formats the liners are always provided with a slight angle. The liners of the mirror mould are also subject to less wear than the liners of entry moulds. Logically, the back side relief is engraved on the lower punches.

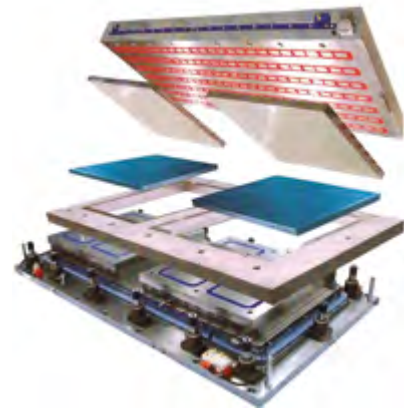
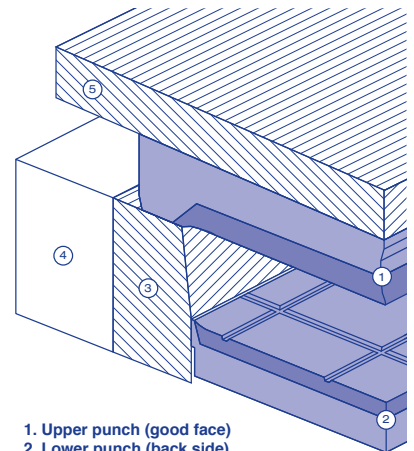


Figure 5.6. Mirror mould with two outlets, upper and lower punches and punch holder plate.



1. Upper punch (good face)
2. Lower punch (back side)
3. Liners
4. Die box.
5. Upper punch holder plate

Figure 5.7. Pressing method with mirror mould.

⁵⁷ Their dimensions were slightly larger than those of the cavity, with sizes ranging from 5 to 10 mm per side. It was not advisable for overhangs to be very large because, in small and medium-sized formats, they could limit the number of outlets which the mould could possible have.

Deaeration takes place through the clearances between the punch and the die box, both at the bottom of the mould and at the top, and extraction takes place by the upward movement of the lower punch. Deaeration with this type of mould is more difficult than with the entry mould.

At the time, the mirror mould had the advantage of minimal upper punch wear and, as mentioned above, virtually no edge wear, which gave these moulds a long service life. However, a problem associated with this mould is the possible displacement of the upper punches, which affects the edges. This was corrected by the installation of lugs that prevented this displacement.

5.4.1. Stages of the pressing cycle with a mirror mould.

In essence, the stages of the pressing cycle (Link 5.2 and Figure 5.8) with this type of mould are the same as those described for the entry mould, with one difference. During the first and second pressing the mobile die box, which in the entry mould is fixed, descends accompanying the upper punch which does not penetrate the cavity, and for the extraction of the tile the die box ascends to its initial position.

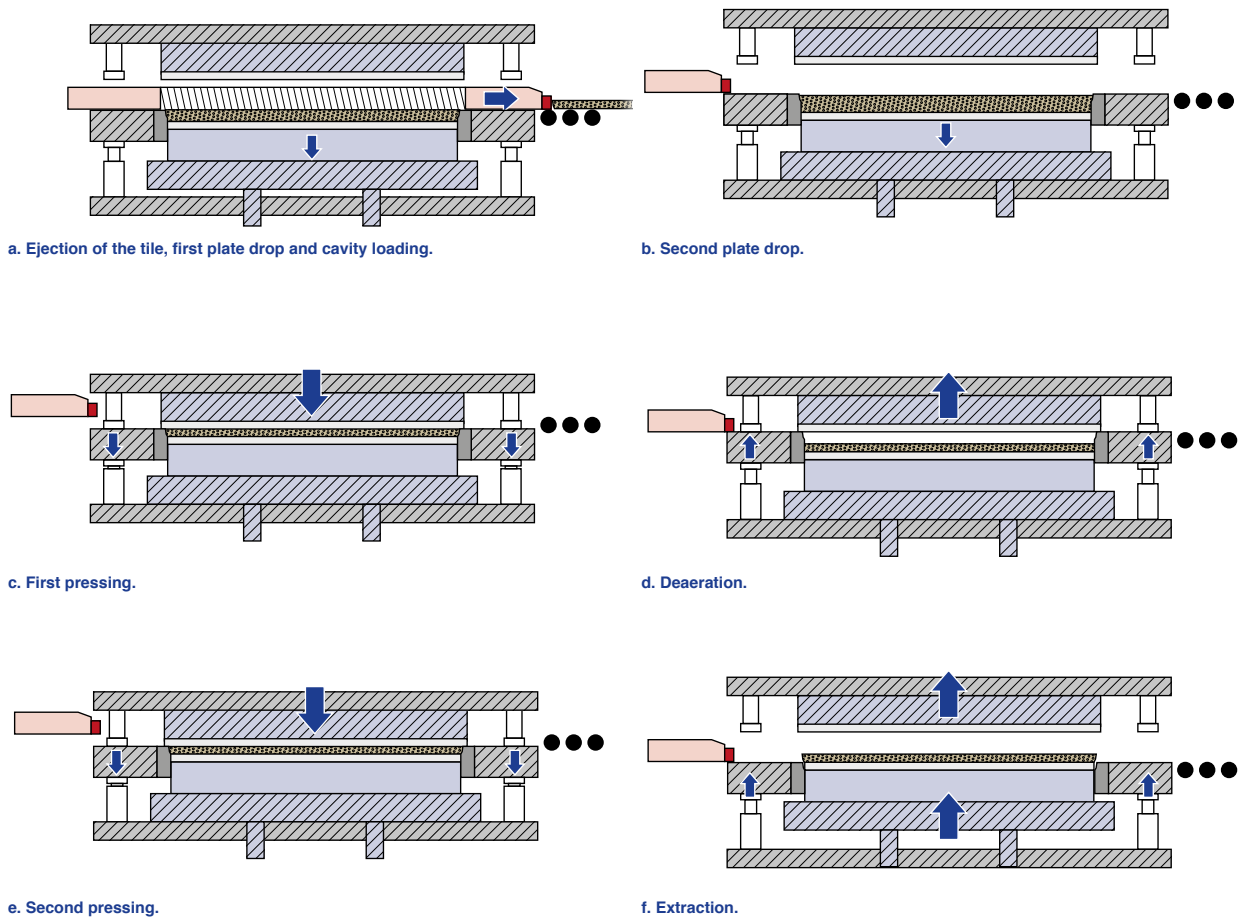


Figure 5.8. Pressing cycle with a mirror mould.

Table 5.4 summarises the main characteristics of this type of moulds.

Characteristics	
The upper punches rest on the die box.	Pressed with the good face upwards. Upper punch: face to be glazed. Lower punch: back sides.
The pressure is applied when the die box perform a vertical downward movement.	No turner required. Increases the service life of the upper punch.

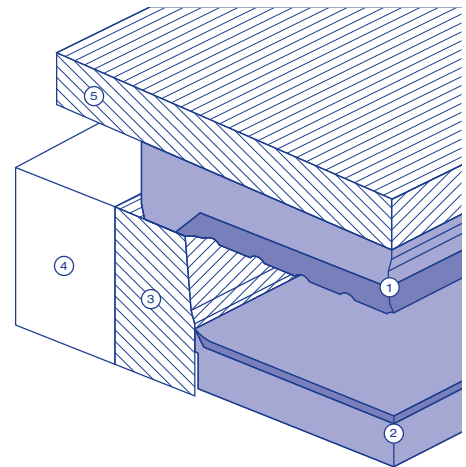
Table 5.4. Main characteristics of mirror moulds.



In the attached QR code you will find a link to an animation of the pressing cycle with a mirror mould. Link 5.2

5.4.2. Inverted mirror moulds.

A variant of this mould is the inverted mirror mould, where the pressing way of the mirror mould is maintained, with the upper punch having a larger surface area than the cavity and with the die box having an upward and downward motion. Nevertheless, the tile is formed with the good face in an inverted position and therefore with tiles provided with spacers (Figure 5.9).



1. Upper punch (back side)
2. Lower punch (good face)
3. Liners
4. Die box.
5. Upper punch holder plate

Figure 5.9. Pressing cycle with an inverted mirror mould.

5.5. DOUBLE MOULDS.

When pressing porcelain stoneware or single fast firing tiles, whether or not they are decorated in press, it is advisable, and sometimes even necessary, for the good face of the tile to be formed by the upper punch. This would require the use of mirror moulds, described in section 5.4. However, it has already been shown it is not possible to produce tiles with spacers using mirror moulds and having the good face upwards at the same time, as the extraction the tile would not be possible to . The technological solution that prevailed at the time was the double mould (Figure 5.10); a much more technologically complex mould, which is conceived as a synthesis between mirror moulds and entry moulds. The mould design allows pressing tiles with spacers and with the good face upwards, as can be seen in Figure 5.11.

This type of mould consists of two parts with a certain formal similarity: the lower part has hardly any differences with traditional mirror moulds, i.e. it has a bench plate, ejecting plate, magnetic blocks, lower punches and a die box equipped with liners without radii and, unlike mirror moulds, without angle. They are normally provided with 0.1 mm "lugs" to facilitate venting through the bottom.

The die box is attached to the bottom plate by means of hydraulic pistons that allow it to move up and down.

The important differences with the mirror mould are to be found in the upper part of the mould, which is structurally similar to the lower part of the entry mould and in which a die box with rod bars is rigidly joined to the upper plate by means of pilasters, and where a piston extraction equipment is installed.

The tiles are formed in the upper die box, which is why this type of mould is also called "top-forming mould"⁵⁸ and it is therefore the upper liners that shape the side profiles of the tiles. Once the tiles have been pressed, the mould itself carries out the extraction process using a system of hydraulic pistons located in the upper part, which allows the movement of the upper punch holder plate, and therefore the extraction of the tiles.

The isostatic punches are the lower punches, although it is also possible to install solid ones, i.e. non-isostatic lower punches, e.g. for pressing polished porcelain tiles.

The liners installed in the lower die box can be removable, although conventional liners are often installed. In addition, conventional liners are also preferred in the upper die box.

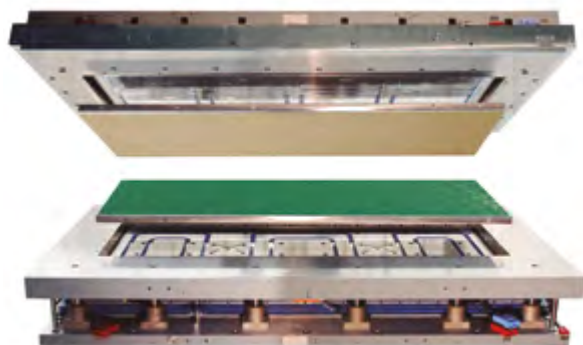


Figure 5.10. Double mould for a large format plate, 770 x 1950 mm.

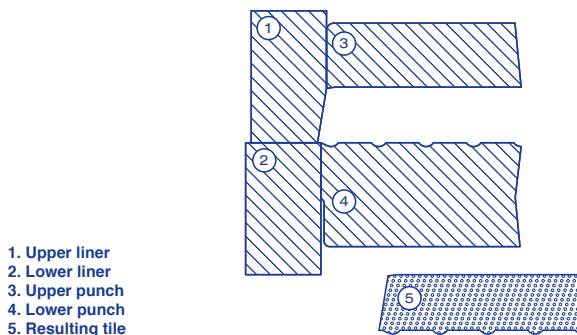


Figure 5.11. In a double mould the tiles are pressed with spacers and with the good face upwards.

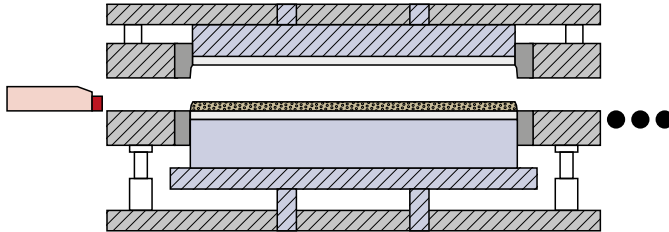
5.5.1. The pressing cycle stages with double moulds.

The first plate drop, cavity loading and second plate drop stages are similar to those described for the previous moulds. However, in this case, the tile is formed inside the upper part of the mould which, remember, has a fixed die box and the upper punches form the good face. Extraction must be carried out in two phases. In the first one, the entire assembly formed by the lower punches and the upper and lower die boxes are lifted, separating the tiles from the cavities of the upper die box by the action of a hydraulic extraction system located in the upper part of the mould. During the second phase, the upper part of the mould returns to its initial position and the tiles are pushed towards the roller assembly.

⁵⁸ It is also known by the acronym SFS for "Stampo a Formatura Superiore".

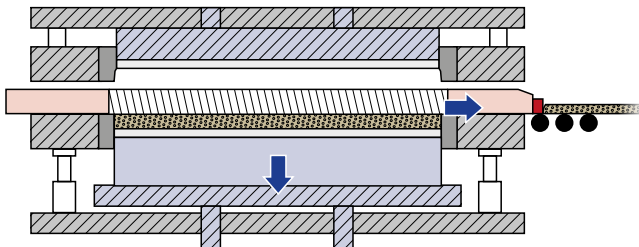
0. Start of the cycle.

As described in entry moulds, the cycle starts with the plunger at the 0 level and the lower punch aligned with the die box level. The extractor pistons at the upper part of the mould are at level 0.



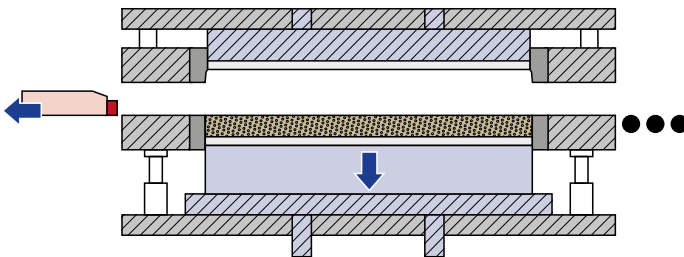
1. Ejection of the tile, first plate drop and cavity loading.

The ejection of the tile and the loading of the cavities are carried out in the same way as described for the entry mould. The loading also takes place with two drops of the lower punches. However, these moulds allow for press and double-load decorations, so in these cases there are three plate drops, the first to receive the support load, the second, which regulates the upper layer and the third which lays the ejector plate over the bench plate and prepares the set to receive the pressure.



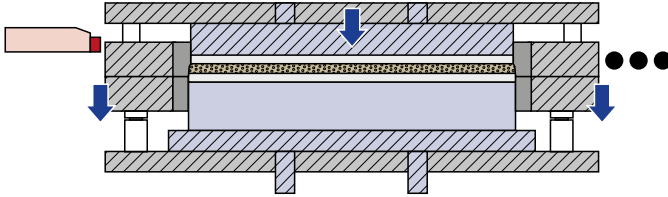
2. Second plate drop.

This operation is identical to the one described in the previous typologies: the feeder car returns to the starting position and the assembly of lower punches, blocks and ejector plate are lowered until the latter makes contact with the bench plate.



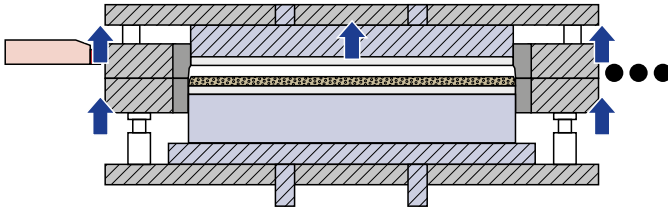
3. First pressing.

The plunger is lowered and this downward movement is accompanied by the lowering of the lower die box, so that the tile is formed in the cavity defined by the upper die box, which makes possible to press and remove the tiles with spacers and in "face up" position. In this position the first pressure is applied in order to remove as much air as possible.



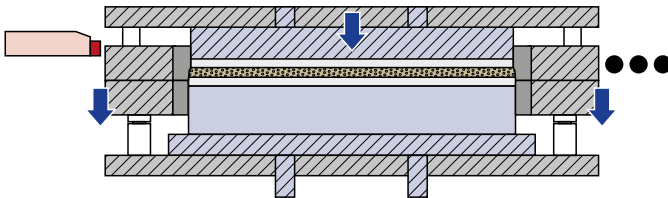
4. Deaeration.

The deaeration is carried out when the pressure of the first pressing is released, through small slots in the liners, and through the clearance between punches and liners, therefore a slight upward movement of the plunger and the lower die is necessary.



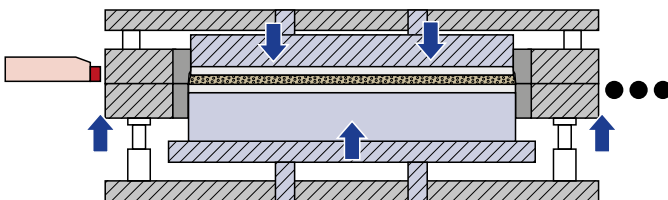
5. Second pressing.

The plunger is lowered again and the maximum cycle pressure or pressing pressure is developed. The ejector plate-"blocks"-lower punch assembly remains in its lowest position and the lower die box descend slightly as the tile reaches the required compactness.



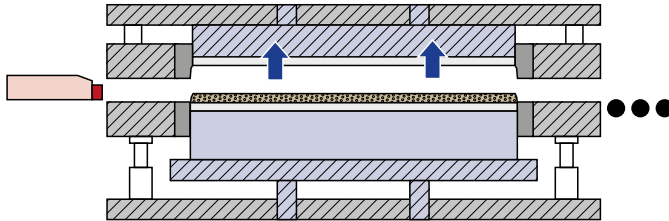
6. First extraction phase.

The extraction of the tile from the upper part of the mould takes place in two stages or phases. In the first one, which is the one shown in the attached image, the ascent of the whole assembly formed by the lower punches, the lower die box and the upper die takes place. The tiles are separated from the upper die box cavities by the action of a hydraulic extraction system located in the upper part of the mould, which gives the upper punches a slight downward movement.



7. Second extraction phase.

In the second extraction phase, shown in the attached figure, the hydraulic system, the upper punches and the lower die box return to their initial position, allowing the tiles to be ejected towards the roller assembly and the start of a new pressing cycle. The extraction system of this type of mould must always work as a sandwich extraction system.



In the attached QR code you have a link to an animation of the double mould pressing cycle. Link 5.3

5.5.2. Main characteristics of double moulds.

Table 5.5 summarises the main characteristics of this type of moulds.

Characteristics	
It is a synthesis between the mirror mould (lower part) and the entry mould (upper part). The forming of the tile takes place inside the upper part of the mould.	Upper punch: good face. Lower punch: back sides.
	No turner required.
	Double die box.
	Tiles with spacer.
	Extraction takes place by the push of the pistons located inside the upper part of the mould.

Table 5.5. Main characteristics of double moulds.

The upper forming with the good face upwards has the advantage of eliminating the risks of recompressing, sticking and chafing when the tiles are ejected from the pressing area, as well as avoiding the turning over assembly at the press exit.

5.5.3. Manufactured products.

These moulds have been widely used for the manufacture of porcelain tiles and large formats with press decorations, or for the second pressing of tiles obtained by double pressing technologies with pre-compaction with press or belt compactor. Today they are used for all types of products and formats. They are also suitable for pressing tiles with subtle reliefs. Due to the pressing with the good face upwards, the tiles are not damaged when deposited on the roller assembly, as can happen when pressed with the

entry mould. However, very pronounced reliefs should be avoided as they can make extraction difficult or cause differences in compaction which can lead to problems in the absorption of glazes and pinholes, especially in single fast firing tiles.

5.5.4. Thickness regulation in double moulds.

In this type of mould it is, generally, very difficult to adjust the thickness of the pressed tiles at will, this parameter being conditioned by the construction characteristics of the mould itself. However, MACER has introduced technical improvements that allow the thickness to be varied within 3 mm (Figure 5.12).

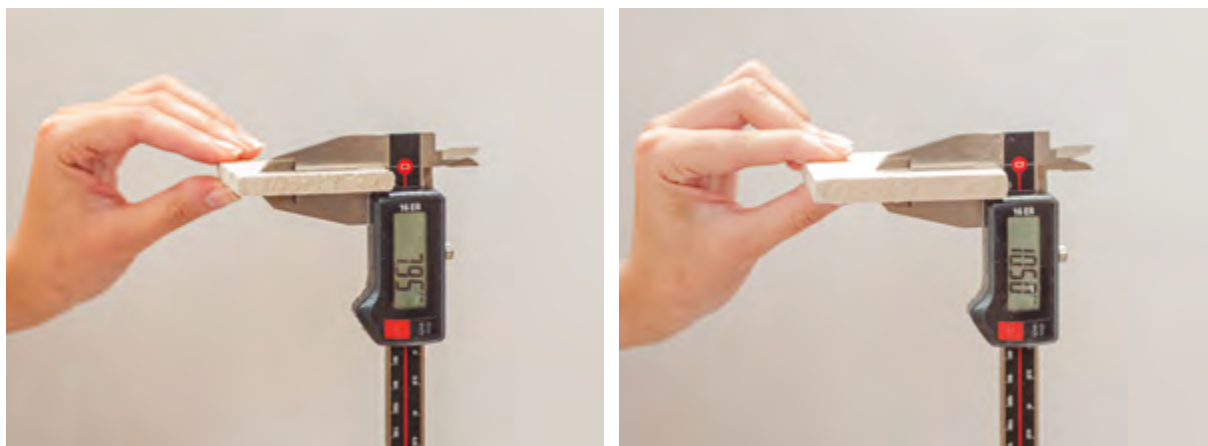


Figure 5.12. Adjustment of different thicknesses with the double mould of MACER.

5.5.5. Hydraulic compensation plates.

5.5.5.1. Hydraulically compensated punch holder plate.

Some of these moulds incorporate an isostatic punch holder plate (Figure 5.13). These plates used to have an internal hydraulic system that connected all the lower punches, thus achieving the hydraulic compensation. This system is derived from the isostatic compensation on each punch and was used with the intention of minimising the number of gauges produced. In this type of mould, hydraulic compensation was carried out on the lower punches, as it was easier to install and the lower punches are the ones that form the face of the back side. However, with the use, it was noticed that the system could unbalance the load of the cavities.

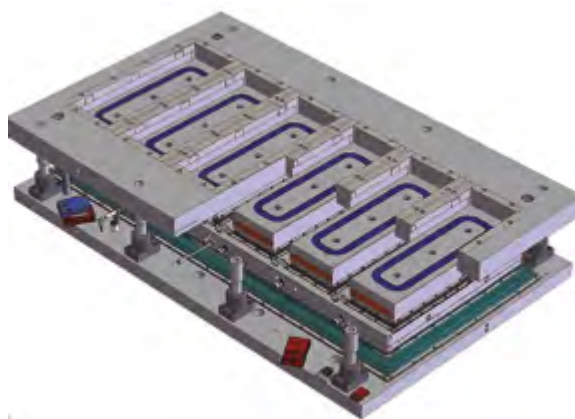


Figure 5.13. Mould equipped with hydraulic compensating punch holder plate (lower compensation).

5.5.5.2. Hydraulically compensated upper plate.

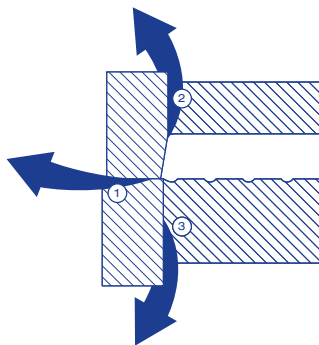
Due to the problems of unbalanced load of the cavities detected in moulds with hydraulic compensated punch holder plates, it is currently preferred to install the hydraulic compensation on the upper plate in double moulds, in spite of being a far more complex technical solution (Figure 5.14), as the upper part of a double mould is responsible for carrying out the ejection movements, which is a task that, in other types, is entrusted to the press hydraulics. For this reason, this type of mould has double-acting pistons incorporated inside the mould itself, with all the mechanisation and hydraulic circuitry this implies. Therefore, if in addition to this an isostatic compensation system is incorporated, it necessarily adds another hydraulic circuit independent of the previous one, with the complexity that this entails, given the reduced space available for it.



Figure 5.14. Mould equipped with hydraulically compensated upper plate.

5.5.6. Deaeration problems.

The closed structure of this mould makes the deaeration stage extremely delicate and difficult, especially if we take into consideration that large format tiles are generally pressed with this type of mould and therefore large masses of air must be evacuated. Deaeration occurs mainly between the upper and lower liners and through the clearances between punches and liners (Figure 5.15).



1. Deaeration through the liner slots
2. Deaeration through the upper top
3. Deaeration through the lower top

Figure 5.15. Double mould deaeration ways.

5.5.7. Stops on the die box and the double moulds centring elements.

When decorations are made on the press, it is not possible to skim or level the load, as this would blur the decoration. This can result in atomised powder residue on the surface of the die box and the lower liners, which prevents perfect contact between the liners during pressing. This can lead to lack of adjustment problems between the upper and the lower part of the mould. To avoid this, MACER has incorporated in its moulds some **stops** inside the lower die box, even with the die box, and others inside the upper die box, which level stand a few tenths of a millimetre above the liners, so that during pressing, the contact between both components of the mould occurs on top the stops and not between the liners as usually happens in this type of moulds. Moreover, the upper stops have an air blowing system that ensures a clean contact. The stops are made of tempered steel, which considerably reduces wear.

In this type of mould it is very important to ensure a perfect fit to avoid asymmetric edge forming. For this purpose, MACER has developed a **centring system** for the upper and lower part of the mould. The system consists of hardened steel bushings inserted in the lower die box and their symmetrical ones into the upper one, so that they coincide when the mould is perfectly centred. To ensure that the pockets are perfectly aligned, steel balls are placed on the lower bushings during adjustment (Figure 5.16), and then the upper die box is placed over the balls so that they get inserted into their correspondent upper bushings. This way a quick centring of the mould is achieved.

