PORCELAIN TILE LARGE-SIZE CERAMIC SLABS

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INTRODUCTION

Examples of architectural structures from the past have left us building facades whose tilings feature characteristic architectural motifs.

The building systems of the time and the economic resources, though only for a select few, yielded surprising architectural results, which might today be repeatable at a reasonable cost.

Currently, modern technologies and the use of new solutions for enriching building facades allow obtaining similar results from a plastic-architectonic viewpoint, to those achieved in the past with natural materials, with undoubtedly more functional technical characteristics, particularly as regards protection against weathering agents, insulation and durability.

Many significant examples of contemporary architecture, representative of current projects and building constructions, exhibit a strong trend towards a return to decorating building facades with new materials such as glass, steel, etc., as well as more traditional materials such as terra cotta, stony materials and ceramics.

These new architectural concepts require implementing more advanced building methods, such as curtain walls.[1]

[1] *I manuali del Saie, Le pareti ventilate,* Edizioni Tipografia Nettuno (1999)

At the same time, the evolution of ceramic technology in general has permitted the industrial production of large-size porcelain tile suitable for internal and external tiling applications. These ceramic tiles are also used to make kitchen worktops, bathroom furnishings, and steps, just like natural stone.

The present study will however examine the key technological features of the facilities developed to make large-size slabs.

An aspect also considered in this paper is the possibility of producing smaller modules from the slabs, thus optimising ceramic plant manufacturing flexibility.

Before going into the characteristic technological features of porcelain tile, a few notes are presented on the general characteristics of the most important types of tile at present.

GLASS

Glass belongs amongst the first architectural experiences in modern building cladding.

Besides being used as facade cladding, glass was also one of the first materials to be employed in partition walls, on having been set in the wall-bearing structure. Its main characteristic is its transparency. The aesthetic content is subjective. The use of large sheets of glass depends on glass thickness, in view of its low impact resistance. However, glass has excellent resistance to atmospheric agents, is simple in upkeep, etc. When large projects are involved, glass also helps keep the architecture "lighter".

TERRA COTTA

Porous terra cotta, understood as a tiling material, has been one of the most widely used materials in the past as listels, tiles, etc., fixed wet with mortar and/or adhesives.

One of its main characteristics is its "MATERIAL" value, which in time and "ageing" can acquire ever-more attractive aesthetic characteristics. Traditional terra cotta is a material, which, even with reasonable porosity, exhibits medium mechanical characteristics and frost resistance. Maintenance with time must be considered unstable and this makes it resemble natural stony materials.

The situation is different in the case of the vitrified type of terra cotta such as clinker, which exhibits superior characteristics. The new building tendencies with brick facings involve technological joining systems with grids or frames anchored dry in the bearing wall [2]. This new way of using terra cotta as a covering entails an evolution of "traditional tiles" and a wide range of special pieces (Figure 1).

Figure 2 shows a facade made using different pieces of clinker. The combination of traditional materials with modern architectural elements can yield highly prestigious aesthetic solutions.

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[2] M.C. Torricelli e L. Marzi, *Le facciate ventilate in cotto di Renzo Piano,* Costruire in Laterizio, 71, 36-47 (1999)

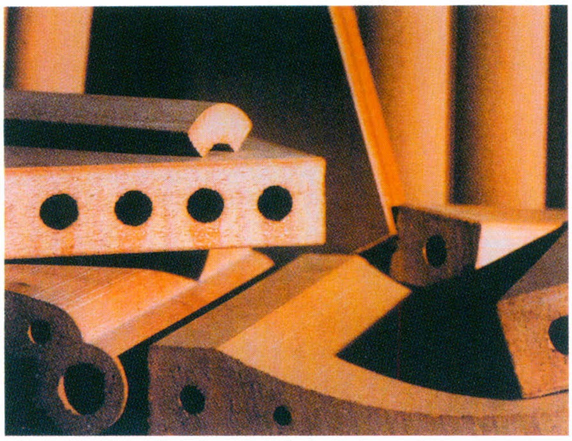

Figure 1. *Special pieces in terra cotta [production: Sannini Impruneta].*

Figure 2. *Facade with special pieces of clinker [postdammer Platz: project by Renzo Piano].*

CONCRETE AND FIBROCEMENT

These types of cladding are used when economic aspects prevail over aesthetic characteristics. Concrete coverings are made of Portland cement with the addition of inert aggregates. The thickness of the slabs is about 5-6 cm.

In the case of fibrocement, the cement components are mixed with glass fibre. The reinforcement provided by the glass fibre is very high and yields very interesting impact resistance values, despite the limited specific weight. The fibrocement slabs are formed by a pressing process and stabilised in an autoclave. They are used when it is necessary o have materials that add a limited "weight" to the bearing structures.

The dimensions of the slabs can vary from a minimum of 500x500 mm to a maximum of 1500x3000 mm. Their weight is related to size, fibre-cement ratio and thickness, which normally varies from 4 to 6 mm.

The aesthetic aspect of these materials needs to be considered medium/low and largely depends on the degree of finishing after coating.

STONY MATERIALS

By *"stony materials"* are meant categories of material such as marble, granite, travertine, natural stone, etc.

These belong to the most widely used materials for making facade claddings.[3]

The stony materials, depending on the category to which they belong (marble, travertine, etc.), exhibit a certain permeability and a certain sensitivity to chemical attack. Their frost resistance is not optimum and is lower than that of other materials.

