Objective criterion for evaluation of the quality decoration in ceramic floor tile production prior to the sintering process

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Abstract

In the ceramic tile decoration process, the set of variables that can cause hue variation is quite wide and independent of the methodology used in the production. The understanding of the effects of these variables over the final expected result is of great importance to the producers, especially if it could be done before the ceramic tile's sintering stage. The quality of the decoration is linked to the deposited dot shape and its filling with ink. It is proposed in this paper the determination of a 'quality index', comparing the theoretical deposition pattern and a real deposition obtained with samples. Measuring the values of the areas with and without ink, using the statistical tool of the ROC curve, it was obtained the values for sensibility=0.791, specificity=0.830, precision=0.802 and quality index=0.768. The method is intended to be used prior to the sintering step for hue variation control.
Keywords: quality index, ceramic tiles, decoration, ROC curves, laser engraving, silicone cylinder, hue variation.

INTRODUCTION

The production of ceramic tiles is growing each year all over the world. This scenario in Brazil is not different. The historical data of the sector shows production of almost 9 billion of square meters produced in 2015, adding up the production of the five main countries in ceramic tile production, against almost 7.5 billion of square meters produced in 2012. Brazil increased its production from 868.9 million of square meters in 2012 to 899.4 million of square meters produced in 2015 [1]. Although the ceramic tile sector had observed a slight decrease in the production in the last two years, about 790 million square meters in 2016, there is a perspective of increase; in 2017 was about 3.8% higher comparing with 2016, closing the year of 2017 with a production of 820 million of square meters [2], and a hope of another increase in 2018. Invariably with the growth in production, statistically, also increases the number of defective tiles in a productive process. Although the development of newer equipments that aim to reduce the waste, the costs associated with the acquisition of these equipments could be a barrier in the process of quality control improvement during the production. In particular, the development of simple techniques for defect analysis and identification before the ceramic tile sintering should be of great help in the process because it provides an easy way to identify and redirect the discarded tile for reuse within the production cycle at a lower cost at the end of the production.

This paper focus in one of the many problems that can occur on a ceramic tile production: the hue variation (on the same or on different batches), since it has great effects on the producers as well as over the costumers, as the ceramic tiles are set to form a panel, side by side, where defects of this kind can easily be seen. The development of a quick and accurate methodology to analyze these tiles can help the quality control staff to modify the production line set up in a fast way, so this pre-classification won't let the final tile quality (after sintering) index to decrease, as a big volume of tiles has already been produced out of standard. The manner how the ink is transferred from the alveolus engraved by the laser to the ceramic enamel surface provides, macroscopically, the perception of definition and hue, given that usually more than two cylinders are used to compose a final image to be reproduced, each one with a different and particular ceramic ink hue. Therefore, the hue of this tile is directly linked to the amount of ink transferred from the alveolus to the tile surface, that is, if the laid-up dots are full (complete) or not. A technique used to analyze data in this kind of situation is the ROC (receiver operating characteristic) curve, first developed to radar signal analysis during World War II [3]. Several areas of science use the technique when it comes to the determination of distinct characteristics (A or B); for example, chose a medical diagnose A or B for a patient, financial credit request, determining the likelihood of payment or not, and filtering incoming e-mail messages, coming from reliable fonts or spam messages [4]. The technique by itself can be extrapolated furthermore to detection in cases with more than two classes.

Basically, the ROC curve is described in a cartesian plane having on the abscissa axis a false positive rate and on the ordinate axis a true positive rate, with the variation of the classification threshold. The curve summarizes the information on the cumulative distribution function of the scores of the two classes previously determined [7]. The points that compose the ROC curve are related to two characteristics that determine the decision threshold which are the sensibility and the specificity. In a perfect

