Technical Evolution of Ceramic Tile Digital Decoration

V. Sanz, C. Ribes, Y. Bautista, C. Feliu, Y. Reig. Instituto de Tecnología Cerámica; Castellón, Spain
Bono, J.V. Integra Synergyc System, S.L.; Villarreal, Spain

Abstract

The first digital systems to appear in the traditional decoration of ceramic tiles were for the manufacture of photolithographs, screen printing screens, and rollers. However, since these systems do not allow direct digital decoration of the ceramic tile, they are not very versatile and constrain productivity.

The formulation of inks with soluble and vitrifiable stains enabled inkjet printing technology to be introduced into ceramic tile decoration. The incorporation of milled inorganic pigments into the inks then broadened the available colour palette. The colloidal instability of these inks and the own constraints of the printing heads made it necessary to reduce the particle size of the pigments used, thus limiting colour saturation.

In order to overcome this technological challenge, pigments with larger particle sizes need to be used, making it necessary to introduce other digital decoration techniques, such as xerography.

The adaptation of this technique to ceramic tile decoration entails the development of ceramic toners and the adjustment of the printing machines. A system has been developed that is able to print ceramic tiles by contact, which has required adjusting the mechanical and electrical properties of the transfer roller.

Introduction

Ceramic tile decorating techniques have evolved significantly in recent years as a result of a number of different factors. On the one hand, products with new aesthetic finishes needed to be launched onto the market to increase the existing range, which favoured the emergence of new decorating systems. On the other, environment-related factors also fostered the development of new application systems or the upgrading of already existing ones, in order to make them cleaner or to reduce the resulting wastes. 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. The traditional printing processes found in the ceramic industry also indirectly used digital systems to transfer the design from the computer to a photolitho or on to a rotogravure roller.

One of the most widespread ceramic tile decorating techniques was flat screen printing, whose use began in the 1960s, or rotary screen printing, 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 preparing the screens for screen printing. One of the disadvantages of this technique was that, in order to reduce decoration costs, the screen needed to be used to print numerous, identical pieces. The rotary screen at least enabled printing commencement to be shifted and, thus, pieces to be obtained that looked different despite being printed with the same design. When this technique was used to decorate just a single piece, the price of the product soared.

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

Screen printing was followed by rotogravure in the 1990s [1] [2], in which photolithos were no longer required: the design to be transferred to the piece was engraved by a computer-controlled laser on the roller. This technique used the benefits of rotary systems, shortening start-up times compared with screen printing and raising productivity, since the piece did not need to be stopped during decoration. In addition, the decoration was applied to the edge of the piece. A disadvantage was the high price of the silicone rollers: numerous printing runs were required in order to make a design profitable. Flexography also appeared in the 1990s [3], though it was less used in ceramic decoration.

Inkjet printing systems are very recent, these being developed between the end of the 1980s and the beginning of the 1990s for office computer system 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 sector, where it first materialised in the year 2000, when the first inkjet printing machine appeared on the market for industrial ceramic decoration. This 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. In printing on ceramics, unlike most other inkjet applications, printing is just one part of the process and printing needs to be followed up by one or more operations, the most important being the firing of the piece. The end quality depends on three critical factors: the type of substrate and the characteristics of the printing machine and the inks [5], [6]. This technology has posed and continues to pose new challenges to basic and applied research in various fields relating to problems in the development of new inks, machinery, and computational applications.

Evolution of inkjet technology in the ceramic sector

The first studies on the possible use of inkjet printing for ceramics 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 100μm. 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, different printing methods and possibilities of use with different substrates being tested. The trials were conducted in the most innovative printing

systems available then without, however, making any modifications to adapt them to printing on ceramics.

The idea of inkjet printing appeared rather to be found in the field of fine ceramics, with extensive research into inks. The great handicap of the printing machines lay in the obtainment of larger-sized decorative patterns and production speeds at least resembling those then found in ceramic tile manufacture. Although the idea of introducing this technology grew steadily stronger, it entailed certain levels of complexity and a very important risk factor. It also highlighted the need to carry out simultaneously research on several fronts, not just with regard to raw materials and ink adjustments, but also to adaptations of the machinery.