For this reason, in the case of using stony materials for assembling facade systems or curtain walls, their thickness must be greater, compared to fibrocement, to provide the material with the necessary strength to withstand the arising stresses. Their aesthetic value, also depending on type, is generally very high, often making them preferred to other products despite their mediocre technical performance characteristics.

PORCELAIN TILE

This material stands out because of its physico-chemical characteristics, which are very high compared to the foregoing materials. The ceramic aspects do not need to be entered into here, as the material is well known; to be highlighted is a water absorption of usually less than 0.1%. During the development of this product, the size has recently grown steadily to the proposed current size: exceeding 2 m^2. The aesthetic effects of the material, produced in the pressing operation and in subsequent decoration, have also evolved. The trend has been and still is to seek surface affects and decorations that imitate stony materials.

Ever more often however, and with reason, there is a close search for characteristic ceramic effects, also with the aim of recovering values and expressions that provide the product with its own singular value.

PRODUCTION TECHNOLOGY OF LARGE-SIZE TILE

It can reasonable be stated that ceramic bodies, including those for porcelain tile, even from different factories and regions, respond to basically uniform composition characteristics.

The development of bodies for producing such ceramic slabs, however, needs to take into account the type of size and ensuing processing needs.

On examining the production process of a ceramic tile made by dust pressing, a whole series of critical aspects can be detected, or aspects worthy of greater attention with regard to what happens in the traditional process.

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[3] C. MONTANI, *Stone 98*, Faenza Editrice (1998)

It should be noted that current porcelain tile production in general needs, amongst other features, a pressing density of over 2 g/cc. Such values are normally produced with standard ceramic powders that are then pressed with specific forces exceeding 400 kg/cm^2.

The pressing production of ceramic slabs sized >2 m^2/piece would find a first limitation in achieving these density values, as the most powerful machines being used today do not allow attaining this density.

This problem has been tackled experimentally by two different approaches and hypotheses:

- **Pressing densification by modifying body plastic properties**
- **Pressing densification by adopting innovative forming techniques**

In the first case, there is the advantage of being able to use existing machines, without particularly affecting the production process after body preparation, (just) adapting the dies, transport lines and storage of semi-processed products. In the second case, the problem has been solved by raising press performance, with a minimum reduction in productivity, acceptable however for this type of product.

In any case, the body will be formulated to respond to the technological demands of the various production stages, particularly with regard to the fast-fire cycle of the pieces being studied.

HYPOTHESIS 1

BODY FORMULATION

Amongst the possible techniques for raising the degree of densification of a ceramic body, the following alternatives have been experimentally studied:

- Raising plastic clay content (mineralogically characterised by the presence of illite and/or montmorillonite)
- Addition of natural binders, or artificial or synthetic ones (polysaccharides, polyphenols, ligninsulphates, carboxycellulose, polyvinyl alcohols, polyvinyl acetates, etc.).

The prime concern is certainly that these modifications should not significantly affect the cost of the body, or its workability, or produce defects of class in firing, or even black coring.

In view of these intrinsic requirements, the study conducted was focused on using plastic clays, polysaccharides and ligninsulphates.

THE COMPOSITIONS

Using a standard porcelain tile body (see Table 1), characterised by a 50% partly kaolinitiç clay fraction, and a partly quartzose feldspar fraction, the montmorillonite clay content was progressively raised (compositions A, B and C) replacing especially the kaolinitic and quartzose components.

This action, which undoubtedly entails a rise in plasticity affects slip rheology.

The alternative sought with the use of chemical additives is shown in bodies D, E, F y G.

COMPOSITION %	STD	A	B	C	D	E	F	G
PLASTIC CLAY		10	15	15				
SEMI-PLASTIC CLAY	40	40	40	45	40	40	40	40
KAOLINITIC CLAY	10				10	10	10	10
FELDSPATHIC QUARTZOSE SAND	15	15	13	10	15	15	15	15
SODIUM FELDSPAR	35	35	32	30	35	35	35	35
POLYSACCHARIDES					0.25	0.50		
LIGNINSULPHONATE							0.25	0.50
CHEMICAL ANALYSIS %								
SiO_2	67	67	66	66	67			
Al_2O_3	21	21	21	22	21			
TiO_2	0.6	0.6	0.6	0.7	0.6			
Fe_2O_3	0.5	0.6	0.6	0.6	0.5			
CaO	0.5	0.6	0.6	0.6	0.5			
MgO	0.4	0.5	0.5	0.5	0.4			
K_2O	1.2	1.0	1.0	1.0	1.2			
Na_2O	4.7	4.5	4.1	3.7	4.7			
L.O.I.	4.1	4.2	4.6	4.9	4.1			

Table 1.

GREEN CHARACTERISTICS

Under substantially the same processing conditions (milling reject, spray-dried powder content, etc.), and in particular a forming pressure of only 250 bar, the different test bodies exhibited very interesting characteristics (Table 2).

As expected, the plastic clay additions raised mechanical strength in the green body (from 0.67 to 0.99 MPa) and especially in the dry body (from 2.1 to 4.6 MPa), with a drop in after-pressing expansion; however shrinkage rose in firing.

The bodies "plasticised" with binders behaved differently. The only significant variation found was the rise in dry mechanical strength, just as in the case of ligninsulphate (3.2 MPa).

	STD		A	B	C	D	E	F	G
Milling reject at 63 µm	1.0		1.0						
Forming pressure, bar	250	400	250						
Moisture content, %	5.4	5.4	5.1	5.6	5.3	5.0	5.4	5.1	5.1
Green scrap, MPa	0.67	0.80	0.89	0.90	0.99	0.72	0.77	0.65	0.64
After-pressing expansion, %	0.6	0.7	0.7	0.6	0.5	0.5	0.5	0.7	0.6
Dry scrap, MPa	2.1	3.1	4.0	4.6	4.5	1.9	2.1	2.5	3.2
Dry shrinkage, %	0.1	0.1	0.3	0.3	0.3	0.1	0.1	0.1	0.1

Table 2.

