INNOVATIVE PROCESS FOR CERAMIC TILE MANUFACTURE BY DOUBLE PRESSING WITH CONTINUOUS PRECOMPACTION

A. Bresciani, C. Ricci

SACMI Imola

ABSTRACT

The recent introduction of systems based on double-pressing production technology has ushered in an interesting development in the manufacture of ceramic products, particularly in porcelain tile, which focuses on imitating natural products (marbles, granites, etc.) consisting of a ceramic body with an appropriately decorated surface coating. The range of attainable "in-pressing" effects has thus been extended, without affecting line productivity.

This paper presents the latest development in this technology, involving the preparation of precompacted ceramic bodies by a continuous process.

The constraints of the traditional charging and compaction systems are thus avoided, achieving total decoration, inside the tile body as well.

The new process can be briefly summarised as follows:

- *powders are fed by a belt, with the possibility of obtaining effects inside the body mass (coloured stripes, tiles with different shades, etc.) by acting directly on the deposition of the powders on the belt;*
- *continuous precompaction of powder thickness directly on the conveyor belt, until achieving intermediate density and mechanical strength values in respect of the final pressing;*
- *cutting on the continuous travelling belt of prepressed pieces into sizes compatible with the final pressing;*
- *surface decoration of the precompacted pieces, combining the most varied techniques currently available;*
- *introduction into the die and repressing of the pieces to standard density and mechanical strength values;*
- *possible reduction to smaller sizes by cutting operations performed on the green pieces.*

The new process allows making sheets and ceramic tiles of any dimension and thickness, particularly products decorated on the surface and inside the piece, at high speed.

In addition, the possibility of varying the aesthetic effects is practically unbounded, as there are no constraints regarding the form or dimensions of the charging systems.

The application of this innovative concept will undoubtedly enable revolutionizing the traditional pressing sections, contributing speed and flexibility to the lines, and opening up new prospects for the evolution of products with enhanced technical and aesthetic features.

1. INTRODUCTION

The most widely used technique for ceramic tile forming is powder compaction by means of uniaxial hydraulic presses, in which the tiles are formed in one or more cavities inside the die.

In the case of dies with a single cavity, these consist of a bottom punch, connected to the compact ejector which moves inside the die, and whose dimensions are slightly larger (generally a few tenths of a mm) than the dimensions of the punch itself. The bottom punch with the die forms the cavity that is charged by the filler carriage with spray-dried pressing powder. The die is completed by the top punch, fixed to the mobile press frame, whose dimensions enable it to enter the die cavity or rest on its top plane; in this last case, the die must be able to slide vertically under the effect of the press stroke. The descent of the top punch until resting gently on the charge and the successive pressure exerted by the main press cylinder are the cycle stages in which the piece is formed.

In the course of the years, ceramic tile manufacture has been increasingly focused on fabricating porcelain tiles that tend to reproduce the aesthetic characteristics of natural stones, like marble and granite. These types of tiles are mainly made by two die filling technologies: the through-body charge and the double charge.

The first technology is based on depositing a charge made up of dispersed veins of coloured powder in the base spray-dried powder in the hopper of the press filler carriage, by the relevant systems.

