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Estimation of the minimum material removal thickness during the polishing process of ceramic tiles by laser triangulation

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ABSTRACT

The possibility of controlling the thickness to be removed from each tile during the honing/polishing process of ceramic tiles would avoid unnecessary wear of the abrasive tools, directly minimizing energy and water consumptions. Such technology requires a conveyer belt capable of adjusting the height of the tile surface, together with a measuring system to estimate the most recommendable removal depth for each tile. While the former requirement is still not promptly available in the market, the on-line characterization of the geometrical characteristics of the tiles could be theoretically performed by many techniques. In this context, this study presents the 3D micro-inspection by laser triangulation as a promising technique to be employed at the production line prior to the honing process. To verify this hypothesis, six types of surfaces with different compositions were characterized in terms of 3D topography, waviness profiles, and surface roughness. The results indicate that the methodology adopted in this study is able to provide precise information regarding the minimum layer to be individually removed from the tile surfaces. In addition, it was also observed a relationship between the surface waviness and the tile composition. In contrast to the value of ca. 10% typically adopted in most ceramic industries, for the surfaces considered in this study, the minimum removal layers were found to be between 1.08% and 2.37% of the initial thickness.

1. Introduction

Surface inspection is an important step in the production of ceramic tiles with high quality. However, in most cases, the surface inspection has been limited to classification cabins in which the final product is evaluated to monitor the final quality of the product, classifying it into the first, second or third line of quality. It is usually done visually and requires highly skilled operators. Currently, it is possible to do this inspection by modern automatic inspection systems which are capable of capturing images up to 160 megapixels from the surface through CCD cameras (charge-coupled device)[1–3]. However, details about the evaluation criteria of defects in final products is still limited in the literature.

In unglazed porcelain tiles, the surface inspections are only done at the end of the finishing process, in which the final surface has a relatively high glossiness. This finishing process is commonly defined in the manufacturing units as polishing, although technically the most appropriate designation is honing.

Usually, the honing process is composed by a sequence of 14–18 polishing heads using different abrasive grain sizes, generally between 36 and 1500 mesh. About 10% of the tile original thickness is removed at this stage [4,5], but there is no study justifying the need for an exact percentage of material removal. The adoption of an exaggerated removal layer rises due to the fact the upper surface of all the tiles onto the conveyer belt must be evenly aligned in order to avoid abrupt breakage of the abrasive tools (known as fickerts). To assure such alignment, the most direct strategy is to perform an aggressive grinding process (leveling step) right before the honing process.

Considering the entire porcelain production chain, the honing process accounts for approximately 30–40% of all production costs [6,7], due to the high consumption of abrasive tools, water, and energy. This also means a high production of waste from the wear of the ceramic plates and the fickerts. According to Y. Wang, Z. Pan and S. Zheng [8], China, as the largest producer of ceramic floor tile in the world, produces on average more than seven millions tons of waste from such wear and tear per year. A topographical study before the honing process

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may generate savings in this aspect, avoiding unnecessary wear on the abrasive tool/ceramic pair. The major challenges, however, are the lack of industrial devices for enabling the on-line control of the surface alignments along the conveyer belt and for estimating the geometrical characteristics of each tile prior to the polishing process. The present paper is focused on the later subject.

Several studies have been done in the field of optimization of the sequence and measurement of glossiness [6,9], as well as in the optimization of the kinematics of the honing operation as feed rate, rotational angular speed, lateral oscillation, contact pressure and honing time [10–12]. How these parameters may influence the tile surface characteristics is already reported [13]. Nevertheless, a study focused on the surface using 3D technology remains a lack in the literature.

1.1. *Laser Triangulation in porcelain stoneware tiles*

The last years has been important to the development of automatic quality control systems. The growth of inspection with 3D technologies has increased the quality control in the diverse sectors of the industry. This system is capable of delivering results and maintaining a quality of inspection on ceramic components with uneven surfaces such as porcelain tiles.

The system is designed to measure three-dimensional coordinates of points on a given surface. The principle of measurement is triangulation. The emitting source and the CCD camera have a fixed distance between them, here represented by *Base b*. The emitting and detecting angles of the emitted beam, in relation of the base b, are represented by β and α, respectively. The angle of reflection on the surface of the tile, Υ, is entirely related to the topography of the surface. Thus, depending on the variation in topography, the distance between the sensor and the object also varies and the pulse reflected by the surface appears at different places in the plane of the image. Thus, the topographic image of the surface under analysis is generated. The CCD camera, the region under analysis, and the laser triangulation are represented in Fig. 1, and the coordinates each point on the surface are defined by Eqs. (1) and (2).

$$\gamma = 180^\circ - \alpha - \beta \tag{1}$$

$$z = \frac{b\sin\alpha\sin\beta}{\sin\gamma} \tag{2}$$

1.2. *Waviness versus roughness in tile surfaces*

Like metallic and polymeric surfaces, the geometry of porcelain stoneware tile surfaces is typically described in terms of three components: form, waviness and roughness, classified according to their wavelengths. The component form refers to oblique surfaces or lack of parallelism, and its wavelength is virtually infinite. The ondulations usually perceived with unaided eyes are commonly described as "waviness", and those of much shorter wavelengths are known by "roughness". The roughness and waviness profiles can be determined together, being commonly referred to as "surface texture", or separately, to identify their individual effects on the surface of the porcelain tile.