Such a synergy emerged between machinery manufacturers and raw materials suppliers at Villareal, 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, with multiple printheads of the SII Printek binary type, in which the drops generated had the same size, about 50µm, corresponding to a drop size of 60pL [8]. The invention involved a device and a process for decorating ceramic tiles by inkjet printing. 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).

Figure 1. *First Kerajet model in the year 2000 (source SECV)*

In order to address these problems, 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 jointly to develop electronics, and software and ink applications. The first industrial printer prototype was exhibited at the international Cevisama trade fair in 2000. The first inks for this machine were patented by *Ferro Corp* the same year [9]. This patent describes a set of four inks (CMYK) for colour printing, each ink including one or more soluble complexes of transition metals. The presentation of this machine caused a great impact. However, though the benefits that inkjet printing provided were clear from the outset, compared with rotogravure printing and flat screen printing, the major technologies in the ceramic process, the technology was insufficiently mature to be implemented. There were problems regarding ink stability and low chromatic intensity when the inks were 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 industry. However, the search intensified for an optimum ink that would display the following specific properties [10]: (a) *high stability*, since precipitation, agglomeration, changes in viscosity could clog the injectors (about 50µm) (this involved addressing pigment degree of milling and specific surface area; ink solids content, colloidal stability, and rheological behaviour); (b) *high colouring strength*, since the small quantity deposited and the possible problems of diffusion on the substrate (7–70pL) could decrease the intensity of the resulting colours and produce low quality decoration (involving surface tension and drop drying velocity); (c) *neutral pH*, to avoid corrosion of the printheads. (chemical compatibility between the injector and the ink).

In recent years numerous research papers and patents have been published on the development of new printing inks for ceramic decoration, whose composition includes inorganic pigments for inkjet technology (Figure 2). The number of these researches has increased as this technology has been progressively implemented in ceramic decoration. This has grown steadily, particularly since 1998, the year 2004 standing out [11].

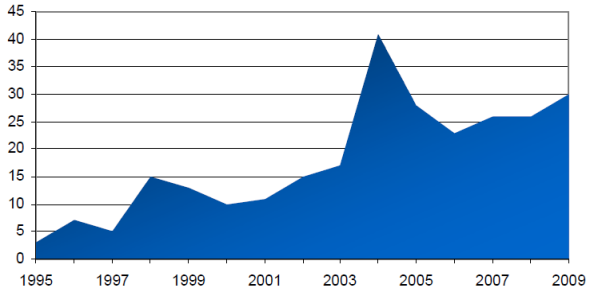

Figure 2*. Number of patents relating to the development of ceramic inks for inkjet printing in the ceramic sector*

In parallel to the development of the inks, the inkjet printing equipment used in ceramic decoration has also evolved. Most of these developments have been successively presented at the most important ceramics trade fairs, *Cevisama* in Spain and *Tecnargilla* in Italy.

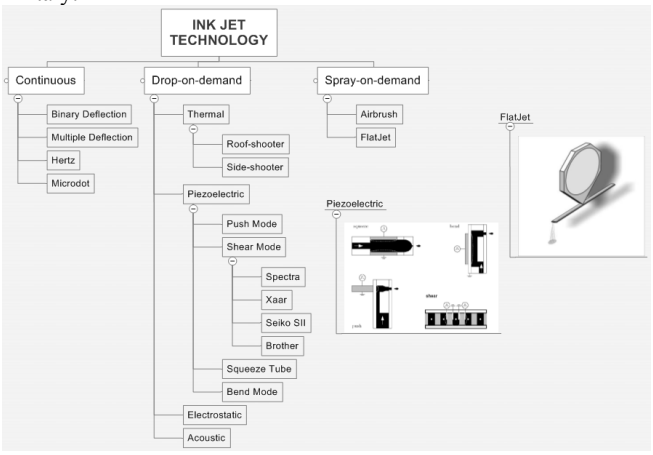

Figure 3*. Schematic illustration of the existing inkjet printing technologies*

Figure 3 presents a schematic illustration of the existing inkjet printing technologies [12].

