

DEVELOPMENT OF AN INK-JET PRINTING SYSTEM FOR CERAMIC TILE

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ABSTRACT

The ink-jet printing system has many advantages compared with conventional printing systems. For example, works with concavo-convex surface can be printed because ink-jet printing is a non-contact printing system. An ink-jet printing system can also print to works from digital data directly, so blocks for printing and the time for changing the blocks are not required. The works can be manufactured at the time we need them. Furthermore, all we have to do is to prepare only the reference four colours of ink, so it is not necessary to prepare the trial ink colour. For these reasons, it is expected that the ink-jet printing system will continue developing for ceramic tile industry.

Nowadays several kinds of systems have been developed and put to practical use.

Our company has also developed its own system. In this system, the piezo-electric drop-on-demand method is adopted. The aqueous suspension system of four colours of inks, black, magenta; blue and yellow, is used, so it has a big advantage compared to organic solvent ink systems. The resolution of this system is 360dpi, the maximum printable width is 460mm and the printing capacity is 24m per minute by arranging printing head unit including four colours in 13 rows.

Several kinds of products have been commercialized for the Japanese market by using this ink-jet printing system.

1. INTRODUCTION

Over the past ten years, the possibilities of ink-jet printing for the decoration of ceramic tiles have been explored and significant advances have occurred in the underlying technologies of printed design and ink formation. Several commercial printing systems, both for in-line and off-line use, are now on the market^[1]. There were a total of 548 machines for decorating ceramic tiles at the end of 2010. And the forecasts for 2011 show no sign of slowing^[2].

The reason why ink-jet printing is expanding rapidly is that it has advantages compared to conventional methods for decorating ceramic tiles.

First, it is a digital process. The location of each droplet of material can be predetermined on an x-y grid, and if necessary can in principle be changed in real time, for example to adjust for distortion or misalignment of the substrate. Since the pattern to be printed is held as digital data, there may be significant cost saving over processes which involve the use of a physical mask or template.

Second, it is a non-contact method. The only forces which are applied to the substrate result from the impact of very small liquid drops. Non-flat substrates can be printed, since the process can be operated with a stand-off distance of at least 1mm, and in some cases much more.

Third, a wide range of materials can be deposited. The only limitations are that, at the point of printing, the material is in liquid form with its physical properties (mainly viscosity and surface tension) lying in an appropriate range. Pigments, dyes, glass frits and metallic particles are readily printed from suspensions, as well as a wide range of other materials which can be used to perform optical and electronic functions.

Specifically, the following benefits have been claimed in comparison with conventional printing methods. Digital image definition and the flexibility of the process mean that each tile can be different if required, allowing more realistic representation of natural material such as stone, and also the possibility of printing one-off products such as murals or unique floors. Different patterns of tile can be processed in sequence or even together. High image definition can be achieved. Overall production times for prototypes and new products are shortened. Customization, through small changes to a basic design, is straightforward. Storage of designs in the form of digital data is simple and very low cost. Edge-to edge printing allows uninterrupted patterns across tile boundaries. Profiled tiles can be decorated automatically, avoiding costly manual handling. Set-up times are significantly lower than for conventional printing methods. Changes to image size can readily be made to accommodate different tile sizes. Process colour capability is achieved with a small range of inks, typically the standard four colours (CMYK) used in conventional printing: cyan, magenta, yellow and black. There is more efficient use of inks, and so less wastage. Machine footprints are smaller than for conventional processes.

Most ceramic ink for ink-jet printing system introduced in the ceramic tile industry consists of a solid phase and a non-aqueous liquid phase^[3]. Our company has developed its own system using an aqueous suspension system for inks. It has big advantage compared to organic solvent ink systems. In this paper, the outline of our ink-jet printing system is described.

2. OUTLINE OF THE INK-JET PRINTING SYSTEM

First, the constitution of the ink-jet printing system is shown in Fig. 1. The system is composed not only of the ink-jet printing apparatus but also of aqueous ceramic ink, glaze composition and adjustment of design. Ink-jet printing is a technology that has been integrated into ceramic technology.

