FULL DIGITAL DECORATION PROCESS COMBINED WITH DRY GLAZING

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1. ABSTRACT

The remarkable development of digital decoration technologies has undoubtedly revolutionized the ceramic tile production process. It has done so mainly by increasing the graphic quality of finished products, yet also by providing numerous opportunities to optimize the lay-out and running of glazing departments.

At this time, the potential of ink-jet technology, where applied to the ceramic decoration process, is universally recognized: it makes designing new products much easier and raises the consistency of production quality.

Moreover, the setting-up of glazing and decoration lines has been simplified with respect to more complex traditional configurations. However, in most cases the radical transformation that stems from the application of Industry 4.0 precepts has not yet occurred because, so far, analogical decoration machines been simply been replaced with digital ones.

This partial revamping of glazing lines implies the coexistence of traditional application devices (disc and spray gun cabins, veil systems etc.), based on standard glaze water suspensions, with new-generation digital machines, which perform higher resolution decoration with inks, frits and glazes dispersed into non-polar organic solvents.

This study aims to explore an innovative plant solution that simplifies the entire decoration process by combining dry glazing and digital decoration technologies; this avoids the need to maintain conventional water-based applications, which prevent true renovation of the glazing lines.

More specifically, the proposed decoration process is particularly suitable for large (up to 3 meters or more) porcelain stoneware production using Continua+® technology, which consists of the following steps:

1) batching of a first layer of standard base spray-dried powder on the conveyor belt;
2) application of a second layer of a high quality spray-dried powder, such as engobe/glaze or a special white ceramic body;
3) continuous pressing;
4) high resolution digital ink-jet printing;
5) digital application of glazes and frit grains;
6) drying and firing.

In order to optimize the above process it was necessary to take into account technological factors which affect the flatness of the finished product (and, consequently, the ability to manufacture high-value large tiles/slabs).

Thanks to integration of dry glazing with the following HD digital decorations, this new, proposed process gives the ceramic industry a genuine opportunity to set-up a true "full digital" compact line.

In fact, the main features of the new line may be summarized as follows: extreme technical simplicity, easy running, space saving, high productivity, top product quality and, last but not least, reduced environmental impact with respect to other possible digital solutions based on fully organic decoration materials.

2. FOREWORD

While the very first attempts at digital decoration on a laboratory scale date back to the 1980s, at least two decades would pass before the inkjet printing technique entered the industrial machine market [1].

After some decidedly 'pioneering' years, characterized by few installed machines and considerable difficulties in defining coloring pigments suitable for ceramic technology, digital printing steadily gained ground on markets, firstly in Europe (Spain and Italy led the way) and then worldwide.

Fig. 1 shows digital printing machine sales from the year 2000, when the first inkjet printing machine, with inks suitable for the ceramic production cycle, was launched on the market (Ferro KeraJet [1] [2] [3]).

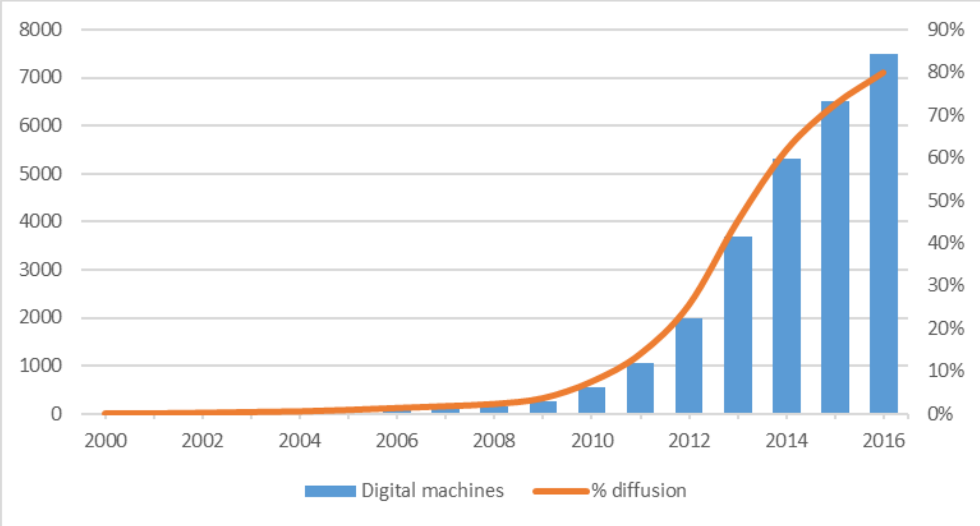

Fig. 1. *Worldwide sales for ceramic digital decoration machines from the year 2000 and % diffusion referred to the total amount of production lines*