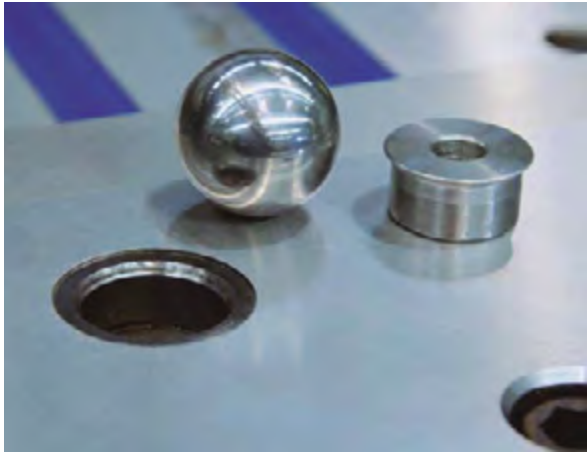


Figure 5.16. Centring system of double moulds.

5.6. ENTRY MIRROR MOULDS.

This type of mould (Figure 5.17), also called "semi-mirror" or "semi-entry", has intermediate characteristics between the entry mould and the mirror mould, and is often used as a substitute for the double mould, due to its greater simplicity and lower cost.



Figure 5.17. Entry mirror mould.

The lower part of the mould is similar to the traditional mirror mould. However, the liners of this mould are different from those used in the mirror mould, as they have the same morphology as those of the entry mould, with the difference that the angle and the spacers are at a higher level, therefore, in this mould, the pressing is carried to an upper level (see Figure 5.18).

The upper part of this type of mould is different from the mirror mould. The upper punches are similar in size to those of the entry mould, but they are inserted up to a pre-established level, usually about 3 mm, as their stroke is limited by stops on the upper plate (Figure 5.19 and 5.20). This measure is not fixed. For example, with hardened metal liners, it must be avoided that the edge of the punch during the pressing process coincides with the junction of the two metals, which make necessary to vary the stroke of the upper punch up to a maximum of 6 mm.

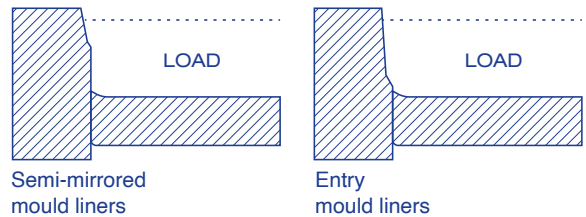


Figure 5.18. Comparison between semi-mirror and entry mould liners



Figure 5.19. Entry mirror mould with stops.

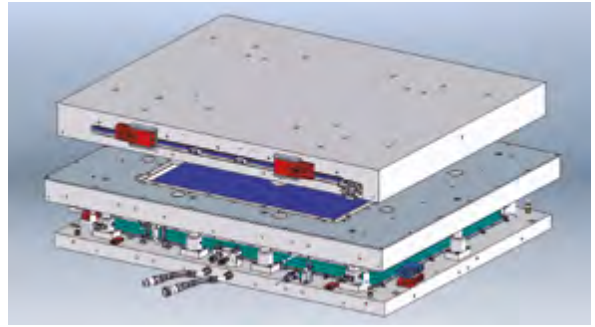


Figure 5.20. Entry mirror mould arrangement with stops.

The low penetration of the upper punches into the cavities reduces the stress on the tile and the wear of the liners and punches, as the die box is retained at its lowest position during extraction and the tile is released with minimum drag and progressive release of the pressing force.

The usual pressing of this mould is with the good face upwards (Figures 5.21 and 5.22).

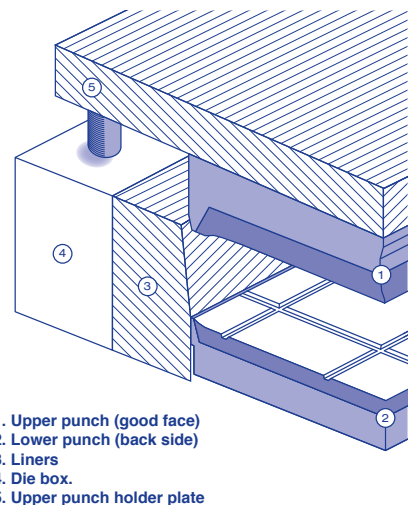


Figure 5.21. Usual pressing mode of a entry mirror mould.

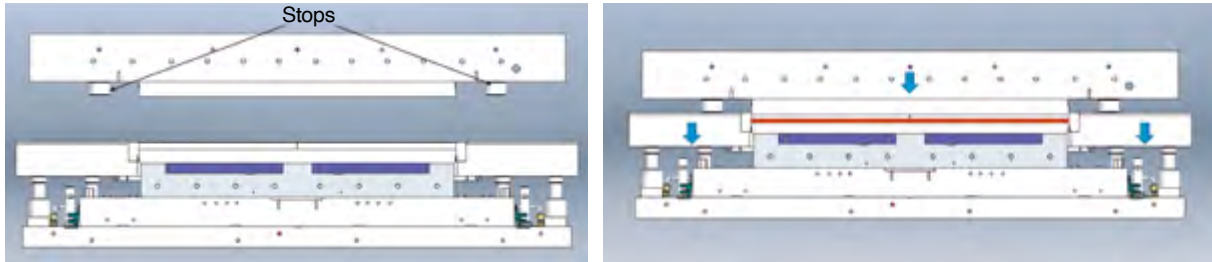


Figure 5.22. Pressing with an entry mirror mould.

5.6.1. Pressing cycle with an entry mirror mould.

The pressing cycle of entry mirror mould (Link 5.4) is quite similar to that of entry mould since the loading of cavities and plate drops occur just the same as in this typology. Even the first and second pressing stages are quite similar, although with one important difference: the upper punches penetrate the cavities, as does the entry mould, but only up to a certain level. It is marked by stops on the upper punch plate and, since unlike the entry mould, the die box is movable, it can be lowered to allow forming to take place at the top of the liners. This allows an easy and stress-free extraction and a longer life of the mould elements subject to wear, reinforced by the possibility of this type of mould to retain the die box in its lowest position, as it incorporates double-acting pistons that enable this manoeuvre.

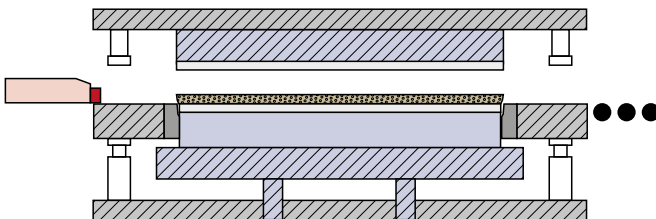


In the attached QR code you will find a link to an animation of the pressing cycle with an entry mirror mould. Link 5.4

In contrast to top-forming moulds, or double moulds, which always have to work with a sandwich extraction system, this type of mould can also work with a delayed extraction, i.e. by releasing the pressure of upper punch and ejecting the tile. If desired, a sandwich extraction can also be performed by synchronising the ejecting movement with the one of the upper punch. The mould also has an additional advantage, since it loses less dust than others due to the fact that the liners have less angle and this is located in the upper part of the liners.

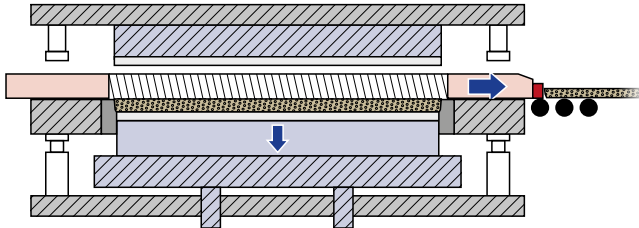
0. Start of the pressing cycle.

The cycle also starts with the plunger at 0 level and the lower punch aligned with the level of the die box and the feeder car.



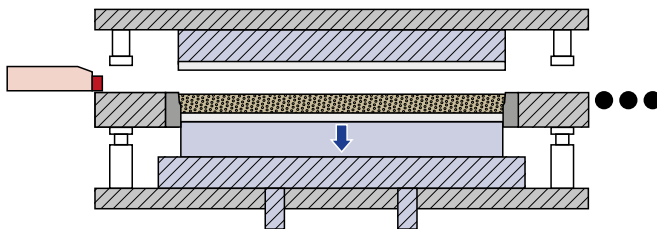
1. Ejection of the tile, first plate drop and cavity loading.

Once again, the tile is deposited on the roller assembly by the push of the elastic stop of the feeder car, while the plates make the first fall to the corresponding level, regulated from the control panel of the press. During these movements, the mobile plunger remains in its high position.



2. Second plate drop.

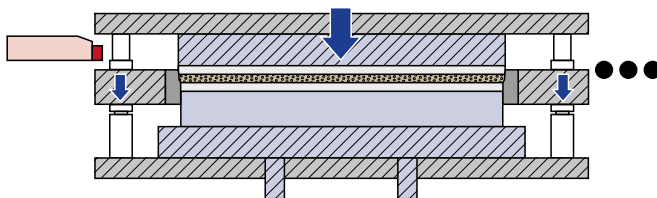
The feeder car returns to the starting position and the assembly formed by the lower punches, magnetic blocks and ejecting plate are lowered until the latter comes into contact with the bench plate, which is ready to receive the pressing force.



3. First pressing.

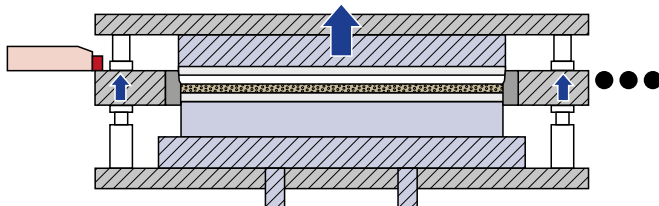
In this type of mould, the die box is also lowered by the mobile plunger (note the difference in level between the feeder car and the diebox), which only descends as far as the stop anchored to the upper plate allows it, and in this position the first pressure is applied in order to remove as much air as possible.

It should be noted that in this mould, unlike the entry mould, the pressing takes place at the top of the liners, which will facilitate the extraction of the tiles.



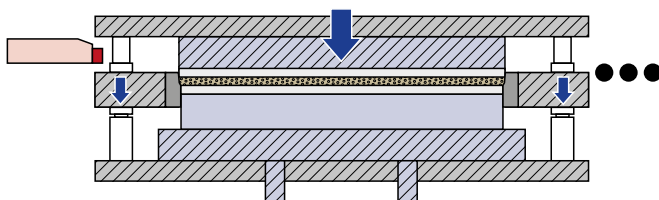
4. Deaeration.

When the force of the first pressing ceases, the die box and upper punch rise slightly to facilitate the release of occluded air through the perimetral clearance between the punch and the liners and slots in the upper liners.



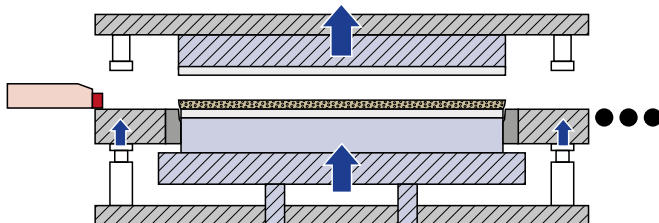
5. Second pressing.

The application of a higher pressing force in the second pressing results in a lowering of the die box and therefore increases powder compaction (remember that the punch holder plate, magnetic blocks and lower punches are in a lowered position with the punch holder plate resting on the bench plate).



6. Extraction.

The pressed parts are ejected from the cavity and brought to the level of the feeder car and the roller assembly by the upwards movement of the lower punches, followed by the upwards movement of the mobile plunger. As the pressing has taken place at the top of the liners, extraction is easy and with less stress due to post-pressing expansion.



5.6.2. Main characteristics of entry mirror moulds.

Table 5.6 summarises the main characteristics of this type of moulds.

Characteristics	
Mobile die box supported by hydraulic pistons.	Good face upwards and back sides shaped by the lower punch. No turner is required. Liners with a different profile than those of entry moulds (see Figure 5.18) Minimal wear of liners and punches. Less stress on the parts during extraction. Possibility to retain the die box in its lowest position.
The upper punch penetrates to a height delimited by stops on the upper punch holder plate.	

Table 5.6. Main characteristics of entry mirror moulds.

5.6.3. Manufactured products.

This mould is used in the pressing of rectified tiles, that the good face of the tiles usually faces upwards, as has been mentioned, thus avoiding mould sticking, recompress and cracks that may occur when turning such large tiles.

These moulds are well suited for pressing large formats and high thicknesses. Nowadays, they can be used to replace the double mould, as their cost is significantly lower, although, due to the slightly inverted angle of the liners, the tiles must be rectified and the glazing line must be adapted to avoid contact between raw tiles.

5.6.4. Deaeration.

The size of the punches of entry mirror moulds allow, as well as with entry moulds, a small clearance to be left in the mould cavity between the liners and the upper punch, which contributes to deaeration. It should be borne in mind that in large formats usually used for porcelain tiles manufacturing, the deaeration stage has great importance as large volumes of air must be evacuated.

5.7. SPECIFIC APPLICATIONS OF MOULDS.

The typologies described in the previous sections admit some modifications that affect both their components and their performance, but, in essence, do not alter their general characteristics or their operational mode. Within these variations, the **quick changeover moulds (CSR)** and **moulds with 380 - 440 V electrical installation** are currently on the market.

5.7.1. Quick changeover moulds.

It is also called **CRS mould**, which stands for “Cambio Rapido Stampo”. These are moulds of any typology prepared for the quick mould changeover systems of SACMI presses^[78]. Figure 5.23 shows an entry mirror mould with magnetic fastening elements and connectors adapted for quick mould changing.

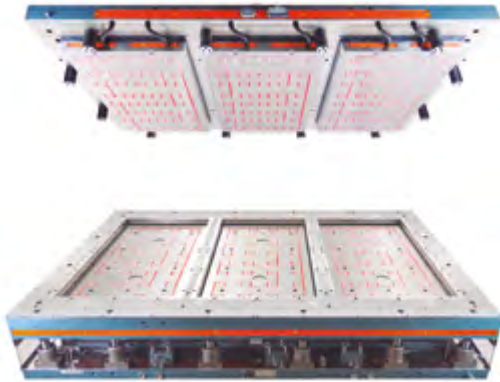


Figure 5.23. Entry mirror mould with quick mould change (CRS) devices.



In the attached QR code you have a link to a video about a quick change mould. Link 5.5

The quick change systems significantly reduce the mould replacement time by simplifying all operations. They also make it possible to adapt to highly flexible production scheduling, motivated by the growing demand for small batches, customised production and a wide variety of formats and reliefs.

These moulds are compatible with the system integrated in SACMI presses, based on magnetic fastening systems and fast plugs, available in presses with high pressing force. All these moulds have 380 - 440 V heating systems.

5.7.2. Moulds with 380 – 440 V power supply.

Most moulds, especially small and medium-sized moulds, are equipped with low-voltage (50 V) heating systems. However, as the format increases or for the moulds developed for high tonnage presses, it becomes necessary to equip them with larger transformers in order to obtain the necessary voltage for the heating circuits.

Moulds with 380 - 440 V electrical installation (Figure 5.24) are moulds of any type where the heating system is supplied with a 380 - 440 V three-phase current. It has the advantage of avoiding large transformers in the press and require a smaller cross-section wiring than would be necessary. Naturally, operating at 380 or 440 V requires very demanding safety systems to be established, including a mould design with internal wiring subject to a number of safety and insulation constraints. This means very closed moulds, specific connectors and heating elements, phase compensation, etc., which increases the cost of the mould.



Figure 5.24. Mould with 380 – 440 V power supply.

5.8. MOULD TYPE SELECTION CRITERIA.

The choice of a particular type of mould is subject to a set of criteria that may have different specific relevance in the final decision. The main criteria for the choice of the appropriate mould are:

- Type of product to be manufactured.
- Format.
- Relief and / or back side.
- Production.
- Edge grinding.
- Manufacturing processes.
- Price.

a) Type of product to be manufactured.

Depending on their application, there are different typologies of ceramic tiles ^[85]. Although at first sight it might seem that any type of mould can be used for the manufacture of all types of ceramic tiles, the type of product (glazed or unglazed porcelain tiles, stoneware, wall single fast firing tiles, press-decorated product, etc.) largely determines the choice of the appropriate mould. On the one hand because the pressing force can be very different from one product to another. For example, the difference in pressing force between porcelain tiles and the rest makes it preferable to avoid removable die box moulds in this type of product. For some products, where forming with the good face upwards is preferred or absolutely necessary, e.g. if press decoration technology is used the mould typology election is critical.

b) Format.

Square or rectangular formats are the most common and there is a very wide variety of them on the market, from small mesh mosaics up to today's large formats.

Pressing in the entry mould with the good face downwards requires turning the pieces on the roller assembly at the press outlet. This is not a complicated operation for small and medium formats, but some manufacturers may be reluctant to turn large format pieces, as it may increase the risk of cracking due to impacts.

c) Relief and / or back side.

In models with relief, the type of back side is determined by the morphology of the relief, so an attempt is made during the design stage to minimise differences in compaction that may occur due to differences in thickness caused by the relief and / or the back sides.

Very pronounced reliefs can present problems in top-forming moulds (double moulds). It should be taken into account that if tiles with a very pronounced relief are formed, their design should be such that they can be easily and cleanly removed.

The best profiles are obtained with the double mould. However, the best compensation is obtained with the entry mould.

d) Production.

The double mould has, compared to the other typologies, a lower production rate because its pressing cycle is more complex, especially regarding the tile extraction phase. For the same format and product, a double mould can have 1.5 strokes per minute less on average than the other moulds.

When the dominant criteria is production, the entry mould is a good alternative as it allows us to perform a shorter cycle and therefore achieve a higher number of strokes per minute.

With the entry mirror mould, an intermediate production between an entry mould and a double mould is obtained.

e) Edge grinding.

As is well known, pressing with the good face downwards, in other words, with the good face formed by the lower punches, as is done, for example, in the entry mould, was originally necessary if the pieces were to be provided with a spacer. However, this type of mould presents many problems of scratches, chafing, cracks due to turning, etc., which it has been solved with the introduction of other types of moulds that allow pressing with the good face upwards.

Pressing with the good face downwards however, is not necessary if the tile has to be rectified, as it removes the spacers.

f) Type of press and press-drying equipment.

Any type of mould can be incorporated into today's large presses. Nevertheless, in small presses it may be impossible to adapt any type, especially the double mould if they do not have **sufficient clearance**.

The **length of the plunger** also determines whether a mould can be installed in a particular press. For example, in top-forming moulds (double mould) the upper punches must be in the projection space of the plunger (Figure 5.25) to avoid bending the punches. However, in entry moulds the punches may be larger and slightly overhang the dimensions of the plunger as this can be corrected with a thicker magnetic plate.

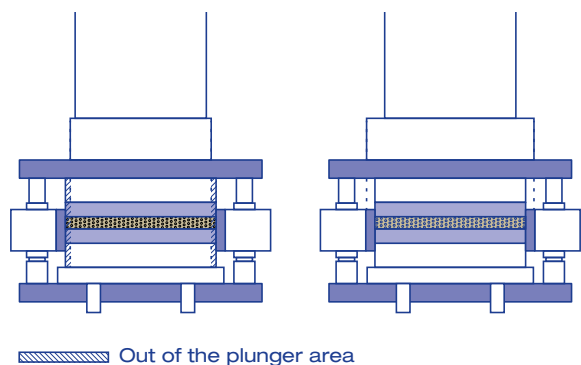


Figure 5.25. Relationship between the dimensions of the plunger and the upper punches of a double mould.

It is also important to take into account the installations of the pressing - drying section, roller and turner assemblies, type of dryer and dimensions etc. because this can condition the format to be manufactured and, consequently, the mould.

Sometimes the choice of a type of mould may be conditioned by the need to solve some type of manufacturing defect that occurs on a regular basis. For example, in some cases, entry moulds have been replaced by double moulds to avoid the occurrence of recompressed burrs. This can be particularly serious in large formats due to the high cost associated with the defect and can economically justify the replacement of the mould type.

And finally, it is not uncommon for the choice of a type of mould to be made on the basis of the company's own experience with this type, and even more if it is the mould type most commonly used in the company. In any case, this choice should always be made in consultation with the mould supplier.

Maintenance.

Chapter 6



6.1. GENERAL MAINTENANCE CONCEPTS.

In general, industrial maintenance is understood as the set of activities carried out on equipment, machines or the company's infrastructure itself, to prevent their deterioration and repair faults or breakdowns, with the aim of guaranteeing their correct operation and extending the life of the equipment, machines and installations with optimum performance and in conditions of safety and environmental protection over time.



Figure 6.1. Maintenance activities.

When referring to maintenance, three basic types are commonly referred to: **preventive maintenance**, **predictive maintenance** and **corrective maintenance**.

The purpose of **preventive maintenance** is, as its name suggests, to anticipate future equipment problems that may occur, generally by means of an established schedule that emanates from the indications of the manufacturers of the equipment themselves. This maintenance can also be scheduled during shutdown periods, depending on the production cycle of the company or the equipment itself. The results obtained from the equipment checks provide valuable information which, if properly processed, can provide the probability of failure and anticipate equipment breakdown before it occurs. This type of maintenance is known as **predictive maintenance** and is often more effective than preventive maintenance in the long run.

Corrective maintenance, on the other hand, consists of solving the failure when it occurs, in order to return equipment and machines to their operational status. The appearance of faults in industrial equipment, as will be understood, has negative effects on the production cycle of any company.

It should be noted that "**operational status**" means the state of the equipment in working conditions with appropriate quality, safety and environmental protection.

On the other hand, the **service life** of machinery and equipment is the actual working time during which it maintains the required conditions of quality, safety and environmental protection and at operating costs that make it cost-effective.

Thus, the main **objective of maintenance**, in general, is to have a production system in optimal operating conditions, with all equipment, machines and installations available in good state whenever they are required and at the lowest possible cost.

The division of industrial maintenance into the three types mentioned above, corrective, preventive and predictive, is quite common in industry, even with certain nuances and adaptations to the specific conditions of each company, which is why it is described in more detail in this text. However, a general classification, adaptable to any reality and which generates consensus, is the one described in the **UNE-EN 13306 standard: 2018** of mandatory adoption by the countries forming the European Union and which establishes a "standardised maintenance terminology table" [2] with the intention of arriving at a universal common language and establishes a reference point in terms and definitions for the rest of the European standards related to maintenance.

On the other hand, we have considered of interest the classification of maintenance activities made by the **French AFNOR NF X 60-000 (2016) standard** [3], which divides these activities according to the set of competences, skills and knowledge developed in each of them into five levels.

Table 6.1 shows the main characteristics of the types of maintenance described in our first classification.

Type of maintenance.	Characteristics
Corrective.	A set of maintenance activities aimed to correct malfunctions as they occur. This is the most basic type of maintenance and consists primarily of troubleshooting and repair. It is therefore based on the need to correct or repair malfunctions in a timely manner at a given point in time. The most frequent activities performed during this type of maintenance are the repair and replacement of failing components. This type of maintenance is only carried out when the equipment is incapable of further operation and is therefore it can not be planned. It must be carried out as quickly as possible to avoid costs, damage and/or contamination, so it can be considered as emergency maintenance, which has the disadvantages that it involves costs that cannot be accurately predicted, cannot prevent breakdowns and requires a bulky stock of spare parts, which suppose a significant cost for the company.
Preventive.	A set of maintenance activities aimed at finding and correcting the causes of failures before they occur. This type of maintenance aims to reduce corrective maintenance activities, and therefore their costs, through a routine of periodic inspections accompanied by the replacement of elements that may cause breakdowns. Preventive maintenance activities are carried out according to a set schedule called a "maintenance programme". This plan indicates the checks to be carried out on each piece of equipment and the frequency they should be carried out. It has the advantages of better maintenance of industrial installations, reducing the number and cost of repairs, increasing the quality of production and improving the safety and environmental protection conditions of the industrial plant.
Predictive.	A set of maintenance activities aimed at predicting the likely point of failure of machines in order to act on them before they fail. It is based on a thorough knowledge of the operation and condition of machines, equipment and industrial installations. This knowledge is obtained from the collection of a large amount of data that is processed and the information is obtained is used to anticipate failures. If this information is available, maintenance activities can be scheduled that do not affect the production process, thus optimising production, labour and spare parts costs. This avoids major and costly breakdowns and speeds up interventions.

Table 6.1 Types of maintenance.

In a similar but more elaborate line, is the classification of maintenance types described in the **UNE-EN 13306 standard: 2018 "Maintenance. Maintenance terminology."** [2] [84]. This standard classifies the types of maintenance according to two general scenarios or conditions: whether or not the maintenance activities modify the intrinsic design features of the machine, equipment or installation being maintained, without changing its original function, or whether it is possible to schedule the execution of the maintenance activities in advance.

- In the **first scenario** (Figure 6.2) **maintenance activities which do not change the characteristics of machines and equipment** can be subdivided according to whether they take place before malfunctions occur or afterwards. On the other hand, activities that change characteristics without changing the function are considered improvement maintenance activities. The concept of **improvement maintenance type** is applicable when maintenance is aimed at creating a positive change in one of the characteristics defined in the design of the equipment, but does not change its original functions.

Preventive maintenance is subdivided according to whether degradation of equipment characteristics is observed or not. In the first case, when degradation occurs, it is referred to as "**condition-based maintenance**" and if no degradation is observed, it is referred to as "**default maintenance**".

Condition-based maintenance is a type of preventive maintenance that includes the assessment of physical conditions, analysis and possible subsequent actions. It refers to the assessment of the condition of the equipment, machine or installation, which may be carried out by an operator or a team of operators, by observation, testing or monitoring of the system's operating parameters. This activity can be scheduled in advance, or can be carried out on request.

"Predictive maintenance" is defined in this standard as condition-based maintenance, i.e. based on the prediction obtained from the results of the assessment described above.