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discrimination test, the ROC curve values pass across the upper left corner, which means that both sensitivity and specificity have a 100% match without the overlapping in the two distributions. This configuration indicates that when there is a coincidence of the ROC curve with the upper left corner, more accurate is the test [5]. The method uses the magnitudes sensibility, specificity, and precision, which together enable the decision making related to the quality of the decoration made. The sensibility is the capacity of correctly classify the results considered as positive. In this study, it refers to the classification of the area effectively covered by ink related to the total area that should be covered. The specificity is the capacity of correctly classify the results considered as negatives. In this case, refers to the areas that were wrongly covered related to the total area that should not be covered with ink. It can be noticed that unlike others applications where the weights of the results of positive and negative classifications are discrete, such as the separation between healthy and sick people, in the studied case both the incorrect coverage and the incorrect absence of covering lead to a lower quality result on the ceramic tile production. In its turn, the magnitude precision refers to the reproducibility of the test, verifying how much the result could be reproduced, regardless of the sensibility and specificity measured. The use of this methodology is powerful and very simple, and so widely applied on the health/medical area, such as a validation test in [6], for the detection of true diagnostics separating healthy and sick patients. Joy et al. [3] showed the usefulness of the ROC curve on breast cancer diagnoses not only from the medical professional, but also using the computer-assisted detection, showing the fraction of confirmed breast cancer (true positive) detected against a fraction of false positives. In a study applying the ROC theory on breast cancer in China, it was reached values of 53.33% on the sensibility and 77.69% in specificity, reaching 73.39% of positive prediction on the analysis, demonstrating that the methodology is helpful on the determination or separation and certification of data for a specific purpose [7]. In Brazil, Heise et al. [8] applied the ROC curve theory on the evaluation of neuromuscular disorders with data obtained from repetitive nerve stimulation exams; the objective in this case was the determination of the limit on the cut-off levels to optimize the method in this application.

This work aims to create an algorithm to determine the quality on a tile decoration (quality index) based on the ROC curve theory, using the analysis of images obtained after the tile decoration and prior to the sintering step. Usually the algorithms used to do so are based on the confrontation of a photograph made from a set of special cameras with a series of pre-obtained photos of a number of ceramic tiles considered as free of defects and within the range of standard hue. The use of such equipment is applied mostly at the end of the ceramic line production, after sintering. Determining the decoration quality of a ceramic tile before sintering could save energy, time and consequently money for manufacturers.

MATERIALS AND METHODS

The variables of the decoration process that were kept fixed in this work were: ink formula (pigment, ceramic flux and medium); type of tile (same enamels and support); silicone cylinder (T1, Shore A hardness between 10 and 19, 720 mm [9], type of engraving); and same artwork. The silicone cylinder laser engraved decoration process was chosen as a source of analyses, where, in a previous work, seven variables were studied with the possibility to be a source of hue variation on the process (ink density and viscosity, ceramic tile surface temperature, production speed, cylinder pressure over the tile, blade pressure and blade angle over the cylinder and finally tile surface humidity). A variable at a time was changed and studied using the other six constants. In this process a digital image is transferred to the cylinder with laser shots, making an ellipse-shaped hole (with dimensions of fractions of millimeters), and depending on the type of engraving and image definition (px/in) used, these holes can vary on dimension and/or number inside an area to represent a gray scale [10-12]. The evaluated characteristics through the decoration results, that is, the dots formation laid-up over the ceramic tiles were analyzed using an optical microscopy (Zeiss, Axio Scope A1), with the software Axio Vision v.4.8.2 image analyzer.

The decoration characteristics studied were dot geometry (how close to the ideal form, round) and covered area after decoration. All tests were performed with a Rotocolor S5 Universal. The study was performed on the images of ceramic tiles decorated with the full area of 25% of the gray scale in a decoration with 04/45° engraving, acquired with the variations of the previously described conditions. A standard grid marked the positions where the decorated dots should be, according to the image definition of the chosen engraving. A decoration standard established was: the deposited dot area full of ink and the areas outside the dots with no ink deposited. The determination of the classes TP, FP, TN and FN (true positive, false positive, true negative and false negative, respectively) were carried out under the perspective of the perfect formation of the decorated dots, that means, TP - area of the dots completely full of ink, TN - area outside the dots positions without ink, FP - area external to the location of the point with the presence of the decoration ink, and FN - area of the decorated point partially filled with ink, being in practice measured by the analysis and quantification pixel by pixel of each image, with the calculation of sensitivity, specificity and precision shown respectively in Eqs. A, B and C. The quality index, Eq. D, measured how much the decoration is far from the perfect theoretical value, equal 1. The smaller the index the worse the decoration quality is.