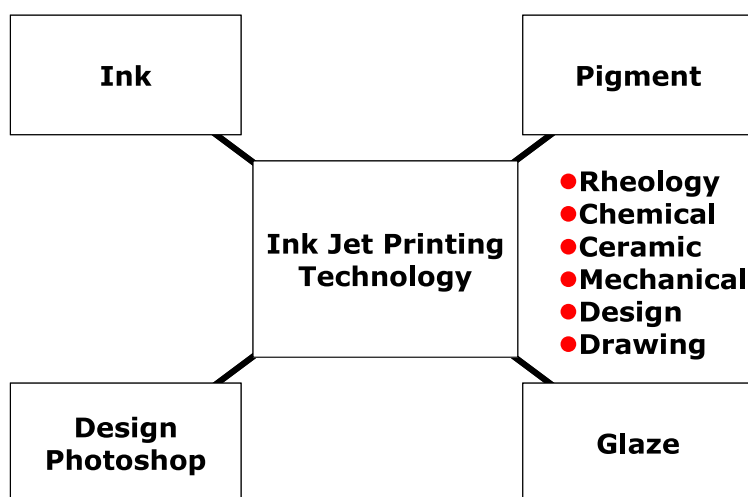


Fig. 1 The constitution of the ink-jet printing system.

In principle, the process by which ink-jet printing can be used to decorate ceramic tiles is straightforward. In order to integrate ink-jet printing efficiently into a tile production line, a single-pass process is required, in which the tiles pass in a continuous flow through the printing machine. In that single pass, the printer must deposit accurately and reliably the correct intensities of colour over the whole surface to be decorated. Fig. 2 shows the appearance of the ink-jet printing apparatus and Fig. 3 shows schematically the components of the system for four-colour, single-pass printing.



Fig. 2 The appearance of the ink-jet printing system.

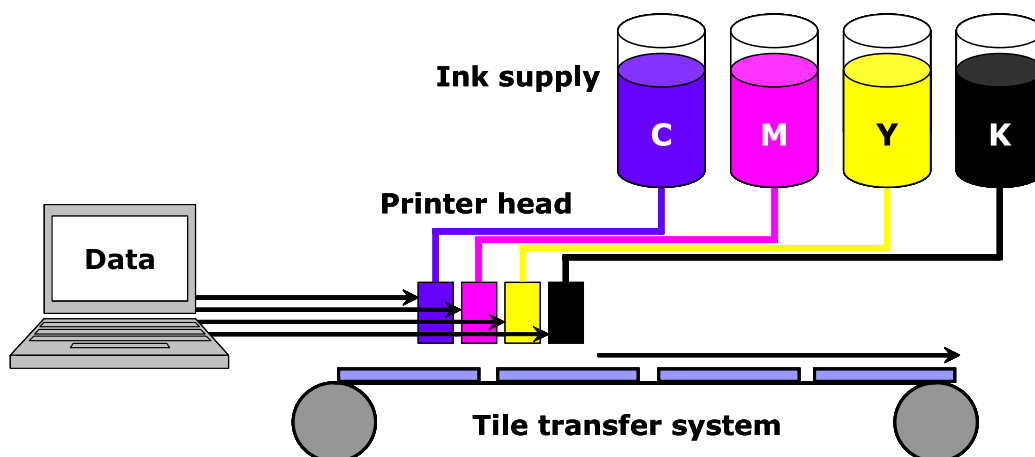


Fig. 3 Scheme of the components of the system.

For each colour, printheads are assembled into an array (known as a printer) which presents a continuous row of nozzles across the width of the tile. For this case, 13 printheads are rowed.

3. INKS FOR CERAMIC TILE DECORATION

3.1. Composition of ceramic inks

The inks used for ceramic tile decoration must satisfy at least two important criteria. First, they must have the correct rheological and other properties to be usable in this process, i.e. they must be printable. Second, they must produce the desired final colours after application to the tile and its further processing. In the aqueous ceramic inks, the inks are composed of pigment (15-20%), deflocculant (up to 1.0%), surface tension conditioner (about 1.0%), glycerine (30-40%) and water (40-50%). Glycerine is used to prevent ink drying. And chemical additives, i.e. deflocculants and surface tension conditioners, are used for stabilizing ink physical properties.

3.2. Preparation of ink pigments

The physical and chemical properties of ceramic inks are shown in Table 1. The particle size of pigments in the inks for ink-jet printing should be under 150nm. Generally speaking, most pigments lose colour with fine grinding. The pigments used in ink-jet printing must lose very little colour, even in very fine particles. The pigments are developed by cooperation with pigment manufacturing company. They are prepared by milling to under 150nm before firing in order to maintain their colours under fine grinding.

