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Technical Evolution of Ceramic Tile Printing

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Abstract. *Ceramic tile decorating techniques have evolved significantly in recent years. Digital inkjet printing technology has enabled digital systems to be used for the direct decoration of ceramic tiles, revolutionizing ceramic tile decoration and providing many advantages over traditional decoration techniques. It was the formulation of inks with soluble and vitrifiable stains that allowed inkjet printing technology to be introduced into ceramic tile decoration. The incorporation of milled inorganic pigments into the inks broadened the available color palette. However, the colloidal instability of these inks and the constraints of the printing heads themselves made it necessary to reduce pigment particle size, thus limiting color saturation and the color gamut. In order to increase color saturation and obtain a set of pigmented inks with colors more closely resembling CMYK colors, pigments with larger particle sizes need to be used. Indeed, other digital decorating techniques, such as xerography, allow larger particle sizes to be used, while also providing the advantages associated with digital decoration. However, the implementation of this technique for ceramic tile decoration requires the development of appropriate ceramic toners and adaptation of printing machines. This article reviews the technical evolution of ceramic tile printing and describes the development of a prototype, based on xerographic printing, that is able to print ceramic tiles directly and provides greater color intensity and a wider color gamut. © 2012 Society for Imaging Science and Technology.*
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INTRODUCTION

Ceramic tile decorating techniques have developed significantly in the last twenty years as a result of a number of different factors. On the one hand, products with new aesthetic finishes were needed to increase the existing range, which favored the emergence of new decorating systems. On the other hand, environment-related factors have fostered the development of new application systems and the upgrading of already existing ones, in order to make decorating techniques cleaner and reduce the resulting waste. Finally, economic factors, which continuously drive the development of high-quality products at the lowest possible cost, have also played their role.

Digital inkjet printing technology has enabled digital systems to be used for the direct decoration of ceramic tiles. It may be noted that the traditional printing processes found in the ceramic industry also used digital systems, albeit indirectly, to transfer the design from the computer to a photolitho or onto a rotogravure roller.

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Major ceramic tile decorating techniques of the recent past include flat screen printing (Figure 1(A)), which began to be used in the 1960s, and rotary screen printing (Fig. 1(B)), which appeared in the 1970s. The development of computer-aided design allowed photographic systems to be replaced with specific printers for making the photolithos used in screen preparation for screen printing. A drawback to this technique was that, in order to reduce decoration costs, the same screen needed to be used to print numerous, identical products. The rotary screen enabled the printing start to be shifted and, consequently, products to be obtained that looked different despite being printed with the same design. When this technique was used to decorate just a single item, the price of the product soared.

Screen printing decoration has progressively evolved over the years. Computer-to-screen technology emerged, enabling photolithos to be dispensed within the screen preparation process for light curing. This technique scarcely had any repercussions in ceramic tile printing.

Screen printing was followed in the 1990s by rotogravure,[1,2] in which photolithos were no longer required: the design to be transferred onto the tile was engraved on the roller by a computer-controlled laser (Fig. 1(C)). In this technique the ink is applied directly onto the cylinder and then transferred from the cylinder to the substrate. The technique implemented the benefits of rotary systems, shortening start-up times in the production line compared with flat screen printing and raising productivity (for the same decoration, once the gravure cylinder or flat screen had been engraved), as it was no longer necessary to stop the product being decorated during the process. In addition, the decoration was applied to the edge of the tile. A disadvantage was the high price of the silicone rollers: numerous printing runs were required to make a design profitable.

Flexography also appeared in the 1990s,[3] though it was less widely used in ceramic tile decoration. A flexographic print is made by creating a positive mirrored master of the required image as a 3D relief in a rubber or polymer material (Fig. 1(D)). Flexographic plates can be created with analog and digital plate-making processes. The image areas are raised above the non-image areas on the rubber or polymer plate. The ink is transferred from the ink roll, which is partially immersed in the ink tank. Then, it transfers to the anilox roll, whose texture holds a specific amount of ink as it is covered with thousands of small wells or cups that enable