$$\text{Sensitivity} = \frac{TP}{TP + FN} \tag{A}$$

$$\text{Specificity} = 1 - \frac{FP}{FP + TN} \tag{B}$$

$$\text{Precision} = \frac{TP}{TP + FN} \quad (C)$$

$$\text{Quality Index} = 1 - \frac{FP + FN}{TP + TN} \quad (D)$$

The analyzed image (test) was then compared with a standard image in several translational positions over a matching grid with dimensions equal to half vertical and horizontal distances from the center to center of the dots on the same line. This comparison aimed to find the position that maximized both the sensibility and the specificity and, in cases with equivalent values for the same position, one can use the precision value as a tie-breaking value. Found the best position by this first grid, the routine restarted searching a smaller grid, centering over the coordinates of the position that maximized the variables as so on, until it found the best position below a given limit, which in this study reached one pixel on the resolution. Therefore, the joint maximization of the values for sensibility and specificity found was the adjustment between the standard and the decoration made, and so one it was proceeded to the quality index calculation, which measured the decoration quality. The tests were performed trying to maintain the same characteristics of the ceramic tile lines, and so, the workflow sequence was: fixation of the test conditions and set up of the decoration equipment; tiles were left in the muffle furnace between 120 and 130 °C until the temperature stabilization. After removal from the muffle furnace, they received a water cover spray for the correction of the surface humidity and homogenization of the working temperature; then they were taken to the decoration in the mentioned equipment. According to the manufacturer of the silicone cylinder, the working height must not be more than 1.5 mm below the thickness of the decorated tile. Thus, for the tests, in addition to the standard height, variations between 0.8 and 1.0 mm were analyzed.

RESULTS AND DISCUSSION

The standard grid used looks like the image on Fig. 1, representing what should be a perfect decoration. The method is illustrated in its application in model figures and its comparison with the perfect theoretical impression. Artificial alterations were made in the template generating figures with 3 types of decoration defects, which were: figure with failure to unload ink from the point, that is, lack of ink in the decorated points (Fig. 2a), figure with ink outside the place of the dots (Fig. 2b), and figure composed by the two types of print defect (Fig. 2c); all three of them represent, therefore, extreme (and feasible) situations in relation to a perfect impression. The graphical representation of this analysis can be seen in Fig. 3, which present the respective template adjustments to each of the figures, with recognition of the areas that were outside the appropriate decoration standards. The red color represents the lack of ink deposited,

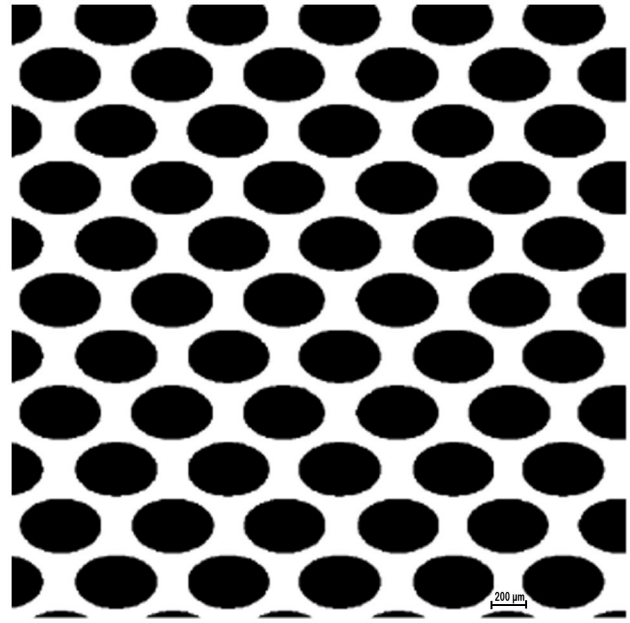

Figure 1: Standard grid used.

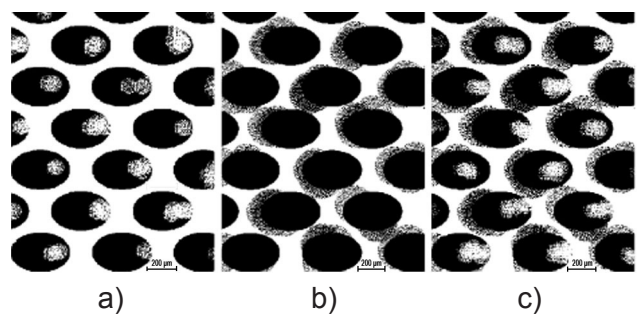

Figure 2: Theoretical model images with decoration defects.

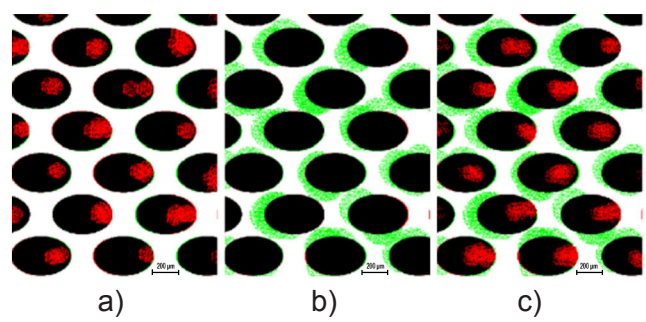

Figure 3: Adjustments of decoration to the grid theoretical template with quantification of the defect decoration zones.

where it should be and the green color represents the excess of ink (blurred), that is, in places where it should not be deposited.