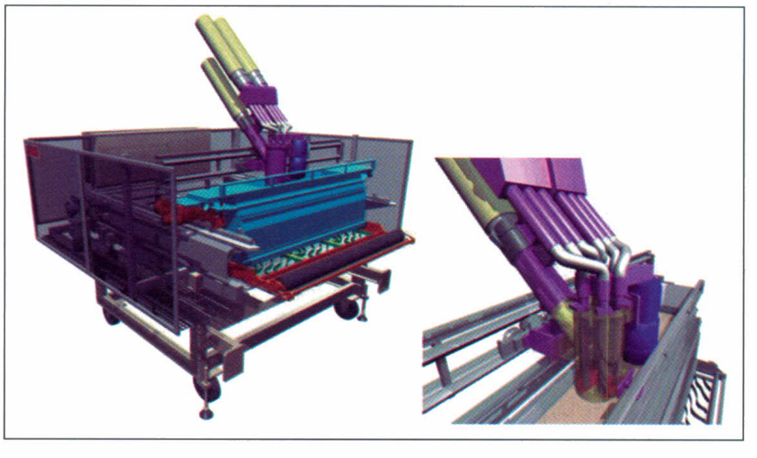

Figure 1. Through-body charging systems

The charge is released from the hopper onto a grid located below, which then conveys it to the die cavity. The grid must correspond as closely as possible to the coloured veins present in the hopper to subsequently arrange them appropriately in the tile. The coloured veins and the effects that were present in the carriage hopper thus reappear throughout the whole tile, which explains the term "through body". This technology is particularly suitable for fabricating mixed products, with different shades and veins.

As the term indicates, the double-charge technology consists of filling the die cavity in two different moments of the cycle (Figure 2).

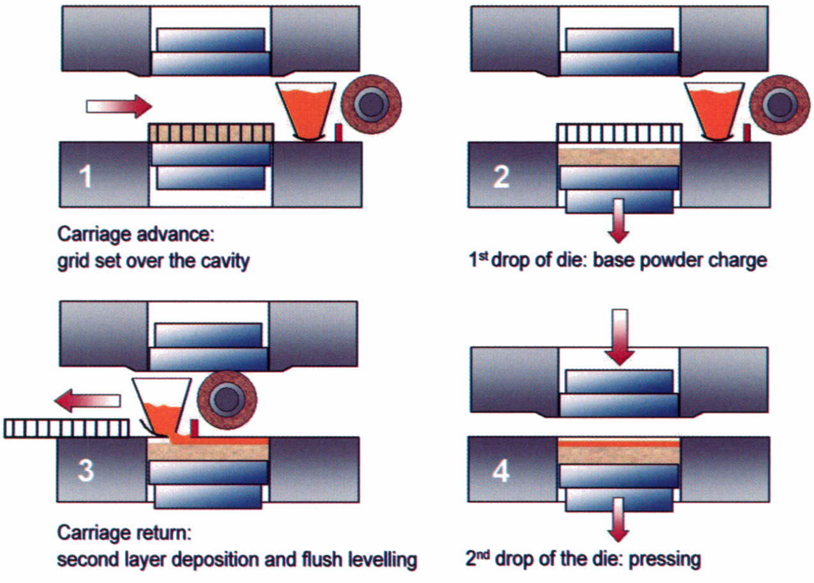

Figure 2. Schematic of the double-charge operation

First, the base powder is deposited, i.e., a layer of generally plain material or at most with a salt and pepper effect, which forms the main part of the tile body. Subsequently, a dispenser that is able to pass through the die opening applies a second layer, generally a few millimetres thick, which forms the actual tile decoration. The second layer can, for example, to be made up of micronized powders, if tiles with characteristics similar to those of Travertine-type marble are to be made, or of grits and flakes for manufacturing products similar to granite, or spray-dried glazes for fabricating rustic products, where the multiplicity of inks that fuse reciprocally contributes great naturalness and depth of effect.

However, the two foregoing technologies display certain disadvantages.

The through-body charge is particularly limited when it comes to obtaining different aesthetic effects from one piece to another. The aesthetic effect that is obtained, in addition to the arrangement and variable quantity of colours used, is strongly linked to the fixed geometry of the grid that conveys the charge to the die cavity. In fact, this feature generates repetitivity in the decoration, which is generally rather unattractive in the tile installation.

Another negative feature of this technique is determined by the fact that in the die charging stages, the spray-dried powder first slides on a sheet and then on the die; this movement inevitably causes a remix of this powder, at the expense of the definition of the effects obtained with the colour veins in the grid.

The main disadvantage of the double-charge technology is, however, the low productivity of the line due to the long time required by the carriage to run a cycle. In fact, filling of the press die cavity takes place in two separate stages, with a considerable increase in pressing time.

In order to eliminate this problem and respond to the growing need for greater creative freedom in the search for more carefully wrought aesthetic effects, a new double-pressing production technology has recently been introduced in the market, which enables obtaining absolutely innovative products, unattainable with the preceding techniques.