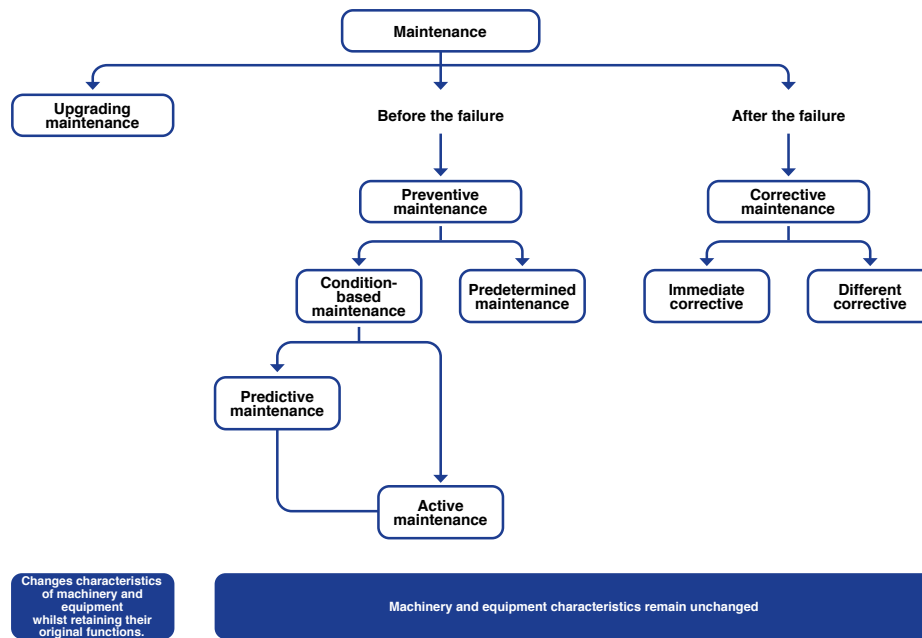


Figure 6.2. Types of maintenance depending on whether the specific characteristics of machines and equipment are modified or not (Standard UNE-EN 13306: 2018).

"Active maintenance" may form part of both preventive and corrective maintenance and is defined as the set of activities carried out directly on a machine or equipment to maintain or restore its operating condition so it can perform the required function.

- The **second scenario** contemplated by the UNE-EN 13306 standard: 2018 refers to the **possibility to schedule maintenance**, i.e. the possibility to allocate dates and resources for the execution of maintenance activities in advance. It divides maintenance into "scheduled maintenance" and "unscheduled maintenance" (Figure 6.3).

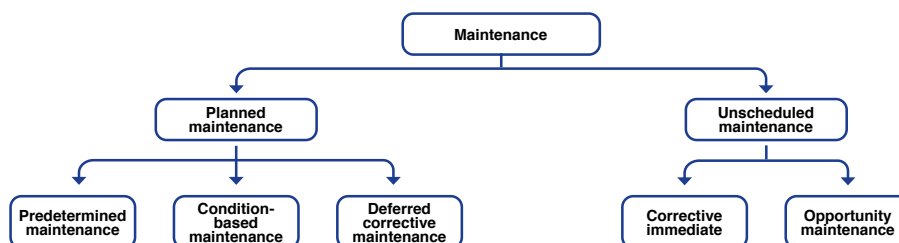


Figure 6.3 Types of maintenance according to whether or not scheduling is possible (Standard UNE-EN 13306: 2018).

Unscheduled maintenance is subdivided according to this standard into “prompt corrective maintenance” and “opportunity maintenance”. The former refers to activities that are executed without delay after a machine failure in order to counteract its consequences and the latter refers to the set of unscheduled maintenance activities that can be qualified as preventive and/or deferred corrective maintenance.

Scheduled maintenance is subdivided into:

- **Default maintenance:** cyclical preventive maintenance without prior assessment of the equipment to be maintained.
- **Condition-based maintenance:** preventive maintenance based on a prior assessment, or prediction, of the condition of the equipment to be maintained.
- **Deferred corrective maintenance:** corrective maintenance which is not carried out immediately after detection of the failure and is scheduled to be carried out according to established criteria.

A complementary criterion to the above types is to divide maintenance activities according to their degree of complexity, i.e. according to the set of competencies required for their performance, the training required and the degree of complexity of the operations performed, as described in AFNOR NF X 60-000 (2016) ^[3] (Table 6.2).

Level of maintenance.	Main tasks	Examples
First level.	They are a set of simple actions foreseen by the manufacturer on accessible elements, which do not require complicated assembly and disassembly. Lightweight tools are always used. They do not pose a particular safety risk if the essential instructions are available.	• Cleaning of punches and moulds. • Vacuum cleaning of the mould.
Second level.	Repairs by replacement of parts in accordance with the established procedure, which do not require the complete disassembly of the equipment. They must be carried out by a qualified technician who has received safety and risk training.	• Repair of terminals and electrical connections of the mould, located in view.
Third level.	Fault identification and diagnosis. Repairs due to change of functional elements. Complex interventions preceded by diagnosis and identification. They can be carried out on site or in a maintenance workshop, and must take into account the equipment as a whole, as the modification of one element may have consequences on its overall functioning. They must be carried out by specialised technicians using the tools specified in the maintenance instructions for the machine.	• Change of fixed liners. • Change of removable liners. • Replacement of the wear resistant plate. • Removal of punches. • Installation of punches.
Fourth level.	Complex operations requiring specific technical knowledge. They must be carried out by a specialised technician or a team of technicians with a specific qualification, under the supervision of a specialised manager. Major preventive maintenance operations.	• Assembly or disassembly of the mould.
Fifth level.	Complex actions carried out by the equipment manufacturer or by a company authorised by the equipment manufacturer itself. It comprises actions similar to those carried out in the equipment manufacturing process. Refurbishment or rebuilding work, which is carried out by the equipment manufacturer itself.	• Mould rectifying.

Table 6.2. Levels of maintenance according to their degree of complexity.

6.2. GENERAL MAINTENANCE AND CONSERVATION PROCEDURES FOR MOULDS.

In order to describe the general maintenance and conservation procedures for moulds, it is necessary to distinguish between the complete mould and its replacement components, such as liners (if removable), upper and lower punches, and other elements, such as coupling supplements, wear plates, connectors, etc.

6.2.1. Storage and preservation of moulds and components.

We will distinguish between two possible cases: when the mould arrives at the tile manufacturing company and when a mould that has been working is replaced, either because of a problem that requires its transfer or to store it and replace it with another one.

When the mould arrives at the industrial facility, it may be installed in the press immediately or it may be stored for later installation. In the latter case, the mould must be unpacked and placed in a place suitable for its preservation⁵⁹

The **moulds** should be stored on shelves in covered, dry, dust-free and easily accessible spaces (Figure 6.4 and 6.5). They should never be deposited directly on the ground, nor in close proximity to areas with high humidity or high ambient temperatures, such as kilns or drying rooms. Ideally, the warehouse should be located close to the press section but isolated from dust. It is completely inadvisable to deposit the mould in the same press section without insulation and protection, as the dust generated there can penetrate through the same venting holes of the mould.

For proper preservation, the mould must be protected with a thin film of a suitable lubricant to prevent oxidation, covering the surface of the die box and the liners.

With regard to consumables or additional mould elements such as liners, punches, coupling supplements, etc., the same criteria can be applied in terms of location, although it is advisable to have identification, location and traceability procedures in order to quickly and accurately identify the location of all the components. In this sense, some companies already have smart warehouses for their spare parts.

It should be borne in mind that the liners and punches are the components of the mould that form the tile and therefore require the greatest precision in their manufacture and special attention to their storage and conservation conditions.



Figure 6.4. Storage and movement of moulds and components.

⁵⁹ As will be seen in this chapter, the moulds destined for export are placed in wooden boxes and those destined for companies in the Spanish ceramics sector, due to their proximity, are placed on pallets and suitably packed.

Both upper and lower punches, are usually rubber coated, so they must be carefully cleaned with a sponge dipped in water, and care should be taken to ensure that the steel is completely dry. Then, if possible, it should be lubricated with a suitable lubricant. They shall be stored flat (Figure 6.5), in a place away from direct light, in a dry environment or with as little humidity as possible, and protect the rubber side if other punches are placed on top of them, in order to avoid marking. If possible, it is recommended never to store punches on top of each other or vertically. The storage of the punches must be very careful, as even those that have never been used, can see the rubber deteriorate if they remain stored for a long period of time, as it loses properties with prolonged exposure to the environment (light, heat, dust, humidity) and, therefore, the punches are no longer suitable for work and must be gummed again in order to be used. It is also important to note the number of strokes made by the punches that have already been used.



Figure 6.5. Punch storage facilities.

When the number of punches to be stored is very high, which is not uncommon in many companies in the sector, storage modules are an optimal solution that has already been adopted by some companies (Figure 6.6). The **storage modules** are computerised storage devices with trays arranged in a tower that allow flexible and intelligent storage.

On the other hand, when a mould is replaced, a series of guidelines must be followed to ensure the correct preservation of its components. In this case it is advisable to remove the punches and store them separately. Once the mould has the punches removed, it is necessary to **revise** some of its **components** in order to ensure an optimum performance in the next start-up:

- The **bellows** should be checked for damage or holes. For this purpose, it must be cleaned of dirt to facilitate visual access to it, and in addition, if the bellows is made of leather, a protective grease (such as horse grease) can be applied before storage. If the bellows is made of elastomer, its general condition is visually checked. An indication that the elastomer bellows is in the correct condition is the uniformity of its colour.



Figure 6.6. Storage module.

- **Liners** are also checked, first of all for cracks. They are also checked for wear. These checks are initially made visually and by touch, although it is useful to know the number of strokes of the mould, as indicated above.
- The surface of the **die box** must also be checked for wear. If it is protected by a wear resistant plate, its wear condition caused by the passage of the feeding car must be checked.
- All the electrical wiring is also checked, as well as the electrical elements of the mould, such as the magnetic blocks coils and resistors and the die box resistors. Check that all wiring is securely fastened and that there are no loose wires. In these cases they should be checked they are all in perfect condition and, failing this, either replaced or sent to the workshop for repair if necessary.

6.2.2. Mould cleaning procedures.

Cleaning the mould or any of its components after the mould has been disassembled and cleaning of its components when the mould is installed and stopped are two completely different procedures.

In the first case, the mould is cleaned before maintenance activities are carried out or before storing it, while in the second case, cleaning is a complementary activity to the maintenance activities that are carried out when the mould is stopped, such as the changing of removable liners.

As a general rule, it should be taken into account that, for reasons of hygiene, manual cleaning by blowing should always be avoided if correct dust extraction cannot be guaranteed, so the cleaning of the mould, both when stopped or when the mould is disassembled, is carried out by suction, using the appropriate personal protective equipment (PPE).

When the mould is working, dirt and dust in general, and especially the accumulation of powder between the die box cavity and the ejector plate, must be avoided. The procedure for cleaning this area, while the mould is working, varies according to the manufacturer. MACER has incorporated specific blowers in its moulds that work with compressed air and are installed in the ejector plate or in the punch holder plate if there is one, as described in Chapter 3. The assembly is completed by a suction system at the rear of the mould. When a blower and suction system is installed in the mould, it is very convenient to close the mould on three sides to optimise the suction. The blowing-suction system in closed moulds is effective if there is sufficient suction, but this cannot always be guaranteed. If the vacuum system of the plant is used for this purpose, it can be effective when there are very few presses installed, but is insufficient when there are many. It is advisable in this case for the press manufacturers to install individual vacuum systems for each of the presses.

On the other hand, manual cleaning of this area with the mould stopped or disassembled can be difficult. Generally, the dust is vacuumed by means of a Hoover with a suitable nozzle to reach all corners. It is important to protect this nozzle to avoid damaging the bellows during the cleaning process. In general, manual cleaning of the back of the mould, when it is mounted in press and stopped, is more complicated due to the inaccessibility of this area. This cleaning could still be done with difficulty on small presses equipped with traditional feeding cars, but actual ones prevent access to the back of the mould without removing the feeding car, so regular maintenance cleaning must be scheduled where the feeding car is removed and the area is vacuum cleaned.

In presses equipped with SACMI's quick mould changeover, the rear part is closed and equipped with a suction system that allows the cleaning of this area of the mould while the press is operative.

6.3. COMPONENT REPAIR OR REPLACEMENT PROCESSES.

The main repair or component replacement processes in the moulds are the replacement of liners, both fixed and removable, and the replacement of punches. Other less frequent activities that are worth mentioning are the replacement of the wear resistant plate or the revision of electrical connections.

6.3.1. Replacement of fixed liners.

The liners used in the moulds for pressing ceramic tiles can be divided into two main groups, as seen in Chapter 3, according to the way they are installed in the frame box: the **fixed liners** and the **removable liners** (Table 3.5).

For a long time, fixed liners were the only type of liners available until MACER introduced removable liners ^[71] in the sector in 2003.

They are called "fixed liners" because they are mounted and adjusted inside the die box in the mould workshop, and therefore cannot be disassembled in the press, nor in the plant, and the mould must be transferred back to a mould workshop for disassembly and replacement. In a highly concentrated industrial sector such as the Spanish ceramics sector, this operation is feasible due to the short distances between manufacturing and auxiliary companies, although it is also costly, as it requires the removal and transport of the mould. On the other hand, in widely dispersed sectors, as for example in Latin American countries, this substitution requires the company to have qualified personnel for this purpose, as well as access to the necessary technological means.

The liners must be replaced when they have suffered excessive wear that can no longer be compensated by the mould heating system and therefore lead to pressing defects, as will be seen in Chapter 7. Worn liners can be removed and ground a certain number of times, at most until they have lost 2 to 3 millimetres of thickness due to wear. In the mould workshop, the faces will be ground and then the profile will be machined, providing them with the necessary spacer and taper.

To change the liners in the mould workshop, the die box must be removed from the mould. The short liners are extracted with the aid of socket set screws, located into horizontal holes, which are tightened against the die box pushing the liner out of its housing. When the short liners are removed, the long liners, which are held in place by the short ones, are released. Next, once the liners have been

disassembled, they are rough rectified and prepared for the next rectifying process for the taper and spacer, and then reassembled and fitted back into the die box. Since the liners have lost thickness due to wear during the grinding process, they must be supplemented with foils on the die box contact faces until the required cavity dimensions are achieved.

The liners are fastened into the housing machined in the die box, by means of screws in horizontal holes, and/or by means of holes at the tops of the long liners, and sometimes of the short ones, depending on the format. This assembly is done by hand and requires great precision.

The central liners, i.e. the liners that separate the cavities when, due to lack of space, no partition walls are machined between the cavities, cannot be rectified and must always be installed new, because if they are ground, the liners on the opposite side must be supplemented to maintain the dimensions of the format and, therefore, the centres of the cavities are lost, which causes the punches to be off-centred.

6.3.2. Replacement of removable liners.

There may be different cases where a change of removable liners is required:

- *Format changes in multi-format moulds.* For this type of moulds, there are as many different types of liners available as there are mould formats or shapes, so when a change of format or shape has to be made, the liners must be changed accordingly. If the replaced liners are still suitable for production, they should be reserved for future production.
- *Replacement of removable liners when the mould is not multiformat.* In this case, the liners are replaced when they reach the end of their life cycle, either due to wear or possible breakage, in which case they must also be removed and replaced with new ones. In any case, it is always preferable to make this change on the press itself, as it will facilitate replacement operations.

The removable liners are designed to be removed in the factory, either inside or outside the press, without the need to take the mould to the workshop, as is required with fixed or conventional liners. In both cases, when the liners must be removed from the mould, it is preferable to do so with the mould mounted in the press, as we can use the press's extraction mechanism to remove the liners more easily than if the mould is removed and therefore located outside the press.

6.3.2.1. Removable liner change on the press itself.

The liners are changed with the mould installed on the press itself. For this case, the following guideline is followed:

1. The mould must be completely clean to change the liners, so it must be thoroughly vacuumed, especially in the space between the magnetic blocks where dust may accumulate. Each liner is cleaned, especially the upper part, to leave in sight the screws that hold it to the die box.
2. Unscrew each of the mentioned screws in the previous point, leaving the liner freed in order to continue with the next step.

3. The liners are then removed using suitable extractors (Figure 6.7). The extractors are positioned so that their tops are placed in the space between the bottom of the liner and the inner gap of the die box machined beneath the liner housing. The middle part of the extractors is placed on top of the lower magnetic block. Having positioned the extractors, and with the press in manual mode, the ejecting plate and magnetic blocks assembly is raised, which causes these extractors to push the liner out of its housing (Figure 6.8). Note that we are talking about multiple extractors and not just one, as we must use at least 2 units per cavity to be able to carry out an effective manoeuvre.



Figure 6.7. Liner extractors.



Figure 6.8. Extraction of removable liners.

4. Once the liner to be removed is out of the die box, the entire housing is cleaned to make it ready for installation of the new liner.
5. With the help of the same extractors used to remove the previous liner, the new one is slid inside its housing into the die box and with the downwards movement of the ejecting plate, the liner fits perfectly into the gap.
6. The liners are then tightened with screws in good condition; if necessary, new ones are installed, since a screw in poor condition can cause delays in the future removing process.

When performing this process is of great importance to do it carefully, especially when inserting the new liner into the die box, as there is little room for manoeuvre this can cause the liner to get stuck if its position is not parallel, and if it is forced, it can damage the housing where the liner is installed.

It is advisable to keep the die box heated so that the gap expands, as the liner to be mounted will be cooler and therefore a little smaller than when it reaches the same temperature as the die box, thus obtaining a clearance that facilitates its assembly.

6.3.2.2. Removable liner change out of the press.

In case of having to remove the liners outside the press, the method is different as it does not have the support offered by the press and therefore is not possible to use extracting elements. In these cases the procedure to be followed is:

1. Since the mould is not installed in the press, it is assumed that it has already been vacuumed and is clean, as required for any maintenance operation. In any case its state of cleanliness is checked and if necessary, as in the previous case, each liner is cleaned, especially its upper

part, in order to leave in sight the screws that hold it to the die box.

2. Unscrew each of the screws mentioned in the previous point, leaving the liner freed in order to continue with the next step.
3. The removable liners are designed with threaded holes for grub screws installed only for the liner removal only. These elements are threaded in such a way that when tightened they will come out through the lower part of the liner pushing against the base of the housing. Once the grub screw makes contact with the die box, the liner starts to rise from its housing. Special care must be taken in this operation, as several grub screws must be adjusted during this operation, they must be tightened at equal intervals in order to pull the liners out in parallel position, otherwise the liner may get stuck in its housing.
4. Once the liner to be removed is out of the die box, the entire liner housing is cleaned to make it ready for the new liner to be installed.
5. Since, as mentioned above, these operations are being carried out outside the press, there is no mechanical assistance from the press, so installing the new liners requires the operator to have a great expertise since the liner has to be fit inside its housing manually (Figure 6.9). This operation can be simple for small formats, but for the larger liners, the grub screws must be used to support the liners and must be untighten with the Allen key at equal intervals allowing the liner to descend into its housing , i.e. the reverse movement as explained in point 3, where their removal was described.
6. Lastly, the liners are screwed on. It is very important to use screws that are in perfect condition, since a screw in poor condition can cause delays in the disassembling process in the future. It is advisable to always use new bolts when the change is necessary.



Figure 6.9. Removable liner change out of the press.

6.3.3. Extraction and installation of punches.

When changing punches, we will find different possibilities, as it will depend on the type of mould, the format in question, or the position of the punches, which can be upper relief punches or upper back side punches, as well as lower relief or back side punches.

Assembly of punches.

Regardless of the type of mould, **lower punches** are always inserted into the mould in the same way, i.e. by sliding them into the cavity. To make this operation easier, the ejecting plate and the magnetic blocks are raised to receive the punch about 3 or 4 mm from the edge to make its attachment easier.

Assembling upper punches is different and its operating procedure depends on the type of mould:

- In **mirror moulds** the upper punch has a guiding system with the plate or the die box, which facilitates centring.
- The assembly and centring on **entry moulds** is done with the lower punch mounted, since a support will be placed on it. This, if possible, will be a type of rigid elastomer, which does not damage the rubber of either of the two punches, as the upper punch will be placed on top of this support. The support shall have the thickness of the part to be pressed with a margin of 1 mm above or below. This way we will have the upper punch at its working position level, and it is there where we must align it with the liners. For this centring, metal or paper sheets are used, which are inserted in the gap between the punch and the liners. As the adjustment at this point is between 2 and 3 tenths of a mm, these sheets allow us to adjust the centring position.
- In **entry mirror moulds** the operating procedure is the same as that described for the entry mould, with the difference that the support used must be twice as thick as the part to be formed. Otherwise, we can damage the liners when installing or removing the upper punches, because their position would be below the spacer (if it has one) and/or the angle.
- The operating procedure in **double moulds** is similar to the previous ones, with some minor differences. The lower punches are mounted in exactly the same way as they are mounted in entry moulds. With the upper punch, a similar procedure is followed as in these moulds, taking into account that the movement of the plunger and the upper plate is accompanied by lowering of the die box until it stops. In this type of mould, the upper die box facilitates the centring of the punch, so it is not necessary to carry out the centring operations described for the entry mould.

The operations described above are relatively simple when carried out with punches of small weights and sizes, as they are easy to handle. However, as the size and therefore weight increase, the task becomes more difficult and may even pose a risk to the safety and integrity of the operator. It has already been seen in Chapter 3 that in order to facilitate these operations, the large-format magnetic blocks are equipped with anchored pistons which allow the punch to be raised to a level above of the die box to facilitate the installation and removal of the punch which is moved by means of a sliding system (Figures 6.10 and 6.11 and Link 6.1).



Figure 6.10. Punch sliding system

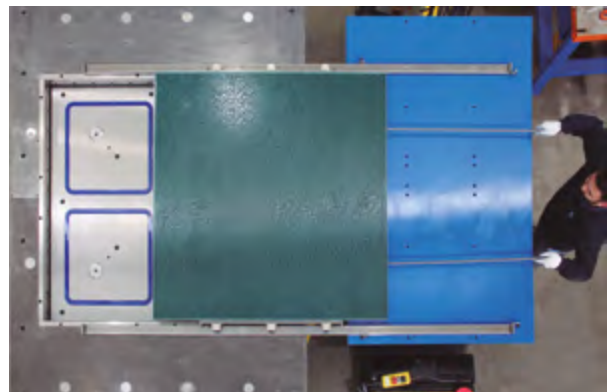


Figure 6.11. Installing of a large-format punch.



In the attached QR code you have a link to a video where you can see the procedure for moving and installing a lower punch in a large-format penetrating mold. Link 6.1

All these operations must be carried out by appropriately trained staff and respecting all established safety instructions. From 25 kg onwards, all loads (punches, plates, etc.) are lifted with the aid of hoists or other mechanical aids (Figure 6.12), and the transport and movements for the installation of the punches must be carried out with the punch holder trolley. This is hydraulic either manual (Figure 6.13) or electric operated (Figure 6.14).



Figure 6.12. Lifting and handling of large loads with the aid of hoists and magnets.



Figure 6.13. Manual hydraulic trolley for changing punches.



Figure 6.14. Manual hydraulic trolley for changing punches.

6.4. THE PROCESS OF CHANGING MOULDS.

The process of replacing a mould in the press involves the removal of the active mould and the installation of a new one. It is a complex operation that must be carried out by properly trained personnel following a strict protocol and respecting all safety and environmental protection specifications.

Replacing a mould installed in a press must be carried out when, due to production requirements, a change of format must be made; due to wear or due to some kind of mould failure, such as a bellows breakage, etc. Less frequently, there may also be some circumstantial situations that require a change of mould, such as serious failures in a press that force us to change the mould to another one, etc.

Mould change consists of a series of operations common to all types of moulds and presses, with some important variations in the procedure depending mainly on the type of press and, to a lesser extent, the type of mould.

Mould changes can be done with the help of a forklift truck or using a specific cart for mould changes, as shown in Figure 6.15.

Depending on the type of press and the press installation itself, the mould can be changed by operating from the front or the rear side of the press. Most modern presses are equipped with removable feeder cars which allow the mould to be changed easily from the rear side by previously removing the feeder car.

In general, in all presses equipped with a traditional extraction system with pistons and candles, the mould is changed from the front side, and therefore in all older SACMI presses up to the PH 1400 press⁶⁰ the mould is changed this way, previously removing the roller assembly. In all presses equipped with quick changeover system, such as the latest generation of SACMI presses, like the PH10000, the mould is changed from the front side. This is because all of them are now equipped with this device, as there are new elements that allow this, such as new mould change carts, in addition to the already mentioned quick changeover moulds.

Most modern SITI B&T presses allow mould change from the rear side of the press. All SACMI 2000 series presses, up to the PH 3590, also had the mould replaced from the rear side, while the new generation of lower tonnage presses, also from SACMI, switched back to changing the mold from the front side.

Changing moulds from the rear side usually makes replacement operations convenient as there is usually more room to manoeuvre, although this is not always the case, especially in older installations. Of course, this operation requires the removal of the feeder car, as mentioned above, which is often used for maintenance activities such as cleaning, replacement of worn parts, bearing checks, etc.

Regarding the type of mould, there are no differences in the operating procedure of changing between entry, mirror and entry mirror moulds. The procedure is different for the double mould.



Figure 6.15. Transport of the mould for installation or replacement.

⁶⁰ These presses are known in the ceramics industry as "green presses".

First of all, the mould ejecting plate must be **uncoupled from the press loading and extraction system**. This procedure varies depending on the type of extraction system installed, which, as is known, in today's presses is different depending on the manufacturer:

- SACMI currently equips its presses with the SPE® system, where the movements of the ejecting plate - "blocks" assembly is achieved by four synchronised pistons, which are capable of performing up to five plate drops. In this system, the anchoring is done with ring candles as shown in figure 3.7.
- For their part, the SITI B&T presses have the SYNCRO® or E-SYNCRO® systems consisting of a central piston that moves the punch holder plate in the downward direction, and four hydraulic cylinders that carry out the upward movement and accompany the downward movement. Ball joint bearings as shown in Figure 3.9 are used for anchoring.
- In addition to these systems, many presses are equipped with traditional piston and candle loading and extraction equipment, where the anchoring is done by means of a swing plate. There are also presses equipped with SACMI's old SMU® system, where the only thing that needs to be done is to unscrew the bolts that join the bench plate to the press bed, as in this equipment, the hydraulic extraction system is incorporated into the mould.