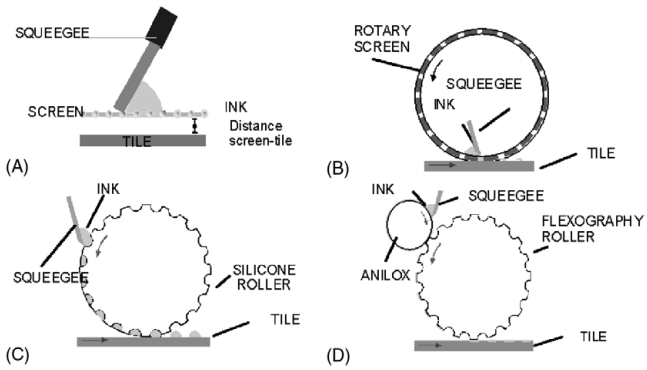

Figure 1. Schematic illustration of traditional printing processes found in the ceramic tile industry. (A) flat screen printing; (B) rotary screen printing; (C) rotogravure printing; (D) flexography printing.

it to meter ink to the printing plate in a uniform thickness evenly and quickly.

Inkjet printing systems emerged between the end of the 1980s and the beginning of the 1990s for office computer applications. When this development was transferred to the industrial field and, in particular to the continuous manufacture of serial products, issues surfaced that made technology transfer or development difficult. This delayed the implementation of digital inkjet printing technology in the ceramic tile sector, where it first materialized in the year 2000, when the first inkjet printing machine appeared on the market for industrial ceramic tile decoration (Figure 2). The ceramic tile sector has since witnessed an accelerated revolution in decorating processes and techniques.[4,5] Compared with the traditional techniques used in ceramics, inkjet printing technology is an entirely different printing process. Unlike most other inkjet applications, in decoration on a ceramic tile, printing is just one part of the process and needs to be followed up by one or more operations, the most important being the firing of the tile. End quality depends on three critical factors: type of substrate, characteristics of the printing machine, and inks.[5,6] The technology continues to pose new challenges to basic and applied research in various fields with regard to the development of new inks, machinery, and computational applications.

EVOLUTION OF INKJET TECHNOLOGY IN THE CERAMIC TILE SECTOR

The first studies on the possible use of inkjet printing for ceramic decoration date back to the 1980s, when W. Roberts[7] of British Ceram Research proposed a continuous inkjet system, using nozzle aperture sizes between 20 and 100 μm. Research increased, focusing on the adaptation and upgrading of ink properties, particularly ink flowability and conductivity, until the mid-1990s. This was aimed at making the inks appropriate for use in the printing systems available at that time, and different printing methods and applications on different substrates were tested. The trials were conducted in the most innovative available printing systems without, however, modifying these systems for use on ceramics.

Inkjet printing drew attention particularly in the field of fine ceramics, with extensive research being conducted into inks. The great handicap of the printing machines lay in obtaining larger-sized decorative patterns and production speeds at least resembling those then found in ceramic tile manufacture. Although the idea of introducing this technology continued to gather strength, implementation entailed a certain degree of complexity and a very important risk factor. It became clear that research needed to be conducted simultaneously on several fronts, not just with regard to raw materials and ink adjustments, but also to adaptation of the machinery.

Such research synergy emerged between machinery manufacturers and raw materials suppliers at Villarreal, a town with a great ceramic tile manufacturing tradition, located in the ceramic district of Castellón (Spain). In 1998, J.V. Tomás Claramonte, owner of a small company devoted to computer engineering for ceramics, patented an inkjet printing machine for decoration by a single pass of ceramic tiles,[8] with multiple printheads of the SII Printek binary type, in which the drops generated had the same size, about 50 μm, corresponding to a drop size of 60 pL. The invention involved a device and a process for decorating ceramic tiles by inkjet printing (Fig. 2). The main constraint at that time lay in the inks, owing to the formation of agglomerates larger than the size of the injector nozzle aperture (about 50 μm).

In 1999 J.V. Tomás Claramonte and his partner established *Kerajet*, a new company, and they were joined in their research efforts by the company *Ferro Enamel Española SA* (a subsidiary of the multinational *Ferro Corp*) in order to jointly develop electronics, software, and inks for inkjet printing systems. The first industrial printer prototype was exhibited at the international Cevisama trade fair in Valencia, Spain, in 2000. The first inks for this machine were patented by *Ferro Corp* in the same year.[9] That patent describes a set of four inks (CMYK) for color printing, each ink including one or more soluble complexes of transition metals. The presentation of this machine caused a great impact. However, although the benefits that inkjet printing provided in comparison with rotogravure printing and screen printing (the major technologies in the ceramic process at that time) were clear from the outset, the technology was insufficiently mature to be implemented. There were problems with regard to ink stability and low chromatic intensity when the inks were

Figure 2. The first Kerajet model in the year 2000 (source SECV).