The TwinPress® system allows forming a tile in two pressing stages, with two quite different presses, incorporating between both, multiple wet and dry decoration systems. The piece is essentially formed in the first press in a completely conventional manner, if the fact is excluded that forming pressure in this first press remains very low (50-80 bar). This precompacted tile is then put through a line equipped with several dry and wet decoration systems, including possible applications of flakes and other semi-processed products. The second press is located at the end of the line, and this press, fitted with an appropriate system for introducing the precompacted and decorated piece in the die cavity, applies the final pressing at the traditional compaction pressure (400-500 bar).

At this point, the tile is perfectly formed and ready to be dispatched to the subsequent manufacturing process stages.

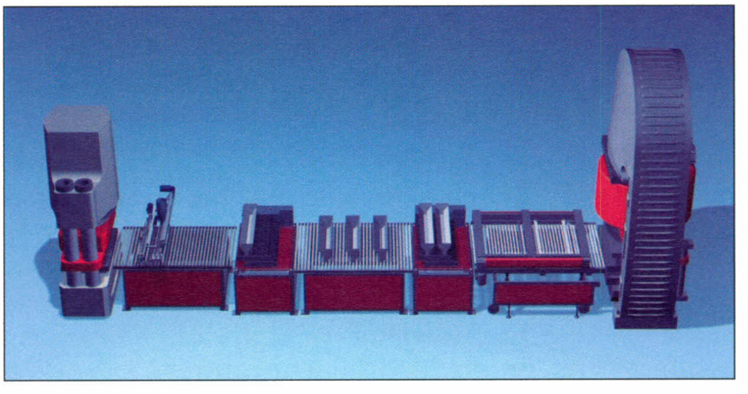

Figure 3. Schematic of the facility with double-pressing technology and only dry decoration

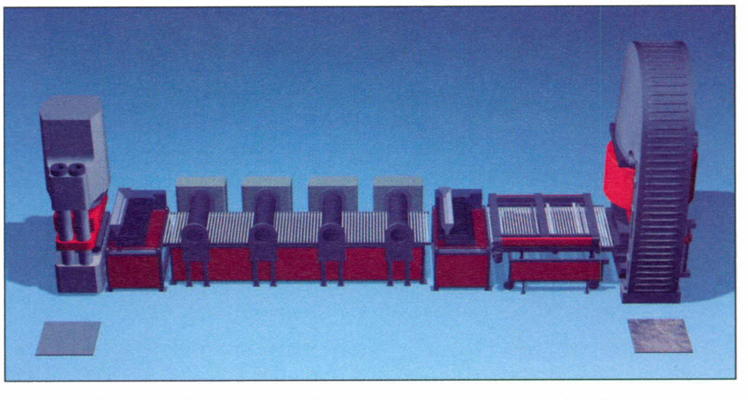

Figure 4. Schematic of the facility with double-pressing technology and mixed wet and dry decoration

As the foregoing brief description has set out, the double-pressing technology provides remarkable freedom in the search for aesthetic effects, since the deposition of the decoration occurs in the wide space between the two presses. The limitations of the double charge therefore fall away, i.e., the need to use a system inside the die opening and the reduction of the pressing cycle rate due to the time lost in the deposition of the second charge layer inside the cavity.

In essence, this technology represents a truly effective response to the demand to make decorated tiles in pressing, since this provides unlimited aesthetic potential without in any way penalizing line productivity.

Even so, from a compaction point of view this new technology, as described above, is wholly based on traditional hydraulic pressing systems resembling those already used in production.

Though from a practical standpoint this favours integration with the current way of working, from the point of view of research, it is certainly interesting to study new solutions.

The concept of continuous powder precompaction has thus been developed, which offers interesting theoretical and application opportunities.

2. THEORETICAL PRINCIPLES OF CONTINUOUS PRECOMPACTATION

From a purely conceptual point of view, continuous precompaction can be appropriately carried out by subjecting the layer of spray-dried powder to the action of a pair of rigid rollers, with axes horizontal and perpendicular to the powder direction of advance (Figure 5).