As Fig. 1 illustrates, digital technology took a decade to reach the point where it took off [4] [5]. At present, its diffusion with respect to the total number of production lines in the world is over 75% and this trend is set to increase, albeit at a lower rate than that observed in the first few years after 2010. It is important to point out that this value is much higher in Spain and Italy, where over 95% of lines employ the new technology.

Such sudden development of digital decoration technologies – without equal in industrial fields similar to the ceramic one – revolutionized the ceramic tile production process. Gradually, we have succeeded in making optimal use of the specific advantages of digital techniques, namely:

- very high resolution (photographic quality)
- printing without contact (up to the edge and on the reliefs)
- no physical printing equipment (the screens, rollers, etc. connected to each decoration)
- graphic design can be modified without stops
- stable coloring and consistent quality
- flexible production lots

In the glazing department too, digital printing brought marked simplification compared to the complexities faced in the past. Previously, decoration was obtained by overlapping (with contact) several applications (up to or over 10) of glaze and decorative material; this involved (flat or rotary) silk-screen printing machines or engraved silicon roller decorating machines (such as Rotocolor®). At the end of the 1990s, decoration lines 100 meters or more long, with dozens of application machines, were a common sight. Fig. 2 illustrates such a typical decoration and glazing department, with multiple parallel lines and lots of floor space.

***Fig. 2**. Decoration department with traditional technology*

Despite the objective success of digital technology, we have not yet witnessed the radical transformation of decoration departments but merely a simple replacement of analogical machines with digital ones.

Nowadays, such partial renewal involves the coexistence of traditional applications, typically based on conventional glazes in aqueous suspension and related devices (disc cabins, glaze veil applications, airless cabins etc.), and latest-generation digital systems for high definition decoration and glazing with inks and frits having an organic dispersant base.

3. AIM OF THE STUDY

This study focuses on an innovative plant engineering solution (called "full digital"). It aims to simplify the decoration process by combining dry glazing and digital decoration technologies, thus eliminating the need for a conventional glazing line based on the application of glazes in an aqueous suspension.

This innovative approach allows attainment of the following results:

- a shorter decoration line (saving manufacturing facility floor space)
- elimination of chemical-physical incompatibilities between aqueous-base and solvent-base glazes
- higher decoration quality
- general cost reduction

Of course, achieving these goals requires optimization of the materials to be applied. This is especially true for dry materials as they must, on the one hand, match body characteristics perfectly and, on the other, ensure unchanged surface quality and colour development during the subsequent digital application of inks and finishing glazes.

Moreover, careful attention must be paid to cost control (i.e. application of dry materials in only the minimal quantities needed to cover the underlying base body surface).

This can be achieved through perfect control of dosing/distribution of the powders that make up the high quality layer.

4. THE NEW DECORATION PROCESS

This proposed "full digital" decoration process is particularly interesting if adopted on large porcelain stoneware slab lines equipped with Continua+® forming technology, which can be used to manufacture tiles 3 meters or more long and 3 - 20 mm thick [6]. In fact, traditional wet application becomes difficult on such slabs due to their enormous (especially transverse) dimensions. Wet glaze waterfall techniques (consolidated for medium-small sizes) become critical when the advancing edge of the piece is over one meter wide.

The continuous compaction line is illustrated in Fig. 3 in one of its possible configurations. It forms porcelain tiles / ceramic slabs from standard spray-dried powders; the latter are laid on a lower steel conveyor belt that travels at constant speed underneath a series of electronically controlled application devices. The powder then arrives at the compacting station, where the "soft powder" is progressively compressed by an upper steel belt until definitive compaction is achieved. Afterwards, cross-cutting (in order to define the longitudinal size) and high definition surface decoration are performed. The thus-obtained slabs are then ready for the following drying and firing phases.