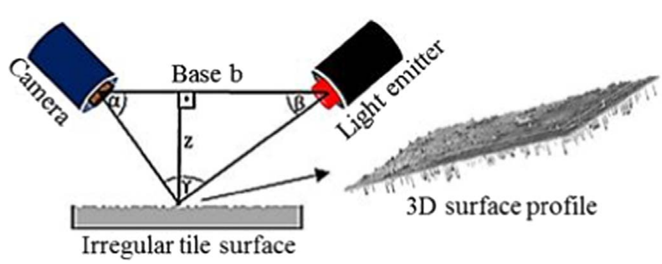

Fig. 1. Laser triangulation in porcelain tiles.

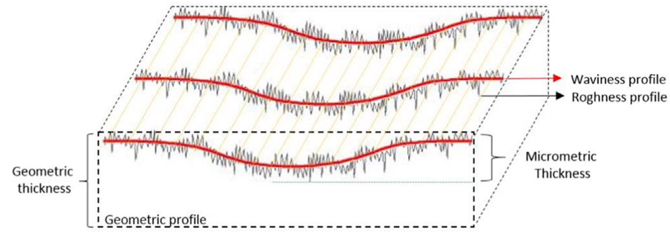

Fig. 2. Illustration of waviness versus roughness profiles in tiles surfaces.

In the technological point of view, the term polishing refers only to the elimination of the roughness [14]. In the ceramic sector of floor tiles, however, the term "polishing" colloquially refers to the reduction of both waviness and roughness together. The reduction of the waviness is made in the surface leveling stage, subsequently, in the honing step, the effects of the surface roughness are reduced, implying greater light reflectance perceived as glossiness. The majority of the thickness measurement devices in production environments are only capable of measuring the thickness considering the straight surface, here represented by the geometric thickness. As already mentioned, 10% of the geometrical thickness is generally reduced in the honing process. Fig. 2 illustrates (out of scale) the surface parameters and the terms used in this study. These parameters are expressed in micrometric scale.

The main goal of this study is to use laser triangulation technique as a pre-honing process step, in order to verify its potential use for future devices. For this purpose, different surfaces of porcelain tiles were 3D mapped, and their waviness profiles and surface roughness were determined.

2. Method

In order to develop different surfaces to be evaluated, six different compositions were prepared. The compositions investigated include the use of two mineral residues (named as 1 and 2), as an alternative raw material since its addition may influence the microstructure and the final properties of the tiles [17,18]. The characteristics of the raw materials used, regarding the chemical composition and mineralogical phases, are shown in Table 1.

The developed compositions are given in Table 2, together with two main parameters that characterize them as porcelain stoneware tile: the

Table 1
Chemical and phase mineralogical characteristics of the raw materials used.

Oxides	Concentration (% Weight)				
	Clay / Kaolin	Feldspar	Quartz	1	2
SiO_2	56.49 / 49.21	73.61	98.03	64.99	54.96
Al_2O_3	24.35 / 34.78	19.37	0.89	14.98	22.51
Fe_2O_3	2.26 / 0.44	0.45	0.1	3.65	8.94
K_2O	0.59 / 0.7	2.96	0.1	5.63	3.4
CaO	0.34 / -	0.11	–	3.34	1.57
MgO	0.69 / -	–	–	0.97	3.12
TiO_2	0.7 / -	–	–	0.53	1.02
Na_2O	0.17 / -	2.51	0.14	2.53	1.66
*Traces	0.31 / 0.27	0.21	0.05	0.6	0.42
**L.I	14.1 / 14.6	0.78	0.69	2.78	2.4
Phases	***Concentration (% Phases)				
Kaolinite	62.00 / 97.00	–	–	7.00	–
Quartz	38.00 / -	2.00	100	35.00	28.00
Albite	–	–	–	–	48.00
Ilite	–	–	–	–	24.00
Muscovite	/ 3.00	2.00	–	57.00	–
Rutile	–	–	–	1.00	–
Microcline	–	96.00	–	–	–

* Total sum of oxides with values less than 0.1%.
** Loss on ignition, 1000 °C.
*** Approximate values.