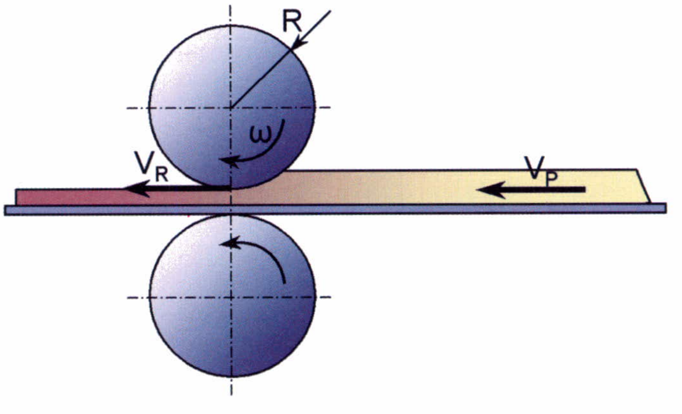

Figure 5. Conceptual scheme of continuous precompaction

The powder is conveyed at a uniform velocity V_P equivalent to the peripheral tangential velocity V_R, according to the relation

$$V_R = \omega R \quad (1)$$

where ω is roller angle velocity and R its outer radius.

Advancing through the gap between both rollers, the powder layer undergoes progressive compaction that increases its bulk density up to the final output value.

In order to evaluate the compacting action, density and pressure applied to the powder, a model needs to be derived for the compressibility of the ceramic powder. The Kawakita and Lüdde model [1] has thus been adapted, according to which density d depends on compaction pressure p, according to the relation:

$$d = d_0\left(1+\frac{c_1 c_2 p}{1+c_2 p}\right) \qquad (2)$$

where d_0 is bulk density of the non-compacted powder and c_1 and c_2 are the characteristic constants to be determined from case to case. The mean values for porcelain tile bodies with a moisture content of 5.5%, which will be assumed as the basis for these considerations, are:

$d_0 = 1.016\ g/cm^3$
$c_1 = 1.1753$ (dimensionless)
$c_2 = 0.0131\ bar^{-1}$

The variation of density versus compaction pressure (assuming the above values for the constants) is plotted in Figure 6.

As the graph shows, the density gradient decreases with increasing pressure. This indicates that in order to obtain intermediate densities relative to the normal final values, the precompaction stage can be limited to very low pressures. In the plot, point **A** marks the density of the non-compacted powder, point **C** the normal compaction value for porcelain tile (400 bar, density 2.02 g/cm^3), and point **B** a reasonable precompaction target (70 bar, density 1.59 g/cm^3).

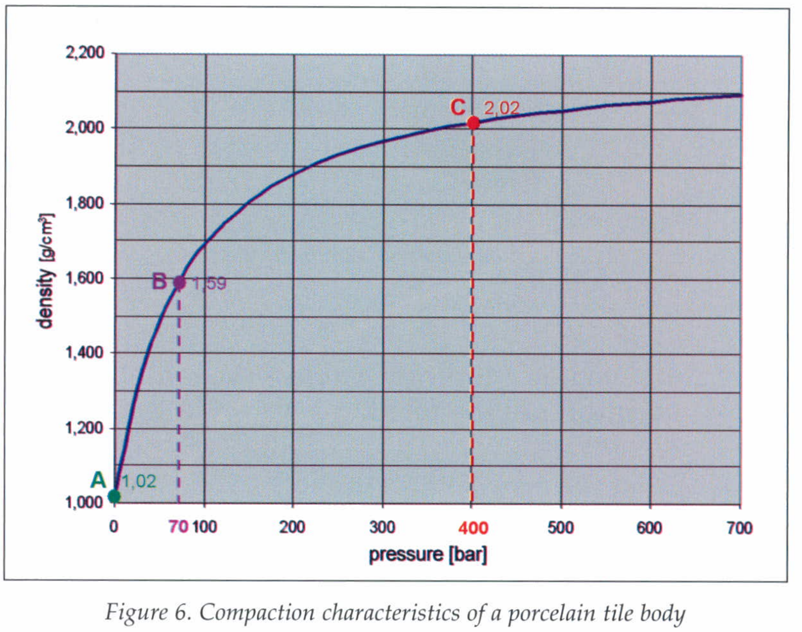

Figure 6. Compaction characteristics of a porcelain tile body

After selecting the compaction model, it is possible to calculate the variation of the pressures that develop in compression by the cylindrical surface of the compacting roller.