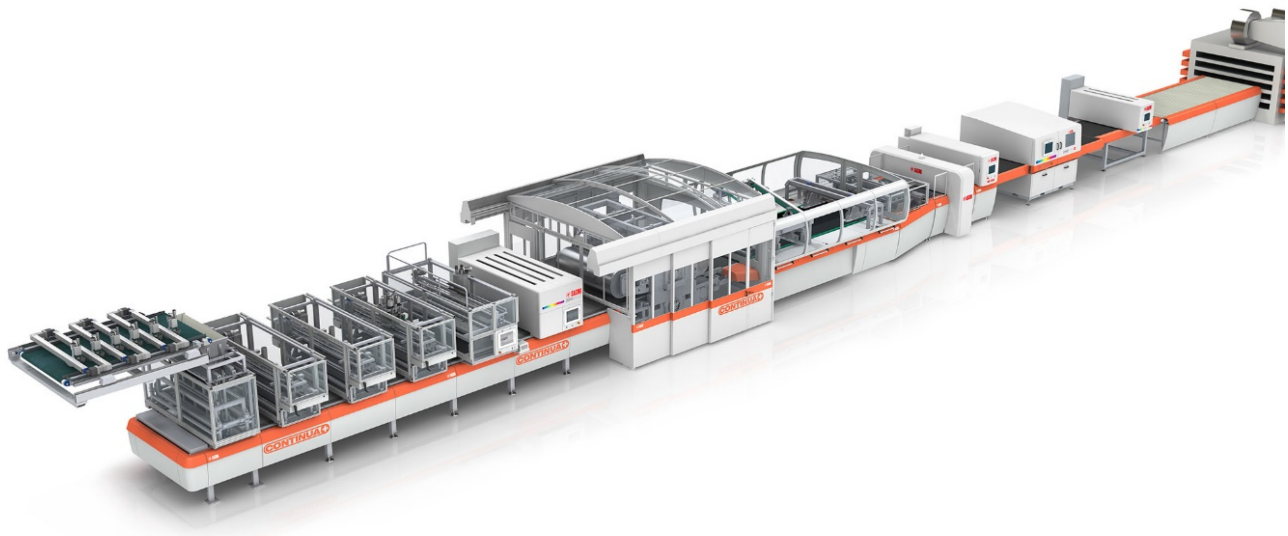

Fig. 3. *Continuous forming line*

The new "full digital" decoration process consists of the following stages:

1) deposit, on the conveyor belt, of a **first layer** of spray-dried base powder;
2) application of a **second layer** of spray-dried powder having higher added value, composed of engobe or glaze or another "white" ceramic body;
3) continuous forming;
4) digital printing of the decoration, at high resolution, by inkjet;
5) digital printing of protective frits and frit grains;
6) drying and firing.

As can be seen, the entire process (without adding water) allows the product to be finished on an extremely compact (despite the huge dimensions of the final slab), productive (up to 14.000 m^2/day) line.

A further advantage of glazing with spray-dried powders (thus avoiding water) is that inkjet printing takes place on a "cold" surface (at ambient temperature) as the slabs are not dried before decoration. This allows prevention of the water vapor condensation phenomena which often affects ceramic inkjet printing machines and provides the advantages of better printing quality, reduced assistance requirements and higher productivity.

In order to avoid the application of excessive (and thus costly) quantities of a second "noble" layer, dry glaze is deposited by special digitally controlled dosing devices (Fig. 4). Dosing accuracy is ensured by a series of independent blades placed side by side, each one electronically controlled, which feed small quantities of spray-dried powder as a function of the graphic design.