Most current systems using inkjet technology to decorate ceramic tiles use drop-on-demand (DOD) principle. In this technology there are several methods of producing the pressure pulse, depending on whether piezoelectric, thermal, electrostatic, or acoustic printheads are involved. The most widely used printheads in ceramic decoration are piezoelectric, the main suppliers of this type of technology for ceramic decoration being *Xaar*, *Spectra*, and *Seiko*.

According to certain authors, the key features in the development of this digital technology for ceramic decoration were 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 posed significant engineering challenges [5].

The appearance of the first printing machine for ceramics in the year 2000 has been followed by other, improved machines. In 2005, in collaboration with *Durst Phototechnik AG*, a company devoted to image processing, *Torrecid*, a multinational frit, glaze and ceramic colour producer, launched a range of pigmented inks [13]. These inks were designed for single-pass digital inkjet printing machines with Fujifilm Dimatix (*Spectra*) printheads [14], also of the binary type. After the appearance of this new option in the market, inkjet printing began to spread more quickly in the ceramic sector.

The development of inkjet printing systems has since surged in companies that manufacture decoration equipment for ceramics. At present, thirteen different machines are available in the market, which are all suitable for ceramic printing. In this period, machines with grey scale DOD printheads have emerged, patented by *Xaar* [15] [16], which provide a higher-quality image with the same nozzle aperture, in which the size of the injected drop can be individually regulated, obtaining drops ranging from about 1 to 70pL.

Parallel to the use of DOD printheads, another company has committed to the spray-on-demand technology, using the FlatJet technique. This system is able to spray small drops using larger supply tubes (500µm), 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 the DOD printheads. Since pigmented inks can be used with a larger particle size, the chromatic field and the intensity are enhanced, though the resolution is much lower [17]. On the other hand, it is possible to work with water-based inks. This machine is marketed by *Sacmi Imola SC*. Another company that has committed to a different technology from the DOD technology is Talleres Foro, S.L., which in 2010, together with Colores Cerámicos, S.A., presented a new system of digital ceramic decoration by a continuous inkjet with multiple deflection using water-based inks.

The rapid spreading of ceramic inkjet technology in the last four years may be observed in Figure 4, which shows the number of companies that have offered on-line machines in the last ten years. Figure 5 shows the number of machines that have been installed up to April 2010, 48.6% of the machines installed in the world being of Spanish and 31% of Italian origin [18].

The digital market in ceramic decoration is currently estimated at 5–6% of the total business volume. It is estimated that this percentage will continue to grow considerably in the coming 5–7 years and then to stabilise.