For this, the scheme of Figure 7 is used, where h_0 is powder input thickness, hf is compacted band output thickness, x the abscissa parallel to the powder direction of advance, and R the outer radius of the compacting roller.

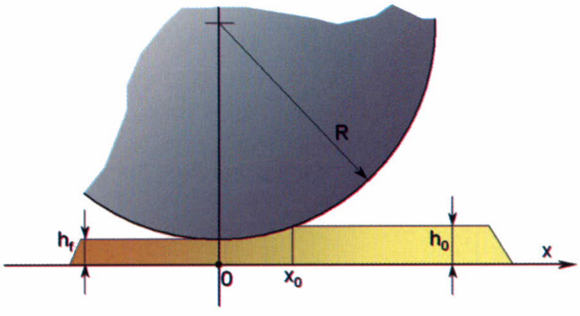

Figure 7. Geometry of the system

For a generic value of the x abscissa between 0 and x_0 (corresponding to the initiation of powder and roller contact), the corresponding thickness is:

$$h(x) = h_f + R\left(1 - \sqrt{1 - \left(\frac{x}{R}\right)^2}\right) \qquad (3)$$

so that the value of the abscissa x_0 in relation to h_0 is

$$x_0 = \sqrt{R^2 - (R - h_0 + h_f)^2} \qquad (4)$$

Bulk density rises during compaction, i.e., moving along the abscissa from x_0 to 0 (which is equivalent to going from h_0 to h_f), and is inversely proportional to thickness h(x). It is therefore possible to set density as a function of abscissa x:

$$\mathbf{d(x) = d_0 \frac{h_0}{h(x)} = d_0 \frac{h_0}{h_f + R\left(1 - \sqrt{1 - \left(\frac{x}{R}\right)^2}\right)}} \qquad (5)$$

Inverting relation (2) and taking compaction pressure p as a function of bulk density d gives:

$$p = \frac{d - d_0}{c_2\left(c_1 d_0 - (d - d_0)\right)} \qquad (6)$$

Introducing the density relation (5) in Eq. (6) yields an expression for compaction pressure as a function of h(x)

$$p(x)=\frac{d_0\dfrac{h_0}{h(x)}-d_0}{c_2\left(c_1d_0-\left(d_0\dfrac{h_0}{h(x)}-d_0\right)\right)}=\frac{\dfrac{h_0}{h(x)}-1}{c_2\left(c_1-\left(\dfrac{h_0}{h(x)}-1\right)\right)} \tag{7}$$

Figure 8 plots the variation of the functions h(x), r(x) and p(x) with the assumption of precompaction in a single throughput (with a cylindrical roller), from 22 to 14 mm thick, at a theoretical output density of 1.59 g/cm^3, corresponding to a maximum end compaction pressure of about 70 bar.

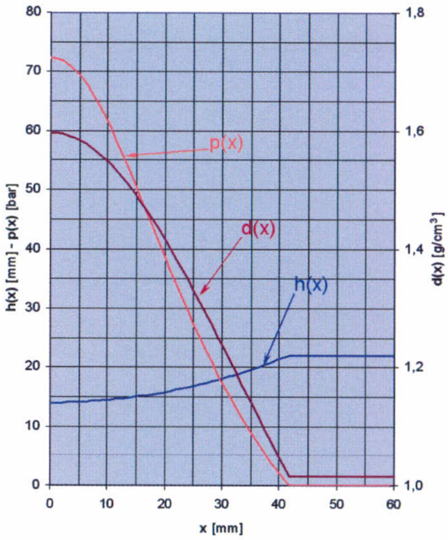

Figure 8. Variation of h(x), d(x) and p(x) (cylindrical roller)

In order to avoid problems of spray-dried powder escaping at the entrance of the compactor (abscissa x_0) with the ensuing refusal of the powder to let itself be compressed, it is important to use high R/h_0 ratios, i.e., much higher compaction radii to input thickness. The use of the roller minimizes friction resistance and allows the system to achieve interesting total efficiencies, with reduced installed power.