The values obtained are shown in Table I, for the 95% confidence level, that is, $\alpha/2=2.5\%$. For the calculation of the confidence interval, the Eq. E was used:

$$p' - z_{\alpha/2}\sqrt{\frac{p'(1-p')}{n}} \leq p \leq p' + z_{\alpha/2}\sqrt{\frac{p'(1-p')}{n}} \quad (E)$$

where: n - number of elements (pixels) analyzed in each of the analyzed images; p - actual value of each of the calculated

Table I - Values of the decoration quality measurement quantities with their respective confidence half-amplitude interval.

Figure	Sensibility	Specificity	Precision	Quality index
Lack of ink inside the dots	0.852±0.003	0.980±0.001	0.979±0.001	0.905±0.002
Ink outside the dots	0.9881±0.0008	0.847±0.003	0.785±0.003	0.887±0.002
Two defects simultaneously	0.838±0.003	0.831±0.003	0.788±0.003	0.801±0.003

parameters, which were ratios between analyzed pixels; p' - estimated value of each of the calculated parameters, from the best approximation performed by the algorithm of image overlap and obeying the applicability criteria of the equation $np \geq 5$ and $n(1-p) \geq 5$; $z_{\alpha/2}$ - the value of the variable z of the reduced normal distribution, under a confidence level equal to $\alpha/2$. The values were treated and analyzed by obtaining cutting thresholds, which represented the minimum quality acceptable for decoration, directly from the ROC curve.

The following are two real figures, one with the worst actual decoration quality (Fig. 4a) and the other with the best decoration quality (Fig. 4b). Table II shows the numerical results of the analysis of the two images in Fig. 4, for the 95% confidence level, that is, $\alpha/2=2.5\%$. From this analysis, the final user could, based on the quality standard adopted on their production, delimit a cut-off value for the quality index, adopting a value that allows the acceptance of decorations that can be considered with minimally acceptable quality.

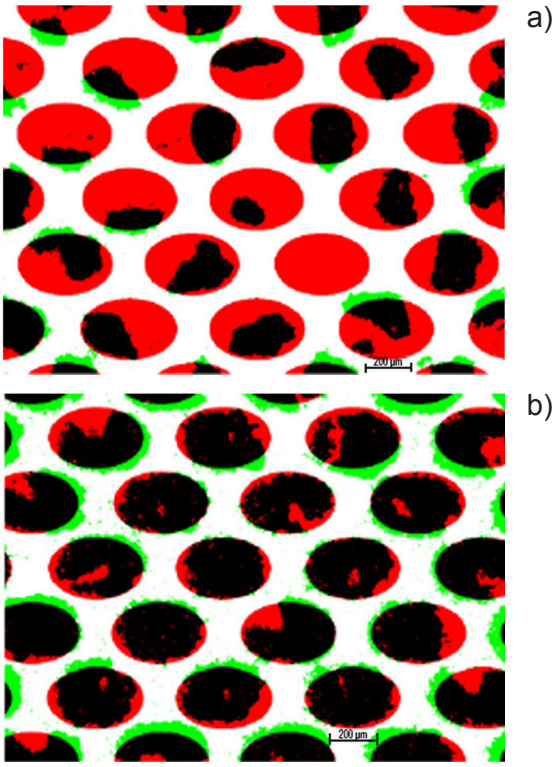

Figure 4: Worst and best real qualities for the analyzed decoration samples.

CONCLUSIONS

As a first approximation in the development of the algorithm for the analysis of images obtained in ceramic tile lines, the establishment of the decoration quality index could be validated. The use of the ROC curve methodology allowed the best comparison between theoretical and experimental images and, from this adjustment, it was possible to determine the quality of the decoration. This methodology can be automated, allowing the verification of production quality in an objective and fast way.

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Table II - Values of the print quality measurement quantities for actual decoration with their respective confidence semi-amplitude interval.

Figure	Sensibility	Specificity	Precision	Quality index
Worst visual decoration quality	0.550±0.004	0.865±0.003	0.932±0.002	0.392±0.004
Best visual decoration quality	0.791±0.003	0.830±0.003	0.802±0.003	0.768±0.003

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