After deanchoring, all electrical connections are disconnected and the screws that connect the bench plate to the press are unscrewed, except in the case of quick changeover moulds, which do not have these screws. Once removed, the threads should be checked with a tap and if the threads are in good condition, the screws are cleaned and can be used again, unless a thread defect is observed or they do not screw in properly. In this case they must be replaced.

6.4.1. Changing entry, mirror and mirror-entry moulds.

The disassembly and sequence of operations on these moulds may vary depending on whether the moulds are equipped with a fixed top plate or an isostatic one.

Generally, **the lower part of the mould is removed first**, which allows sufficient space to lower the upper plate, isostatic or fixed, with the press in manual mode, onto a pallet and then remove it with the help of a forklift truck.

- If the mould is equipped with a **fixed top plate** and its dimensions are compatible with the new mould to be installed, it is recommended to leave it mounted. Some companies choose to install large fixed magnet plates on their presses, compatible with any format to be produced, and never change them. Although it is a time-saving solution for mould change, it is possible that in some formats strokes per minute may be lost with this solution, because the size of the plate limits the position of the feeder car when it is in the back position in the pressing cycle. Very large plates force the feeder car to start from a position further away from the cavities and therefore increase the time spent loading the cavities during the pressing cycle, with a consequent loss of press output.
- On the other hand, if the removed mould had an **isostatic top plate**, it will be incompatible with the new mould and must be removed also, following the procedure described above.

For the **assembly of the mould**, the following procedure is used:

- If you want to mount a **mould with a fixed top plate**, the top plate can be installed first and does not need to be perfectly centred, as the upper punches will need to be centred. The lower part of the mould is then installed, centring the upper punches according to the procedure described above.
- If you intend to install a **mould with an isostatic top plate**, install this first, but do not tighten it completely as, unlike the fixed top plate, this plate must be correctly centred. The lower mould is then installed and the upper punches and the plate are centred on the lower mould. In this regard, it should be noted that most modern isostatic plates are equipped with centring devices to facilitate this operation. This centring is done by lowering the plunger and adjusting the punch inside the cavity with the help of the centring devices previously mentioned. After centring, the final tightening of the plate is carried out.

6.4.2. Changing double moulds.

The procedure for changing the upper forming mould or double mould also varies according to the press manufacturer. The process requires first the removal of the installed mould and then set up the new one.

6.4.2.1. Dismantling process of the mould installed in the press.

The general procedure for the removal of a mould installed in the press is to remove first the lower part of the mould and then the upper part. Of course, it is possible to do it the other way round, but the procedure described above is preferable because removing the lower part first creates a large space in the press and makes it easier to remove the upper part.

In SITI B&T presses, it is possible to remove the mould entirely, with the upper part fitted to the lower part, with the lower punches having a protective layer to prevent their deterioration, although it should be borne in mind that this is not advisable if the intention is to check the inner parts of the mould, as it is not possible to do so. This is not easy to do with very large moulds, as the entire mould is much heavier and forklift trucks capable of lifting such weight are not always available.

6.4.2.2. Process of assembling the new mould.

The process again shows some differences depending on the press manufacturer, due to the different loading and extraction systems installed in the press.

To assemble the double mould of the SACMI presses, the lower part of the mould is installed first⁶¹ and then the upper part is mounted.

⁶¹ Although this is the recommended procedure, it is also possible to assemble the new mould by installing the lower part first and then the upper part.

To install the lower part of the mould, the SPE system must be anchored to the ejector plate. To perform this operation, the ejector plate must be immobilised. For this purpose pressure is applied on the lower part of the mould with the help of specific pressure elements provided by the press manufacturer, exerting pressure on these through the downwards movement of the plunger of the press, set in the manual mode, which allows the ring candle to be tightened.

The upper part of the mould is then installed by the screwing the bolts to the plunger, but without being fully tightened as is done with other types of moulds equipped with an isostatic top plate.

With the lower mould anchored and tightened, the mould is centred.

To carry out the **centring operation of the double mould**, the retaining screws of the upper part of the mould have to be loosen and the centring balls are installed inside the bushings machined on top of the lower part. These balls are part of the centring system MACER equips its top-forming moulds and has been described in section 5.5.7.

With the press in manual mode, the plunger is lowered, until the upper die box rests on top of the balls previously installed on the lower die box. Since the upper part has been previously loosened, the steel balls ensure the centring of the two parts, as mentioned above. This manoeuvre is repeated two or three times until it is certain that the centring is perfect and at this point, with the plunger lowered and the upper die box resting on the centring balls, at least four of the retaining screws of the upper part of the mould are tightened and the plunger can be raised. Finally, the remaining screws are tightened and the balls are removed.

The installation of the upper forming moulds on the **SITI B&T presses** follows similar operations, although to anchor the SYNCRO loading and extraction system to the mould it is not necessary to exert pressure on the lower part of the mould, as described for the SACMI presses.

In these presses, the upper part of the mould is first installed and left loosen at a distance of one to two millimetres from the mobile plunger. The lower part is then mounted, so the SYNCRO system must be anchored with the ball joint bearings already described in section 3.2. This part of the mould is now rigidly fastened to the press bench with the corresponding fastening screws. The mould is then centred following the procedure described above and the upper mould is tightened.

6.5. Packing and transport of moulds.

In both packaging and transport, a distinction must be made between moulds or mould components that are moved over short distances (local transport) and moulds destined for export.

6.5.1. Local transport.

The Spanish ceramic tile manufacturing sector is highly concentrated geographically. In the province of Castellón, 94 % of the total production of the sector is produced and 80 % of the companies are located here, mainly in the area delimited by L'Alcora, Onda, Nules and Castellón ^[20]. Thus, most of the distances between companies are very short and communications are excellent, so that the transport of moulds can easily be carried out by road with the mould manufacturing company's own means (Figure 6.16).

When a mould is transported between companies in the sector, it is placed, lubricated, on a pallet with dimensions appropriate to the size of the mould and covered with a heat shrinking plastic bag. On arrival at its destination, the mould is unloaded with a suitable forklift and if not immediately assembled, it is stored on suitable racks as it is received. Appropriate storage and preservation conditions have been described in section 6.2.1 of this chapter.

When punches are moved locally, they are also deposited on pallets, horizontally and if it is necessary to deposit them in stacks, they are adequately protected to avoid damage during transport.



Figure 6.16. Truck loading for local transport of moulds.

6.5.2. Export.

All moulds or components intended for export must be packed and placed in wooden boxes (Figures 6.17, 6.18 and 6.19). The box is made specifically for each mould and is designed with the exact dimensions calculated for the mould fits perfectly and does not move inside. Where necessary, wooden stops are placed inside to ensure that the load is completely immobilised.

For punches or liners, the box must also be manufactured specifically for this purpose and its dimensions are exactly calculated. For this purpose, MACER has a calculation programme to optimise the design of the boxes according to the elements to be packed, their dimensions and quantity.



Figure 6.17. Packaging of a mould for export.

Moulds are always exported in wooden boxes. Micro-organisms can live and thrive inside the wood and could cause pests or health problems, so there are international regulations for the treatment of wood packaging material for exportation.

The FAO (Food and Agriculture Organisation of the United Nations) developed in 2002 a regulation for wood packaging material used in international trade, for all types of commodities, and the International Standards for Phytosanitary Measures (ISPM 15 or ISPM 15) ^[65] was created. According to this regulation, the wood used in these boxes must be treated by conventional heat treatment at 56°C for 30 minutes in a kiln, or by methyl bromide treatment. New regulations published subsequently provide other types of treatment. The wood used for packaging must be debarked and free of holes of more than 3 mm in diameter. Chipboard, processed wood fibre, veneer of less than 6 mm thickness and plywood are exempted from treatment.

The moulds, or their components, are plastic coated before being placed inside the boxes to ensure protection against possible water infiltration.

Transport to America, Asia, Africa or Australia is by ship and to European countries by road.



Figure 6.18. Box of a mould for export.



Figure 6.19. Loading of moulds for export.

Mould-related pressing defects.

Chapter 7



In the previous book published by Macer, "Presses, Moulds and Pressing" ^[49] the reader has a comprehensive overview of pressing defects, their identification, evaluation, causes and possible solutions. This text studies the pressing operation as a whole and describes in detail the defects which origin is to be found in this operation, considering all the process variables related to the input product, generally atomised powder, the press variables and those of the output product, i.e. row tiles. Defects are also described which, having their origin in the pressing operation, manifest themselves in other manufacturing operations or concern the quality of the finished product. In this new text that the reader has in his hands, dedicated to the mould for tile pressing, this Chapter is partially extended by focusing exclusively on those defects or non-conformities in the pressing operation that are, in one way or another, caused or conditioned by the mould, relating them to the design parameters of the mould, to its components and to its manufacturing and assembly process.



Figure 7.1. Selection of tiles.

7.1. METHODOLOGY FOR THE ANALYSIS OF MANUFACTURING DEFECTS.

A defect can be defined as a lack of qualities of a product with respect to a pattern or standard adopted as a reference ^[66]. The production of defective parts entails a significant cost, which has an impact on the price of the product and therefore on the competitiveness of the company.

It is unquestionable that daily work in production requires making quick decisions and solving problems, such as the occurrence of manufacturing defects, as efficiently and as quickly as possible. However, this is not possible without a substantial theoretical and practical background.

The solution of manufacturing defects is one of the tasks that require an in-depth knowledge of the production process, as it involves identifying defects and assessing their severity; analysing their possible causes, which are often interrelated; and finally, proposing and carrying out corrective or preventive activities and monitoring them.

The systematic study of manufacturing defects should include the assessment of their severity, their nature and cause(s). It must clearly identify how the defect manifests itself and in what way the technical and/or aesthetic properties of the tile are altered and, of course, propose possible solutions with the available equipment, facilities and resources. The diagram in Figure 7.2 summarises a methodology for the study and solution of a given defect, applicable to the identification and correction of pressing defects, especially those related to the mould. This methodology should be interpreted as a way of organise knowledge about a problem and acting accordingly.

1. When a manufacturing defect appears, it must be **identified** clearly and all information about it must be **collected**. In this sense, it is very useful to create and maintain a database where graphical and technical information on manufacturing defects is collected. It is therefore advisable to take photographs and to write down all relevant data, corrective actions taken and results obtained, etc. for future reference when the problem arises again.
2. The severity of **the defect must be quantified**. It is convenient to identify for each defect, its frequency, i.e. the **frequency**, how often the defect appears, its **amplitude**, or incidence of the defect and its **intensity**, which can be estimated as the loss of value of the pressed tile. This study must be complemented with preventive control methodologies for the variables related to the main defects or non-conformities in the process.
3. **Identifying the probable cause(s)** of the defect. This may require some testing or the ruling out of possible causes based on some manufacturing evidence. In cases where the severity of the defect makes it advisable, a more in-depth study of the causes may be carried out, requiring more complex tests and even reproduction on a laboratory or industrial scale.
4. Once the cause of the defect has been identified, **possible solutions are proposed**, which should be twofold; on one hand, the solution of the defects detected in production and, on the other hand, the establishment of preventive measures to avoid or at least minimise the risk of the defect reappearing or to reduce its consequences.
5. The outcome of this process is therefore twofold. On one hand, the adoption of corrective measures and, on the other, preventive measures. Naturally, this requires the monitoring of all these measures and the evaluation of the results obtained. If the results are not positive, the process must be restarted, either in identifying the causes or in proposing new solutions. If the result is positive, the preventive measures taken should be maintained over time.

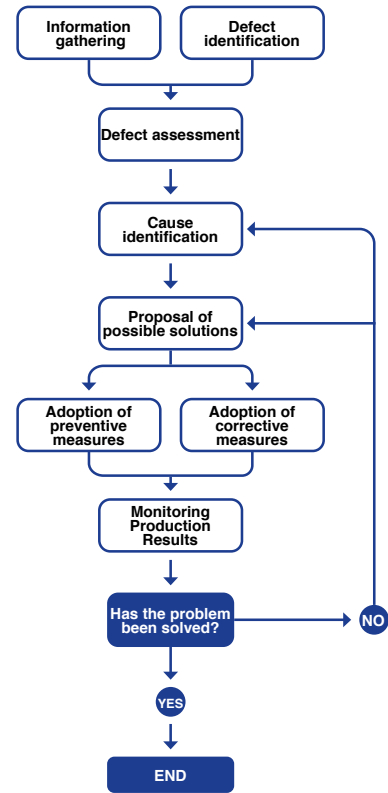


Figure 7.2. Methodology for the analysis of manufacturing defects.

7.2. DEFECT CLASSIFICATION CRITERIA. PRESSING DEFECTS.

In the ceramics industry, defects are usually classified according to different criteria, such as their physical appearance, cause, stage of the manufacturing process where the failure occurs, etc. For practical purposes, it is quite common to use the criterion of classifying defects according to the stage of the production process when they are generated. This criterion is frequently used in the literature, although not exclusively [9][21][22][53][61][62][66], and logically, it requires the exact location of the cause of the defect, which in some cases may be somewhat difficult, since a defect is often not due to a single cause, but to a coincidence of factors that lead to the appearance of the defect. In this chapter, a mixed approach has been adopted for the classification of defects or non-conformities related to the pressing operation, combining the criteria of the cause of the defect with those of the physical appearance of the defect (Table 7.1). Defects directly related to the mould have been highlighted in this table.

Defects caused by poor powder loading or lack of parallelism between the punches.	Rectangularity defects.
	Crescents.
	Wedging.
	Waves and load marks.
	Grid marks.
	Perimetral frame.
Defects caused by poor extraction.	Curvatures and bulges.
	Extraction cracks.
Defects coming from the mould itself.	Burrs.
	Recompressed.
	Punch sticking.
	Powder sticking.
	Expulsion scrapes, stripes and scratches.
	Fragile corners. Broken corners.
	Incorrect thicknesses and profiles in double moulds pressed tiles.
	Chipping.
	Flakes.
Cracks and breaks (due to various causes)	Defects caused due to mould being off-centered.
	Impact cracks caused by insufficient compactness.
	Cracks caused by powder heterogeneities.
Lamination.	
Defects caused by oil droplets and impurities.	
Sizes.	

Table 7.1. General classification of defects related to the pressing operation.

As can be seen in this table, sizes are included as a "defect". Strictly speaking, sizes cannot be considered as defects but as a criterion for the selection, classification and marketing of tiles, based on their actual size. However, it is clear that the production of tiles with different sizes in the same format is a major problem and an additional cost, as its management requires more space for storage, a greater effort and cost in the marketing of productions with sizes and, of course, it is difficult to market the "peaks" or residual productions, of a few m², which often reduces the profit margin. On the other hand, it should be remembered that size production is related to the variation in the linear shrinkage of the tiles and may originate from the pressing and/or firing operations. Further information on sizes can be found in [49].

7.3. DEFECTS CAUSED BY UNEVEN DISTRIBUTION OF COMPACTNESS.

One of the common causes of dimensional defects in pressed parts, such as **rectangularity defects, crescents and sizes** is the heterogeneous distribution of compactness within the tile or between tiles. Although the origin of these defects can be diverse, one of the most frequent causes is to be found in an **irregular loading of the mould cavities**. As an example, Figure 7.3 shows a map of bulk densities of a tile with rectangularity defects with the value of the bulk density according to the colour attached, and Figure 7.4 shows the map of bulk densities of two tiles corresponding to the cavities of a mould with two outlets, which reflects the differences in compactness between the central part and the sides of the tiles^[58]. These differences lead to the production of tiles with crescents or rectangularity defects, given that the central part of the tile has a higher bulk density than the side loaded on the outer part of the mould.

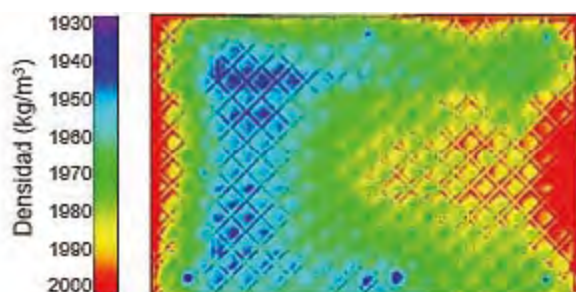


Figure 7.3. Map of bulk densities of a tile obtained with a DENSEXPLORER x-ray absorption equipment.^[58]

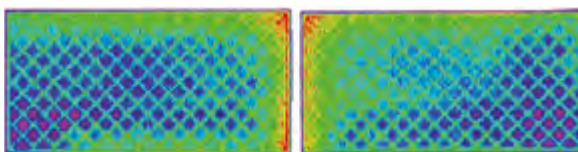


Figure 7.4. Map of bulk densities of two tiles obtained with a DENSEXPLORER x-ray absorption equipment.^[58]

On the other hand, poor loading of the mould cavities can also lead to visible ripples through the enamel layer; feeder car grid marks or the defect known as "peripheral frame".

The loading of the cavities, together with the variables of the paste preparation and pressing operations, determines the compactness; and this important parameter in turn determines the properties of the raw ^{[8][18]} and fired ^{[6][7][11][14][17][40][83]} tile. Compactness is related to linear shrinkage after firing, so that significant differences in shrinkage in areas of the same tile may cause shrinkage differences that result, after firing, in loss of orthogonality (rectangularity defects, crescents, etc.). If the differences in compactness occur between tiles of the same batch, this may result in tiles with unacceptable differences in size within the same format, which makes it necessary to classify them in different batches called "sizes".

To ensure homogeneous compactness throughout the tile, a homogeneous cavity loading and pressure distribution must be achieved. It is therefore understandable that strict control of the homogeneous and constant loading of the cavities is a necessary condition for maintaining quality standards in the pressing operation. However, it is not always easy to achieve and maintain a homogeneous load, especially in very large formats or with pronounced reliefs, as there are many parameters that condition it. Some, such as fluidity, depend on operations prior to pressing. Others are directly related to the regulation of the pressing cycle, such as the type of grid used; the regulation of the plate drop synchronisms; the position of the feeder car at the moment of opening the press hopper; timing of the first drop and the regulation of the plate drop speeds; feeder car speed during its movements. In addition, it is also very important to keep the operating parameters of the press constant, such as the leveling of the feeder car or the

verticality of the plunger axis. Thus, the measurement of compactness, or its indirect measurement through bulk density, has a great importance for the control of the pressing operation. Annex IV describes the technique for measuring compactness in ceramic tiles by XRD absorption, DENSEXPLORER, and the construction of bulk density maps that describe the distribution of compactness in the same tile and for all the cavities.

Differences in raw or dry compactness in the same tile are usually related mainly to deficiencies in the loading of the cavities, as explained above, although occasionally they can be caused by wrong installation or mould design deficiencies such as **lack of parallelism between the upper and lower punches**; the **wear of the upper punches** which can cause powder leaks on one of the sides of the tile or the **uneven distribution of pressures**, especially in large tiles, due to an inadequate relationship between the dimensions of the press, especially the mobile plunger and the dimensions of the mould (see figure 5. 25).

7.3.1. Defects caused by the absence of parallelism between punches.

The lack of parallelism between punches causes the defect known as "wedge" or "wedging". This defect occurs when there is a marked difference in thickness between two parts of the tile (Figure 7.5). These differences can be attributed to poor pressing due to the lack of parallelism between the upper and lower punches. Wedging can also occur due to poor levelling of the feeder car, deficiencies in powder distribution or, in large formats, wedges caused by bending of the mobile plunger if the press develops excessive force⁶².

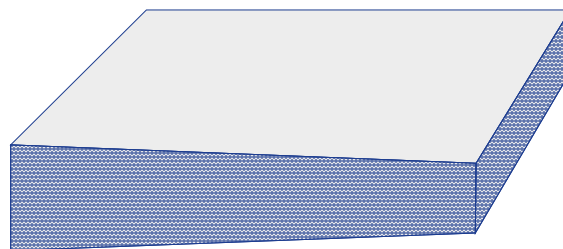


Figure 7.5. Wedged tile (not to scale).

Modern extraction equipment (SYNCRO®, SPE®) allows some load corrections to be made to correct for thickness differences. For example, SACMI's SPE® system allows five load corrections to be made during feeder car return in order to compensate for differences in tile thickness in the direction of feeder car travel (forward - backward).

Although the lack of parallelism between punches may happen due to poor punch installation, a more likely cause may be a possible breakage of the bellows (Figure 7.6), which causes the deposition of dust between the mould's bench plate and ejector plate (Figure 7.7), with the result that the punches lose parallelism during pressing, causing wedging and a slight inclination of the ejector plate-"block" system. This means the punches lose parallelism during pressing, causing wedging and rectangularity defects of the tile, as well as a slight inclination of the ejector plate-"blocks"-lower punches system, which ends up resulting in premature wear of the latter.

⁶² In general, press manufacturers advise not to exceed 80 % of the maximum pressing force.



Figure 7.6. Breakage of a leather bellows (detail).



Figure 7.7. Atomised powder between bench plate and ejecting plate due to bellows rupture.

7.3.2. Defects due to uneven pressure distribution caused by the mould.

If the pressing force is transmitted by a single central piston, which is generally the case in presses used for large format tiles equipped with large moulds, the pressure may be unevenly distributed, concentrating in the centre of the pressing surface and decreasing towards the ends, as the large plunger may tend to deflect due to its size and the pressure it is subjected to. Press manufacturers have come up with different solutions to this problem. For example, WELKO has designed presses equipped with two pressing pistons (WK2 series) for large formats, such as the WK2 4800. On the other hand, in large format presses from SACMI, the piston is fixed and inverted and it is the cylinder that transfers the pressing force to the upper punches, constituting the pressing element, which allows a better distribution of the pressures on the surface of the large format tiles.

7.3.3. Curvatures and bulging.

The occurrence of curvatures and other flatness defects is often considered as a problem characteristic of the firing stage, as these curvatures frequently occur during the heating and firing phases, e.g. curvatures associated with thermal expansion - contraction and pyroplastic deformations; or they occur during the cooling stage, due to a poor dilatometric agreement between the glaze and the substrate. However, some curvatures may originate from the pressing operation, if there are large differences in the distribution of compactness, and hence linear shrinkage, between the edges with respect to the central part of the tile. These defects become more common as the thickness of the tiles decreases ^[62] although they can be partly minimised by an appropriate design of the back relief.

7.3.4. Waves.

These are small variations in thickness that are clearly visible on the noble side of the tile, especially in glazed tiles with glossy, crystalline or satin glazes or in lapped tiles.

They are due to an irregular distribution of the load and their origin may be in an excessive backward speed of the feeding carr; vibrations or sudden movements caused by a deficient programming of the load phases. The problem can be solved by reprogramming, if possible, the load to a constant and not excessive speed (if the production demands of the press allows) and rectifying or replacing the scraper ^[25].

7.4. DEFECTS CAUSED BY POOR EXTRACTION.

In the extraction stage, the plunger and the punches rise to the initial position, releasing the pressed tile from the cavity. During pressing, the tile stores elastic energy under the action of the deforming pressing force. This energy is dissipated when the deforming force ceases, causing an increase in the dimensions of the tile which can lead to some defects, such as curvatures, bulges and extraction cracks. As it is known, the extraction can be carried out in two different ways, free ejection, which is carried out by slightly delaying the ascent of the lower punches with respect to the ascent of the plunger, so the punches and the plunger ascend separately, and pack extraction, also known as "sandwich extraction", which is carried out by synchronising in speed and time the ascent movement of the lower punches and the mobile plunger so the tile is removed from the cavity "packed" between the two punches. Practical experience seems to show that, under the same pressing conditions and for the same type of paste, post-pressing expansion is greater when extraction is carried out as a package, which would justify that for interlock formats, free extraction should always be carried out to avoid the appearance of cracks inside the inner corners of the profile.

Faulty extraction can lead to two types of defects, extraction curvature and extraction cracks.

7.4.1. Curvatures caused by poor extraction.

It is a type of curvature associated with the pressing operation, which can be generated inside the cavity if the ejection of the part in free extraction is excessively delayed. This curvature is caused by the elastic energy accumulated by the particles during pressing, so the tiles curve convexly inside the cavity, which can cause them to break on the brushes of the roller assembly located at the exit of the press. This curvature may subside considerably after drying. On the other hand, if the press is stopped without finishing the cycle and the tile is confined inside the die box, the post-pressing expansion can only take place upwards, so the tile will curve and may break.

In order to avoid bending of the workpiece inside the cavities, the extraction must be properly synchronised by adjusting the control parameter "extraction delay" ^[49].

Very pronounced bending due to delayed removal may also be accompanied by the appearance of cracks in the central part of the tile.

7.4.2. Cracks originated during extraction.

During extraction, the stresses generated at the edges may cause small cracks in this region of the pressed tiles. These cracks originate at the upper edges of the tile (we mean the edges in contact with the upper punches) after the pressure release or during the extraction of the tile from the mould [5].

When the pressure applied by the upper punch ceases, the tile face in contact with it, expands axially if the punch is removed, which occurs when free extraction is performed (Figure 7.8). However, at the upper edges of the tile, this expansion is prevented by the mould liners, which generates stresses that can lead to cracks on the sides of the tile if they exceed the value of its mechanical strength in this area.

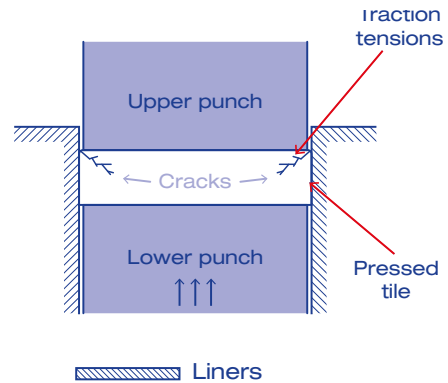


Figure 7.8. Crack formation during pressure releasing according to [5].