Figure 3 presents the effects of the plasticising additives on dry tile mechanical strength.

The comparison of the two systems used to improve the mechanical strength of the green bodies shows the greater effectiveness of adding plastic clay compared to using chemical additives. The optimum range of dry mechanical strength for good industrial handling of a green pressed slab was found to lie between 3.0 and 4.0 MPa, the lower limit being attainable with standard pressed bodies at 400 bar and the upper limit with certain clay additions.

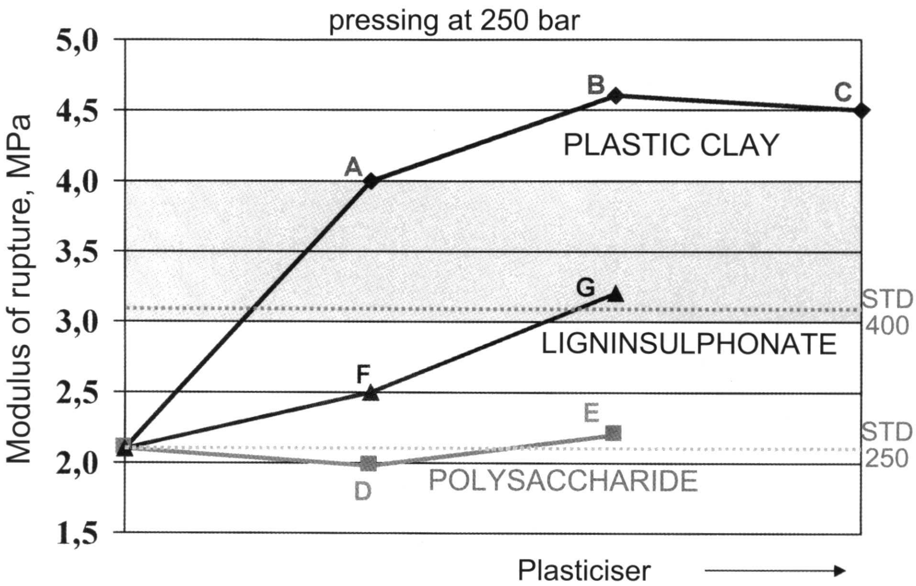

Figure 3. Effect of plasticising additives on dry mechanical strenght.

HYPOTHESIS 2

PRESSING TECHNIQUE

In this case the objective was to produce large size porcelain tile slabs by pressing without adding plasticising additives, but raising the compaction efficiency of the press used, thus achieving the required density in this working stage.

This was achieved thanks to a patented system capable of displacing, at different times, the application of total pressing force on parts of the tile surface.

The effect on the density of the tiles pressed under different conditions and with different bodies is schematically depicted in Figure 4. The tests showed that a traditional porcelain tile body can achieve a green density exceeding 2 g/cc, typical for pressing above 400 bar, attained using the special forming system mentioned above.

The mechanical accuracy achieved at present by the pressing operation and the high green mechanical strength obtained on using plastic bodies and/or specific pressing techniques, allow forming slabs with a variable thickness from 5 to 30 mm (and even thicker).

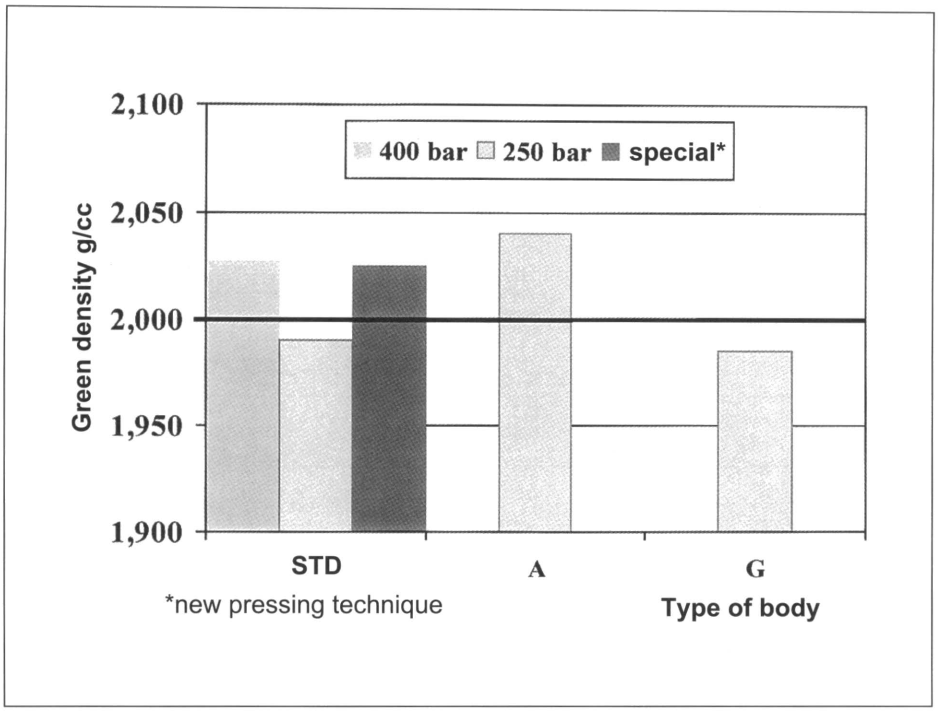

Figure 4. Variation of compaction density according to type of body and pressing.

