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Improvement of color quality and reduction of defects in the ink jet-printing technology for ceramic tiles production: A Design of Experiments study

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Abstract

The aim of the present work was to study the effect of different process parameters on the color and defects of tiles produced by ink-jet printing technology. The Design of Experiment approach was used to guarantee a rational planning of the experiments and to ensure objective conclusions through the statistical analysis of the data. Particularly, correlations between the process parameters and the quality of decorated tiles in terms of color and presence of surface defects were extensively investigated. Microstructural analysis was used to explain the results derived by the statistical analysis of the data obtained by the rational plan of the experiments allowing further insight in the structural features and mechanisms correlated to the macroscopic properties of the tiles. The study supplied an efficient way to control the final quality of the decorated tiles satisfying the quality standards required by the market demand.

Keywords: B. Defects; Ceramic tiles; Ink jet printer; Color; Design of Experiments

1. Introduction

Ceramic tiles industry has undergone significant changes in recent years to meet the latest market demands [1–3]. This trend has highlighted the need to control the entire production process to ensure an effective reproducibility of the final material in addition to maintaining high standards of quality. It is known that the production of ceramic tiles is a complex process influenced by many variables ranging from those directly related to the technology to those linked to the environmental conditions during production [4,5]. These variables directly affect the final product in terms of color, dimension and presence of defects on the surface [6].

One of the more recent innovations in the production of ceramic tiles regards the decorating technique, and in particular the introduction of inkjet printing technology that enables high quality printing on ceramic support and a wide range of aesthetics properties [7]. The limitations of the traditional decoration techniques such as screen printing done directly onto weak and fragile green bodies, resulting in significant quantities of breakages, inefficient screen printing to the edge of the article and inadequate screen resolution for trichromatic prints, leads to a rapid expansion of the printing. Its advantages compared to the conventional methods [8] are mainly related to the fact that it is a digital process and a non-contact method therefore fragile substrates and non-flat substrates, which are difficult to be treated in the conventional printing methods, can be processed and a wide range of materials can be deposited on the substrate (pigments, dyes, glass frits and metallic particles).

Moreover the digital image definition and the flexibility of the process allow a more realistic representation of natural materials that is one of the main interesting effects in the tiles market.

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Despite the advantages of this printing technique, its performance in ceramic production strongly depends on how well the printer is integrated in the production line. Different process variables can directly affect the final properties in terms of presence of defects, accuracy and reliability of color intensities over the whole decorated surface. The knowledge of the correlations existing between process variables and final aesthetic properties allows to control and therefore to improve both efficiency and quality of the manufacturing process. This skill represents an extremely powerful tool to design and optimize tiles with specific features encountering the market demands. To achieve this goal a strong collaboration between industrial partners (System S.p.A and Savoia S.p.A) and the research group expertizes in statistical analysis was established leading to an effective interconnection between all the parts.

The analysis of the quantitative relationships between process parameters and the aesthetic features of the ceramic product has been the objective of a wide research in the last two decades with the main aim to improve the color matching (prediction perspective), the automatic detection of both color and morphological defects. It is important to underline that in the inkjet printing technologies the color matching and its management is achieved by the Color Management System (CMS) software and therefore no operator intervention is required adding a more reproducible results if compared to the tintometric system used in the traditional analogic printing.

Regarding the first task, many efforts were devoted in developing new mathematical and statistical framework and applying several instrumental techniques [6,9–12] in order to increase the efficiency and the rate of quality control. As concern the second task the studies focused the attention on the influence of raw materials grade [13,14], the firing temperature [15–17], the viscosity and the amount of both deposited ink and upper glaze [18] on the final colors of the ceramic tiles. Moreover, Lassinantti Gualtieri et al. [19], pointed out that the raw material mixture proportions in stoneware affect the amount of amorphous phase leading to a change in the chromatic aspects of the final product in terms of CIELab color parameters.

Regarding the surface grade and hence the aesthetic behavior of a glazed tile, it was demonstrated the influence of the particle size distribution [20] and the composition of the original glassy matrix on microstructure and crystalline phase content on the surface of glass-ceramic glazes [21]. Moreover the formation of defects is hard to control and could derive by external factors, for example by pollution [22] or internal factors, in most cases the composition, that often leads to an unsuitable interactions among the glass components [23,24].

The state of the art clearly reports that color rendering and the quality of surface are directly influenced by many factors but despite various attempts to investigate and analyze the quality of decorative tiles, a systematic and real in-line study was only preliminary performed by Erginel et al. [18].

In this work, the Design of Experiments (DoE) [25,26] strategy was used to provide an extensive evaluation, through mathematical models, of the correlations between the process parameters and the quality of decorated tiles in terms of color and presence of surface defects. In this way, an improvement of the in-line process control and then of the quality of the final products was ensured.

To achieve this goal several process variables such as temperature of green body (TGB) at the dryer exit, the amount of deposited engobe (AM1), glaze (AM2) and glass (AM3), the resolution of the printer (DPI), the type of glaze (GTY) and the maximum temperature of firing cycle (TMX) were considered in order to verify their potential effect (main or interaction) on the final aesthetic properties in terms of L^* a^* b^* (CIELab). Moreover a *consensus panel* approach was used to obtain qualitative evaluation of the presence of defects in the final material. Further experimental analysis on the final products was conducted to explain the cause–effect mechanisms deriving by the DoE finding.

2. Experimental procedure

2.1. Methodologies and process

A schematic layout of the tiles production line considered in this work is showed in Fig. 1. During the experimental test we decide to keep constant all the variables (manufacturing line, printer, green body, density, viscosity and granulometry of deposited materials) except the ones directly considered in the DoE plan. All the tests were performed by using a dedicated industrial process line in which only the factors indicate in Table 1 were allowed to vary in specific ranges.

It is worth noting that to better control the TGB parameters a manual procedure using a pyrometer was implemented during the experimental test: tiles were blocked in the line after the dryer until the temperature reaches the value requested by the experimental plan.

The openings of the nozzles, positioned along the industrial lines were varied in order to control the amount of engobe (AM1), glaze (AM2) and glass (AM3) deposited on the tile surface ($60 \times 30\ cm^2$). It is important to know that 10 g of

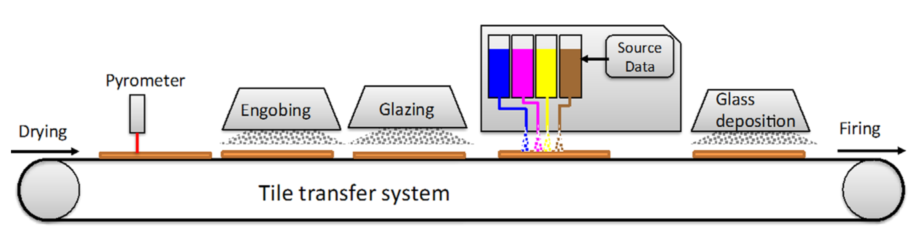

Fig. 1. Scheme of components of the in-line manufacturing tile process.