Another type of extraction cracks can occur as the tile is removed from the mould and its cross-section increases in size (Figure 7.9), i.e. it is generated when part of the tile is still inside the cavity and part of it has already come out and expands. This expansion leads to stresses along the upper edge causing longitudinal cracks when the value of these stresses exceeds the mechanical strength in the area. This type of cracks is rare in today's presses, where the extraction can be much better regulated, acting at will on the upward movement of the mobile plunger to carry out the extraction in a controlled manner.

To solve both types of cracks, the post-pressing expansion of the tile must be reduced, which can be achieved by pressing at higher humidity and lower pressure, or by increasing the mechanical strength of the raw tile. When cracks are generated when the pressure exerted through the upper punch ceases, the problem can be solved by performing a sandwich extraction. Ultimately, in both cases, the extraction angle or "conicity" of the liners can be revised to improve part extraction.

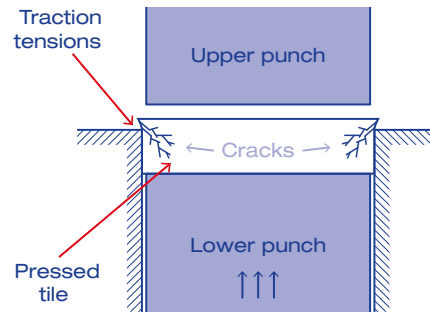


Figure 7.9. Crack formation during tile expansion according to [5].

It is advisable to always remove large format tiles in pack, while free extraction should be performed on "interlock" format tiles, as sandwich extraction of this type of tiles can cause small cracks inside the sharp inner corners of the profile.

7.5. DEFECTS COMING FROM THE MOULD ITSELF.

Some pressing defects may be caused by the moulds used. Possible causes include the use of unsuitable materials in some of the mould components, especially those subject to greater wear such as punches or liners, or the wear of these elements themselves.

7.5.1. Burrs.

Burrs consist of thin layers of powder that are compacted in the gaps between the punches and the liners. These thin layers of compacted powder remain adhered to the sides of the tile (Figure 7.10).

In entry moulds, burrs are always present on the back relief side and occur especially when the mould is heavily worn by use and therefore the clearances are greater. In this case, the defect can be minimised by heating the punches, but when they are very worn, the only solution is to replace and rectify them. This, logically, has a limit and must be done with great care to avoid damage to the punches, so a maximum number of cycles must be decided for each mould and once this number has been exceeded, they can be replaced and rectified.

In the moulds that press with the noble face upwards, burrs may form, through the same process, on the good face of the tile (Figure 7.11), which must be removed at the exit of the press by means of any mechanical device such as brushes, scrapers, etc.



Figure 7.10. Burrs on the back side relief.



Figure 7.11. Burrs on the good face.

7.5.2. Recompressed.

The recompressed (Figure 7.12) are small portions of compacted material, usually from burrs on the die box, which are deposited on the surface of the lower punch prior loading, carried by the suction generated on them during the first plate drop or by the movement of the feeding car. This problem often occurs at the front of the tiles depending on their position in the mould. In this case it can be minimised by acting on the delay of the first pressing. Once pressed, these portions are easily detectable as they have been compacted twice.



Figure 7.12. Recompressed.

This problem is characteristic of moulds that operate with the noble face on the lower punch, such as the entry or sometimes the entry mirror, and therefore the recompressed defects are manifested on this face and result in lower quality. The double mould always operates with the noble face on the upper punches and therefore it never presents this defect.

The problem can be minimised by making burr formation more difficult, installing dust extraction nozzles at the front of the die box and blowers for cleaning it. Another possible course of action is to reduce the descent speed of the mobile plunger shortly before impact with the dust contained inside the cavity. Some manufacturers ^[82] recommend a speed between 25 and 30 mm/s.

7.5.3. Punch sticking.

Punch sticking (Figure 7.13) manifests itself as an irregularity on the surface of the noble face of the tile, which occurs when dust adheres to the punch which forms the noble face of the tile. Not to be confused with recompressed flaws.

This is a characteristic defect of the old steel surface punches. This defect caused frequent production stops, so the press operator had time to clean the moulds. In order not to interrupt the feed of the dryer, a compensator was installed between the press and the dryer, aiming to maintain a constant flow of tiles to the dryer, as the continuous stops in the press caused delivery cuts in the tile flow towards the entrance of the dryer and, therefore, important changes in the surface temperature of the tiles at the exit, with the consequent breakage of the following glazing operation. Even so, it was difficult to keep the flow towards the dryer constant.

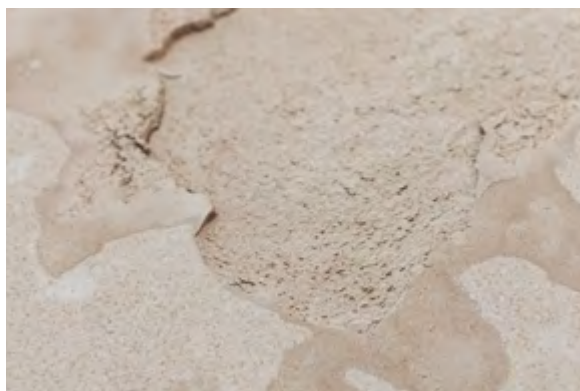


Figure 7.13. Punch sticking.

The implementation of rubber moulds in the early 1980s almost completely eliminated this defect, and in some cases even made the compensator unnecessary. However, it should be noted that this defect may occur when polished punches are used to obtain high surface qualities in porcelain tiles or if punches with rubber hardnesses higher than Shore A 92 are used. Very hard rubbers offer excellent detail definition, but when pressed, they behave almost like polished metal, increasing the possibility this defect may occur. In order to avoid this, thinner rubbers are used, so details don't lose sharpness and sticking is avoided.

The use of highly plastic pastes, which have a greater tendency to stick, favours the appearance of this defect ^[61].

7.5.4. Powder sticking.

This defect should not be confused with the previous one. These are portions of paste or powder present on the die box surface during the pressing operation, which adhere to the noble face of the

tile pressed in an entry mould, when they are deposited on the roller assembly pushed by the top of the feeding car.

These patches can be removed by installing a die box scraper (Figure 7.14), which is a system that scrapes and removes the paste stuck on the good face of the tiles before the turner. The device consists of a metal bar with a support where a rubber lip is installed and it is placed at the die box outlet.

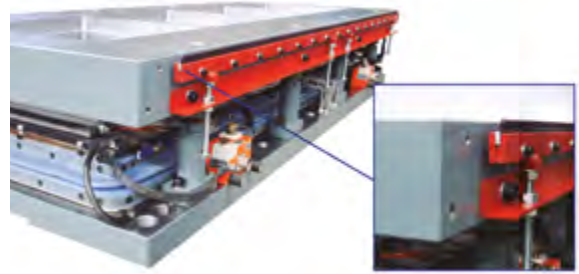


Figure 7.14. MACER die box scrapers.

7.5.5. Expulsion scrapes, stripes and scratches.

This is also a defect resulting from the entry mould pressing process. When the stop of the feeder car pushes the freshly extracted tiles out of the cavities and deposits them on the roller assembly, the tiles drag their noble face over the die and during this movement they may suffer scuffs and scratches which may be visible after firing. These scratches are more evident when the tiles are shaped with a noble side relief.

7.5.6. Fragile corners. Corner bluntings.

The “corner bluntings” (Figure 7.15) are the result of the partial loss of some of the vertices of the tile as a consequence of an impact. We refer here to the breakage of some corner generated with the raw piece, either green or dry, mainly due to a low compactness on the sides, which causes a low mechanical resistance. This low compactness may occur due to excessive wear of the upper punches in the entry moulds and/or the liners, causing powder to be ejected outside the die box; or due to the tension generated between the tile and the mould ^[57]. They can also happen due to the low humidity of the pressing powder, which leads to insufficient compactness of the tile.

Excessive adjustment of the upper punch to any corner of the liner leads the powder to be compacted inside the angle and adhere to it, causing the loss of the corner when the tile is ejected. The problem can be solved for the moment by stopping the press and manually removing the adhered powder with a small scraper, but the ultimate solution is in the design, by placing a small tab on the upper punch to remove the adhering dust.



Figure 7.15. Corner bluntings.

Another possible cause of corner bluntings is excessive wear of the liners near the corners (Figure 7.16). Although this is not an area where the liners suffer a lot of wear compared to the central area of the cavities, they can suffer appreciable wear when pressing thick tiles, causing the loss of some corner during extraction.

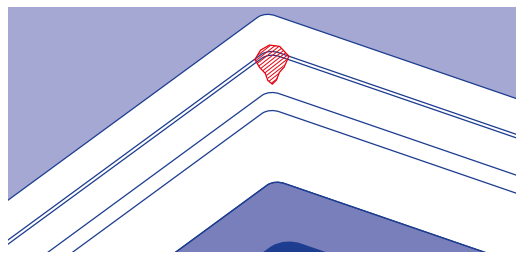


Figure 7.16. Liner wear zone inside the liner.

7.5.7. Incorrect thicknesses and profiles in double mould pressed tiles.

The double mould design allows the pressing of tiles with spacers and with the noble side facing upwards. As we have already seen in Chapter 5, in this type of mould the tiles are formed in the upper die box and therefore the liners of the upper punches are in charge of forming their side profiles. The extraction of the tile from the upper cavities is carried out by a hydraulic pistons system located inside the upper part of the mould.

The double mould has a rather restricted regulation of the thickness of the tile. In practice, it depends almost entirely on the constructive characteristics of the mould. In this regard, MACER has introduced technical improvements that allow the thickness to be varied within a range of 3 mm.

Incorrect adjustment of the stroke of the extraction pistons in the upper part of the double mould can lead to irregularities on the profile of the pressed tiles. The upper punches should always be of the same thickness to prevent the tiles from getting stuck inside the upper cavity during the extraction stage and bursting due to linear expansion. (section 7.5.8). It must be taken into account that the extraction pistons of the double mould have a constant stroke and if the thickness of one punch to another changes, the level the tiles in each cavity reached during extraction process changes.

Pressing tiles with a **thickness greater than that permitted by the mould** may cause part of the side profile of the tile to be formed by the lower liners (Figure 7.17.a), resulting in irregularities in the profile that can lead to corner bluntings and occasionally breakage on extraction.

If the **thickness is lower than the thickness permitted by the mould**, the lower punch penetrates inside the cavity defined by the upper liners, where the tile is formed (Figure 7.17.b). This can put the mould at risk and again leads to irregularities in the profile, which can result in blunting corners.

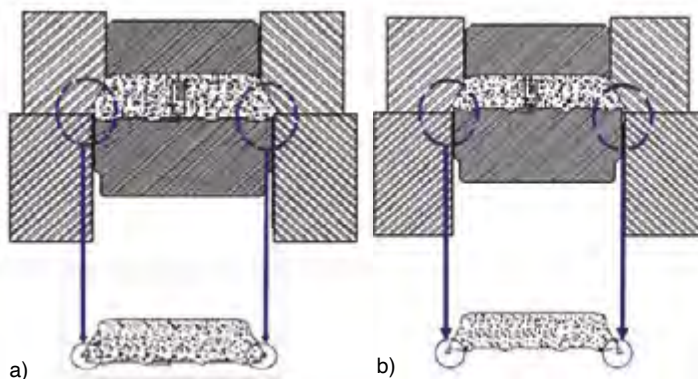


Figure 7.17.

- Defects resulting from incorrect thickness regulation in the double.
- a) Thickness regulated higher than permitted.
 - b) Thickness regulated lower than permitted.

7.5.8. Chipping.

Chipping are small breaks in the bevel of the tiles, caused by chafing during the extraction stage. This chafing can be caused by inappropriate clearance, poor mould heating regulation or incorrect part removal.

If the plunger rises too quickly during the pressing cycle with the penetration mould and this movement is not followed immediately by the extraction system, the parts may start to expand inside the cavity, resulting in a defect similar to the serrations, known as "bursting" ^[25] of the profile.

7.5.9. Flakes.

The defect appears on the edge of the tiles after grinding and appears as a small, deep, ascending crack that propagates along the entire side profile of the tile. This defect is very accentuated in large formats and can compromise the integrity of the edges of the piece. It can be caused by excessive wear of the liners, so the use of wear resistant liners is recommended to prevent this defect from occurring.

In the absence of a rigorous study to address this characteristic problem of rectified tiles, it seems to be proven that the defect is related to postpressure expansion, so that production experience indicates that it manifests itself more frequently with high values of this, especially when pressed at high pressures.

7.5.10. Defects caused due to mould being off-centered.

The mould instalation in the press (see section 6.4) must be carried out by qualified operators and with great precision, since small misadjustments in the assembly can cause major defects in the tiles and even put the equipment itself at risk.

The most important parameters to be checked during mould assembly are the perfect centring of the moving parts, i.e. the upper and lower punches, in relation to the cavities, the clearances between the punches and the liners and the parallelism between the upper and lower punches.

A bad centring of the mould causes different defects depending on the type of mould:

- In the **mirror mould**, the off-center of the upper punches causes the lateral displacement of the tile bevels, which are therefore shaped asymmetrically (Figure 7.18).

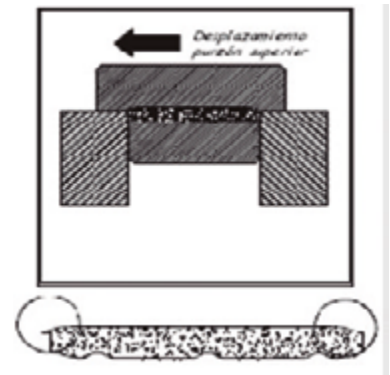


Figure 7.18. Defect caused by an off-centre mirror mould.

- In the entry mould and in the entry **mirror mould**, poor centring of the upper punches, or even their wear, leads to uneven deaeration with areas where the occluded air has more difficulty in escaping, which can lead to the appearance of laminations and also scratches due to chafing on the side of the tile (Figure 7.19). On the other hand, the off-center of the mould also generates zones where the air is preferentially expelled, which can also lead to the entrainment of particles and agglomerates, especially the finer ones, and therefore to the appearance of a compactness gradient that generates dimensional defects such as crescent or rectangularity defects and even cracks, especially in single fired products (see section 7.6.4).
- In the **double mould**, on the other hand, any offset in the installation never leads to laminations, as the off-center would affect the entire upper part and not just the punches. If this occurs, it is manifested by chafing one side of the tiles similar to that mentioned for the entry mould (Figure 7.19).



Figure 7.19. Side scratches caused by off-centre mould.

7.6. CRACKS.

Cracks may appear in pressed raw ceramic tiles when green or dry, or they may occur during the following manufacturing stages, especially during firing. There can be a wide variety of causes and even combinations of causes.

Some of the most frequent typologies, related to the pressing operation, are caused by low mechanical resistance and are usually caused by impacts during transport. In other cases, cracks appear at the top edges or at the sides after the tile extraction and they are related to excessive post-pressing expansion or to a deficient regulation of this operation. Cracks may also appear in the enamel due to heterogeneities in the distribution of moisture in the powder.

7.6.1. Cracks caused by impacts and due to insufficient compaction.

A decrease in the pressing pressure or insufficient moisture, as a result of the accidentally feeding of dryer powder to the press; or by partial drying of the powder contained inside the feed hopper during a press stop, leads to a decrease in the compactness of the tiles pressed with it and, therefore, to a decrease in their mechanical strength. If tiles with a low mechanical strength receive a side impact during glazing operations or during transport or storage, they are likely to show cracks near the corners (Figure 7.20).

In this case, cracks may occur mainly at the entrance or exit of the dryer, during occasional impacts on the glazing line due to a bad regulation of the speeds of the different sections, in the roller box loading machines or at the entrance of the kiln. If they are caused by impacts at the entrance of the dryer, they are easily detectable by applying diesel oil or paraffin by brush on the hot tile (Figure 7.21). Another procedure to detect cracks at the press or dryer outlet is to impregnate the area with methylene blue and then observe it with the help of ultraviolet light.

To avoid this type of cracks, it is essential that the mechanical resistance to bending of the raw tile is adequate (greater than 25 Kg/cm²).

Cracks of this type are often accompanied by blunting defects, also caused by impacts before firing.



Figure 7.20. Crack caused by impact (in tiles with insufficient compaction).



Figure 7.21. Crack detection procedure at the exit of the dryer.

7.6.2. Cracks caused by heterogeneities in compaction.

Uneven compaction of the tiles leads to the occurrence of the non-orthogonality defects described above. On the other hand, significant differences in compactness in nearby areas of the tile cause stresses that determine the behaviour of the tile with respect to the mechanical and physical stresses it undergoes after pressing, which may lead to the appearance of cracks or even breakage of the tile, especially in single fired products.

Irregular filling of the cavities, with the load distributed in such way that the sides are filled more than the centre, leads to the pressing of tiles with a central area of low compaction compared to the sides, which can cause the appearance of a central crack extending towards the sides of the tile (Figure 7.22).



Figure 7.22. Central crack due to uneven cavity loading.

In interlock formats, small localised cracks may occur inside the sharp inner corners of the edges [56] due to differences in bulk density caused by load deficiencies, resulting from the difficulty of homogeneous filling of the cavity with interlock profiles. Figure 7.23 shows these density differences, measured with a DENSEXPLORER RX absorption measuring device (see Annex IV). As can be seen, the areas of lower compactness are located at the tips of the angles and the differences between tips and corners are large, leading to differences in shrinkage during firing, which are indicated by arrows. This may lead to the appearance of stresses that cause cracks. To avoid this problem, the design of this type of formats should be made slightly rounding the inner corners by giving them a small radius (small curvature). This action on the inner corners prevents them from

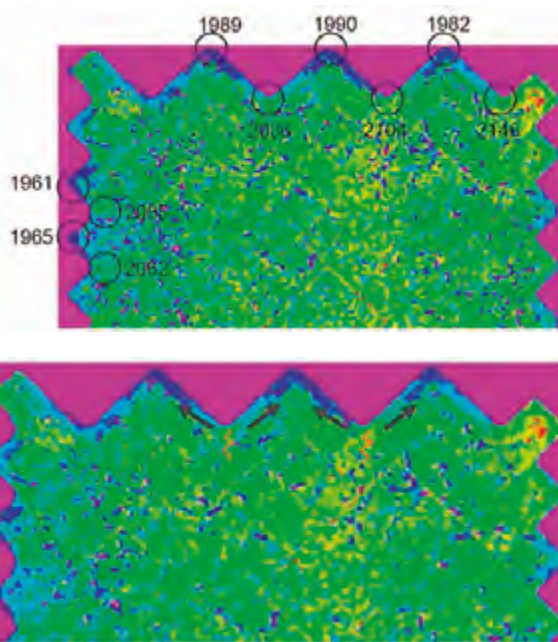


Figure 7.23. Differences in bulk density and the cracks they cause in the profiles of an "interlock" format according to reference [56].

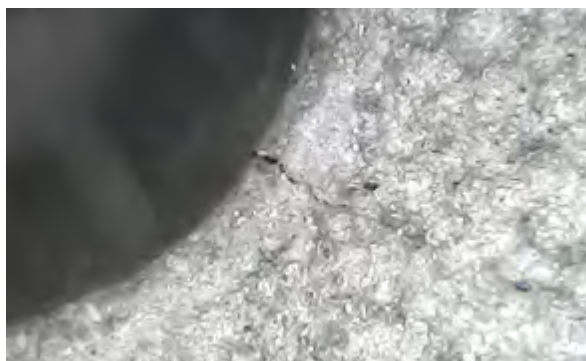


Figure 7.24. Micro-crack in the rounded area of an interlock format.

acting as a stress accumulation point, although it should be noted that this may sometimes not completely solve the problem if the differences in bulk density are very large (Figure 7.24).

7.6.3. Cracks caused by powder heterogeneities.

If there are granules or agglomerates in the atomised powder with a moisture content that differs significantly from the rest of the powder, they can cause small cracks in the enamelled surface, especially if the granules are larger than 750 μm [62].

Very wet or very dry granules, located close to the surface of the tile, will form areas of uneven porosity, as they were pressed at the same pressure as the rest of the tile but have a significantly different moisture content, so the absorption of water from the glaze will be uneven, and their behaviour during firing will also be different. In both cases, these differences in humidity cause surface cracks in the enamelled surface. Thus, for example, very wet granules close to the surface cause after pressing, very localised areas of low porosity, and therefore low absorption of glaze water, which dries more slowly, giving defects of homogeneity in the glaze stretching and cracks.

If there are very dry granules close to the surface, probably from dry detachments from the atomiser itself, from the belts and buckets or from the silos, they will also cause surface cracks to appear, in this case due to a lack of compaction ^[62], or lamination.

The presence during pressing stage of large atomized powder granules, which are not very deformed, can generate micro-cracks that could be the source of the tile fracture.

7.6.4. Cracks caused by powder leakage.

The migration of fine particles towards the periphery of the cavity during pressing stage is known as "powder leakage". It manifests itself in the form of small cracks in the central part of the sides of the tile oriented perpendicular to the edge, known as "comb" or "bevel crack" (Figure 7.25). This can occur if the atomized powder has non-agglomerated particles from the silos, is dryer or has a very fine particle size. The defect is caused by excessive speed of the mobile plunger at the time of the first pressing (or insufficient slowing of the plunger) and excessive clearance between the upper punches and the liners due to the wear of both. The small cracks appear in the centre of the sides of the tile, as this is the area where the liner can open most. When this defect occurs, it is advisable to lower the heating temperature of the die box.



Figure 7.25. Comb or bevel cracks.

7.7. LAMINATIONS.

The defect, known as laminations, consists of layers or pockets of trapped air between layers of compacted material (Figure 7.26 and 7.27). This defect is easily detectable in the tiles when they come out of the press, although it may go unnoticed when it is of small magnitude and become very clear after firing. In all cases this is a serious defect, as it completely invalidates the tile.

The defect occurs when air is trapped inside the powder and it is impossible to remove it during the first pressing and deaeration stages of the pressing cycle, which are precisely the stages this function must be performed.

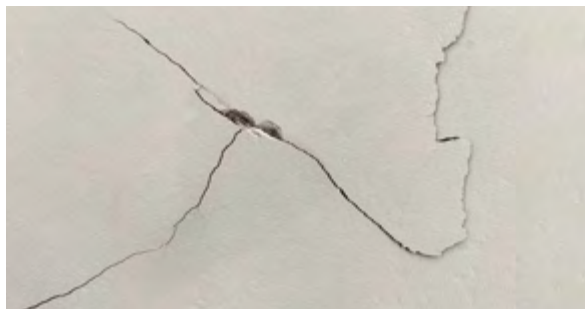


Figure 7.26. Lamination (tile surface).



Figure 7.27. Lamination (cut).

This is a well-studied and profusely described defect ^{[1] [9] [21] [22] [61] [62] [80]} Many factors are involved and there are many causes that can lead to it, although not all have the same weight, nor are they all easily solvable. Some causes are located in the physical characteristics of the pressed powders, such as their moisture and particle size distribution, both of primary particles and aggregates as the atomised material; and others in their composition and plasticity. Clearly these factors must be taken into account at the product development stage, because once production is launched they are difficult to solve.

All of these causes can be found in the literature cited above and the reader can find a collection of them at ^[49]. On the other hand, in this book we will focus on the causes that affect the mould directly or indirectly through the pressing cycle.

As far as the pressing cycle is concerned, the first pressing and deaeration stages aim to evacuate as much air as possible and should be done in such way to achieve the best results, although often at the cost of slightly increasing the cycle time (and thus decreasing production). The press must have the regulation and control mechanisms that allow easy action to be taken on the pressing cycle without compromising quality. The mould also plays an important role, as it **must be provided with sufficient air evacuation channels** so this operation can be carried out quickly.

7.7.1. Influence of the pressing cycle.

The aim of the first pressing is to extract as much air as possible from the powder bed. To make this possible it is advisable, it should have a high filling density so that the amount of air to be extracted is as small as possible. The first pressing and deaeration should be carried out in such a way to allow the air to be extracted.

As will be recalled (Chapter 5), the first pressing must be carried out at low pressures, generally between 20 and 50 bar, so that the tile is sufficiently permeable to allow air diffusion. An excessively high impact of the punches on the powder bed must be avoided. For this purpose, a slowing of the plunger is usually carried out just before the impact and, generally, the pressing is carried out directly with the pressure of the circuit and sufficient time to facilitate the extraction of air. After the first pressing, a slight rise of the mobile plunger allows the air to be extracted (deaeration stage). An excessively short time of this stage or insufficient clearance between the punches and the liners can lead to laminations.

On the other hand, an incorrect adjustment of the upwards movement of the mobile plunger after the first pressing can also cause laminations on the tiles, because if the upwards movement is excessive, the punches can trap air that will be pushed back into the cavity.

Naturally, an excessively short duration of the first pressing can also lead to laminations, as this complicates the deaeration of the powder.

As a guideline, we can say that the deaeration time in a standard cycle in medium formats can be around 300 ms, although depending on the format it may vary. The larger the format, the greater the volume of air that must be removed, the longer the cycle. And, of course, it also depends on the type of mould used, as entry and mirror entry moulds are easier to de-aerate than top-forming moulds. When lamination problems occur due to the difficulty of evacuating the air in the deaeration stage, the time

of this stage can be increased up to 700 ms ^[82], although it must be borne in mind that, as has already been repeated on other occasions, this leads to an increase in the pressing cycle time and, therefore, a decrease in production.

In some older, small-tonnage presses, the mobile plunger is raised after the first pressing by means of dampers, so in the event of venting problems, the dampers must be correctly adjusted.

7.7.2. Influence of the mould.

In **entry moulds**, the air is extracted through the clearance between the upper punches and the liners, which must be large enough to allow proper evacuation, but not so large as to cause burrs and recompressing. Therefore, incorrect centring of the punches or poor regulation of the mould heating can lead to laminations, as it causes preferential deaeration in the areas with greater clearance and difficulty in deaerating areas with smaller clearance. Logically, the laminations will occur in the vicinity of the areas where there is less clearance between the liner and the punch.