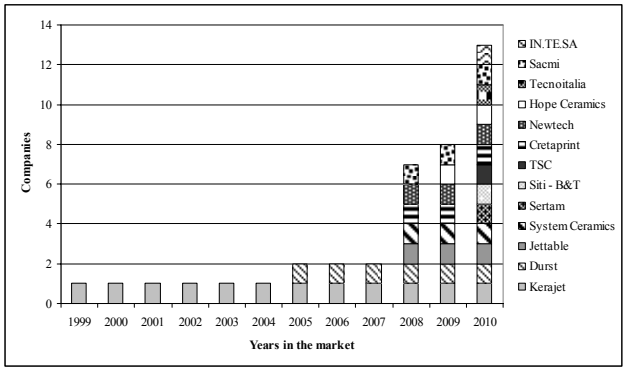

Figure 4. *On-line machines for inkjet decoration of ceramic tiles*

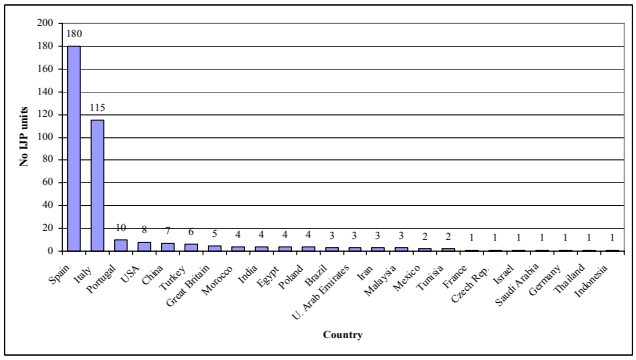

Figure 5 *Machines for ceramic decoration installed by countries up to April 2010 (source: Ceramic World Review no. 86/2010)*

As noted above, the greatest surge in the implementation of this technology in ceramics 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 increased their facilities and/or number of workers and have all their production sold, so that they are giving considerable waiting times for the start-up of new machines.

Advantages and disadvantages of inkjet printing technology in ceramic decoration

Many of the limitations of traditional decorating systems in the ceramic sector, such as screen printing, flexography, rotogravure, etc., have been technically overcome by inkjet technology, which is therefore replacing those. Inkjet technology provides many advantages in decorating ceramic tiles. These include: no printing contact, which allows pieces with relief to be printed; the possibility of decorating the edges of the piece in the same process; the need for smaller quantities of consumables than with traditional systems; ease of design change, enabling designs to be quickly and readily switched and a greater variety of designs to be achieved; simple on-line correction of the design; greater manufacturing and colour control; simple product customisation and shorter product development times. However, despite the technology has multiple advantages, it also presents certain drawbacks. These include: a more limited chromatic variety

compared with that of other techniques, while the colloidal instability of these inks and the own constraints of the printheads have required the size of the pigments used to be reduced, thus limiting colour saturation. In theory, inks are available in the four primary colours CMYK, but these colours are not exactly the appropriate ones and do not allow certain colours be obtained. A further drawback is the appearance of lines in the print, owing to printhead clogging. These inks are also more expensive than traditional inks and do not allow the application of thicker layers. As a result, the technological challenges that directly affect the ceramic sector are related to the development and optimisation of the inks used, improvement of ink colloidal and rheological stability, upgrading of the systems, reduction of production costs, optimisation of the chromatic quality of the primary inks, and the use of other inkjet materials (for metallised finishes, functional properties, etc.) [11]

Introduction of xerography as an alternative to inkjet printing

The obtainment of images with high colour saturation and a greater chromatic variety are the main challenges that inkjet technology needs to address for ceramic tile decoration. Successfully resolving this technological challenge entails using pigments with larger particle sizes, which makes the introduction of other digital decorating techniques, such as xerography, appear interesting. This technique would enable pigments with a larger particle size to be used, which would provide greater colour intensities and a greater chromatic range on ceramic tiles than current inkjet technology. The xerographic decoration of ceramic tiles would also furnish higher resolution than current inkjet decoration. Another benefit would be the lower economic outlay required for this type of technology compared with that for industrial inkjet printers. An industrial printer of up to 36" could thus be constructed using standard elements at cheaper prices. An inkjet printer needs a great number of printheads in order to print large sizes, which considerably raise printer costs. One of the limitations of inkjet printing is ink stability, since inorganic pigments in suspension tend to agglomerate and settle, so that they must be used within a relatively short time (1–3 months). Toners present no stability problems, and can be stored for months or even years without losing their properties, provided they are stored in a dry place at a temperature not above the polymer Tg. On the other hand, the influence of humidity on toners is a disadvantage. This can be minimised, however, by controlling ambient humidity during printing and in toner storage. In addition to the advantages noted, the system would also share the advantages of inkjet printing stemming from a digital printing system: immediacy from design to execution; greater variety of designs; versatility of the series…

One disadvantage of this system, compared with current inkjet technology, is the need for contact with the piece in printing, which limits its use to flat pieces without any relief. A further limitation would be slower production speed compared with that of inkjet printing.

