CONTINUOUS COMPACTION OF CERAMIC SLABS WITH INTEGRATED FASTENING SYSTEM

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ABSTRACT

In recent times we have seen a progressive spreading of porcelain ceramic slabs for architectural use, as external walls for buildings (façades).

In spite of the well-known advantages offered by these ceramic products (great variety of chromatic and material effects, excellent physical and mechanical characteristics, resistance to atmospheric agents, quite cheap costs), porcelain slabs for façades suffer the disadvantage of requiring the realization of appropriate systems for fastening them to support structures. As a matter of fact, the features making the ceramic product a favourite (hardness, in particular) also represent the cause of long working times and high costs for preparing the fastening system (drilling, cutting, etc. to be carried out on the vitrified product).

As a result of these high costs, porcelain slabs have difficulty in imposing themselves on the market since they have to compete with other materials (natural stones, glass, etc.), for which a.m. processes are cheaper.

To overcome the current limitations, a new application of Continua® compaction technology is proposed, in order to integrate appropriate metal fastening systems in the ceramic matrix, thus achieving slabs ready to be fixed to façade support structures.

In fact, the peculiarity of the Continua® compaction process allows the introduction, when the slab is still in the form of soft powder, of suitably designed metal inserts, which are then compacted, without jeopardizing the following working phases and plant productivity.

The new (patented) process can be summarized as follows:

1. accurate positioning of the metal inserts on the conveying belt by automatically controlled dispensers;
2. loading of proper ceramic powder layers, in case decorated with effects on the surface or inside the mass;
3. compaction by continuous pressing in order to integrate the inserts into compacted ceramic mass;
4. decoration, if such is the case, and final pressing of the ceramic product;
5. reduction, if required, to the desired sizes by green cutting before firing;
6. drying, firing, polishing (if such is the case) and edge rectifying of the resulting tiles or slabs.

For the first time, this application allows industrial production of ceramic slabs to be assembled on external walls equipped with integrated fastening system.

The experimental study carried out shows how the interconnection between the vitrified ceramic mass and the metal insert gives high tearing resistance, according to the standards and good building practice.

Besides, the additional functionality of integrated fastening does not compromise the normal use of the slabs, while it permits considerable savings in the processing and assembly of the finished products.

New opportunities for the use of ceramics for ventilated façades thus arise, thanks to the higher efficiency and reduced cost of the proposed solution.

1. STATE OF THE ART

An interesting use of ceramic tiles/slabs is in cladding external walls of buildings, according to the technique known as the "ventilated façade" (Figure 1). The ceramic tiles/slabs are fastened on auxiliary assembly structures, composed of metal bars (uprights and crossbars), firmly fixed to the building wall through brackets and anchors [1] [2]. Between the tile plane and the building wall there is a space (hosting the assembly structure) where the air flows due natural convection, ensuring benefits with regard to thermal protection, ventilation and weatherproofing of the wall itself [3].