In the double mould, deaeration is carried out around the entire perimeter of the tile between the upper and lower liners slots and through the gaps between punches and liners (Figure 5.15) and is a slightly more complicated stage of the pressing cycle. This is partly due to the fact that these moulds are usually used to press large formats and therefore require a larger amount of air to be extracted. This is mainly due to the closed design of the mould, with two die boxes and tile forming in the upper side of the mould. All these factors make difficult construction of adequate deaeration channels. MACER has improved the de-aeration of its upper forming moulds by installing stops, so that during pressing, the contact between the upper and lower mould components occurs at the stops, and not between the liners.

By heating the mould, it is possible to regulate and modify the clearances between punches and liners and thus act on the deaeration process. When the mould is new, or in moulds with little wear, if there is a laminations problem, the die box is heated and the temperature of the punches is maintained to improve de-aeration, increasing the clearance. As the wear of the elements subject to greater abrasion increases, such as the punches and liners, the temperature of the die box is maintained or even decreased, increasing the temperature of the punches to partially mitigate the wear of these components, but if this operation is carried out incorrectly, it can cause laminations by making it difficult to obstruct the airflow.

Often, in case of lamination problems, the temperature of the punches is lowered to slightly increase the clearance, thus facilitating deaeration. However, it should be noted that this can facilitate the burrs defects, and can also lead to recompress problems in the entry or inverted entry mirror moulds, as mentioned above.

7.8. SIZES.

“Size” is a commercial designation defining a batch of a certain format, characterised by the fact that all the tiles composing it have the same real dimensions within accepted limits.

To define the lot or size, it is necessary to establish the limits of the tile dimensions or upper and lower tolerances that make the tiles to be considered the same size. The maximum accepted difference between the upper and lower size or "gauge tolerance" is specified in UNE-EN 14411:2016 as 0.6 % of the side, although compliance is voluntary. In practice, this tolerance is stricter and is decided by the company itself according to commercial and technical or quality policy considerations, and is usually around 0,15 %, ranging from 0,5 to 1 mm depending on the format. Parts with differences in actual size greater than the established tolerance are considered and classified as different sizes.

The production of sizes is related to variation in linear tile shrinkage or differences in firing temperatures or firing cycles and may originate from pressing and/or firing operations (Table 7.2).

When the **origin** of the **sizes** is found in the pressing stage, it may be occur due to poor loading or poor leveling of the load, and will occasionally be accompanied by lack of rectangularity. It can also occur due to other types of non-conformities, such as dirt under one of the punches, incorrectly mounted punches, bellows breakage, etc. If the origin of the simultaneous production of sizes is located in the press, it is likely that there is a relationship between press punches and the sizes and, therefore, it will be relatively easy to check if there is a predominance of tiles from one or more press punches with a particular size, which will certainly help to solve the problem.

However, the majority of tiles have different sizes to those intended to be manufactured are produced, not simultaneously but over the production time of a format and model, due to the variability of the process, incapable, when this occurs, of maintaining the final dimensions of all the tiles within the same size.

Origin.	Production of parts with different sizes.	Cause.
Pressing.	Tiles with different sizes are produced simultaneously.	Deficiencies in cavity loading leading to differences in compactness. It may be accompanied by rectangularity problems.
	Tiles with different sizes are produced throughout the production of a format.	High variability of the process leading to differences in compactness between tiles.
Firing.	Tiles with different sizes are produced simultaneously.	Differences in firing temperature, firing time or transverse temperature gradients (red paste and white paste stoneware). Differences in the firing cycle, in the heating stage , between 800 and 950 °C (wall tiles).
	Tiles with different sizes are produced throughout the production of a single format.	High process variability (wall tiles and stoneware).

Table 7.2. Causes of the production of sizes.

Annexes.



PELIGRO RADIACIÓN /
X-RAY HAZARD

No gesticule ni produzca ruidos. No manipule.
Do not gesture or make noises. Do not
manipulate.



macer

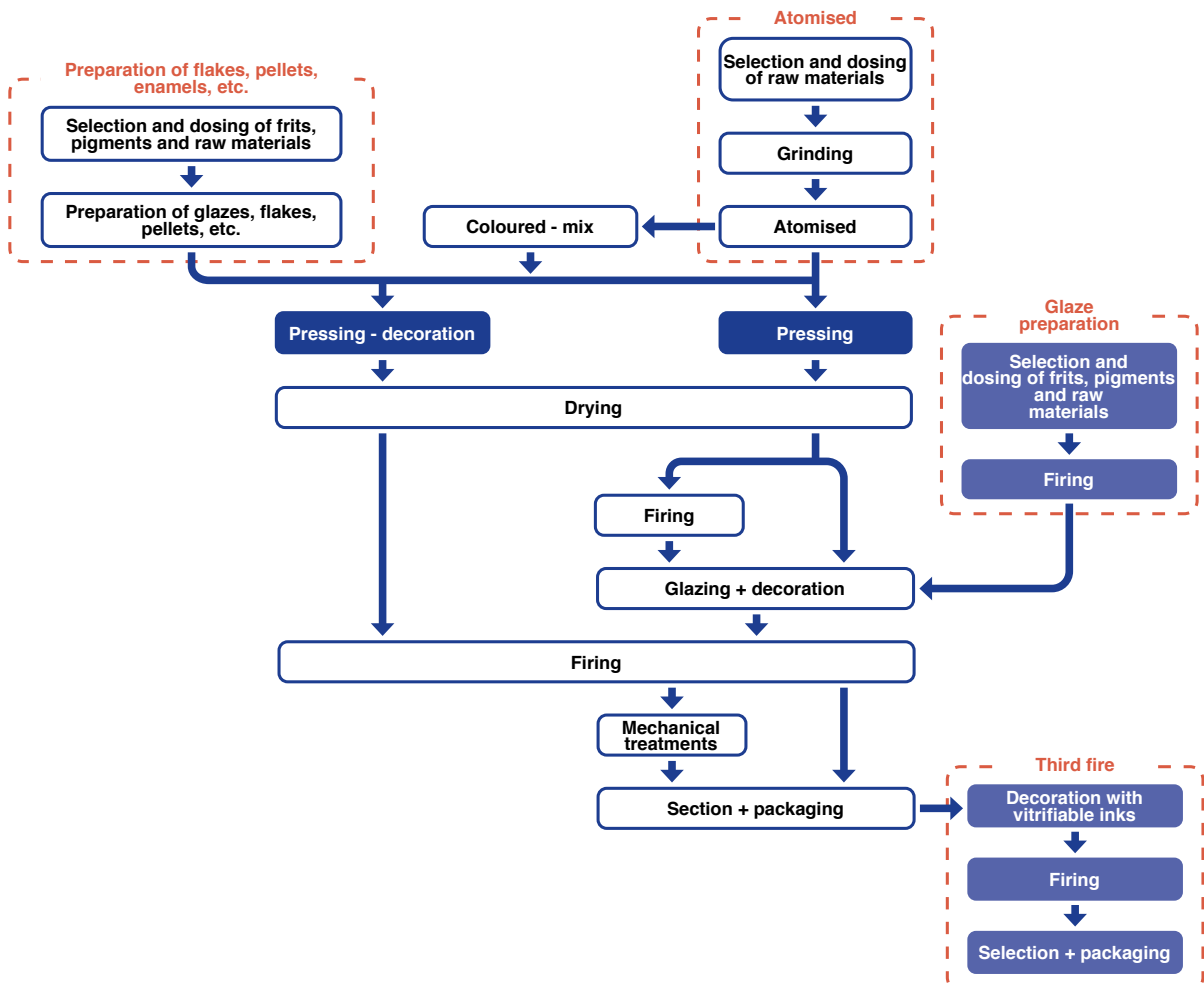


PRECAUCIÓN / CAUTION:

MANEJO DE MATERIALES RADIOACTIVOS
HANDLE RADIOACTIVE MATERIALS

DENSEXPLORER

ANNEX I. Manufacturing process of ceramic tiles and plates.



ANNEX II.

Forming techniques for ceramic products.

There are different forming techniques for ceramic products, which are characterised by similar technology and a common set of process variables, based on similar principles. These techniques are classified according to the amount of water used to prepare the paste.

Some materials are formed by a combination of different techniques; for example, some types of roof tiles are made by extruding flat sheets that are shaped by wet pressing. Electrical insulators are manufactured by extruding cylinders which are cut to the required dimensions and shaped by gauging.

Status.	% of water.	Forming techniques.	Some products obtained.
Semi-dry.	5 to 10	Unidirectional pressing.	Tiles. Ceramic plates. Refractory plates. Dishes and trays.
		Isostatic pressing.	Tenacious ceramics.
Plastic.	15 to 20	Manual or semi-automatic moulding.	Pottery.
		Extrusion.	Construction materials.
		Calibration.	Electrical insulators. Tableware.
		Wet pressing.	Roof tiles.
Suspension.	30 to 50	Casting.	Decoration and ornamentation. Tableware. Sanitary. Tenacious ceramics and ceramics for technical and laboratory use.

Table II.1. Forming techniques.

ANNEX III. Hardness tests.

Definition:

Hardness is a measure of the resistance of a material to permanent deformation at its surface.

It is therefore understood that hardness is a property of the surface layer of a material and not a characteristic property of the material.

Measurement:

There are different methods for measuring the hardness of materials. All of them consist of producing a local deformation on the surface of the material by means of a penetrator applied with a certain load. In other words, in all of them, a known load is applied to the surface of the material and the permanent deformation caused by this load is measured. The hardness values obtained depend on the load, the type of indenter, its dimensions and the time of application of the load, so the values obtained must always be accompanied by an indication of the method used and the test conditions.

Hardness tests can be classified into two main groups, static and dynamic tests (table III.1).

In all static tests, it is true that the hardness of a material is inversely proportional to the size of the imprint left on its surface when a deformation force is applied.

The indenter used in the test shall have a hardness greater than the material tested and shall not be subject to any deformation.

Type of test	Description	Tests
Static	The load is applied statically. A penetrator presses against the surface of the material by applying a load relatively slowly. The hardness measurement results from the quotient of the applied load and the area of the indentation left by the indenter on the surface or from the measurement of the depth of indentation.	Brinell. Vickers. Knoop. Rockwell.
Dynamic	The load is applied in the form of an impact. A penetrator with a known energy is dropped onto the surface to be tested and the rebound energy after impact is measured.	Shore. Leeb.

Table III.1 Classification of hardness tests.

Measurement tests.

a) Brinell hardness.

The test is standardised. UNE-EN ISO 6506-1:2015 and ASTM E 10-78 standards. A hardness tester is used and the values are expressed on a scale such as **BHN**.

A load **P** is applied using a very hard steel ball of known diameter (**D**) as an indenter for t time. The

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indenter leaves a spherical cap imprint in the measured material, the measurement of which allows the hardness of the material to be determined (Figure III.1).

The size of the ball is chosen according to the thickness of the specimen to be analysed. And the value of the load to be applied in the test (**P**) is determined as a function of the diameter of the ball (**D**), taking into account the limits within the deformation of the ball due to the action of the load does not influence the result obtained. The expression is $P = k \cdot D^2$. The values of k are tabulated, so for irons and steels $k = 30$, so the applied load for 10 mm balls is 3000 kg. The following table shows the values of the load to be applied for irons and steels and the ball diameter, depending on the thickness (**e**) of the probe to be tested.

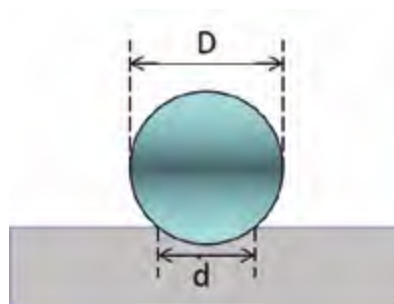


Figure III.1. Brinell hardness test (diagram).

Probe thickness (mm)	Diameter of the ball (mm)	Load to be applied (kg) (irons and steels $k=30$)
More than 6 mm	10	3000
Between 3 and 6 mm	5	750
Less than 3 mm	2.5	187.5
	1.25	46.9
	0.625	11.7

Table III.2. Brinell hardness test. Parameters.

The hardness value obtained (number **HB**) is simply obtained by dividing the load by the surface of the footprint, which, since it is a spherical cap, can be determined from the measurement of the ball diameter (**D**) and its height, which is the depth of the footprint (**h**):

$$HB = \frac{P}{\pi \cdot D \cdot h}$$

The penetration level can be set as a function of the ball diameter (**D**) and the diameter of the base of the spherical cap (**d**), resulting in the expression:

$$HB = \frac{2P}{\pi D (D - \sqrt{D^2 - d^2})}$$

The two formulae are equivalent, the former measuring the indentation depth (**h**) and the latter the diameter of the indentation (**d**), although it is preferable to use the latter as the **d** measurement is much more reliable than the **h** measurement. An accuracy of 0,01 mm is required for dimensional measurements.

The time of load application (**t**) can also influence the test result. In steel measurements it is usually between 15 and 30 seconds.

Some modern hardness testers are equipped with electronic systems that determine the hardness value directly, without the need for measurements or tables.

In practice, tables or calculation programs can be used where it is only necessary to enter one of these data to obtain the Brinell number.

In the expression of the result, the Brinell hardness has to be accompanied by the test conditions, i.e. indenter diameter (**D**), applied load (**P**) and application time (**t**), as follows: “**HB_{D,P,t}**”.

b) Vickers hardness.

This test is recommended for very hard materials. The procedure used is similar to that seen for Brinell hardness, however in this test a small load is used and the indenter used is a regular diamond pyramid with a square base whose lateral faces form an angle of 136°. On penetration of the indenter against the specimen, the indenter shall leave a square impression on the specimen material.

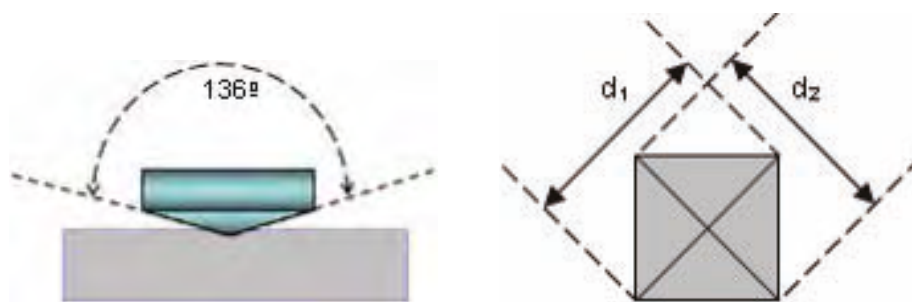


Figure III.2. Vickers hardness tests (diagram).

As reference test parameters, a load of 30 kg, applied for 15 seconds, is usually used. After the test, the diagonals (**d₁** y **d₂**) of the resulting square impression on the surface of the tested specimen are measured.

The Vickers hardness (HV) is calculated by applying the expression:

$$HV = \frac{1,854 \cdot F}{d^2}$$

When measuring **d₁** and **d₂**, an accuracy of ± 0,001 mm is required and the value of **d** is the average of the two diagonals.

Loads can vary from 1 to 100 kg depending on the thickness and type of material. In general, the 30 and 50 kg are the most commonly used.

The load used must be indicated in the expression of results. For example, if a load of 30 kg has been used and a hardness of 570 has been obtained, it should be expressed as **570 HV 30**.

The Vickers hardness test gives values similar to Brinell for materials up to 300 HB hardness (see Table at the end of this annex). It is considered a more accurate method than Brinell due to the lower deformability of the indenter.

c) Rockwell hardness.

It is the most widely used method, as it is considered easier to perform than Vickers and Brinell tests, and is suitable for all types of materials. The loads are lower and the penetrators used are smaller, so the footprint caused in the material is smaller and shallower. It is a standardised test procedure (ASTM E-18 standard). It is a standardised test procedure (ASTM E-18 standard).

It is also based on the measurement of the depth of penetration of a penetrator or indenter into the sample under the action of a predetermined load. The determined values are expressed on an HR scale.

Two types of indenters are used depending on the hardness of the material to be tested:

- For hard materials ($HB > 200$), a 120° cone-shaped diamond with a rounded tip and a radius of 0.20 ± 0.01 mm is used.
- For soft materials ($HB < 200$) a hardened steel ball is used. Depending on the type of material to be tested, $1/8"$, $1/16"$, $1/2"$ and $1/4"$ diameter balls can be used.

The laboratory hardness tester test procedure is as follows: the specimen is raised until it touches the indenter, generating an initial load of 10 kg which produces a small deformation (point a in Figure III.3). At this point the equipment is reset to zero and a second load of 50, 60, 90 or 140 kg is applied, according to the material to be tested. When the additional load is applied, the material flows plastically, resulting in a total penetration **b**. Subsequently, the additional load is removed, allowing the elastic recovery of the material, resulting in a final penetration **c**. Once the loading ceases, the hardness value is read on the indicator of the equipment and depends directly on the distance **a-c** (Figure III.3).

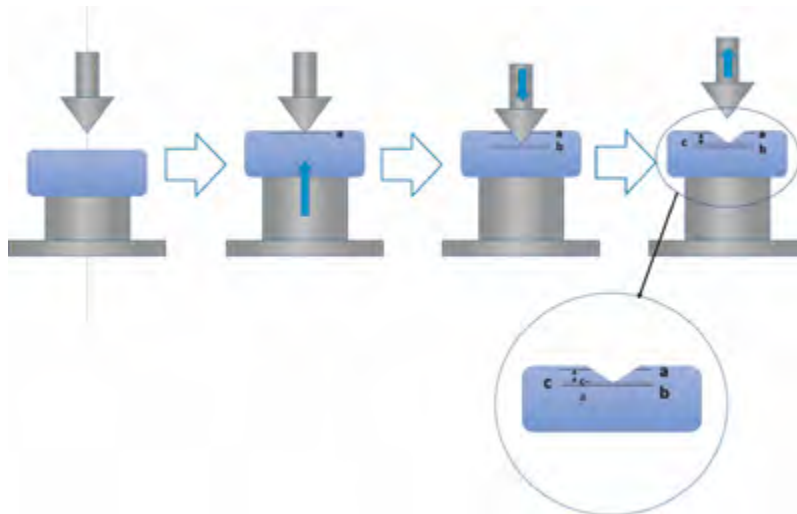


Figure III.3. Procedure for measuring Rockwell hardness.

The results obtained are expressed on different scales, depending on the type of indenter used and the load applied.

Scale	Indenter	Load (kgf)	Uses
A	Diamond	60	Treated and untreated steels. Very hard materials. Hard and thin sheet metals.
B	Sphere 1/16"	100	Annealed and normalised steels.
C	Diamond	150	Heat-treated steels.
D	Diamond	100	Cemented steels.
E	Sphere 1/8"	100	Soft metals and anti-friction.
F	Sphere 1/16"	60	Annealed bronze.
G	Sphere 1/16"	150	
H	Sphere 1/8"	60	
K	Sphere 1/8"	150	

Source: <https://ingemecanica.com/tutorialsemanal/tutorialn218.html>

Table III.3. Rockwell hardness test. Parameters.



Figure III.4. Rockwell hardness test (diagram).

Summary of the tests

A schematic summary of the Brinell, Vickers and Rockwell hardness tests is shown in Table III.4.

Test.	Penetrator.		Load.	Formula for determining the hardness index.	Comments.
Brinell.	10 mm diameter sphere made of steel or tungsten carbide.		P	$BHN = \frac{2P}{\pi D \left(D - \sqrt{D^2 - d^2} \right)}$	Not very accurate for hard materials, but very simple procedure.
Vickers.	Diamond pyramid.		P	$VHN = \frac{1,72P}{d^2}$	Recommended for very hard materials.
Rockwell.	Diamond cone.	A	60 Kg	$R_{(A,C,D)} = 100 - 500 \cdot t$	These are the most widespread tests, as hardness is obtained by direct measurement and is a test suitable for all types of materials. It is usually considered as a non-destructive test because of the small size of the footprint. C
		C	150 Kg		
		D	100 Kg		
	1/16" diameter steel sphere.	B	100 Kg	$R_{(B,F,G,E)} = 130 - 500 \cdot t$	
		F	60 Kg		
		G	150 Kg		
	1/18" diameter steel sphere.	E	100 Kg		

Table III.4. Hardness tests.

Moulds for the pressing of ceramic tiles

The following table shows the approximate relationship between hardness and tensile strength.

Rockwell			Vickers	Brinell		Tensile strength
HRB	HRC	HR 15 N	HV	P= 3000 kg D = 10 mm	HB	N/mm ²
52.0			95	6.15	90.2	305
56.2			100	6.00	95.0	320
			105	5.90	99.8	335
62.3			110	5.75	105	350
			115	5.65	109	370
66.7			120	5.55	114	385
			125	5.45	119	400
71.2			130	5.35	124	415
			135	5.25	128	430
75.0			140	5.15	133	450
			145	5.10	138	465
78.7			150	5.00	143	480
			155	4.95	147	495
81.7			160	4.85	152	510
			165	4.80	156	530
85.0			170	4.72	162	545
			175	4.65	166	560
87.1			180	4.59	171	575
			185	5.53	176	595
89.5			190	4.47	181	610
			195	4.42	185	625
91.5			200	4.37	190	640
92.5			205	4.32	195	660
93.5			210	4.27	199	675
94.0			215	4.22	204	690
95.0			220	4.19	209	705
96.0			225	4.13	214	720
96.7			230	4.08	219	740
			235	4.05	223	755
98.1	20.3	69.6	240	4.00	228	770
	21.3	70.1	245	3.96	233	785
99.5	22.2	70.5	250	3.92	238	800
	23.1	71.1	255	3.90	242	820
(101)	24.0	71.6	260	3.86	245	835
	24.8	72.1	265	3.82	252	850
(102)	25.6	72.5	270	3.78	257	865
	26.4	73.0	275	3.75	261	880
(104)	27.1	73.4	280	3.72	266	900
	27.8	73.8	285	3.68	271	915
(105)	28.5	74.2	290	3.66	276	930
	29.2	74.5	295	3.63	280	950
	29.8	74.9	300	3.60	285	965
	31.0	75.6	310	3.54	295	995
	32.2	76.2	320	3.49	304	1030
	33.3	76.8	330	3.44	314	1060
	34.4	77.4	340	3.39	322	1095
	35.5	78.0	350	3.34	333	1125
	36.6	78.6	360	3.30	330	1155
	37.7	79.2	370	3.25	352	1190
	38.8	79.8	380	3.21	361	1220
	39.8	80.3	390	3.17	371	1255

Rockwell			Vickers	Brinell		Tensile strength
HRB	HRC	HR 15 N	HV	P= 3000 kg D = 10 mm	HB	N/mm ²
	40.8	80.8	400	3.13	380	1290
	41.8	81.4	410	3.09	390	1320
	42.7	81.8	420	3.06	399	1350
	43.6	82.3	430	3.02	409	1385
	44.5	82.8	440	2.99	418	1420
	45.3	83.2	450	2.95	428	1455
	31.0	75.6	310	3.54	295	995
	32.2	76.2	320	3.49	304	1030
	33.3	76.8	330	3.44	314	1060
	46.1	83.6	460	2.92	437	1485
	46.9	83.9	470	2.89	447	1520
	47.7	84.3	480	2.87	(456)	1555
	48.4	84.7	490	2.84	(466)	1595
	49.1	85.0	500	2.81	(475)	1630
	49.8	85.4	510	2.78	(485)	1665
	50.5	85.7	520	2.76	(494)	1700
	51.1	86.0	530	2.73	(504)	1740
	51.7	86.3	540	2.70	(513)	1775
	52.3	86.6	550	2.68	(523)	1810
	53.0	86.9	560	2.66	(532)	1845
	53.6	87.2	570	2.63	(542)	1880
	54.1	87.5	580	2.61	(551)	1920
	54.7	87.8	590	2.59	(561)	1955
	55.2	88.0	600	2.57	(570)	1995
	55.7	88.2	610	2.54	(580)	2030
	56.3	88.5	620	2.52	(589)	2070
	56.8	88.8	630	2.50	(599)	2105
	57.3	89.0	640		(608)	2145
	57.8	89.2	650		(618)	2180
	58.3	89.5	660			
	58.8	89.7	670			
	59.2	89.8	680			
	59.7	90.1	690			
	60.1	90.3	700			
	61.0	90.7	720			
	61.8	91.0	740			
	62.5	91.2	760			
	63.3	91.5	780			
	64.0	91.8	800			
	64.7	92.1	820			
	65.3	92.3	840			
	65.9	92.5	860			
	66.4	92.7	880			
	67.0	92.9	900			
	67.5	93.0	920			
	68.0	93.2	940			

Note: Values in brackets indicate hardness values outside the zone defined in the standardised test.

Source: RAZYA. <https://www.ayzar.com/calidad-pdf/TABLA%20dureza%20-%20resistencia%20RAZYA.pdf>

Table III.5. Relationship between tensile strength and Rockwell, Brinell and Vickers hardness values.

ANNEX IV.

Measurement of compactness by X-Ray absorption. DENSEXPLORER.

Compactness and bulk density.

Compactness (Φ) is defined as the ratio of the actual volume occupied by the solid

(V_s) and apparent volume (V_a), so that

$$\Phi = \frac{V_s}{V_a}$$

and their values also range between 0 and 1

$$0 < \Phi \leq 1$$

Compactness is an important property of pressed tiles as it is related to its behaviour in the following stages of the production process, especially firing, and to the properties and quality characteristics of the finished product. However, given the complexity of industrially controlling compactness, it is usual to experimentally determine another parameter directly related to it and much easier to measure, such as the **dry bulk density (ρ_a)**, which is defined as the ratio of the weight of a dry piece (w_s) and the volume it occupies, or apparent volume (V_a).

$$\rho_a = \frac{w_s}{V_a}$$

It is therefore easy to deduce that

$$\Phi = \frac{\rho_a}{\rho_s}$$

Expression where ρ_s is the specific weight of the solid and relates compactness to bulk density.

Procedures for measuring bulk density.