The following table compares certain characteristics of xerography and inkjet digital printing systems and ceramic tile decoration by a rotogravure system.

Table 1. Comparison of ceramic decorating techniques

	Rotary	Inkjet	Xerography
Reliefs/ curvatures	Small	Medium	Small
Gamut/ Intensity colour	High	Medium	High
Resolution	Low	Medium	High
Speed	High	High	Medium
Printer price	Medium	High	Medium
Printing cost	Low	Medium	Medium

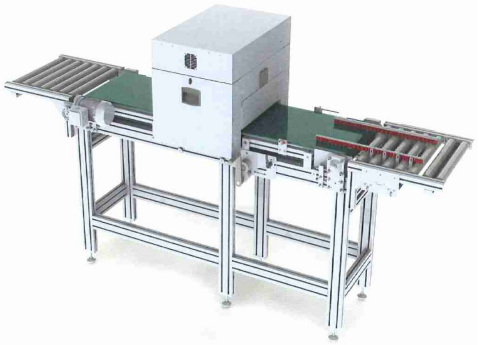

Figure 6. *Machine for ceramic decoration by xerography*

ITC, together with the company Integra Synergy System, S.L., has developed a prototype for direct digital printing on ceramics based on the xerographic system. The prototype has been built by the company CTG PrintTEC GmbH according to the requested specifications. The technology is protected by a portfolio of patents owned by Integra Synergy System, S.L. and ITC, related to the application of this technology on ceramics 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 ceramics decoration for printing decals, for subsequent transfer of the image to the piece, as an indirect decoration in fine ceramics and in some decorative pieces made upon demand in a 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, which are transported by a conveyor belt synchronised with the transfer roller that enters into contact with the tile, transferring the design to the tile. The tiles are introduced at about 110 ºC in order to fix the toner, which then allows successive prints to be applied before firing.

The developed prototype is monochrome and provides high-resolution printing and good colour development of both unfired and fired ceramic pieces. Two types of ceramic toner have been used for this purpose: one synthesised by the traditional method (extrusion, pulverisation, and classification) and another synthesised at ITC by suspension polymerisation [19]. A print made with a magenta toner synthesised by suspension polymerisation is shown in Figure 8. The image was printed on a fired white ceramic tile heated to a temperature of 110 ºC in order to fix the toner on to the substrate. After printing, the tile was fired

at a temperature of 1100 ºC in order to achieve appropriate integration of the pigment into the glaze.

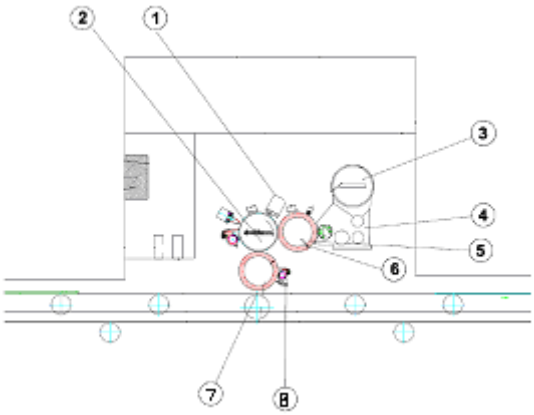

Figure 7. *(1) Laser Image Scanner (2) Photoconductor drum (3) Powder cartridge (4) Developer unit (5) Conditioning roller (6) Cylinder magnet (7) Transfer roller (8) Cleaner blade*

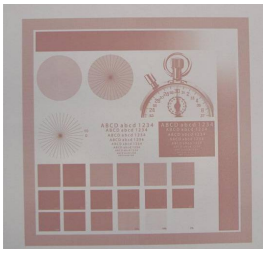

Figure 8. *Example of a ceramic tile print obtained in the prototype shown in Figure 6, using a magenta ceramic toner synthesised by suspension polymerisation*

Conclusion

The feasibility of xerographic printing on both unfired and fired ceramic tiles has been demonstrated, designs being obtained with great resolution and colour development. After firing, the design was perfectly integrated into the tile, displaying no cracking or differences in colour. This demonstrates the potential of xerographic printing, which could compete with existing inkjet systems for ceramic tile decoration. At present, a demonstration prototype is available, which can 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. This work leaves the door open to the introduction of xerographic printing in ceramic decoration.