Indeed, it is interesting to use a series of rollers with decreasing heights, sheathed in a very rigid material; the sum of all this being equivalent to a roller of infinite radius, with evident advantages for compaction efficiency.

Figure 9 plots the variation of the characteristics h(x), d(x) and p(x) in the case of a constant inclined compaction plane, where the function h(x) adopts the form:

$$h(x)=h_f+\frac{h_0-h_f}{x_0}x \tag{8}$$

where x_0 is the initial abscissa of powder contact with the inclined plane, defined by the geometry of the system. In the case shown, h_0 = 22 mm, h_f = 14 mm and x_0 = 300 mm.

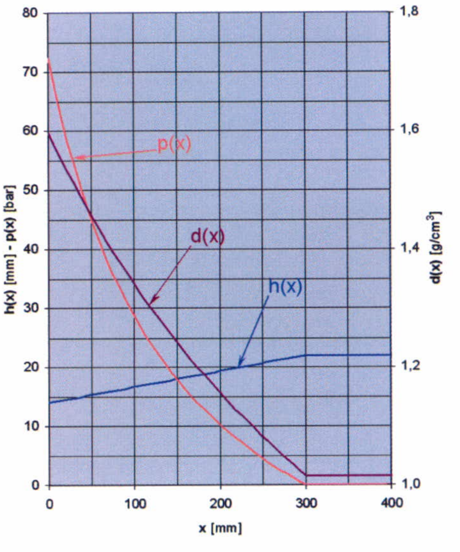

Figure 9. Variation of h(x), d(x) and p(x) (inclined plane)

3. CONTINUOUS PRECOMPACTION APPLICATIONS

The purpose of continuous precompaction is to make ceramic tiles or sheets with body effects of singular value.

This objective is achieved by depositing a continuous layer of spray-dried powder with the desired decorative effects throughout its entire thickness on a conveyor belt, with the appropriate systems, (please see the scheme in Figure 10). Appropriate dimensioning of the powder conveyor belt allows increasing the complexity of the decoration at will (in terms of successive applications/elaborations), without conditioning the productivity of the system, which remains at the maximum values allowed by the successive phases.

After crossing the application/elaboration stations, the belt conveys the powder into the continuous compactor, which puts out a continuous compacted band with values of density and mechanical strength comparable to those of the tiles precompacted with the TwinPress technology®.

Thus, the powder suitably deposited on the conveyor belt is put through the compactor without any movements or mixing, thus "freezing" the effects present and preserving these unaltered for the subsequent forming stages.

As a last step in the process, the material exiting the precompaction system is subjected to transverse cutting on the fly and side rectification, to obtain a suitable rectangular size for direct placing in the traditional press cavity for the definitive pressing.