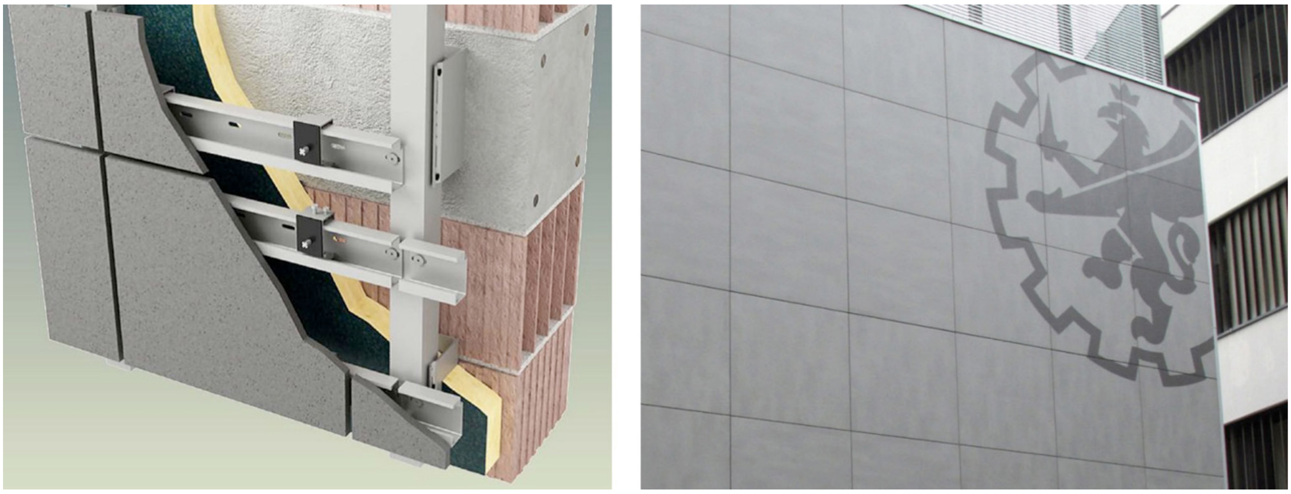

Figure 1 – Example of ventilated façade

The presently known systems for the application of ceramic tiles/slabs to ventilated façades are explained below, highlighting the weaknesses which have limited their spread to date.

a) External brackets

It is a visible fastening method, which does not require working on the ceramic slab. The slabs are hooked, at the four corners, by U-shaped metal clips fixed to the back metal structure (Figure 2).

In spite of its simplicity, this fastening system is however visible (anti-aesthetic) and not suitable for heavy, large-sized slabs.

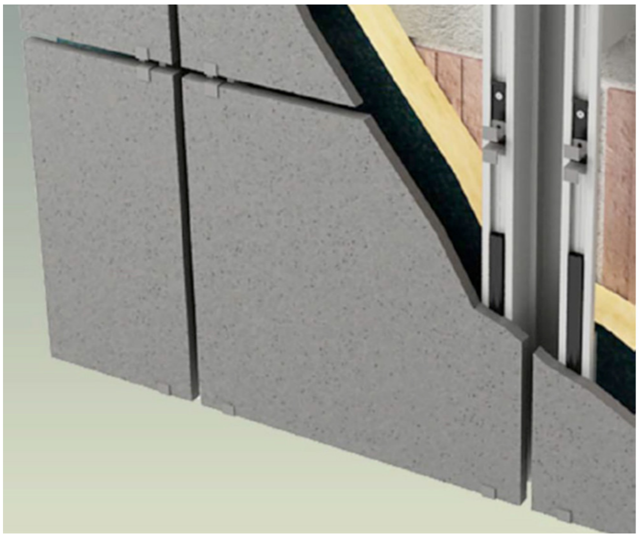

Figure 2 – Fixing by external brackets

b) Metal expansion anchors

It is a hidden fastening system (invisible from the outside) [4]. Blind holes (i.e. depth lower than slab thickness) are realized in the ceramic slab by means of diamond tools. A metal expansion anchor is introduced into the hole. The anchor ends in a bolt projection, on which the bracket is engaged to the assembly structure (Figure 3).

The drilling phase of such holes is an expensive process, as it requires special shaped diamond tools and a CNC drilling machine; besides, the hole depth is considerable (more than half of slab thickness), thus implying the risk of breakages during machining.

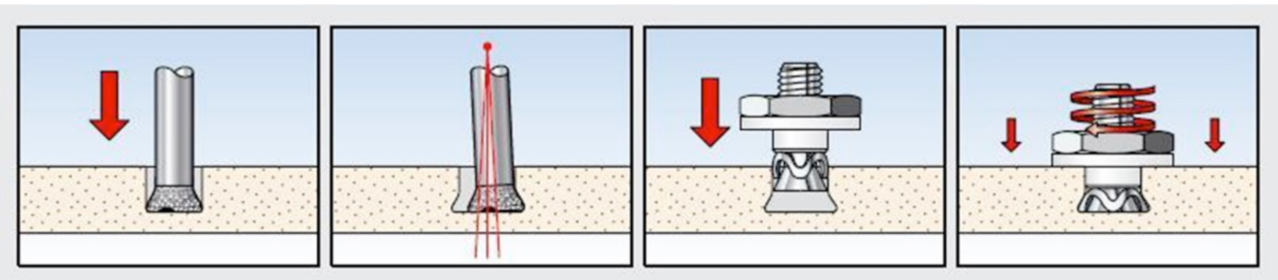

Figure 3 – Assembly sequence of the expansion anchor (type Fischer FZP K)

c) Inserts applied in engraved slots

This is a hidden fastening system. The fixing metal clips are engaged in slots engraved in the slabs. The slots, realized by means of diamond tools, can be placed on the sides or in the back with oblique engravings (Figure 4).