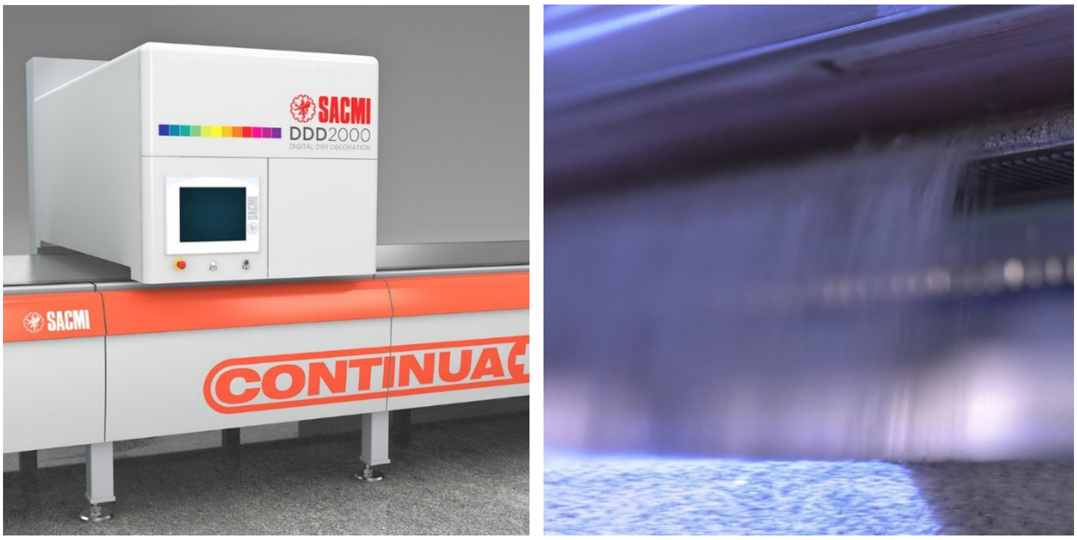

***Fig. 4**. Dry Digital Decoration machine (left). Close-up of powder feed (right)*

This makes it possible to apply very precise, controlled quantities of glaze/engobe, with a final thickness of 0.5 ÷ 2 mm.

As an example, Fig. 5 (left) shows a close up of a sample (before firing) obtained using this technique. As you can see, the upper glaze/engobe thickness is perfectly consistent. The image on the right shows a micrograph of the cross-section of fired sample. Note the general homogeneity, with excellent compactness and integration between layers.

The specific characteristics of continuous compaction technology make the pressed slab surface extremely smooth, almost shiny. This is thanks to the surface finishing performed by the pressing belt, made of very hard stainless steel. This characteristic is particularly useful for optimizing the following decoration and digital finishing stages.

Fig. 5. *Detail of double-layer slab: before firing (left) and micrograph after firing (right)*

5. EXPERIMENTATION

In order to assess this innovative double loading process, consisting of a first layer of spray-dried base body and a second layer of spray-dried glaze/engobe, it was first necessary to study the technological factors that allow attainment of good finished product flatness.

This aspect is fundamental to sound manufacturing of large dry-glazed tiles and slabs.

More specifically, two body compositions, coded P1 and P2, for glazed porcelain stoneware were studied in combination with 6 glaze/engobe compositions, coded E1 … E6.

Table 1 shows the main technological parameters of the employed bodies. The grey fields show the most important ones needed for a proper match with the glaze/engobe.

Body characteristic		P1	P2
Green bending strength	N/mm^2	1.3	1.4
Dry bending strength	N/mm^2	5.8	6.9
Max. firing shrinkage	%	5.0	5.8
Water absorption	%	0.3	0.1
Bending strength after firing	N/mm^2	59	66
Thermal expansion $\alpha_{(30°\text{-}400°C)}$	$10^{-7}/°C$	77	75
Thermal expansion $\alpha_{(30°\text{-}650°C)}$	$10^{-7}/°C$	91	82
CIE whiteness index (L)		61	72

Table 1. *Technological characteristics of the used bodies*

With reference to the glazes/engobes, the following compositions, formulated both at Sacmi and in co-operation with some suppliers, were examined.

Table 2 shows the main technological parameters of used glazes/engobes.

Glaze/engobe characteristics		E1	E2	E3	E4	E5	E6
Green bending strength	N/mm^2	0.7	0.6	0.7	0.7	0.6	0.6
Dry bending strength	N/mm^2	3.7	3.4	2.1	2.6	3.3	1.8
Max. firing shrinkage	%	4.6	4.5	8.0	6.9	5.8	7.7
Water absorption	%	0.3	0.3	0.1	0.0	0.1	0.1
Bending strength after firing	N/mm^2	59	62	77	70	61	53
Thermal expansion $\alpha_{(30°\div400°C)}$	$10^{-7}/°C$	76	75	75	72	70	65
Thermal expansion $\alpha_{(30°\div650°C)}$	$10^{-7}/°C$	86	86	87	82	79	70
CIE whiteness index (L)		92	92	91	91	91	89

Table 2. *Technological characteristics of the used glazes/engobes*

The first required characteristic is good pressing aptitude: a minimum green bending strength value (MOR) of 0.6 N/mm^2 is considered suitable, in combination with the following ratio

$$\frac{MOR_{dry}}{MOR_{green}} \geq 3$$

As can be seen, all the engobes used during our study meet the above requirements.