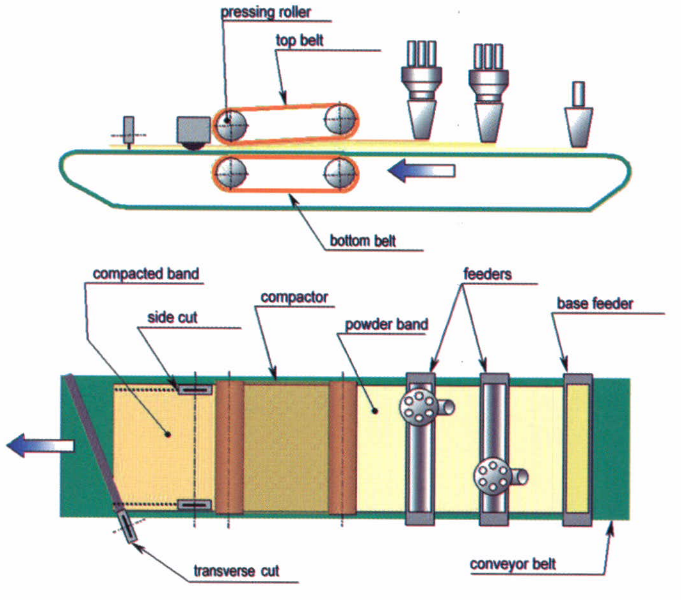

Figure 10. Schematic of continuous precompaction

Cutting is performed by high-speed rotating diamond disks, and enables obtaining high dimensional accuracy. Figure 11 presents the difference between the profile obtained with a cutting operation on the fly and the desired theoretical geometry, for a final fired size of 600x1200 mm. To be noted is the maximum error of the longest sides (cut on the fly) of 0.35 mm in a length of around 1300 mm, which is therefore quite acceptable in view of the subsequent repressing stage. The error on the shorter sides is practically negligible.

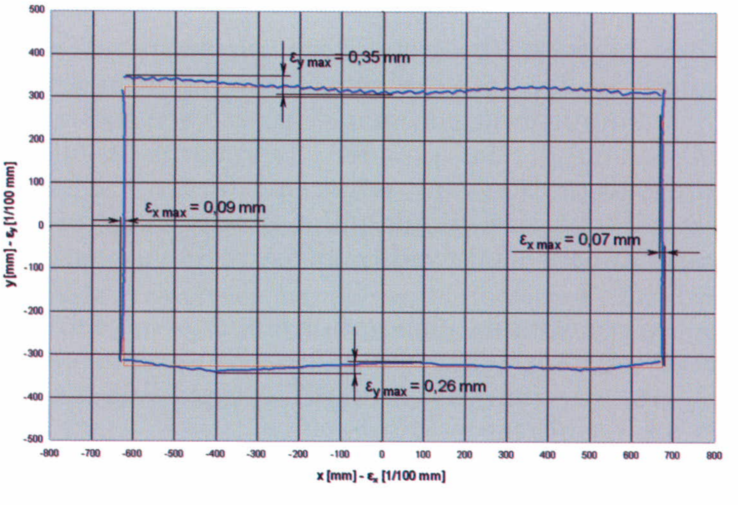

Figure 11. Real and theoretical cutting profiles

The stages of the new forming and decoration process can therefore be summarized as follows:

<u>Powder feed</u>

The spray-dried powder is fed by means of the appropriate proportioning systems directly onto the conveyor belt; this enables easily realizing effects in the body (veins, shades, etc.) using numerous automatic and robotized systems.

Continuous precompaction

The deposited powder layer is precompacted between two belts to a mechanical consistency that enables it to be transported and worked.

Cutting on the fly

The precompacted material is subjected to a transverse cutting operation on the fly without interrupting the advance; at the same time, the edges are also rectified with a view to obtaining a piece with a well-defined geometry.

Subsequent decorations

The precompacted piece is conveyed on rollers for possible further surface decoration, combining the most varied techniques currently available.

Final pressing

Finally, the precompacted and decorated piece is introduced in the die and given its definitive pressing to density and mechanical strength values analogous to those of traditional porcelain tile.