	Cyan	Magenta	Yellow	Black
Pigment	Co-Al	Cr-Sn	Ti-Cr-Sb	Co-Cr-Fe-Al-Ni-V
Particle size (nm)	90	<150	<150	<150
Surface static tension (mN m ⁻¹)	<30	<30	<30	<30

Table 1 Physical and chemical properties of ceramic inks.

The inks prepared by means of this synthesis process are susceptible to phenomena of instability deriving from the submicronic solid-solvent dispersions. The first of these phenomena is particle migration, which may result in excessive sedimentation of the solid phase. The use of special additives in the ink formulation stage and a suitable milling process help to slow down this process enormously.

3.3. Chemical additives for stabilization of ceramic inks

Another typical phenomenon associated with submicronic milling is that of agglomeration. Due to the large specific surface area that is created and the charges that are formed on the surface of individual particles, during milling these particles have the tendency to re-aggregate and form agglomerates (a process referred to as flocculation). For this reason it is very important in the ink preparation process to stabilize the particles so as to avoid the occurrence of flocculation phenomena over time^[4].

These flocculation phenomena must be avoided at all cost because the formation of these aggregates results in clogging of the printhead nozzles giving rise to defects (lines) on the printed tile. The particles can be stabilized against flocculation by addition of polycarboxylic graft copolymer. It involves covering the particles with polymers whose end chains act as physical separators or spacers between the particles. This is called steric stabilization and it is the most widely used method in the preparation of pigmented ceramic inks. Fig. 4 shows the illustration of steric stabilization of polycarboxylic graft copolymer.

Inks are characterized by numerous chemical and physical properties, some of which (speed, size, consistency of the drop) significantly affect their ability to be fired through printheads using drop-on-demand technology.

Viscosity, surface tension and density are all factors that to some degree influence droplet formation. The sound wave generated by the deformation of the piezoelectric element, which causes the droplet to be ejected from the printhead nozzle, is strongly dependent on viscosity. Using inks with as close to Newtonian behaviour as possible and with viscosity values of between 7 and 11cp ensures optimal droplet formation without the occurrence of undesirable satellite droplets (much smaller droplets located around the main droplet), which give rise to defects during printing.

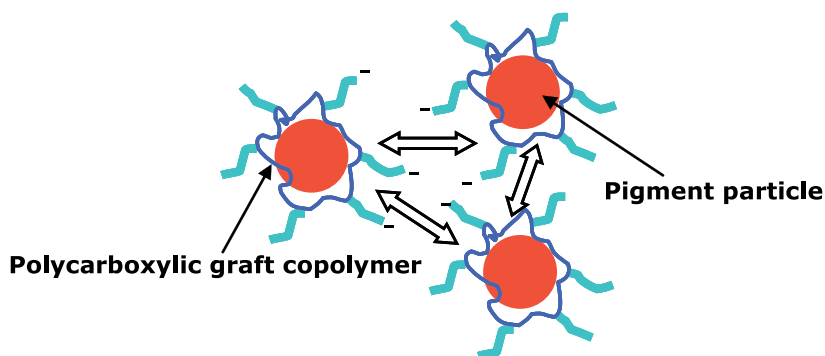


Fig. 4 Illustration of steric stabilization of polycarboxylic graft copolymer.

Surface tension also has a direct influence on droplet formation. High values of surface tension require a higher voltage to achieve a constant droplet speed, whereas low values may lead to breakage of the meniscus inside the nozzle. This may result in air entrapment, causing breaks in the ink flow and the consequent

occurrence of line defects during printing. Values of between 22 and 30mN/m allow for good ink management during production. Olfine is used as the surface tension conditioner. It is added to keep the cut condition at discharge from the head and improve the sinking into the glaze layer at landing. If the dynamic surface tension of the ink is high, it cannot discharge at high printing speed. So it must keep below 40mN/m. Olfine is composed of additives containing acetylenic alcohol and acetylene diol. Acetylenic alcohol is a highly volatile surfactant that can also provide wettability. The main uses of this substance include metal surface treatment and applications with base elements of reactive synthesis. The additives containing acetylene diol are produced as surfactants by our company and provide wettability in addition to anti-foaming effects.