Independently of the working hypothesis used to achieve the desired density of the pieces, special attention must be paid to the die in forming pressed ceramic slabs.

To avoid turning operations of the pressed slab, in view of the considerable size and mass, it is preferable to work with dies that form the slabs with the front or proper face up.

The most suitable types of dies for this purpose are:

- Superior forming die (SFS)
- Mirror die with thrusters.

The superior forming die certainly has the greatest technological content, but entails a series of constructional complications that would only be justified by the need to have a spacing edge on the slab edge. This is not always necessary in the very large-size slabs, as the edge is nearly always subjected to grinding.

Therefore, to solve all the problems mentioned with pressing large and very large sizes, a type of die has been designed, which is a development of the mirror die and the die with the penetrating punches.

This die, called the mirror die with thrusters, is very similar to the traditional mirror die, as shown in Figure 5.

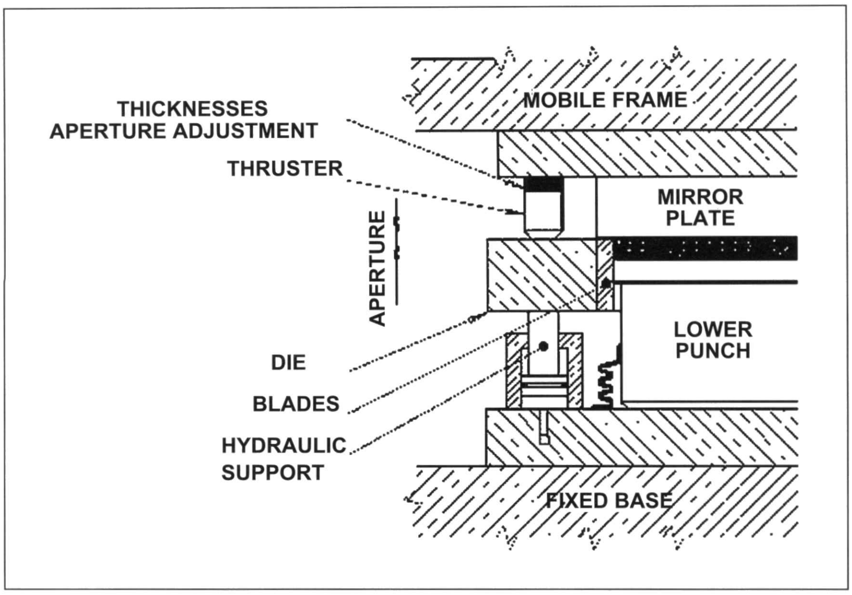

Figure 5. *Schematic illustration of a mirror die with thrusters.*

Using this type of die, there is always a small perimeter aperture between the blades and the plates in the die cavity, which noticeably favours de-airing of the powder in the cavity during pressing. This is fundamental, in view of the large volumes of air to be evacuated owing to pressed slab size.

THERMAL TREATMENTS

Besides being influenced by the physico-chemical properties of the ceramic body, these process stages are also influenced by slab size, which can reach dimensions of over 2 m^2 and variable thicknesses ranging from 5 to 30 mm or more.

Limiting ourselves for the moment just to considering the most common ceramic slabs with a medium thickness (20 mm), the following reference thermal cycles were found:

- 60÷75 minutes for drying in the horizontal roller dryer
- 150÷180 minutes for firing

As the drying stage presented no significant problems (therefore matching the normal situation), a specific description is not given of the operations performed. The optimum experimental drying cycles were derived from calculation models based on the typical dimensions and characteristics of the product:

$$Teo=\left[(S)^{3/2} + (0.02 \cdot Lm)\right] \cdot K0$$

Teo = drying time
K0 = material coefficient
S = thickness
Lm = largest side

The max. working temperature in the fast roller dryer is always lower than 200°C and the characteristic values of the semi-processed product obtained are detailed in Table 2.

With regard to the firing operation, two critical parameters were basically subjected to point analysis: the tendency of the bodies to become disordered, accentuated by slab size and geometry on exiting the kiln.

Making large-size slabs of finely textured ceramic material therefore requires a more profound assessment of the physical properties during firing, with a view to optimising the firing diagram, on the one hand considering to need to keep excessive stresses from arising in the manufactured product, particularly in cooling, and on the other, the opportunity to achieve compatible firing cycles with industrial production demands.

Sacmi's experience with porcelain tiles with a nominal fired size of 1250x1800 mm, whether decorated by pressing or coated with semi-glossy glazes, has demonstrated that the pre-heating and actual firing stages do not present any important difficulties if the slabs reach the kiln appropriately dried.

Naturally the times needed for pre-heating and firing are to be related to the thickness of the slabs, as these condition the dynamics of conductive heat transfer in the ceramic body.

The times observed experimentally are presented in Table 3:

Firing stage	Thickness 8 mm	Thickness 20 mm
Pre-heating to 900°C	45 minutes	65 minutes
Maturing 900°-1200°-1000°C	25 minutes	45 minutes
Fast cooling 1000°-750°C	10 minutes	15 minutes

Table 3.

What really conditions the firing cycle is the cooling stage, in which the size and thickness of the slabs have a greater effect.

Cooling necessarily needs to take into account the state of stress produced by the difference in temperature between the front and rear side of the slab, with regard to kiln advance, and by the difference in temperature between the inside and the surface.