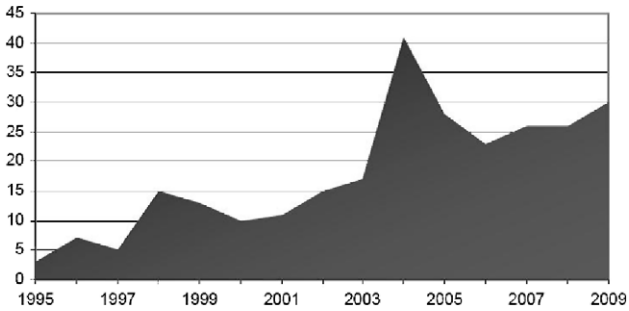

Figure 3. The number of patents relating to the development of ceramic inks for inkjet printing in the ceramic sector.[11]

introduced into the industrial process. These constraints, together with the price of the materials, acted as a barrier to the rapid expansion of this technology in the ceramic tile industry. However, the search intensified for inks that would display the following specific properties[10]: (a) *high stability*, since precipitation, agglomeration, and changes in viscosity could clog the injectors (this involved addressing pigment degree of milling and specific surface area; ink solids content, colloidal stability, and rheological behavior); (b) *high coloring strength*, as the small quantity deposited and the possible problems of diffusion on the substrate (6–70 pL) could reduce the intensity of the resulting colors and produce low-quality decoration (involving surface tension and drop drying velocity); and (c) *chemical compatibility* between the injector and the ink (Fig. 2).

In recent years numerous research articles and patents have been published on the development of new printing inks that contain inorganic pigments for ceramic decoration using inkjet technology (Figure 3). These studies have increased as this technology has been progressively implemented in ceramic tile decoration. Research has grown steadily, particularly since 1998, the year 2004 standing out.[11]

Ink development has been paralleled by the evolution of the inkjet printing equipment used in ceramic tile decoration. Most of these developments have been successively presented at two major ceramic trade fairs: *Cevisama* in Spain and *Tecnargilla* in Italy.

Figure 4 schematically illustrates current inkjet printing technologies.[12] Most inkjet systems for decorating ceramic tiles use the drop-on-demand (DOD) principle, in which several methods are used to produce the pressure pulse, depending on whether piezoelectric, thermal, electrostatic, or acoustic printheads are involved. The most widely used printheads in ceramic tile decoration are piezoelectric, the main suppliers of this type of technology for ceramic tile decoration being *Xaar*, *Spectra*, and *Seiko*.

Certain authors consider the key features in the development of this digital technology for ceramic tile decoration to have been the printheads, tile transport system, ink supply system, data feed, and associated control systems. The design and integration of these components in a ceramic production environment has posed significant engineering challenges.[5]

The appearance of the first printing machine for ceramic tiles in the year 2000 was followed by other, improved machines. In 2005, *Torrecid*, a multinational frit, glaze, and ceramic color producer, launched a range of pigmented inks in collaboration with *Durst Phototechnik AG*, a company devoted to image processing.[13] These inks were designed for single-pass digital inkjet printing machines with *Spectra* printheads,[14] which were also of the binary type. The appearance of this new commercial option led to further spread of inkjet printing in the ceramic sector.

The development of inkjet printing systems has since surged in companies that manufacture decoration equipment for ceramic tiles. At present, more than thirteen different commercial machines are available, all of which are suitable for ceramic tile printing. Machines with gray scale DOD printheads, patented by *Xaar*,[15,16] emerged during this period. These provide a higher quality image with the same nozzle aperture, in which the size of the injected drop can be individually regulated, yielding drops ranging from about 6 to 42 pL. Another important advantage of Xaar 1001 printheads in using ceramic inks is ink recirculation. This means that air bubbles and dust particles present in the ink are carried away, significantly improving reliability even in the harshest industrial environment. Moreover, ink recirculation keeps the ink moving and prevents sedimentation and nozzle blocking, particularly in heavily pigmented inks.