The industrial monitoring of compactness is of great importance given the influence this parameter has on the development of the manufacturing operations and on the quality of the fired tiles. This control, like all those made in the industrial plant, should be simple, quick, reliable, reasonably economical, not harmful to health, environmentally friendly, easy to perform and to interpret. At the industrial level, the indirect measurement of compactness is preferred due to its simplicity, speed and economy. It is obtained determining the bulk density, dry or green, since, as we have seen, there is a direct relationship between compactness and dry bulk density, through the specific weight of the pressing powder.

The methods of bulk density measurement are usually divided into three groups [38], measurement of some property directly related to bulk density, measurement of pore volume, and separate measurement of mass and volume of the piece. A description of each of these measurement techniques is given in [49], with the measurement of bulk density by mercury immersion being the most commonly used until relatively recently. However, this technique, developed and patented by the Ceramic Industries Research Association (AICE) [19][39], although fast, reliable and economical, has the disadvantage of using mercury, which is highly toxic, so numerous attempts have been made to develop an alternative technique.

Measurement of bulk density by X-ray absorption: DENSEXPLORER.

The Institute of Ceramic Technology (ITC) has published several papers ^{[10] [16] [46]} where they developed a method for measuring the bulk density of samples and ceramic tiles by means of X-Ray absorption. On the basis of these papers, and as a result of the collaboration between ITC, MULTISCAN and MACER, an industrial equipment (DENSEXPLORER) has been developed which allows the rapid measurement of bulk density and the construction of bulk density maps by X-ray absorption ^[10] suitable for use in industrial plants (figure IV.1).



Figure IV.1. Equipment for measuring bulk density by X-ray absorption.

The main elements of the machine^[58] are an X-ray generation system; two laser rangefinders; a linear X-ray sensor that creates an image with the X-ray signal it receives; and a conveyor system for the movement of the tiles in the measurement operation consisting of a smooth PVC belt moved by a servomotor.

Figure IV.2 shows a diagram^[63] where all the components of the equipment and their location are displayed and Table IV.1 gives a brief description of these components.

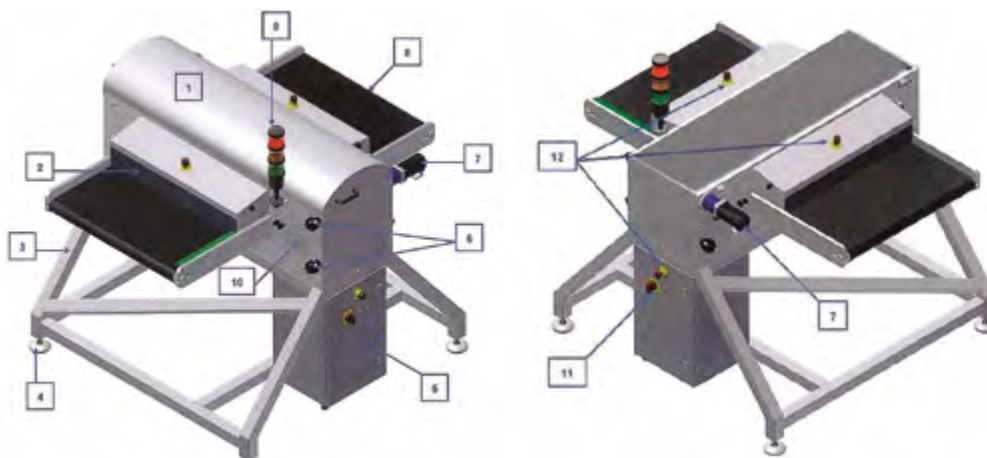


Figure IV.2. Components of a DENSEXPLORER device for the measurement of bulk density by X-ray.
Source: MULTISCAN TECHNOLOGIES.

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No. (Figure IV.3.)	Component.	Description / Function.
1	Inspection area.	This space houses the X-ray generation system, laser rangefinders, an X-ray linear sensor and the movement transmission system.
2	Antiradiation screen.	These are security elements features located at the inlet and outlet of the inspection area. Its mission is to contain the scattered radiation.
3	Support.	
4	Ball joint feet	They are adjustable to facilitate the levelling of the equipment.
5	Control panel.	It contains an emergency button, the X-ray emission permission key, a voltage indicator and the main switch.
6	Bearings.	They allow the rotation of the transmission shafts of the X-ray generator and conveyor belt movement.
7	Servomotors.	These act on the conveyor systems transmitting the movement.
8	Conveyor belt.	Smooth PVC belt driven by a servomotor to move the tiles in and out of the inspection area.
9	Luminous beacon.	It is a colour-coded indicator light that provides information on the status of the equipment at all times.
10	Specs plate.	It gives information on technical characteristics of the equipment.
11	Main switch.	It is located on the control panel.
--	X-ray emission permit key	The equipment can only emit radiation if this key activates the emission device. This key must be in the possession of the person responsible for the equipment at all times.
12	Emergency push-buttons.	They are used to completely block the equipment in case of emergency.
--	Photodiode	This is the sensor that receives the radiation after it has passed through the measured tile. It transmits this information to the computer.
--	Laser rangefinders.	The equipment has two laser telemeters, which measure the thickness at each measuring point of the tiles. The thickness at each point (e) is determined by deducting from the distance between the two rangefinders (L), which is known, the sum of the distances measured by both lasers (x ₁ and x ₂) to the corresponding tile surfaces (Figure IV.3).
--	Lead protections.	All parts of the equipment that may be exposed to radiation are coated with a lead layer.

Source: MULTISCAN TECHNOLOGIES.

Table IV.1. DENSEXPLORER components ^[63].

The ceramic tiles to be analysed are introduced into the inspection area (1) by means of a conveyor belt (8). As the tile passes through, the X-ray generator emits radiation which, once collimated, is incident on a point of the tile. At the same time, the two laser rangefinders measure the thickness, as shown in figure IV.3. These two measurements are made at a single point each, but the back-and-forth movement of the head, induced by the drive belt, as the tile travels across the inspection area, allows a complete scan to be performed.

The radiation passes through the tile and is measured by the linear sensor or photodiode and the information is transmitted to the computer for processing. In accordance with the Lambert-Beer law, knowing the intensity of the incident and transmitted radiation and the thickness of the sample, it is possible, after calibration of the equipment, to know the density at each point of the material measured.

The accuracy of the measurement depends on the feed rate, which varies between 1 and 10 mm/s. At the same time, the X-ray emitting tube moves transversely scanning the tile at a maximum speed of 1000 mm/s. The radiation passing through the tile is measured by a radiation sensor located at the bottom.

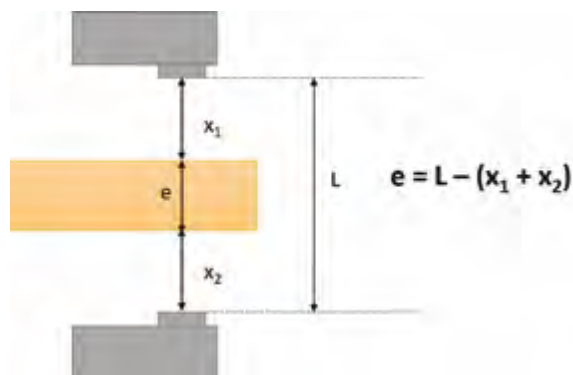


Figure IV.3. Single-point thickness measurement with laser range finders.

The [64] measurements are very simple to carry out. Figure IV.4 shows the main screen of the programme. Once the device has been switched on, the emission permit key is operated and the white balance correction is carried out⁶². The equipment is then calibrated by inserting a calibration plate, which is supplied with the equipment which thickness and density are known exactly. Both operations are performed from the "tools → assistant" menu (Figure IV.5). To finish with the start-up, the same menu is used to configure the tests. Clicking on this tab opens the window shown in Figure IV.6 where presses, formats, models and compositions can be added, deleted and configured, as well as the different levels of resolution. Once the data have been entered, clicking on "accept" takes you to the test start screen (Figure IV.7).

The equipment can obtain bulk density, thickness and loading values in areas of 1 mm² of material, thus obtaining highly accurate bulk density maps.

With this equipment it is possible to construct the bulk density maps of tiles up to 110 cm wide and without length limitation, therefore roller assemblies must be installed at the entrance and exit, as shown in Figure IV.1.

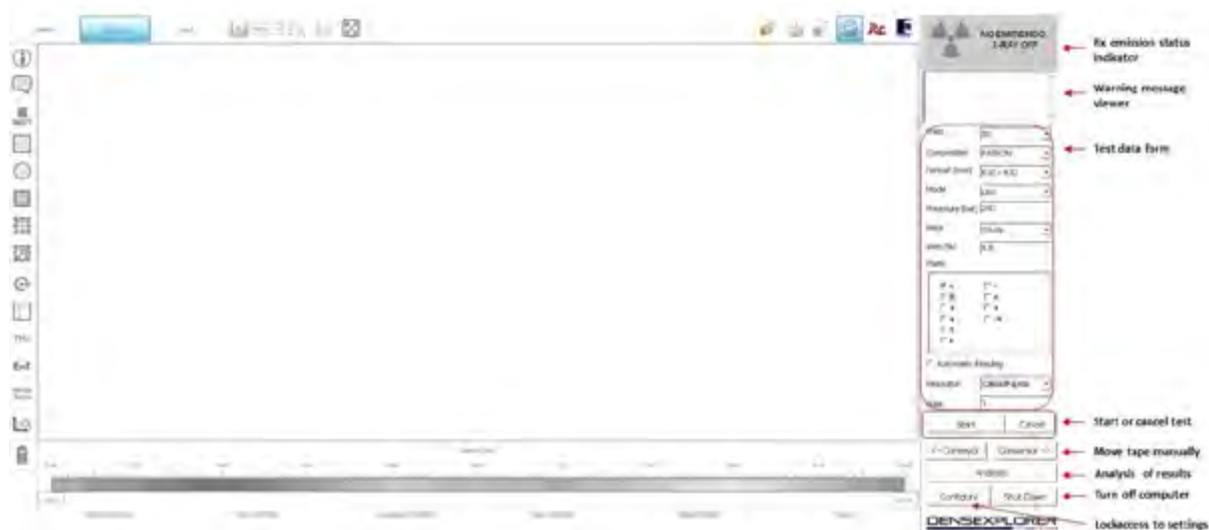


Figure IV.4. Main screen of the DENSEXPLORER management software.
Image: Courtesy of MULTISCAN TECHNOLOGIES.

⁶² "White balance correction" is the measurement process where the value of the signal recorded by the linear sensor is obtained when the emission is made in the absence of tiles or test pieces.

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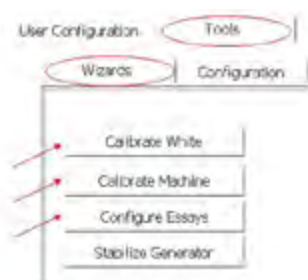


Figure IV.5. "Wizard" screen to activate calibration and test setup.

Image: Courtesy of MULTISCAN TECHNOLOGIES.

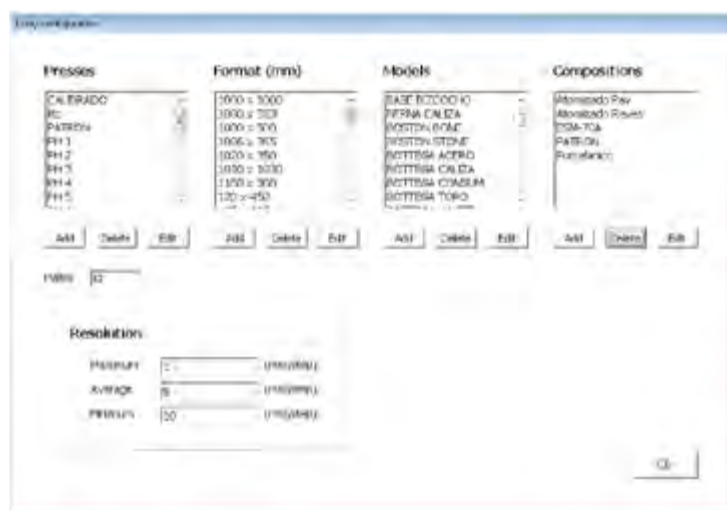


Figure IV.6. Test configuration screen.

Image: Courtesy of MULTISCAN TECHNOLOGIES.



Figure IV.7. Start test screen.

Image: Courtesy of MULTISCAN TECHNOLOGIES.

The test is very fast as the construction of a complete map of bulk densities on a 60 x 60 cm tile takes about 5 minutes. For presses with several outlets, it is possible to obtain an overview of the bulk density distribution and thus the cavities load. The programme can provide the results obtained either numerically or, for ease of interpretation, by means of colour coding. As an example, Figure IV.8 shows the complete bulk density map of the seven outlets of a 22 x 85 cm mould.

As seen in the figure, the equipment provides information on the distribution of bulk densities of the tiles. This distribution is, as can be seen, very heterogeneous and it is not possible to appreciate it with this clarity by means of the mercury or water immersion measurement procedures. Maps of thickness distribution and cavities loading can also be obtained (Figures IV.9 and IV.10).

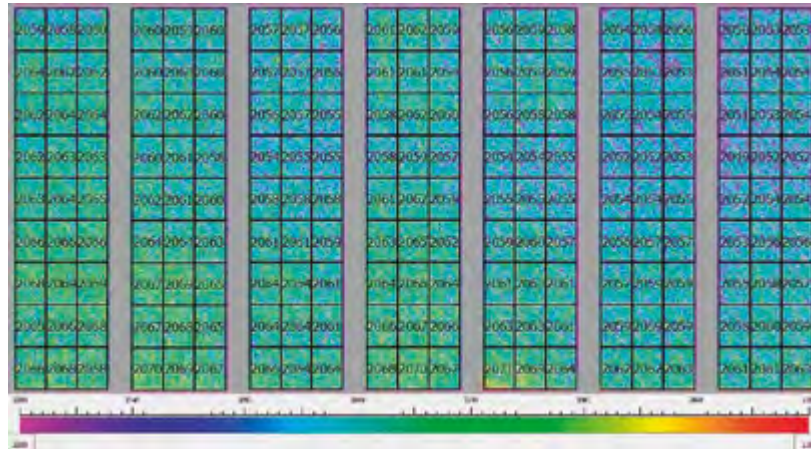


Figure IV.8. Map of the distribution of bulk densities, in kg/m³, obtained by XRD absorption for a mould with seven outlets of 22 x 85 cm. Source: MACER – ITC.

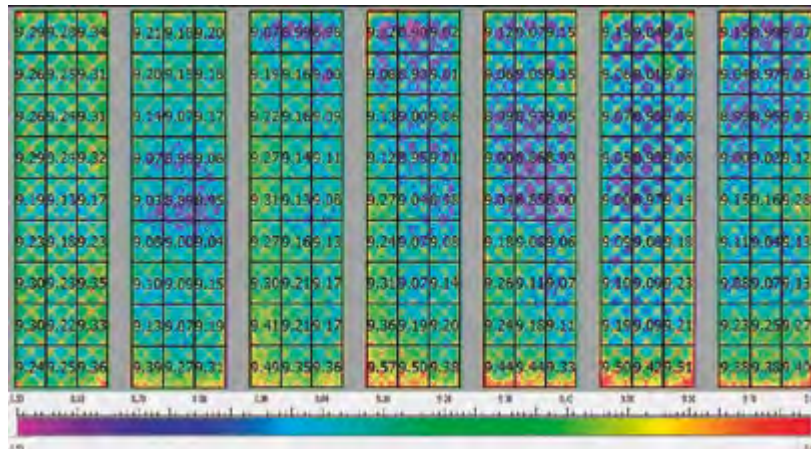


Figure IV.9. Thickness distribution map, in mm, obtained by the DENSEXPLORER equipment for a mould with seven outlets of 22 x 85 cm. Source: MACER – ITC.

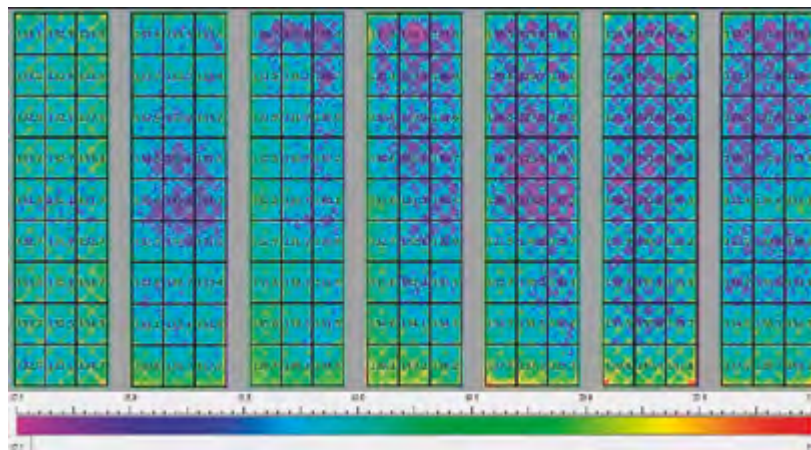


Figure IV.10. Load distribution map, in kg/m², obtained by the DENSEXPLORER equipment for a mould with seven outlets of 22 x 85 cm. Source: MACER – ITC.

Moulds for the pressing of ceramic tiles

The software of the equipment also allows the user to study sections of the part selected at will and to obtain data on the linear distribution of the load, the thickness (Figure IV.11) or the bulk density in a given direction. On the other hand, laser telemeters can give graphic and numerical information of the relief heights on both sides, which makes it possible to study the flatness of the fired tile and to relate possible deformations to variations in apparent density, thickness or load.

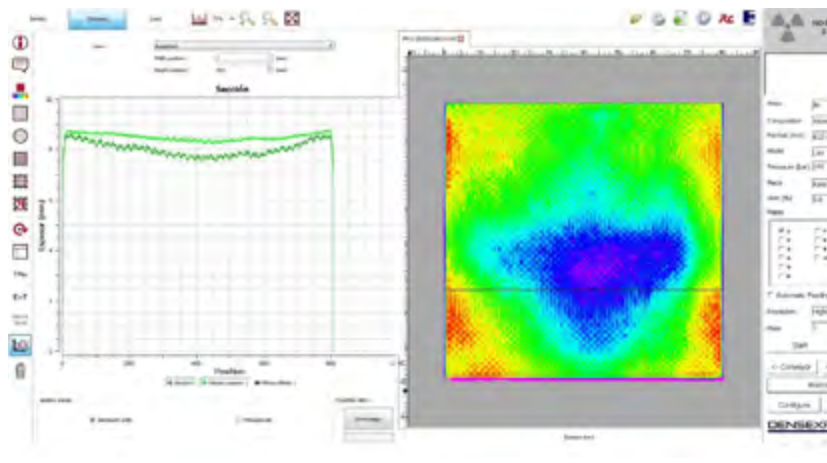


Figure IV.11. Thickness distribution map, in mm, (a) thickness profile along the indicated direction obtained by the DENSEXPLORER equipment.

Source: MACER – ITC.

The measurement accuracy is identical to the mercury immersion method with the advantage of speed, safety and environmental protection. On the other hand, and unlike mercury immersion, it is a non-destructive method, so after establishing the map of apparent densities of raw tiles, these can be fired and the measurement can be carried out again on the same tiles.

Table IV.2 shows the available RX absorption bulk density measurement equipment.

With this equipment it is therefore possible to quickly obtain maps of bulk density, thickness and load of tiles and large formats ceramic plates. Figure IV.12 shows the bulk density measurements, in colour code, of the tiles pressed in a 75 x 75 cm two-outlet mould.

Equipment.	Maximum tile dimensions to be measured (mm).		
	Lenght.	Width.	Thickness.
Densexplorer 750	No limits	750	24
Densexplorer 1100	No limits	1100	24

Source: MACER – ITC.

Table IV.2. Bulk density measurement equipment.

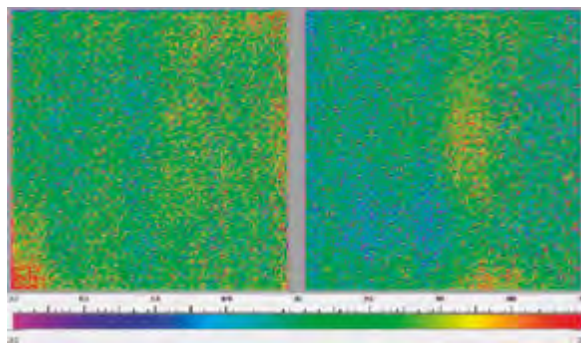


Figure IV.12. Map of the distribution of apparent densities, in kg/m³, obtained by XRD absorption for a two outlets mould. Source: MACER – ITC.

ANNEX V.

Heat treatment of steels.

The heat treatments of steels are heating and cooling processes where their internal structure and, therefore, their properties are modified, and their chemical composition may or may not be modified, depending on the type of treatment. These can be treatments that affect the whole part and are called **total treatments** or treatments that affect only the surface properties and are called **thermochemical treatments**. Total treatments can be continuous or isothermal heat treatments. In this annex we deal with the first ones. There are four continuous heat treatments: **hardening, tempering, normalising and annealing**.

Hardening

Heating of the metal followed by quick cooling. Cooling can be done by different means (often oil, water or air).

By hardening the metal a higher resistance to plastic deformation is achieved.

A hardening treatment specific to steels is **austenitisation**, which consists of heating to a temperature above the austenitisation temperature (727 °C), followed by rapid cooling. This treatment results in a martensitic structure (*).

Steel hardening is never a final treatment because the martensitic structure obtained, although very hard, is at the same time very brittle. For this reason, once the steel has been hardened, it is subjected to tempering heat treatment in order to obtain a more ductile and tough structure. The complete treatment of hardening plus **tempering** is called **bonificado**.

Hardening is a suitable treatment for alloy steels or steels with a high carbon content.

(*) Martensite is a supersaturated interstitial solution of carbon in iron obtained by rapid cooling in the austenitic zone. Crystallises in the body-centred tetragonal lattice. It is the hardest component of steel after cementite.

Tempering.

Heating of the hardened metal below its critical temperature (*), holding and cooling.

It is a complementary treatment to hardening. Its purpose is to reduce the internal stresses created after hardening and thereby reduce the brittleness of the quenched steel.

It is carried out in three phases: heating to a temperature below the critical temperature (carbon steels are heated between 450 °C and 650 °C); maintain this temperature for a period of time in order to homogenise the temperature throughout the piece and cooling it slowly .

(*) The **critical temperature** or AC1 is the temperature at which austenite begins to appear (723 °C).

Normalized.

Heating to near hardening temperature (800 °C to 920 °C) until complete transformation to austenite with air quenching.

This treatment removes internal stresses and uniformises the grain size, giving the steel a structure and properties that are considered to be normal and characteristic of its composition.

It is usually used on parts where it is desired to eliminate defects caused by a previous defective treatment or on parts that have undergone forging, hot-rolling or casting. It is a suitable treatment for low carbon steels as it improves their mechanical properties.

Annealing.

Heating to a temperature similar to the normalizing temperature followed by very slow cooling (*).

The purpose of annealing is to soften the steel and make it ductile and malleable for forming or machining.

(*) The difference between hardening, normalising and annealing treatments lies in the cooling rate which determines the hardness and mechanical strength of the part.

ANNEX VI.

Numerical designation of steels according to UNE-EN 10027:2001.244 standard.

Non-alloy steels		
Base steels		Special steel
0	90 Base steels	10 Steels with special physical properties
	1 91 Structural steels in general with $R_m < 500 \text{ N/mm}^2$	11 Structural steels for pressure vessels and others $C < 0.50\%$
	2 92 Other structural steels not suitable for heat treatment with $R_m < 500 \text{ N/mm}^2$	12 Structural steels for pressure vessels and others $C = 0.50\%$
	3 93 Steels with $C > 0.12$ and / or $R_m < 400 \text{ N/mm}^2$	13 Structural steels, pressure vessel steels and other steels with special requirements
	4 94 Steels with C between 0.12 and 0.25% and / or R_m between 400 y 500 N/mm^2	14 Tool steels
	5 95 Steels with C between 0.25 and 0.55% and / or R_m between 500 y 700 N/mm^2	15 Tool steels
	6 96 Steels with $C = 0.55\%$ and / or $R_m = 700 \text{ N/mm}^2$	16 Tool steels
	7 97 Steels with high P or S content	17 Tool steels
		18 Tool steels
		19 Tool steels

Table VI.1. Non-alloy steels. UNE-EN 10027:2001 standard

Alloy metals							
Steel quality	Special steels						
	Tool steel	Other steels	Stainless and temperature resistant steels	Structural steels for pressure vessels and others			
	20	30	40 Stainless steel with Ni <2.5% free of Mo, Nb and Ti	50 Mn, Si, Cu	60 Cr, Ni with Cr between 2 and 3%	70 Cr Cr, B	80 Cr-Si-Mo Cr-Si-Mn-Mo Cr-Si-Mo-V Cr-Si-Mn-Mo-V
	21 Cr-Si Cr-Mn Cr-Mn-Si	31	41 Stainless steel with Ni <2.5% free of Mo, Nb and Ti	51 Mn-Si-V Mn-Cr	61	71 Cr-B Cr-Mn Cr-Mn-B Cr-Si-Mn	81 Cr-Si-V Cr-Mn-V Cr-Si-Mn-V
	22 Cr-V Cr-V-Si Cr-V-Mn Cr-V-Mn-Si	32 High-speed steels with Co	42	52 Mn-Cu Mn-V, Si-V Mn-Si-V	62 Ni-Si Ni-Mn Ni-Cu	72 Cr-Mo with Mo<0.35% Cr-Mo-B	82 Cr-Mo-W Cr-Mo-W-V
	23 Cr-Mo Cr-Mo-V Mo-V	33 High-speed steels without Co	43 Stainless steel free of Mo, Nb and Ti	53 Mn-Ti Si-Ti	63 Ni-Mo Ni-Mo-Mn Ni-Mo-Cu-Ni-Mo-V Ni-Mn-V	73 Cr-Ni-Mo Con Mo <0,4% + Ni>2,0%	83
	24 W Cr-W	34	44 Stainless steel with Mo but free of Nb and Ti	54 Mo Nb, Ti, V W	64	74	84 Cr-Si-Ti Cr-Mn-Ti Cr-Si-Mn-Ti
	25 W-V Cr-W-V	35 Bearing steels	45 Stainless steel with special additions	55 B Mn-B Cr<1.65%	65 Cr-Ni-Mo with Mo<0.4% +Ni<2.0%	75 Cr-V with Cr<2.0%	85 nitriding steel
	26 W Excluding groups 24, 25 and 27	36 Materials with magnetic properties without Co	46 Chemical and high temperature resistant Ni alloys	56 Ni	66 Cr-Ni-Mo With Mo<0.4%+ Ni between 2.0 and 3.0%	76 Cr-V with Cr>2.0%	86
	27 With Ni	37 Materials with magnetic properties with Co	47 Temperature resistant steels with Ni<2,5%	57 Cr-Ni with Cr<10%	67 Cr-Ni-Mo with Mo<0.4% +Ni between 3.5 and 5% or Mo=0.4%.	77 Cr-Mn-V	87 Heat treatable steels
8 98 Steels with special physical properties	28 Others	38 Steels with special physical properties without Ni	48 Temperature-resistant steels with Ni=2,5%	58 Cr-Ni with Cr between 1.0% and 1,5 %	68 Cr-Ni-V Cr-Ni-W Cr-Ni-V-W	78	88 Non-heat-treatable steels Weldable high strength steels
8 99 Steels for other applications	29	39 Materials with special physical properties with Ni	49 Materials with high temperature properties	59 Cr-Ni with Cr between 1.0% and 1,5 %.	69 Cr-Ni except groups 57 to 68	79 Cr-Mn-Mo Cr-Mn-Mo-V	89 Steels unsuitable for heat treatment High strength weldable steels

Table VI.2. Alloy steels. UNE-EN 10027:2001 standard

ANNEX VII.