To be able to assess the physical modifications that occur in the material during cooling, it needs to be remembered that this is partially made up - to a variable extent according to the nature of the body, peak firing temperature and dwell at this temperature - of an amorphous matrix that acquires consistency during cooling, gradually increases its viscosity and changes from a semi-plastic behaviour at temperatures above about 800°C to an elastic behaviour at lower temperatures.

Two main stages can therefore be distinguished in cooling:

- a first stage of "**fast** cooling ", between about 1000°C and 800°C, in which the material exhibits partially plastic behaviour and is capable of withstanding different expansions without undergoing excessive mechanical stresses. This first stage allows relatively high cooling rates of around 15÷20°C/min.

The interest in accelerating cooling in this range responds to two needs:

- keeping the firing cycle within limits as far as possible to optimise kiln production;
- keeping the recrystallisations in the glossy glazes within limits.

In this stage the upper limit is formed by the need to avoid definitive plastic deformations in the slabs; during the experiments performed at Sacmi with the thermal rates mentioned, no unusual geometrical anomalies were observed.

- In the second stage of "**controlled** cooling", in which the material takes on preferentially elastic behaviour, with an almost constant Young's modulus as temperature varies, of about 60 GPa (1 gigapascal = 1000 N/mm^2), the slab is subjected to a state of compound stress, determined by the different expansions produced by temperature heterogeneity:
- The difference in temperature ΔT_{AP} between the front and the rear of the slab with regard to the direction of advance: the difference is independent of the speed of advance and slab thickness, and depends exclusively on slab length and the temperature-space gradient, thus of the length of the kiln cooling section;
- The difference in temperature ΔT_{IE} between the inside and the outer surface of the ceramic slab, together with the dynamics of conductive heat transfer inside the material (governed by the Fourier equation): the difference is independent of size and largely depends on thickness and the temperature-time gradient, thus also on the speed of advance in the kiln, besides kiln design.

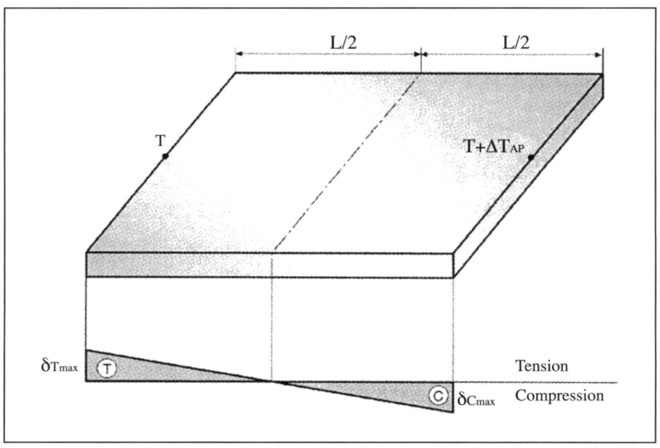

Figure 6. Stress between the front and the rear of the piece owing to the difference in temperature.

As Figure 6 shows, the difference ΔT_{AP} between the front and rear produces tensile stress on the front side of the slab.

Figure 7 shows the state of tensile stress at the surface of the manufactured product, caused by the difference in ΔT_{IE} between the inside and the surface, which can be determined by the Fourier equation for the case involved. The parameters that influence the thermal delay are thickness of the material (s), cooling temperature-time gradient (G), and material thermal diffusion (a).

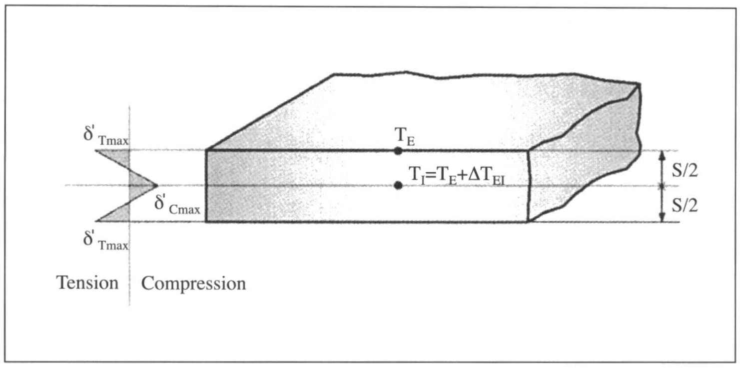

Figure 7. *Stress condition owing to the difference of temperature in the thickness.*

It follows that the surface of the slab front is subject to tensile stress produced by the superimposition of the two effects mentioned.

These considerations are confirmed by the experiments: in the course of fine-tuning the firing cycles, fracture cracking was observed originating in the middle of the front of the manufactured product.

The arising stresses are quantifiable by using the equations that govern the statics of elastic bodies.[4]

The parameters influencing the behaviour of the materials are Young's modulus (E), Poisson's ratio (ν), and the coefficient of linear thermal expansion (α).

The table presents 4 representative cases, taken from an approximate calculation obtained on applying the mean values of the mentioned parameters in the 750°C - 100°C temperature range:

Thermal diffusivity	a =	1.67×10^{-3} m²/h		
Young's modulus	E =	60 GPa	=	612000 kg/cm²
Poisson's ratio	ν=	0.25		
Coeff. linear thermal exp.l	α=	7.0×10^{-6} °C^{-1}		

To determine the difference ΔT_{AP} an industrial kiln was considered with a total length of 100 m, with a cooling section of about 30 m (from 750°C to 100°C), which determines a mean difference ΔT_{AP} of 39°C between the top and rear of a piece with a length of 1800 mm with regard to the direction of kiln advance.