Parallel to the use of DOD printheads, the spray-on-demand technology was also implemented using the FlatJet technique. This system is able to spray small drops using larger supply tubes (500 μm), which piezoelectric impellers mounted on two resonating metal sheets cause to vibrate separately. Given the inner dimensions of the supply tube, the particle size can be 10 times larger than in the case of DOD printheads. Since pigmented inks with a larger particle size can be used, the color gamut and intensity are enhanced, though the resolution is much lower.[17] The system also works with water-based inks. This machine is marketed by *Sacmi Imola SC*. A company that committed to another approach was Talleres Foro, S.L., which in 2010, together with Colores Cerámicos, S.A., presented a new system of digital ceramic tile decoration by a continuous inkjet with multiple deflection using water-based inks. However, these approaches, which differ from the DOD technology, have found scarce implementation in ceramic tile decoration. The

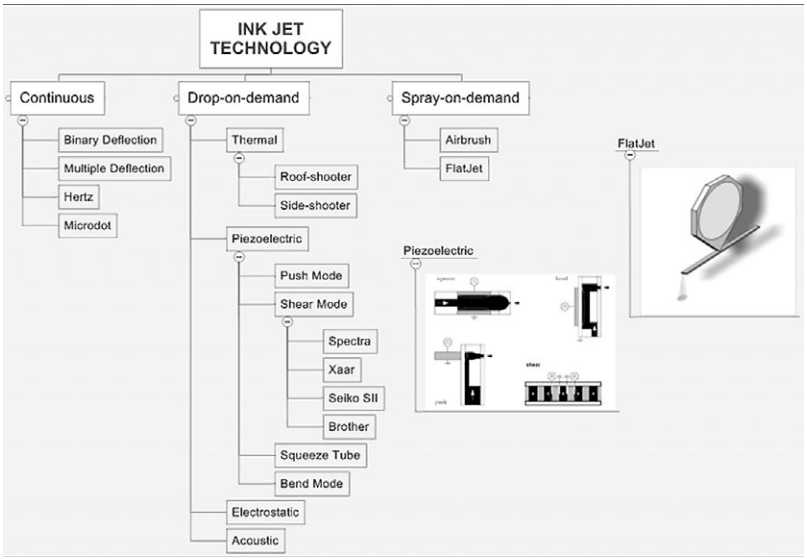

Figure 4. Schematic illustration of current inkjet printing technologies.[12]

Table I. Companies that have marketed on-line machines for inkjet decoration of ceramic tiles in the last few years.

Year	Number of companies	Company
1999	1	Kerajet
2005	2	Durst
2008	7	Cretaprint
		Jettable
		System Ceramics
		Newtech
		Sacmi
2009	8	Hope Ceramics
2010	13	In. tesa
		Tecnoitalia
		TSC
		Siti-B&T
		Sertam

rapid spread of ceramic inkjet technology in the last four years may be seen in Table I, which shows the number of companies that have marketed on-line machines in the last few years.

Despite the slump in technology investment during the worst two years of crisis for the ceramic tile sector, the digital decoration segment has not showed any signs of slowing, indeed quite the opposite. In April 2010 there were a total of 373 machines, of which 295 had been installed in Spain and Italy and 78 in 22 other countries. In just nine months, from April to December 2010, a further 175 machines were installed, a quarter of the total of 664 machines installed by April 2011. The largest number of new installations was again in Spain and Italy. The year 2011 witnessed further growth: 116 machines were installed in the first four months of the year and this figure was expected to reach 360 by the end of 2011. The list of countries using inkjet technology has also grown, new entries including Algeria, Syria, Vietnam, South Africa, Argentina, Venezuela, Australia, Taiwan, South Korea, Ecuador, Sri Lanka, Russia, and Colombia.

Figure 5 shows the number of machines installed worldwide up to April 2011, involving a total of 664 machines.[18] Up to 2010, 48.6% of the machines installed in the world were of Spanish and 31% were of Italian origin.[19]

The digital market in ceramic tile decoration is currently estimated at 5%–6% of the total business volume. This percentage is expected to continue to grow considerably in the coming 5–7 years and then to stabilize.

As mentioned above, the greatest surge in the implementation of this technology in the ceramic tile industry has taken place in recent years. This surge has been such that the three major inkjet machinery manufacturers in Spain have witnessed a great increase in production in the last three years, which have been crisis years for the rest of the sector. It may be noted, furthermore, that the three have considerably expanded their facilities and/or the number of workers and have sold their entire production, leading to considerable delivery times for new machines.