Other basic glaze/engobe parameters are shrinkage during sintering, the thermal expansion coefficient α and, of course, the whiteness index (L).

We thus produced dry-glazed ceramic supports, combining bodies P1 and P2 with the engobes shown in Table 2.

The employed forming technology produced double-layer materials of excellent quality, without any lamination or structural integrity problems.

The thus-obtained dry glazed products, 1280x2560x10.5 mm before firing, were dried in a fast-cycle horizontal drier and then fired in a roller kiln with a 120-minute cycle.

The main evaluation aspects, besides the absence of defects, refer to (qualitative) flatness measurement, giving the results in Table 3.

	E1	E2	E3	E4	E5	E6
P1	–	–	––	––	–	––
P2	––	––	––	=	+	–

Table 3. *Qualitative evaluation of the flatness of double-layer products*

As can be seen, most of the samples show a varying tendency towards deformation/concavity (–) (––), except for the combinations P2/E4 and P2/E5 which are flat (=) or slightly convex (+) as desired.

The reason for such behavior is mainly attributable to two factors:

- homogeneous shrinkage between body and glaze/engobe;
- higher (some points) thermal expansion coefficient of body compared to engobe.

It is thus deducible that body P1, with a lower shrinkage and higher thermal expansion coefficient, cannot achieve perfect flatness with the used engobes.

On the contrary, body P2 matches well with both glaze/engobe E4 (slightly higher shrinkage but a slightly lower coefficient) and glaze/engobe E5 (similar shrinkage and slightly lower coefficient).

The above clearly highlights that it is possible, by adjusting the technological characteristics of the glazes/engobes as a function of production bodies, to achieve large finished products of excellent quality, from both technical and aesthetic viewpoints.

Fig. 6 shows a FEM simulation of the dilatometric behavior of a slab made by combining 9 mm base body P2 and 1.5 mm glaze/engobe E5 (total pre-firing thickness 10.5 mm). It shows the out-of-plane (Y-axis) deformation of the slab after firing (the extent of deformation has been enlarged to make it more visible). Maximum inflection in the center line reaches 2.52 mm, which is absolutely acceptable, also in consideration of the large size. In any case it will be cancelled out during laying thanks to its intrinsic flexibility.

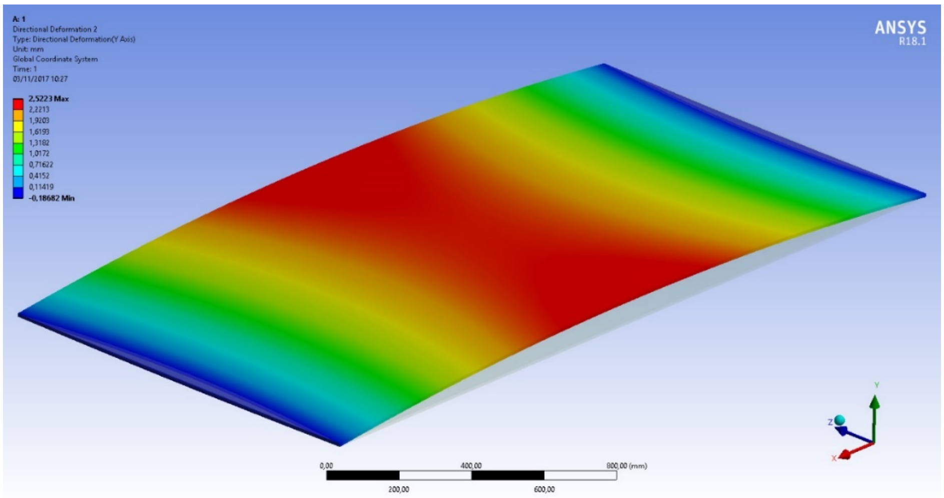

Fig. 6. *FEM simulation of the deformation of an optimized slab*

It is necessary to point out that flatness measurement is extremely difficult with large sizes (side >90 cm); in fact, consolidated measurement methods and specific equipment are lacking. Besides, the slabs, due to their weight, tend to take the shape of the surface they are laid on, masking (sometimes in positive way, in other cases negatively) the result of the measurement itself. Therefore, accurate flatness measurement of large slabs cannot ignore the need for sophisticated (and expensive) instrumental control techniques [7] [8].