However, making the slots is quite expensive, with the possibility of breakages during the process due to the high depth of the slots (especially in the oblique case)

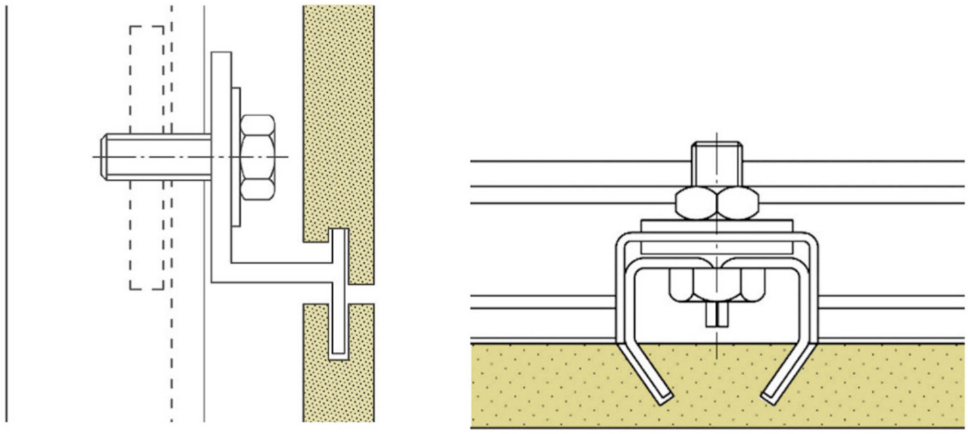

Figure 4 – Slots in the sides (on the left) and in the back (on the right)

d) Fixing by structural adhesives

This is a hidden fastening system. The metal (stainless steel, aluminium, etc.) fixing elements (brackets, clamps, etc.) are glued to the ceramic slab by means of structural adhesives. This method does not require any machining of the ceramic product [5].

However, the gluing phase is very critical and uncertain; as a matter of fact, structural adhesives require a strict control of the process (to avoid joint breakaway) and the chemical bonding is affected by extreme weather conditions and ageing.

2. THE INNOVATIVE PROCESS

A new method for realizing ceramic slabs with embedded fastening systems, ready for assembly on structures of ventilated façades, is presented below.

The new method provides the following advantages:

- perfect integration between the insert and the ceramic matrix, reducing the possibility of detachment or breakage of the slab;
- completely hidden solution with a minimum aesthetic impact (the insert is visible only at the rear side of the slab);
- low production cost, this certainly being less than the previously described solutions (although the a.m. method (a) could have a similar cost, it has worse aesthetic quality).

The new proposed method takes advantage of the capability of the Continua® compaction lines, introduced by Sacmi about 10 years ago [6] and now consolidated in the market. Continua® is particularly indicated for the production of large-sized porcelain slabs with high aesthetic and technical value.

As is well known, the Continua® technology advantageously exploits the loading of soft powders on conveyor belt, followed by a continuous pressing that performs a first compaction at an intermediate density value (about 1.60 g/cm^3).

A recent development of the a.m. system, called Continua+®, allows even higher density values to be reached than traditional pressing (about 2.00 g/cm3), avoiding the discontinuous re-pressing in traditional moulds. This enables slabs to be made with virtually unlimited sizes, at least in length (i.e. 3 meters and more).

The production of slabs with an integrated fastening system, by means of continuous compaction, consists of the following phases (see Figure 5):

1) placing the inserts on the surface of the feeding belt in proper positions, precisely spaced along the feeding direction (distance P) and in two or more rows in the transverse direction (distance T);

2) feeding the conveyor belt with ceramic powder;

3) moving the belt forward to continuous compaction;

4) making the tile/slab the desired size by green cutting before firing;

5) re-introducing, if appropriate, the compacted slab into a second press and re-pressing at high pressure;

6) completing the ceramic production cycle through the drying, decoration and firing phases.