4. MAKING DIGITAL DATA FOR INK-JET PRINTING

One consequence of the process of grinding the pigments to the submicronic dimensions required for ink production is that the colour gamut of pigmented ceramic inks is very narrow compared for example to that of inks used for paper printing. In ceramic applications, owing to technical problems associated with inorganic pigments the colours cyan, magenta, yellow and black (CMYK) are in reality approximations. Cyan (C) is just about designed level but magenta (M) has low intensity, so brightness is lowered in order to get high saturation. And yellow (Y) is pale because of the low colour saturation and black (K) is tinged with red. This results in a very narrow colour gamut. Fig. 5 shows the comparison between the current and the ideal colour of the inks. The colour balance is insufficient, so adjustment is required of the original data to suitable printable data on the PC.

The procedure of making data for digital printing is described as follows.

1. Ready an original drawing
2. Convert to digital data by scanner
3. Make the printer profiling from digital data in order to get the targeted colour for manufacturing
4. Correction of the printer profiling in order to get the targeted drawing on the PC
5. Print and fire to check the colour balance
6. Adjustment of the printer profiling data on the PC
7. Repeat between check and adjustment till getting the targeted image

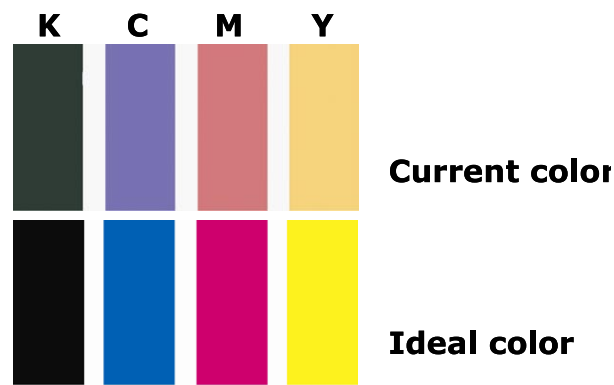


Fig. 5 Comparison between current and ideal ink color.

5. GLAZE COMPOSITION

The glaze composition is also very important for the ink-jet printing decoration technology of ceramic tile. The pigments undergo decomposition and melting by the glaze in the firing process because the pigments for ceramic inks are very fine particles. So the glaze composition should be optimized in order to get the good colour gamut.

Many kinds of metal oxides are used as glaze components. Lithium oxide, boron oxide, zinc oxide, magnesium oxide and antimony oxide inhibit the colouring of all inks so they should not be used as glaze components. If they must be used, they should be kept to a minimum.

Potassium oxide overtops entirely the colouring of inks above that of Sodium oxide. Calcium and barium oxides don't inhibit ink colouring so much, so that they can be used instead of lithium and boron oxide and so on. Tin oxide enhances the red colour but makes everything reddish. Titanium oxide enhances the red and yellow colours but makes everything yellowish and decreases the black colour.

Thus, the metal oxides influence ink colour and it the glaze composition should be optimized in manufacturing, especially the firing conditions.

6. APPLICATION AND FUTURE AGENDA

Fig. 6 shows the examples of ceramic tile decorated by the ink-jet printing system.



Fig. 6 Some examples of the ink-jet printing system used.

The designs were obtained by making full use of the characteristics of the ink-jet printing technology. Sample A and B are decorated on a wavy surface. Sample B's design consists of stripes made up of colourful lines. Sample D is printed on the concave portion of the tile. Their designs cannot be made by conventional decorating methods.

7. SUMMARY AND FUTURE AGENDA

The ink-jet printing decoration system has many advantages compared to conventional decorating methods for ceramic tile manufacturing, as mentioned above. But this is still work in progress. In order complete this system, the development of darker colour inks is necessary and another special colour of inks such as white or dark brown, apart from the CMYK colours, should be developed to expand the colour gamut.

Furthermore, the development of inks including functional materials such as photocatalysts, antibacterial activity, and electrical conductivity is one of the key aims of ink-jet printing technology. The materials involved are very expensive so great amounts of them cannot be applied for the ceramic tile industry. However, by using ink-jet printing technology, they can be mounted only on the surface of the ceramic tile, thus providing great effects with very small amounts of these. It is hoped to develop new functional ceramic tiles by the ink-jet printing system.

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