ADVANTAGES AND DISADVANTAGES OF INKJET PRINTING TECHNOLOGY IN CERAMIC TILE DECORATION

Many of the constraints of traditional ceramic tile decorating systems, such as screen printing, flexography, and rotogravure, have been technically overcome by inkjet technology, which is consequently replacing these systems. Inkjet technology provides many advantages in tile decoration compared with conventional printing systems. These include aesthetic, productive, logistic, and economic benefits. For example, there is no printing contact, which allows tiles with relief or embossing to be printed, tile edges can be decorated

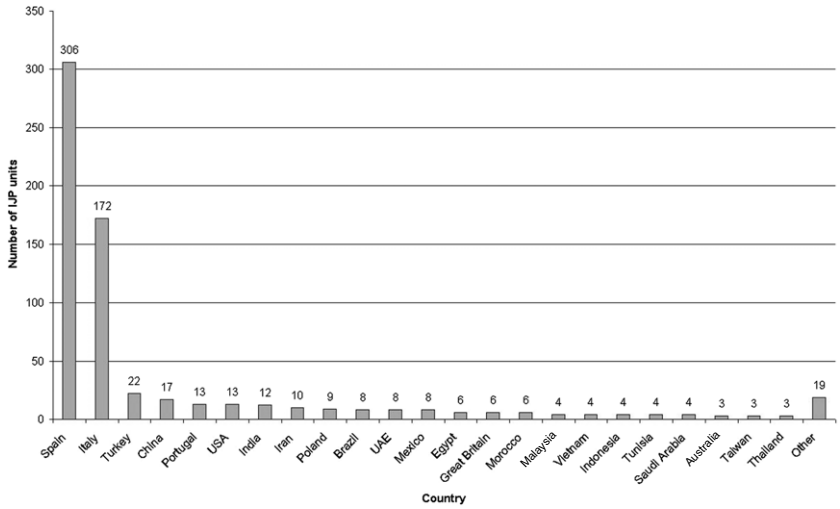

Figure 5. Machines for ceramic tile decoration installed per country up to April 2011 (source: Ceramic World Review no. 86/2010).

in the same process, a greater variety of designs can be realized, designs can be easily corrected on-line, there is greater manufacturing and color control, high image definition can be achieved and other ceramic tile decoration techniques can be reproduced. Further advantages of the digital process include ease of design adjustments and changeovers, simple product customization and shorter product development lead times, improved quality and less tile breakage, the need for smaller quantities of consumables than with traditional systems, reduction in the required number of inks and colors (only CMYK colors), the possibility of printing one-off products, such as murals or unique floors, and simple, inexpensive storage of designs in the form of digital data. It may be noted that most of these advantages are common to other digital printing techniques, such as xerography.

However, although the technology has multiple advantages, it also presents certain drawbacks. There is a more limited color gamut compared with that of other techniques, while the colloidal instability of these inks and the constraints of the printheads themselves have required pigment size to be reduced, limiting color saturation, as some small-sized pigments exhibit color loss or have a lower color intensity. In theory, inks are available in the four primary colors, CMYK, but these colors are not exactly the appropriate ones and do not allow certain colors to be obtained. Printing in CMYK does not reproduce all RGB colors (there is a certain difference between the color spaces, which is quite large, especially for blue shades). This leads to colors being washed out when an RGB image is converted to CMYK. It is therefore important to prepare designs for printing in the CMYK color space.

A further drawback is the appearance of lines or streaks in the print, owing to printhead clogging. The inks involved are more expensive than traditional inks and do not allow application of thicker layers. As a result, the technological challenges that directly affect the ceramic tile sector basically involve the development and optimization of the inks used, improvement of ink colloidal and rheological stability, upgrading of the systems, reduction of production costs, optimization of the chromatic quality of the primary inks, and use of other inkjet materials (for metallized finishes, functional properties, etc.).[11]

INTRODUCTION OF XEROGRAPHY AS AN ALTERNATIVE TO INKJET PRINTING

The ability to obtain images with high color saturation and the realization of a greater color gamut are the main challenges that inkjet technology needs to address in ceramic tile decoration. Not all crystalline structures of traditional ceramic pigments can be used in inkjet printing, as the size of some of these structures cannot be reduced below submicron scale without color loss. The type of crystalline structure of the pigment thus determines the final particle size and resulting color development. Moreover, not all ceramic pigment crystal structures withstand the chemical corrosion of the arising liquid phases during the firing of the glazes or substrates. In certain cases, when the pigment size is reduced and the specific surface area is increased, these structures cannot withstand the chemical corrosion during firing, and color loss occurs.