References

[1] A de Carlo. "The digital revolution in tile decoration", Ceramic World Review 51, 78 (2003)
[2] A. M. Berto "Ceramic tiles: above and beyond traditional applications", J. European Ceram. Soc. 27, 1607 (2007)
[3] M. A. Jimenez-Otero, "The revolution of ceramic printing high-quality flexographic printing on ceramics", Tile & Brick Int. 17, 48 (2001)
[4] A. Moreno, V. Lázaro, A. Mateu, Y. Reig "Innovations and new trends in ceramic tile decoration" *Adv. in Sci. Tech.* 68, 165 (2010)
[5] I. Hutchings, Ink-jet printing for the decoration of ceramic tiles: technology and opportunities. Qualicer 2010: XI World Congress on Ceramic Tile. Castellón, pg. 19 (2010)
[6] B.Y. Tay, M.J. Edirisinghe, "On substrate selection for direct ink-jet printing" J. Mat. Sci. Lett., 21, 279 (2002)
[7] W. Roberts, " Decorating methods for the future" Br. Ceram. Trans. J. 87, 4 (1988)
[8] J. V. Claramonte, "Dispositivo para decorar baldosas cerámicas" EP99949020.4 (1998).
[9] Ferro Corp, J. Garcia, C. Benet, J. L. Fenollosa, J. M. Querol, P. Secrest, "Individual inks and an ink set for use in the color ink jet printing of glazed ceramic tiles and surfaces" WO0151573 (2000).
[10] Monrós, G. Recent Advances in the research for new ceramic-pigments. *Part II. Matt. and Proc.* 2 93-99 (2005).
[11] Observatorio Tecnológico "Decoración cerámica mediante tecnologías de chorro de tinta (INKJET)" ITC-AICE (2010)
[12] H. Wijshoff, "Structure – and fluid-dynamics in piezo inkjet printheads" Published by Herman Wijshoff, Venlo, The Nederlands. IBSN 978-90-365-2582-4 (2008)
[13] Torrecid, S.A.; J. V. Corts Ripoll, F. Sanmiguel Roche, C. Concepción Heydorn, O. Ruiz Vega O. "Ink for industrial decoration" WO2006077273 (2005).
[14] www.dimatix.com (February 2011)
[15] E. Knight, "The Xaar Guide to Digital Print for the Ceramic Sector, White Paper", Xaar plc, (2009).
[16] E. Knight Xaar "Innovative inkjet technology for the ceramic tile industry, in Digital decoration of ceramic tiles" pg. 70 ACIMAC (2009).
[17] B. Burzacchini, P. Zannini, Sacmi Digital. "La nuova tecnologia di decorazione digitale per il settore ceramico. In La decorazione digitale di piastrelle ceramich*"* pg. 40. ACIMAC (2008)
[18] P. Giacomini "A digital future?" Ceramic World Review**,** 86, 56 (2010)
[19] AICE, Integra Synergy System S.L. "Procedimiento para obtener un toner cerámico y toner cerámico obtenido", P201130189, (2011)

Author Biography

Vicente Sanz received his degree in chemistry from Valencia University in 1986 and his PhD in chemistry from University Jaume I of Castellón in 2001. Since 1999 he has worked as R&D Project Co-ordinator at the Instituto de Tecnología Cerámica (ITC) and since 2004 has been Associate Professor of Chemical Engineering at University Jaume I. He has co-authored over 30 research papers, is co-inventor of 8 patents and co-author of 6 books and monographs in the field of ceramic technology. His work has focused on ceramic raw materials and compositions, ceramic processing, and ceramic materials properties.