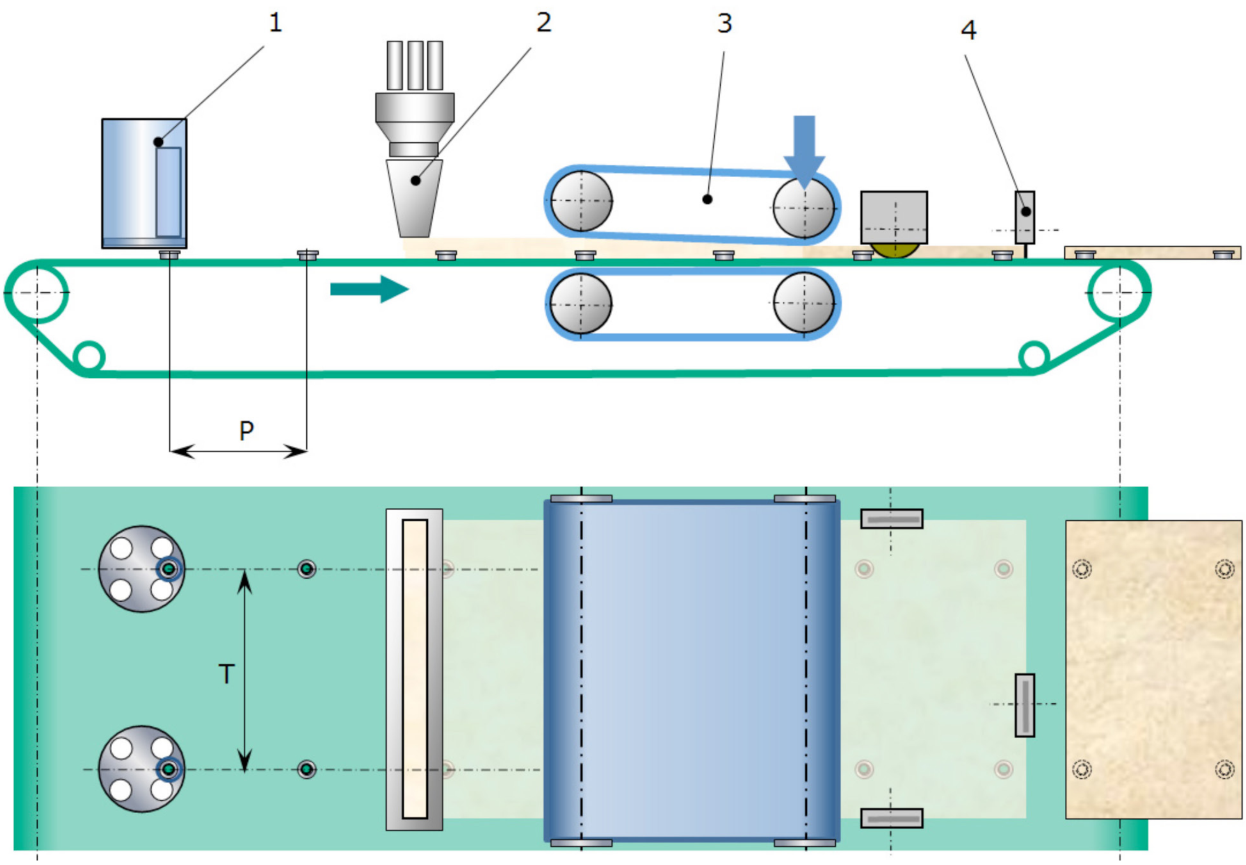

Figure 5 – Automatic insert positioning on the Continua® compaction line

The inserts to be embedded in the ceramic matrix exhibit a threaded hole where the screw will be engaged for fixing to the wall metal structure.

Experimental tests have been successfully carried out using inserts made of stainless steel AISI 304 and AISI 316, with threaded hole M6 or M8 (see Figure 6 and Figure 7).

In order to prevent the hole from being filled with ceramic powder, the hole is protected by a grub screw of suitable height, which is unscrewed and recovered after the firing phase (see Figure 6).

Despite the high temperatures (about 1200 °C) reached in the firing phase, the metal inserts resist and keep their functionality at the end of the thermal cycle.

In order to further increase insert performance, it is possible to use stainless steels with low carbon content (such as AISI 304L and AISI 316L), which are alloys that are better able to resist high temperatures.

Figure 6 – Inserts before (on the left) and after firing (on the right); see (on the left) the protection grub screw, then removed after firing (on the right)

In order to get a good fixing performance, the inserts must be closely joined to the surrounding ceramic matrix. Specifically, they must perform the following functions:

- anti-revolution, in order to prevent the insert from rotating with the screw, preventing fastening;
- anti-extraction, in order to avoid excessive penetration of the screw which, acting on the ceramic, would axially push the insert out.