One possible way of addressing these technological challenges could involve the use of customary ceramic pigments with larger particle sizes by means of other digital decorating techniques, such as xerography. Xerography would enable pigments with a larger particle size to be used, thus providing greater color intensities and a wider color gamut on ceramic tiles than the current inkjet technology while avoiding the crystal break-up and color loss noted above. Xerographic decoration of ceramic tiles would also furnish higher resolution than current inkjet decoration: the standard resolution of inkjet printheads is 360 dpi, whereas the standard resolution of developers in xerographic printers is 600 dpi, this resolution being maintained after firing. Another benefit would be the lower economic outlay required for this type of technology, when standard elements are used, compared with that for industrial inkjet printers.

Table II. Comparison of ceramic tile decorating techniques.

	Rotogravure	Inkjet	Xerography
Reliefs/curvatures	Small	Medium	Small
Color gamut/intensity	High	Medium	High
Resolution (dpi)	∼250	∼360	∼600
Speed (m/min)	40–60	25–60	20–30
Printer price (€)	∼90 000	∼450 000	∼300 000
Layer thickness (μm)	10–30	2	10

An industrial xerographic printer of 43 cm maximum printing width could thus be constructed using standard elements at cheaper prices.

One of the constraints of inkjet printing is ink stability, as inorganic pigments in suspension tend to agglomerate and settle, so that they must be used within a relatively short time (1–3 months). Toners pose no stability problems and can be stored for months or even years without their properties deteriorating, provided they are stored in a dry place at a temperature not above the polymer T_g. On the other hand, the influence of humidity on toners is a disadvantage. This can be minimized, however, by controlling the ambient humidity during printing and toner storage. In addition to the benefits noted, the system would also share the advantages of inkjet printing as a digital printing process: short lead times from design to production, greater variety of designs, versatility of the series, etc.

One disadvantage of electrophotography, compared with the current inkjet technology, is the need for contact with the substrate in printing, which limits its use to flat pieces without any relief or embossing.

Table II compares certain characteristics of xerographic and digital inkjet printing systems and ceramic tile decoration by a rotogravure system.

ITC, together with the company Integra Synergy Systems, S.L., has developed a prototype for direct digital printing on ceramic tiles based on the xerographic system. The prototype was built by the company CTG PrintTEC GmbH according to ITC and Integra Synergy System specifications. In this printing prototype the ceramic toner is electrostatically transferred directly from the transfer roller to a pre-heated ceramic tile (110°C). The technology is protected by a portfolio of patents, owned by Integra Synergy Systems, S.L., and ITC, related to the application of this technology on ceramic and glass. A total of 14 patents are involved, relating to both the printing machine and ceramic toner fabrication. A picture of the developed prototype is shown in Figure 6.

To date, xerography has been used in ceramic decoration for printing decals and subsequent transfer of the image to the tile, for indirect decoration in fine ceramics and some bespoke decorative tiles in very limited series. Figure 7 schematically illustrates the components of the developed prototype. In this prototype, unfired as well as fired tiles can be used. The tiles are transported by a conveyor belt, which is

Figure 6. Machine for ceramic tile decoration by xerography.

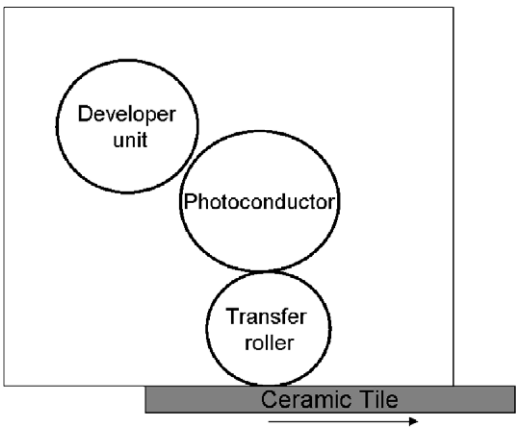

Figure 7. Schematic illustration of the developed prototype: (a) developer unit, (b) photoconductor drum, (c) transfer roller.