Consequently, in order to complete the experimentation, we made finished products at the SACMI Imola R&D Centre pilot plant.

The double-layer slabs formed on the continuous compaction line were decorated directly with glaze/engobe through the application of inks and protective transparent (glossy and matt) frits using the 8-bar digital decoration machine as illustrated in Fig. 7.

Fig. 7. *Decoration line for large size slabs at SACMI R&D Centre*

The completed materials (Fig. 8), 1200x2400x10 mm after firing plus sub-sizes obtained by cutting, show the true potential of the proposed "full digital" decoration process.

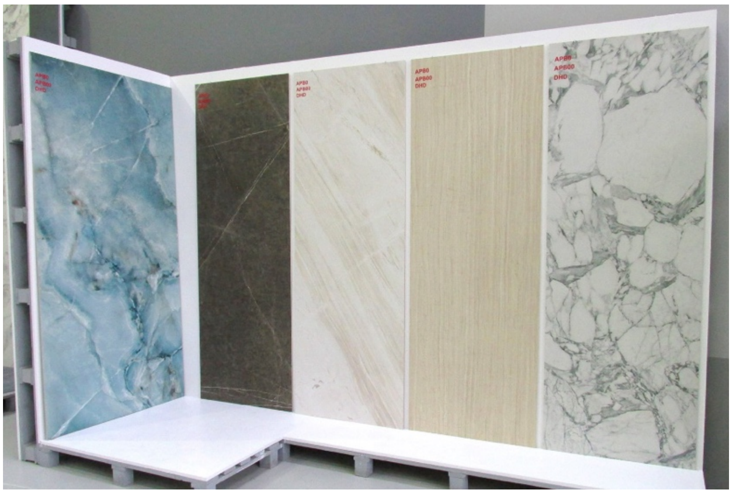

Fig. 8. *"Full Digital" slabs sized 1200x2400mm and 800x2400mm*

6. CONCLUSIONS

An innovative "full digital" process for the production of porcelain stoneware slabs, based on the application of spray-dried glaze/engobe during the forming phase, was experimentally validated.

In particular, we examined the technological parameters that allow an ideal match between the ceramic support and glaze. This is necessary for attaining good flatness, especially important given the large dimensions of the pieces in question.

Lastly, thanks to integration of dry glazing with subsequent high definition digital decoration, the new process is of considerable interest to industry as it allows the establishment of a compact "full digital" line that offers greater technical/organizational simplicity than current plants, which still employ traditional glazing systems.

Last but not least, dry application of glaze undoubtedly involves lower environmental impact when compared to the prospect of adopting digital glazing with use of the organic dispersants currently employed for inkjet decoration.

7. BIBLIOGRAPHY

[1] V. Sanz Solana, "Inkjet printing technology for ceramic tile decoration", *Qualicer 2014*

[2] I. Hutchings, "Ink-jet printing for the decoration of ceramic tiles: technology and opportunities", *Qualicer 2010*

[3] A. De Carlo, "The digital revolution in tile decoration", *Ceramic World Review 51*, 2003, pp. 78-84

[4] G.P. Crasta, "Boom in digital technology", *Ceramic World Review 97*, 2012, pp. 64-67

[5] L. Baraldi, "World production and consumption of ceramic tiles", *Ceramic World Review 123*, 2017, pp. 56-70

[6] A. Bresciani, C. Ricci, "Innovative process for ceramic tile manufacturing by double pressing with continuous precompaction", *Qualicer 2004*

[7] G.M. Revel et al., "On-line deformation monitoring of thin ceramic tiles", *Qualicer 2014*

[8] S. Fazio et al., "Nuovi strumenti per la misura delle lastre ceramiche", *CER 364*, 2017, pp. 50-52