The anti-revolution function is performed by realizing the insert external surface with non-circular geometry (i.e. with a plane surface, engraving, slots, etc.).

The anti-extraction function is performed by realizing an undercut: the insert shows negative tapering (for example conic shape) and the section enlarges on penetrating inside the ceramic matrix.

Of course, the inserts must be embedded in order to ensure their tapering is entrapped inside the ceramic matrix, avoiding their extraction. Such tapering must not be too marked to allow the insert to be completely surrounded by the powder without empty spaces, which could cause pressing defects. Figure 7 schematically shows the positioning of inserts type 1 and type 2.

The figure shows that the height of the insert hi must be considerably lower than the total height (thickness) of compacted ceramic product h_{tot}; this to prevent a non-homogenous compaction of the material with consequent cracks during the pressing or firing phases. The ratio h_i/h_{tot} must be significantly lower than 0.7, preferably between 0.4 and 0.6.

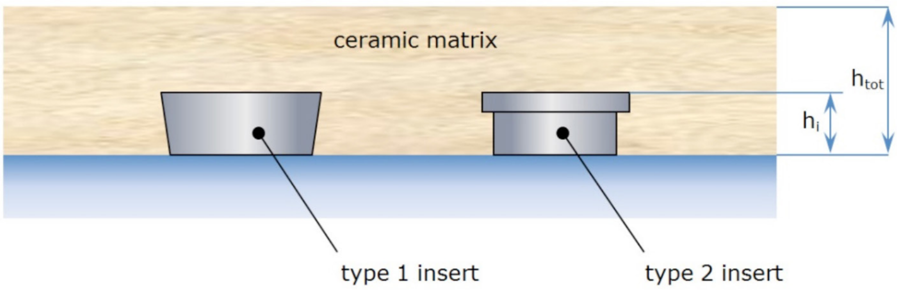

Figure 7 – Positioning of the inserts

In order to evaluate the influence of the metal inserts inside the ceramic matrix during the compaction phase, FEM analysis has been carried out. Figure 8 shows the distribution of the compaction gradient inside the ceramic material, in the case of a truncated cone insert (type 1 shape).

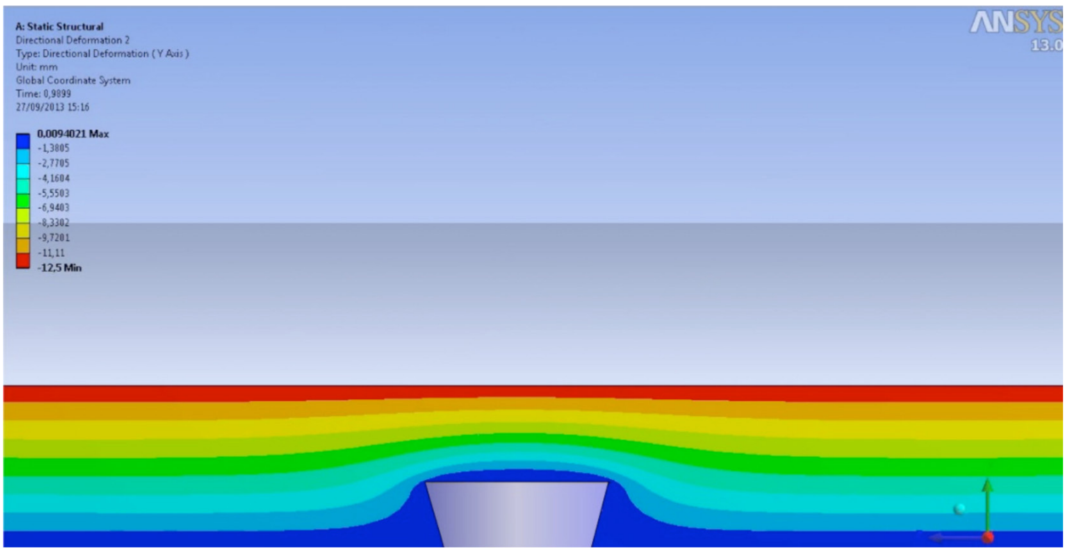

Figure 8 – FEM analysis: distribution of the compaction gradient

At the end of the firing process, the ceramic slab with inserts looks as shown in Figure 9 and it is ready for assembly on ventilated façades.

Figure 9 – Slab with inserts embedded in the ceramic material

3. EXPERIMENTAL WORK

In order to evaluate the efficiency of the threaded insert, namely its cohesion with the ceramic matrix after the sintering phase, some measurements on the resistance to the extraction were performed.