[4] S. P. Timoshenko, *Theory of Elasticity,* 3rd Edition. McGraw-Hill (1970)

ΔT_{AP} = 39 °C constant	**Cooling time 750°C-100°C**	
Tile thickness (mm)	**30 minutes**	**60 minutes**
8	G = 22 °C/min ΔT_{IE} = 6.2 °C σ front tension = 111 kg/cm² σ extern. tension = 18 kg/cm² **σ total tension = 129 kg/cm²**	G = 11 °C/min ΔT_{IE} = 3.1 °C σ front tension = 111 kg/cm² σ extern. tension = 9 kg/cm² **σ total tension. = 120 kg/cm²**
20	G ΔT_{IE} = 22 °C/min σ front tension = 39.0 °C σ extern. tension = 111 kg/cm² **σ total tension.** = 111 kg/cm² **= 222 kg/cm²**	G = 11 °C/min ΔT_{IE} = 19,5 °C σ front tension = 111 kg/cm² σ extern. tension = 56 kg/cm² **σ total tension = 167 kg/cm²**

Table 4.

It can be observed that the cooling of very thick tiles (20 mm) with a large size (1800 mm) entails important mechanical demands, close to the mechanical bending strength, which was around 500 kg/cm² for the material studied.

Obviously, under the same plant conditions (with a kiln having the same design) the temperature differences between the front and the rear of the slab, and thus with the corresponding stresses, increase linearly with slab length. Therefore, for slabs with a length of 3600 mm (twice the size of the ones mentioned above) tensile stresses can be assumed of about 220 kg/cm² due just to the top-rear thermal difference.

However, the cases described are based on rather approximative simplifications, particularly with regard to assuming a mean coefficient of linear thermal expansion value in the above temperature range, as the β quartz ↔ α quartz transition is found in this range, which determines an important dimensional variation.

A more detailed analysis would involve breaking up the study range (750°C-100°C) into smaller ranges with more uniform thermal and mechanical properties. The simplification was made to allow presenting the whole problem and offer a starting point for designing equipment and procedures (preparing an appropriate firing diagram).

The foregoing observations, based on experimental results, have enabled establishing the controlled coolings detailed in the table, thanks to highly efficient thermal-convective systems:

Firing stage	**Thickness 8 mm**	**Thickness 20 mm**
Controlled cooling 750°-100°C	40 minutes	55 minutes
Complete firing cycle	120 minutes	180 minutes

Table 5.

The indicated firing cycle used in testing the pressed ceramic slabs measuring 1974x1368x20 mm is shown in Figure 8.

The properties of the fired and finished products, made from the analysed compositions are set out in Table 6.

It can be observed that the bodies plasticised with clay (A, B and C) reach vitrification at lower temperatures compared to the standard body and compared to the bodies containing chemical additives, and generally present good geometrical characteristics; furthermore, for these compositions, firing shrinkage was lower, indicating greater densification in pressing.

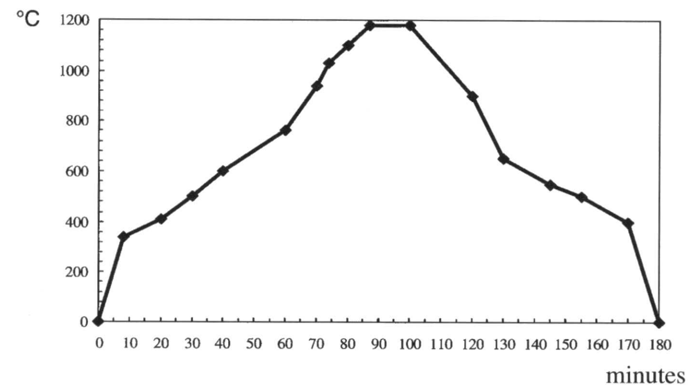

Figure 8. Firing curve for ceramic slabs.

In contrast, the bodies enriched with plastic clays exhibited a greater tendency to form black core, though this can be contained by appropriate kiln regulation, and lower fired mechanical strength, owing to the different relation between the forming crystalline and glassy phases.

	STD		A	B	C	D	E	F	G
Forming pressure, bar	250	400	250						
Vitrification T, °C	1200	1200	1180	1170	1170	1200	1200	1200	1200
Vitrification shrinkage, %	8.3	7.5	7.4	7.5	7.6	8.4	8.3	8.5	8.6
Breaking load, MPa	53	55	47	45	48	61	58	61	60
Black core	no	No	+	+	++	tr.	tr.	no	tr.
Planarity	Ok	Ok	ok	ok	+/-	ok	ok	ok	ok
Tendency to disorder	+	+	no	no	no	+	+	+	+

Table 6.

The dilatometric behaviour of the plasticised bodies deserves special note (Figure 7), with regard to the free quartz content, which should be minimised to lighten the firing end operation.