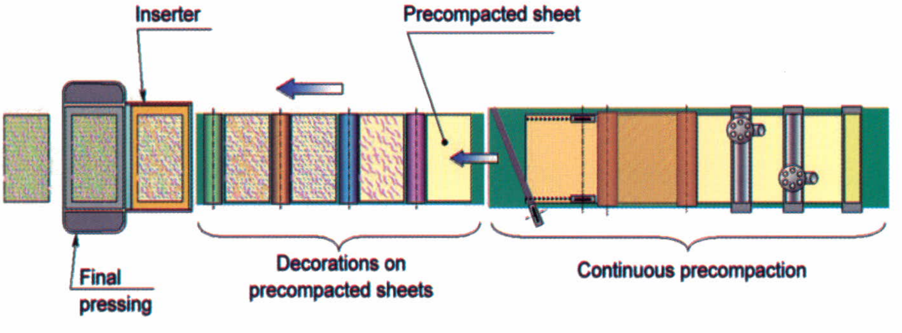

Figure 12. Schematic of a continuous precompaction line

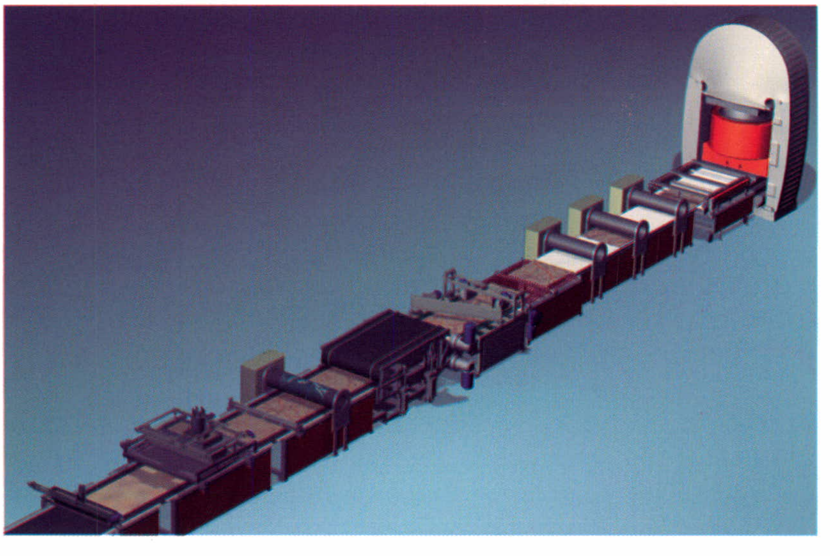

Figure 13. Line of continuous precompaction with successive decorations and repressing

The typical products valorized by the continuous precompaction technology are porcelain tiles (both in square and rectangular sizes), characterized by decorations applied on passing (shades and patches of colour, inclusions and subtle veining), obtained by a differentiated coloured powder charges. The product surface may be natural, satin or polished.

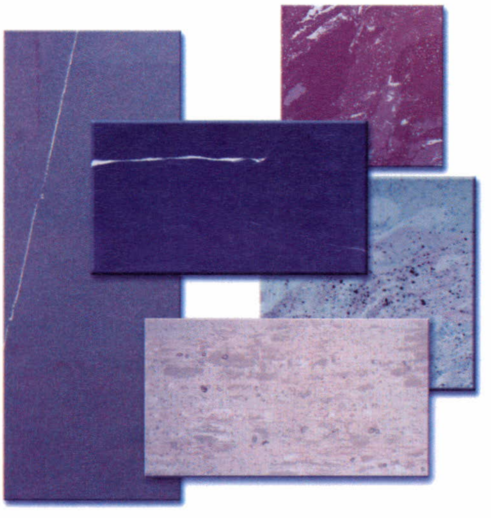

Figure 14. Examples of products obtained with continuous precompaction technology

4. CONCLUSIONS

In the panorama of new technologies for porcelain tile manufacture, the innovative system of continuous precompaction undoubtedly represents a radical change compared with traditional working methods.

In fact, all the current powder compaction systems involve forming individual pieces and batch processing cycles.

A system of continuous precompaction, however, constitutes not only an absolute novelty from a conceptual point of view, but in particular acquires great practical importance, since it allows freely decorating a layer of powder throughout it whole thickness without any repetitivity.

In essence, on the one hand the continuous precompaction system replaces the press carriage, providing absolute freedom in powder charges, while on the other, it solves all the problems of a traditional belt charge, as it conveys to the press not a powder but an inalterable product as soon as it is precompacted.

The objective envisaged by this new technology is the industrial-scale fabrication of porcelain tiles characterized by an extraordinary aesthetic nature.

REFERENCES

[1] Kawakita, K. & Lüdde, K.H., "Some considerations on powder compression equations", Powder Technology, Volume 4, Issue 2, (January 1971), pp. 61-68