Using as reference Italian Standard UNI 11018 [7] –§ 4.6.2.2, the minimum acceptable resistance to extraction in the case of ceramic tiles is:

$$\sigma_{am} = \frac{\sigma_k}{\gamma_s}$$

where σk is the average flexural strength (≥ 27 MPa for porcelain tile) and γs is the safety factor (equal to 2.4 for the anchors).

The minimum acceptable resistance to extraction thus becomes:

$$\sigma_{am} = \frac{27}{2.4} = 11.2 \text{ MPa}$$

The FEM analysis confirms the tension state acting around the insert. Figure 10 shows the range of Maximum Principal Stress (values in MPa) for the ceramic matrix. The extraction force, applied to the insert thread (not shown), was 1500 N; this value can be considered appropriate for façades in standard conditions [5].

The resulting stress in the ceramic matrix, in the area surrounding the insert, reaches max. 10 MPa and is therefore acceptable according to standard UNI 11018, namely:

$$\sigma_{eff} = 10 \text{ MPa} < \sigma_{am} = 11.2 \text{ MPa}$$

In the case of design calculations, the insert average diameter could be considered as equivalent resistant section S_r of the insert.

In the case reported in Figure 10 the average diameter is 12.8 mm, corresponding to a resistant section of about 129 mm^2, from which we get the minimum granted extraction force Fest:

$$F_{est} = \sigma_{am} \cdot S_r = 11.2 \cdot 129 = 1445 \text{ N}$$

value to which a single insert must resist while working.

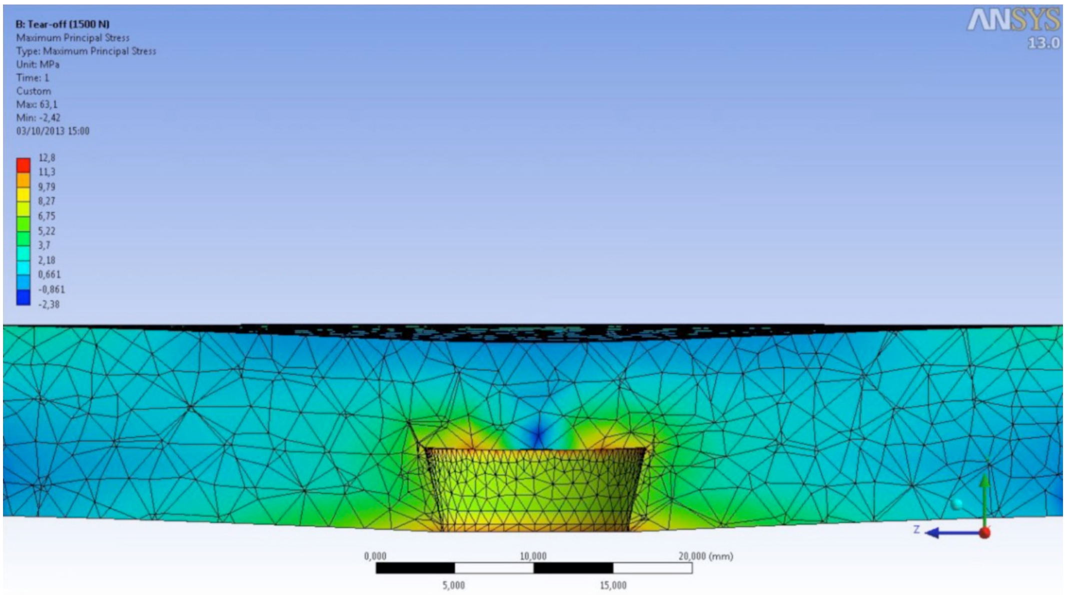

Figure 10 – FEM analysis of the extraction phase (deformations x200)

In order to verify these calculations, a device for testing the inserts embedded in the ceramic slabs has been designed and realized.

The testing device is powered by a pneumatic cylinder with a connection threaded head that replaces the function of the fastening screw. The device gradually applies rising extraction forces up to 1800 N. The cylinder is placed on a spacer, which is in contact with the ceramic slab through a disk of elastic material (polyurethane).

Figure 11 shows a section view of the assembled device; note the spherical articulation in the piston rod eye and the couple of spherical washers for the support of the cylinder body to avoid transversal loads, which would stress the system with bending forces.