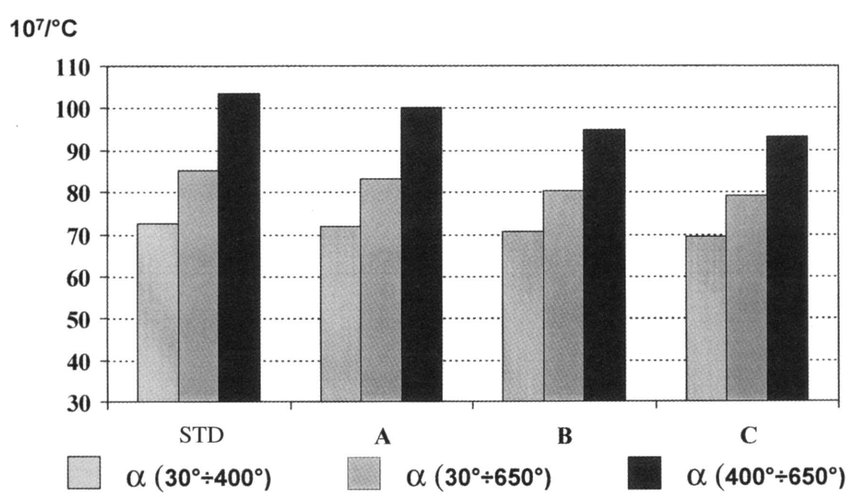

***Figure 9.** Linear thermal expansion of the formulated bodies.*

This objective was almost automatically achieved in the case above of the plastic bodies (where clay partly replaced the feldspathic quartzose sand), but it needs to be investigated when the tiles are made with typical porcelain tile forming pressures in traditional bodies (in this case it would be possible to intervene for example by raising the percentage of pure feldspars in the place of feldspathic quartzose sand).

For the different semi-tested bodies, the diagram presents the values of the coefficient of linear thermal expansion calculated in the temperature ranges 30÷400°C, 30÷650°C and 400÷650°C, that is, before and after the α quartz $\leftrightarrow$ β quartz transition.

The coefficient of linear expansion dropped in both cases with regard to the standard composition on raising body plasticity. Of greater interest however to control tile disorder in firing is the decrease of the dilatometric leap ($\alpha_{400\div650°}$), owing to the presence of free quartz, which goes from $103 \cdot 10^{-7}/°C$ to $93 \cdot 10^{-7}/°C$.

Though in absolute terms the variation is quite contained, in the semi-industrial firing trials the plastic bodies were found to exhibit a lesser tendency to disorder compared to the standard composition.

Based on the tests performed and described, the industrial feasibility was confirmed of making large-size porcelain tile, and developments in this direction can be expected in the near future, also because the market already appears to be prepared to receive materials of such a high technical and aesthetic level, while the cost is quite limited.

The production of porcelain tile slabs has not just been an issue of study with regard to facade cladding, but also to satisfy the demands of tile modularity required for modern architecture.

In fact normal manufacturing, despite the variety of existing presses and dies, is often faced with difficulties when it comes to satisfying customer demands for different sizes.

The introduction of cutting inside the production cycle represents a new and highly valid answer.

In fact, cutting allows harmonising the die size, producing a single monolithic slab, and keeping flexibility in small sizes.

The last advantage consists of a noticeable simplification of feeding powder multiple charge processes, as it unifies, on a single size, the press feeding system and all its accessories.

The proposed scheme is as follows (Figure 10):

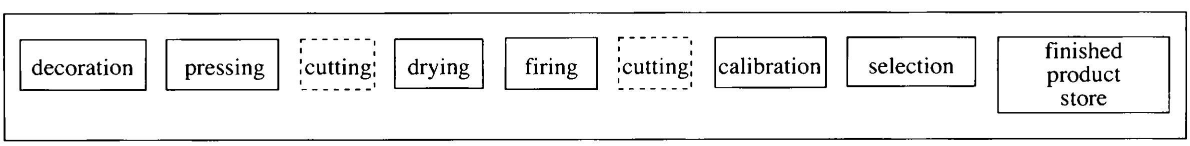

Figure 10.

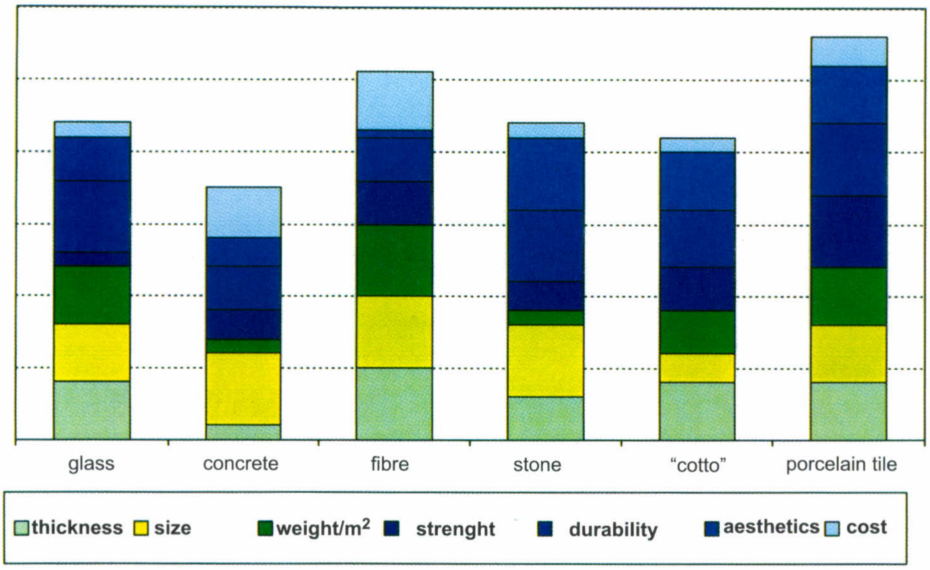

Figura 11. *Product characteristics for external coverings.*

At this point it appears interesting to show in Figure 11 the set of most important characteristics of the materials used as "facade cladding", characteristics that are expressed subjectively and not in absolute terms, but with relative values, to offer a synthetic, legible picture of the characteristics of the different materials, including aesthetic aspects and economic value.

As Figure 11 shows, porcelain tile slabs exhibit very interesting weighted mean values compared to alternative materials.