International equivalents of steels.

Carbon steels							
Europe EN 10083	Spain UNE 36011-12	Germany DIN 17200	Germany STD N°	France NF A35-552-86	Italy UNI 7846	USA AISI/SAE	Japan JIS
	F1110	CK15	1.0401	XC15	C15	SAE 1015	C15C
C25E	F1120	CK25	1.1158	XC25	C25	SAE 1026	S25C
C30E	F1130	CK30	1.1178	XC30	C30	SAE 1030	S30C
C45E	F1140	CK45	1.1191	XC45	C45	SAE 1045	S45C
C55E	F1150	CK55	1.1203	XC55	C55	SAE 1055	S55C
C60E		CK60	1.0601	C60	C60	SAE 1060	S58C
S355	AE355	S355	1.0045	E36-2	FE510	SAE 1024	SCC3
		C21	1.0432			ASTM A105	

Table VII.1. International equivalents of carbon steels.

Alloy steels for quenching and tempering							
Europe EN 10083	Spain UNE 36011-12	Germany DIN 17200	Germany STD N°	France NF A35-552-86	Italy UNI 7846	USA AISI/SAE	Japan JIS
28Mn6	28Mn6	28Mn6	1.1170	28Mn6	28Mn6	SAE 1027	
38Cr2	F1200	38Cr2	1.7003	38C2	38Cr2		
46Cr2		42Cr2	1.7006	46C2	46Cr2		
34Cr4		34Cr2	1.7033	32C4	34Cr4	SAE 5132	SCR430
37Cr4	F1201	37Cr2	1.7034	38C4	38Cr4	SAE 5135	SCR435
41Cr4	F1202	41Cr2	1.7035	42C4	41Cr4	SAE 5140	SCR440
25CrMo4	F222	25CrMo4	1.7218	25CD4	25CrMo4		SCM420
34CrMo4	F1250	34CrMo4	1.7220	34CD4	34CrMo4	SAE 4135	SCM435
42CrMo4	F1252	42CrMo4	1.7225	42CD4	42CrMo4	SAE 4140	SCM440
	F1282				39NiCrMo5		
34CrNiMo6	34CrNiMo6	34CrNiMo6	1.6582	34CrNiMo6	34CrNiMo6		
30CrNiMo8	30CrNiMo8	30CrNiMo8	1.6580	30CND8	30CrNiMo8		
40NiCrMo7	F1272	40NiCrMo8-4	1.6562		40NiCrMo7	SAE 4340	SNM439
36NiCrMo16	F1260	36NiCrMo16	1.6773	35NCD16	35NiCrMo15		
51CrV4	F1430	50CrV4	1.8159	50CrV4		SAE 6150	SUP10
20MnB5	F1293			20MB5	20MnB5	SAE 15B21H	SWRCHB620
30MnB5					30MnB5	SAE 15B28H	
38MnB5		38MnB5	1.5532	38MB5		SAE 15B41H	SWRCHB737
27MnCrB5		27MnCrB5-2	1.7182				
39MnCrB6		39MnCrB6-2	1.7189				

Table VII.2. International equivalents of alloy steels for hardening and tempering.

Spring steels							
Europe EN 10083	Spain UNE 36011-12	Germany DIN 17200	Germany STD N°	France NF A35-552-86	Italy UNI 7846	USA AISI/SAE	Japan JIS
		38Si7	1.5023	40Si7			
	F1451	46Si7	1.5024	46S7	48Si7		
	F1450	51Si7	1.5025	51S7	50Si7	SAE 9250	
	F1440	55Si7	1.5026	55S7	55Si7	SAE 9255	
	F1441	60Si7	1.5027	60S7	60Si7	SAE 9260	SUP 16
		54SiCr6	1.7102	54SiCr6	54SiCr6	SAE 9254	SUP 12
		55SiCr7	1.7106	56SC7	55SiCR7	SAE 9261	
	F1442	60SiCr7	1.7108	61SC7	60SiCr8	SAE 9262	
		46SiCrMo6.3	1.8062	45SCD6	45SiCrMo6		
	F1431	55Cr3	1.7176	55C3	55Cr3	SAE 5155	SUP 9
51CrV4	F1430	50CrV4	1.8159	50CrV4		SAE 6150	SUP 10
	F1460	1.7701	1.7701	51CDV4	51CrMoV4		

Table VII.3. International spring steel equivalents.

Nitriding steels							
Europe EN 10083	Spain UNE 36011-12	Germany DIN 17200	Germany STD N°	France NF A35-552-86	Italy UNI 7846	USA AISI/SAE	Japan JIS
		15CrMoV5.9	1.8521				
	F1711	25CrMo12					
	F1712	31CrMo12	1.8515	30CD12	31CrMo12		
	F1721	31CrMoV9	1.8519		31CrMOV10		
	F1741	34CrAlMo5	1.8507				
		34CrAlNi7	1.8550				
	F1740	41CrAlMo7	1.8509	40CAD6.12	41CrAlMo7		SACM645

Table VII.4. International equivalents of nitriding steels.

Bearing steels							
Europe EN 10083	Spain UNE 36011-12	Germany DIN 17200	Germany STD N°	France NF A35-552-86	Italy UNI 7846	USA AISI/SAE	Japan JIS
100Cr6	F1310	100Cr6	1.3505	100Cr6	100Cr6	6440K ASTM	SUJ2
100CrMn6	F1312	100CrMn6	1.3520	100CrMn6		A485(2)ASTM	
100CrMo7	F1313	100CrMo7	1.3537	100CrMo7.2	100CrMo7	A485(3)ASTM	SUJ4
100CrMo7.3	F1314	100CrMo7.3	1.3536	100CrMo8.3		A485(3)ASTM	

Table VII.5. International equivalents of bearing steels.

Moulds for the pressing of ceramic tiles

Cementation steels							
Europe EN 10083	Spain UNE 36011-12	Germany DIN 17200	Germany STD N°	France NF A35-552-86	Italy UNI 7846	USA AISI/SAE	Japan JIS
C10E	F1510	CK10	1.1121	XC10	C10	SAE 1010	S10C
C15E	F1511	CK15	1.1141	XC12	C15	SAE 1015	S15C
C16E		C16E	1.1148	XC18		SAE 1016	
	F1515	20Mn5	1.1133	20M5	G22Mn3	SAE 1024	SMn420
17Cr3		17Cr3	1.7016	18C3		SAE 5117	
		20Cr4	1.7027				SCr420
16MnCr5	F1516	16MnCr5	1.7131	16MC5	16MnCr5	SAE 5115	
20MnCr5	F150.D	20MnCr5	1.7147	20MC5	20MnCr5	SAE 5120	SMnC21H
	F1551	15CrMo5	1.7262	12CD4FF			SCM21
18CrMO4	F1550	18CrMO4	1.7242	18CD4	18CrMO4		SCM418
20MoCr3		20MoCr3	1.7320	20MoCr3			
20MoCr4	F1523	20MoCr4	1.7321	20MoCr4		4118	SCMV1
16NiCr4	F1581	16NiCr4	1.5714	16NiCr4	16NiCr4		
18NiCr5-4	F1580	18NiCr5-4	1.5810	20NC6			
17CrNi6-6		15CrNi6	1.5919				
15NiCr13	F1540	14NiCr10	1.5732	14NC11	16NiCr11	SAE 3415	SNC21
20NiCrMo2KD	F1522	20NiCrMo2-2	1.6523	20NCD2	20NiCrMo2	SAE 8620	CNCM220
17NiCrMo6-4		17NiCrMo6-4	1.6566	18NCD6	18NiCrMo5		
18CrNiMo7-6		17CrNiMo6	1.6587	18CrNiMo7-6			
	F1560	14NiCrMo13-4	1.6657		15NiCrMo13		9310RH

Table VII.6. International equivalents of case hardening steels.

Cold work tool steels							
Europe EN 10083	Spain UNE 36011-12	Germany DIN 17200	Germany STD N°	France NF A35-552-86	Italy UNI 7846	USA AISI/SAE	Japan JIS
	F5238	120W4	1.2516		U115W4KU	F1	
55WCrV8	F5242	60WCrV8	1.2550	45WCrV8	U55WCr8KU	S1	SKS-41
	F5247	58SiMoCr8	1.2103		U58SiMoKU+V	S5	
90MnCrV8	F5229	90MnCrV8	1.2842	90MnV8	U88MnV8KU	A681(O2)ASTM	
95MnWCrV5	F5220	100MnWCrV5	1.2510	90MnWCrV5	U95MnWCr5KU	A681(O1)ASTM	SKS-3
X210Cr12	F5212	X210Cr12	1.2080	X200Cr12	UX210Cr13KU	A681(D3)ASTM	SKD-1
X160CrMoV121	F5211	X155CrVMo12	1.2379	X160CrMoV12	UX155CrVMo12.1KU	A681(D2)ASTM	SKD-11

Table VII.7. International equivalents of cold work tool steels.

Hot work tool steels							
Europe EN 10083	Spain UNE 36011-12	Germany DIN 17200	Germany STD N°	France NF A35-552-86	Italy UNI 7846	USA AISI/SAE	Japan JIS
35CrMo8	F5307	56NiCrMoV7	1.2714	55NiCrMoV7	55NiCrMoV7KU	L6	STK-4
40NiCrMoV16	F5305	X45NiCrMo4	1.2767	40NiCrMoV16	40NiCrMoV16KU	6437 E ASTM	
X38CrMoV5.1	F5317	X38CrMoV5.1	1.2343	X38CrMoV5 X	X37CrMoV51KU	6437E ASTM	SKD-6
X40CrMoV511	F5318	X40CrMoV5.1	1.2344	X40CrMoV5	X40CrMoV5.11KU	6408A ASTM	SKD-61
32CrMoV12-28	F5313	X32CrMoV3.3	1.2365	32CrMoV12-28	X30CrMoV1227KU	H10	SKD-7

Table VII.8. International equivalents of hot work tool steels.

Easy to machine steels							
Europe EN 10083	Spain UNE 36011-12	Germany DIN 17200	Germany STD N°	France NF A35-552-86	Italy UNI 7846	USA AISI/SAE	Japan JIS
11SMn30	F2111	9SMn28	1.0715	S250	CF9SMn28	SAE 1213	SUM22
11SMnPb30	F2112	9SMnPb28	1.0718	S250Pb	CF9SMnPb28	SAE 12L13	SUM22L
11SMn37	F2113	9SMN36	1.0736	S300	CF9SMn36	SAE 1215	SUM25
11SMnPb37	F2114	9SMnPb36	1.0737	S300Pb	CF9SMnPb36	SAE 12L14	
15SMN13		15S10	1.0710	13MF4		SAE 1115	SUM31
10S20	F2121	10S20	1.0721	12MF4	CF10S20		
10SPb20	F2122	10SPb20	1.0722		CF10SPb20		
36SMN14	F2131			35MF6	CF35SMn10		SUM41
36SMnPb14	F2132			35MF6Pb	CF35SMnPb10	SAE 1137	
35S20		35S20	1.0726	35MF4			
35SPb20		35SPb20	1.0756				
46S20		45S20	1.0727	45MF4			
46SPb20		45SPb20	1.0757				
44SMn28	F2133	44SMn28	1.0762	45MF6	CF44SMn28	SAE 1144	SUM 43
44SMnPb28		44SMnPb28	1.0763	44SMnPb28	CF44SMnPb28	SAE 1144	SUM 43
		60S20	1.0728				
		60SPb20	1.0758				
		C45PB	1.0504				

Table VII.9. International equivalents of free machining steels.

ANNEX VIII. Shore hardness Scales.

Definition:

The hardness of a rubber is a measure of its stiffness against deforming forces. It is expressed in empirical values, (Shore scales) although these are related to its modulus of elasticity.

Measurement:

This is a standardised test (*UNE-ISO 7619-1:2011 standard . "Vulcanised or thermoplastic rubber. Determination of indentation hardness. Part 1: Tester method (Shore hardness))*).



Figure VIII.1. Shore A hardness test.

Shore hardness is measured by means of a hardness tester. The instrument is based on the measurement of the penetration of a tapered tip against the reaction of a calibrated metal spring.

When the Shore A durometer gives readings above 90°, the use of the Shore D durometer, which has a stiffer spring, is recommended. Both methods are described in the Spanish standard UNE 53130, the American ASTM D2240 and the German DIN 53505.

In the various types of pocket hardness testers the force is applied by hand (Figure VII.1), and therefore is indeterminate. Greater precision and reproducibility is obtained with hardness testers fixed on supports, where the force applied is always 1 Kgf for the A durometer (Shore A) and 5 Kgf for the D durometer (Shore D).

Shore scales:

Shore scales are hardness scales for flexible materials. Table VIII.1 shows different Shore scales, adapted to the hardness of each material, and Table VIII.2 shows some equivalences.

Scale	Materials	Penetrator	Load
Shore A	Soft rubbers, plastics, elastomers.	35° truncated cone.	822 g
Shore B	Elastomers, hard plastics, paper and fibrous material.	30° cone.	822 g
Shore C	Gypsum or perlite coatings, elastomers and plastics of medium hardness.	35° truncated cone.	4536 g
Shore D	Hard rubbers and thermoplastics.	30° cone.	4536 g
Shore DO	Dense granular materials and textile reels.	3/32 inches ball	4536 g
Shore O	Very soft elastomers, textile reels, soft granular materials.	3/32 inches ball	822 g
Shore OO	Light foams, sponges.	3/32 inches ball	113 g
Shore OOO	Gels and sponges.	1/2 inch ball	113 g

Table VIII.1. Shore hardness scales.

Shore A	Shore D	Shore O	Shore OO
100	58		
95	46		
90	39		
85	33		
80	29	84	98
75	25	79	97
70	22	75	95
65	19	72	94
60	16	69	93
55	14	65	91
50	12	61	90
45	10	57	88
40	8	53	86
35	7	48	83
30	6	42	80
25		35	76
20		28	70
15		21	62
10		14	55
5		8	45

Table VIII.2. Equivalences between some Shore hardness scales.

Frequently asked questions.

When should the good face relief be compensated with a back side relief?

A very pronounced relief gives way to significant differences in compactness within the same piece, resulting in quality losses. To compensate for differences in compactness, it is common to design the back side relief in such way to reproduce the relief on the back of the tiles, keeping the thickness of the tiles approximately constant and combining it with a back side design that guarantees a base of stable support.

What can happen if the dimensions of the lower punch are much larger than the surface of the magnetic blocks?

An excessive difference between the dimensions of the magnetic block and the lower punch, i.e. an excessive “overhang” of the punch, can lead to punch marking, visible on the finished part, or even to deformation of the lower punch. To prevent this, a perimeter sleeve is installed on the magnetic block called a “jacket”.

Why the wear resistant plates protecting the die box are not reversible?

Because the feeder car, in its movement of loading the cavities, wears the metal sheet and if this is turned over, with continued use, powder penetrates at some points where the wear is greater between the metal sheet and the die box. The small deformation this causes is sufficient to ensure that the loading of the cavities is not uniform.

What type of liners should be installed in a double mould?

Double moulds have, as is well known, liners inside the upper die box and inside the lower die box and any type of liner can be installed. However, the following points should be made:

- Generally, fixed liners are installed inside the lower die box but, if requested by the tile manufacturer, removable liners can be installed which offer greater ease of replacement. This is an important factor in companies where the mould supplier is located at a long distance.
- However, it is often preferred to install fixed liners inside the upper die box, since they offer greater safety for operators when replacing them on the press itself. It is important to take into account the difficulty of handling one-piece liners, especially in large formats, when they have to be removed or installed in the upper part of the mould, which means that in this case, fixed liners are preferred.

Can removable liners of any format be used?

Initially, the format is not a limiting factor for the use of removable liners, although their installation can be a little more complicated. It is possible to install large size removable liners under quality and safety conditions, with the help of tools that allow their transport and installation. However, under the same conditions of quality in pressing, it is advisable to use of fixed liners for large formats.

Can reversible liners be used in any format?

No. They should only be used for small or medium-sized formats, as their use requires the die box to be removed in the factory itself and then installed again, which is a very difficult operation to carry out in the factory on presses equipped with large moulds. This is why for these large presses and formats, this type of liner are useless.

It should also be considered that in large formats these liners weaken the die box as both, fixed and removable liners are embedded and the bottom of the die box keeps its width. However, these liners are bolted to the full thickness of the die box, which limit its width and, therefore, limit its strength.

Can isostatic punches be used on the good face of the tiles?

Technically it is possible, but not recommended, as the isostatic effect of the punches is to compensate for differences in compactness with differences in thickness, which are less visible on the back side than on the good face.

However, some moulds are equipped with isostatic punches for the good face, especially for the forming of some stone-effect models or models with very pronounced reliefs, as the small differences in thickness caused by the isostatic compensation are not visible on these tiles.

Can the number of strokes per minute of the pressing cycle influence the isostatic effect of the punches?

The stage of the pressing cycle which can influence the isostatic effect of the punches is the forming pressure application time, i.e. the duration of the second pressing. Any other stage of the pressing cycle has no effect on the isostatic compensation.

In isostatic grid punches (MACER MRPV type punches) the speed of the second pressing stage can influence the isostatic effect, as the oil passes from one cell of the same punch to another, there must be a pressure difference between them. The oil flow rate to be transferred depends on this pressure difference and therefore, if the speed of the second pressing is increased, it may be too high to compensate for the pressure differences. Naturally, the design of the connections between these cells plays a critical role.

Can isostatic punches cause problems in large format tiles that are going to be polished after firing?

As the isostatic effect consists of maintaining a constant compactness at the cost of slightly varying the thickness, visible defects may occur after polishing tiles pressed with isostatic punches, especially in very large formats. For this reason, in practice, it is always preferred to install solid punches for large format tiles that are going to be polished after firing.

When should isostatic punches be avoided?

It may not be advisable to use isostatic punches if the tiles are intended to receive a lapping treatment after firing, as the small thickness differences caused by the isostatic compensation may become visible after the treatment.

Is it convenient to press tiles with very pronounced reliefs with a double mould?

If the relief is very pronounced, it is not advisable. For this type of tiles the back side relief must be compensated. This makes it difficult to extract from this type of mould and often the tile may even get stuck. This problem can also be aggravated in single fired tiles, as differences in compaction can become visible in some types of glazes and even lead to defects.

Is it possible to adjust the thickness at will with a double mould?

In top-forming moulds, it is very difficult to adjust the thickness of the pressed tiles at will. The thickness is conditioned by the construction characteristics of the mould itself, such as the thickness of the punches. MACER has now introduced technical improvements in their construction that allow the thickness to be varied by a margin of 3 mm.

When is it advisable to use an inverted entry mould?

The inverted entry mould is usually used when looking for its strong points (simplicity, low cost, high productivity) but there is no need to turn the tiles around at the exit of the press, generally in very large formats and/or very thin thicknesses.

It is not advisable to use entry moulds for some reliefs production. Due to their characteristics, they can be easily damaged when they are ejected from the pressing area after extraction and deposited on the roller assembly, such as pointed pyramid-type reliefs, reliefs with very pronounced edges, etc. Therefore, the inverted entry mould may be a good option for them.

Can tiles with spacer be obtained by pressing with an inverted entry mould?

Yes. With the inverted entry mould, the punches are reversed but the liners are kept in the same position as they were in the entry mould and therefore they have angle and spacer. Consequently, when pressing with the good face upwards, the tiles also have a spacer, although in a lower position, i.e. close to the back side.

Why is pack extraction advisable for large format tiles?

Because the increase in dimensions of the tile after pressing and extraction, in absolute value, always exceeds the value that can be given to the angle of the liners. Therefore, if the extraction is carried out with a “delay” (“free extraction”), the tiles rub excessively against the liners, resulting in chafing, cracks or scratches on the edges.

Generally, 60 cm onwards side, it is advisable to perform sandwich extraction.

When is it advisable to press with a third pressing?

A third pressing is usually carried out on special pieces, such as skirting boards, edges, etc. or pieces with a high relief. Also, as a possible solution to the recurrent occurrence of lamination problems.

When is it convenient to perform the sandwich extraction?

It is recommended for large formats (with at least one side longer than 60 cm) and for any format if pressing pastes with excessive post-pressing expansion may cause small expansion cracks.

Which mould gives the best side finish of the tiles?

Double moulds. With an entry mould, a good lateral finish is achieved by performing sandwich extraction. However, in delayed extractions, generally, there is a poorer lateral finish.

Can the liners be changed at the foot of the press?

Any type of removable liner can be changed at the foot of press. To replace the fixed liners, however, the mould must be removed and taken to the workshop.

Is it possible to use the central liners, i.e. the liners that separate cavities without a partition wall, when changing liners?

It is not convenient. These liners must not be rectified and therefore new ones should always be installed. If they are going to be used again, keep in mind the lost measurements during grinding, so the liners on the opposite side must be supplemented to maintain the dimensions of the format. However, this means that the centres of the cavities are lost and the punches are off-centre.

Can a mould be removed and stored all in one piece, i.e. with the upper part fitted on top of the lower part?

This can be done if the contact between the lower punches and the upper ones is avoided. For this purpose, sheets of some strong elastic material are placed between them.

However, storing the mould this way has the disadvantage that almost all of its components are inaccessible for any maintenance activity.

What are the steps for removing a mould and why?

There is not an established procedure but, in general, the lower part of the mould is removed first and then, with the press in manual mode, the upper isostatic or fixed plate is lowered and placed on a pallet in order to be removed with a forklift.

Although this is the common way of removing the used mould by many companies, it can be done the other way around, but the procedure described is preferable because by removing the lower part first, a large space is created in the press and the operation of uninstalling and removal the upper part is easier.

How serious is a possible bellows rupture and what defects can it cause?

A bellows breakage is a serious problem, as it causes the deposition of powder between the bench plate and the ejecting plate. Consequently, the punches lose parallelism during pressing, causing wedging and rectangularity defects of the tile, as well as a slight inclination of the ejecting plate-magnetic blocks-lower punches system, which results in the premature wear of the punches.

A bellows breakage can also lead to breakage of mould components such as candles, limit switches on SMUs, ring candles, pistons, etc.

Is it necessary to use high hardness rubbers such as Shore A 95 to obtain good relief sharpness even if this increases the risk of punch sticking?

This type of rubbers can be used, although in order to avoid punch sticking, a less harder rubber with a reduced thickness can be used. By doing so detail sharpness is maintained and sticking is avoided.

What defects can be caused by off-centre upper punches of an entry mould or an inverted entry mould?

Poor centring of the upper punches leads to uneven deaeration with areas where the occluded air has more difficulty escaping, and areas where the air is preferentially expelled. This may lead to the lamination in areas where it is more difficult to evacuate the air and/or to the dragging of fine particles and agglomerates in areas with preferential air evacuation. The latter can lead to the appearance of a compactness gradient that generates dimensional defects such as crescents and even cracks, especially in wall single fast firing products.

Which factors should be considered when deciding whether a given format can be produced on a given press?

The main parameter that determines the suitability of a given press to produce a given format is its maximum pressing force ($F_{\max}$). With this data it is possible to calculate the number of outlets (N) that can be installed with the expression:

$$N = \frac{0,8F_{\max}}{P \cdot S_A} \cdot 1000$$

Where P is the press pressure and S_A is the surface area of a cavity.

Once the number of outlets has been determined, it is necessary to check if there is enough space in the mould for them. For this, the press clearance (space for the mould) and the maximum loading width of the installed feeder car, are needed. If the dimensions are compatible with the mould, compatibility with other elements such as the dimensions of the plunger and the depth of the press bed must be checked. Finally, it is advisable to check the compatibility of the new format with the rest of the production facilities, such as the dryer, distance between conveyor belts, roller boxes, etc.

Knowing the maximum pressing force that a press is capable of developing, what is the maximum recommended working force? What can happen if this recommended force is exceeded?

Press manufacturers generally advise not to exceed 85 % of the maximum press force.

If manufacturing conditions require it, this value may occasionally be exceeded. For example, when a dryer batch of powder is pressed, increasing the pressure will maintain the set compactness. However, if the press is forced to work continuously at values very close to its limit, the hydraulic circuit may suffer.

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