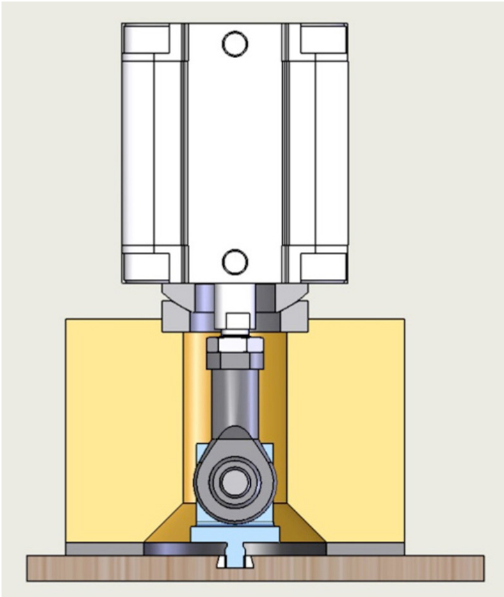

Figure 11 – Testing system for measuring the extraction force

Several 60x120 cm porcelain slabs, produced at Sacmi Imola laboratory, with stainless steel inserts and M6 thread, were measured.

The results are reported in Table 1 and confirm the reliability of the proposed solution, in reference to mechanical resistance to the extraction, which was always greater than the target value (1500 N).

Test	Insert material	Extraction force [N]	Result
A1	AISI 440	1550	OK
A2	AISI 440	1550	OK
A3	AISI 440	1650	OK
B1	AISI 310	1750	OK
B2	AISI 310	> 1800 (*)	OK
B3	AISI 310	> 1800 (*)	OK
(*) no damage of the ceramic matrix occurred at the max extraction force (1800 N)			

Table 1 – Measured values of the extraction force

In addition, note that the values in Table 1 refer to the beginning of the failure of the ceramic material (revealed by a low cracking noise) and not to the complete extraction force. Indeed, the force required for complete extraction would be much higher than the one indicated.

Figure 12, on the left, shows a view of the testing device in operation; the determination of the traction force is carried out by measuring the pressure through the manometer and considering the working section of the pneumatic cylinder.

Figure 12, on the right, shows what the insert looks like after the test; the insert is still embedded in the ceramic material and some radial cracks have formed and created lobe shapes.

Figure 12 – The testing system (on the left) and the insert after the extraction test (on the right)

4. CONCLUSIONS

The application of **Continua®** technology ensures the industrial realization of ceramic materials of both high aesthetic and technical added value. Moreover, the possibility to introduce metal inserts into the soft mass and embed them in the ceramic matrix during the sintering phase provides the slabs with new and unexpected mechanical functionalities.

The present study, carried out at Sacmi Imola pilot plant laboratory, demonstrated the feasibility of the process at industrial level. The developed integrated fastening function exhibits very low costs, considerably less than the other techniques available on the market, while keeping the same mechanical performance.

Hopefully, this application will open up new market opportunities for porcelain tiles, spreading their use in new high volume markets, as "wall façades", thus contributing to the recovery of the ceramic industrial sector.

BIBLIOGRAPHY

[1] L. REIG, "Technical–economic study of facade materials and systems", Qualicer 2006

[2] L. REIG, R. BOGDAN, T. TENDERO, S. BELLMUNT, "Advantages and conditioning factors of ventilated façades with respect to the basic building requirements (TBC)", Qualicer 2010

[3] G. SILVA, V. CANTAVELLA, À. R. GARCÍA, E. BOU, A. MIRALLES, E. UVIEDO, "Study of the energy efficiency of ventilated ceramic façades", Qualicer 2010

[4] J. TSCHOSITSCH, "Undercut panel anchors for concealed fastening of ceramic cladding panels", Qualicer 1994, p. 289-299

[5] K. FELISBINO, H. RAMOS, "Development of a fixing system for ventilated façades with low-thickness porcelain tile", Qualicer 2012

[6] A. BRESCIANI, C. RICCI, "Innovative process for ceramic tile manufacturing by double pressing with continuous precompaction", Qualicer 2004, Vol. 1, P.GI, p. 49-60

[7] ITALIAN STANDARD UNI 11018 "Cladding and anchoring systems for back ventilated external enclosures of buildings. Instructions for the design, installation and maintenance. Ceramic and stone cladding", Enero 2003