With this purpose to serves to briefly highlight a few points on the use of these slabs as singular elements for facade cladding and curtain walls.

By *facade wall* is meant a covering system whose elements can be directly fastened to the built bearing wall, with dry structural fastenings of a mechanical and/or chemico-mechanical type; alternatively they can also be fastened to supporting metal structures with a modest thickness, which are in turn attached to the surface of the wall.

By *curtain wall*, is meant instead, a system that allows the tile to be anchored to the fastening system, keeping a distance from the wall surface of 5÷10 cm, which produces a "chimney effect", which together with the specific aesthetic use of the cladding, provides thermal-acoustic insulation and other advantages.

There are various possible structural choices for cladding fastening, i.e., systems with an aluminium or steel infrastructure with visible or hidden fastenings *(fast clip system).*

The hidden fastenings system is the most suitable for designing the wall covering, and allows using the large-size tiles to the greatest advantage (Figure 12).

To satisfy safety requirements, the materials used as building cladding need to withstand the mechanical actions that can arise with time. Safety depends amongst other factors on:

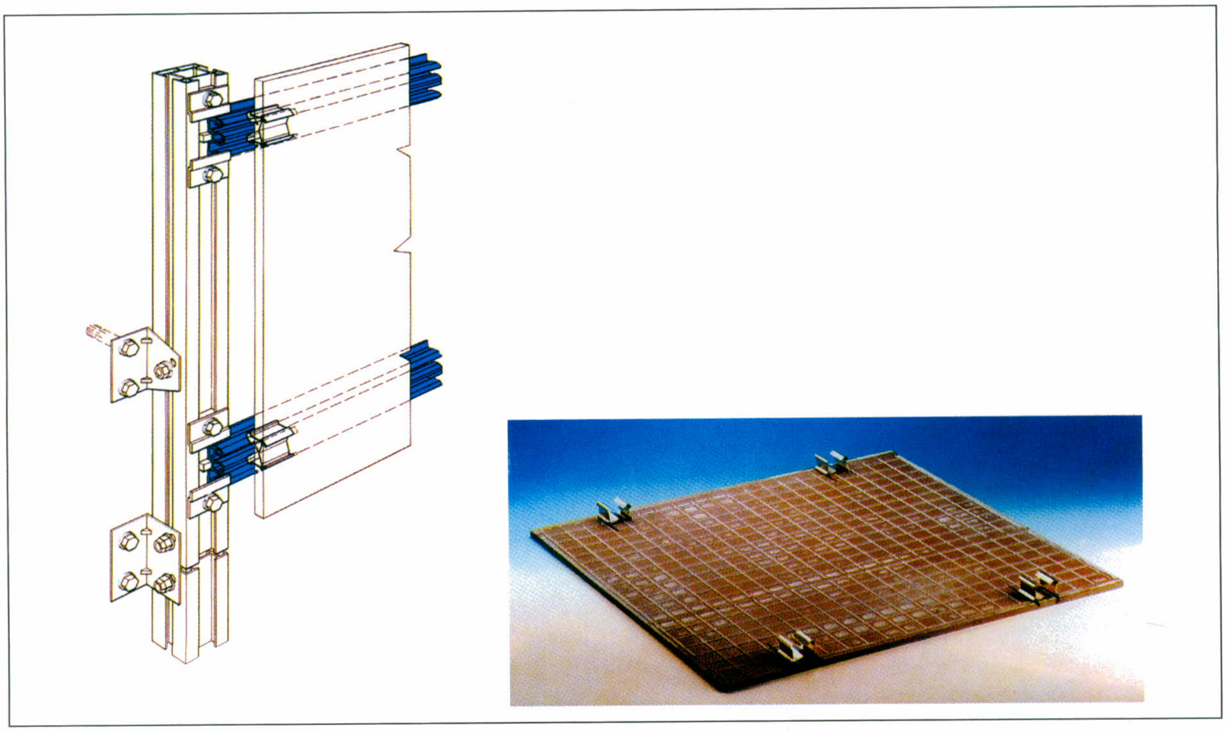

Figure 12. Anchoring system with internal fastenings.

- Cladding weight,
- Failure because of the wind,
- Temperature variations,
- Resistance to chemical and weathering agents.

The relative lightness of the material is an indispensable requirement for not overloading the walls, a fundamental requirement as well in repairs and restoration of existing building facades, which also applies to new building constructions.

The peculiarity of being able to produce ceramic tiles with a thickness of only a few millimetres suggests an absolutely innovative use as a poly-functional architectural element for building construction.

One could imagine obtaining a sandwich type of wall structure consisting of two tiles with a working surface between the two sides.

The space between the two ceramic tiles could be of a different nature and thickness, and would perform different functions (acoustic and thermal insulation, heating, etc.), and the unit could then be anchored to the floor and/or wall or roof with different fastening systems.

This new application would offer ceramic tile the possibility of successively expanding, opening up interesting perspectives for modern architecture (prefabricated walls, restoration, etc.

Thanks to its characteristics, porcelain tile allows achieving comparable or higher strengths than normal stony materials, using much lower thicknesses (and hence weights). For the most widespread sizes in fact, porcelain tile thickness does not exceed 10-20 mm, while the specific weight is similar to that of all stony materials, thus involving a drastic drop in weight (up to 50%), with a great lightening of the permanent loads and simplification of the anchoring infrastructure.

Besides the foregoing physico-mechanical characteristics, porcelain tile aesthetics are continually evolving, enabling this material to thrust itself forward ever more strongly as an alternative to the most commonly used cladding materials.