synchronized with the transfer roller that enters into contact with the tile and transfers the design to the tile. The tiles are fed in at about 110°C in order to fix the toner, which then allows successive prints to be applied before firing. The decorated tile is subsequently fired at a temperature of 1100°C to fix the decoration into the glazed surface. It should be noted that, in ceramics and glass decoration, after the toner application, the products need to be subjected to a thermal treatment at a temperature above 600°C to remove the organic components of the toner and enable the inorganic component to be integrated into the surface.

The developed prototype is monochrome and provides high-resolution printing and good color development of both unfired and fired glazed ceramic tiles. Two types of ceramic toner have been used for this purpose: one synthesized by the traditional method (extrusion, pulverization, and classification) and another synthesized at ITC by suspension polymerization.[20] Both types of ceramic toner contain a ceramic pigment and a flux: the inorganic pigment provides coloration and the flux facilitates pigment integration into the glassy surface at high temperature. The inorganic particle content in the toner particles exceeds 55 wt%, as this needs to be as high as possible in order to assure good color saturation once the organic components have been eliminated by firing.

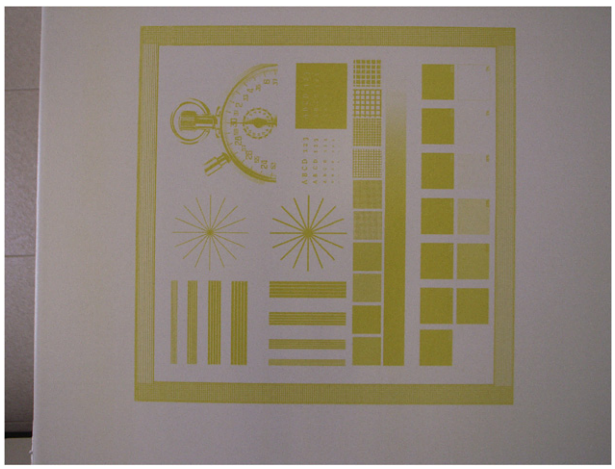

Figure 8. Example of a ceramic tile print obtained from the prototype shown in Fig. 7, using a ceramic toner prepared by mechanical pulverization.

A print made with a yellow toner prepared by mechanical pulverization, obtained in a study by the authors, is shown in Figure 8. The image was printed on a previously fired ceramic tile with a white glaze, pre-heated at a temperature of 110°C, in order to partially fix the toner onto the substrate. After printing, the tile was fired at a temperature of 1100°C in order to achieve appropriate integration of the pigment into the glaze. No shrinkage was observed in the firing process, so that no image biasing was required. The image was obtained with a good color intensity. Note that, in contrast, yellow pigments usually lose their color intensity when they are pulverized to nanometric sizes for inkjet ink formulation.

CONCLUSION

Digital decoration systems have many advantages compared to conventional decorating methods in ceramic tile manufacture. In the last decade, inkjet printing technology has progressed significantly and has the potential to radically change ceramic tile decoration. Ceramic inkjet technology has spread rapidly in the last four years. Inkjet technology provides numerous advantages, though it also presents certain drawbacks. The ability to obtain images with high color saturation and the realization of a wider color gamut are the main challenges that inkjet technology needs to address in ceramic tile decoration.

One possible way of addressing these technological challenges could involve the use of pigments with larger particle sizes. This makes the use of other digital decorating techniques, such as xerography, worth investigating. This technique could enable pigments with a larger particle size to be used, which would provide greater color intensities and a wider color gamut on ceramic tiles than the current inkjet technology.

Studies by the authors have shown the feasibility of xerographic printing on both unfired and fired ceramic tiles, designs being obtained with great resolution and color development. After firing, the designs were perfectly integrated into the tile, displaying no cracking or differences in color. This demonstrates the potential of xerographic printing when greater color intensities and a wider color gamut are required. A demonstration prototype is currently available that could serve as the basis for the design and construction of a complete industrial printer. Using this same technology, a varnishing machine could be obtained that would allow dry glazing, which would provide considerable savings in water and energy. The studies conducted open the door to the introduction of xerographic printing in ceramic tile decoration.

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