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Analysis and laboratory simulation of an industrial polishing process for porcelain ceramic tiles

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Abstract

This paper reports the design and initial tests of a laboratory-scale tribometer to simulate the development of surface finish (roughness and optical gloss) in the industrial polishing process for porcelain ceramic tiles. The mechanical conditions in a typical industrial polishing process have been analysed and the results used to define the conditions to be reproduced in a laboratory simulation. The tribometer allows the relative sliding speed and contact pressure between the abrasive tool and the tile to be controlled. Measurements can be made of changes in roughness and gloss, as well as of the rate of material removal from the tile and from the tool. The evolution of surface roughness and optical gloss of porcelain ceramic tiles has been studied, with a succession of different abrasive tools. These results have been compared with data gathered from an industrial polishing line with a similar sequence of abrasive sizes, and show that the tribometer reproduces the important features of the process well. Surface roughness and gloss are two important variables to assess the final tile properties and also represent the most useful measures of quality at different stages in the evolution of the final polished surface.

Keywords: Ceramic; Vitreous ceramic; Tile; Polishing

1. Introduction

Highly polished, unglazed porcelain ceramic tiles are being increasingly used in high-specification architectural applications as they show excellent performance, including good mechanical strength and chemical, stain and frost resistance, as well as aesthetic advantages over glazed ceramic tiles.[1] Polishing forms the final operation during manufacturing, following surface planing and flattening, and more than 40% of the total cost of the product is attributable to the grinding and polishing process. Typical commercial specifications require a final surface gloss level of 65–70%. Current industrial polishing processes are considered to be inefficient, with unnecessarily high wear of the grinding/polishing tools, high energy consumption, the production of large amounts of polishing waste, excessive numbers of rejected products and poor control of product quality. Typically 0.5 to 0.6 kg of cement-matrix polishing tool material is consumed per square metre of final polished product. There are thus clear opportunities to reduce the cost and improve the quality of the final product, through improved understanding of the polishing process. Previous studies of tile polishing have been carried out on an industrial scale, with the disadvantage of limited control of the test conditions,[2–5] or with a manually-controlled polishing machine with poor control of applied load.[6,7] Studies have also been made of the related problem of the polishing of natural stone, such as granite.[8] Apart from this earlier work, the optimisation of the polishing process has received little scientific attention. In order to develop our understanding of the polishing process further, there is a need for well-controlled experiments on a laboratory scale, in which the effects of the process variables can be carefully studied.

In the present work, a typical industrial polishing process for porcelain ceramic tiles was analysed to determine the

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conditions to which both the tiles and the abrasive materials are exposed, and information from this study was then used to design a laboratory-scale polishing rig (tribometer), which could be used to investigate the polishing mechanisms and polishing rates. Profilometry and optical gloss measurements were the main tools used to study the evolution of the quality of the polished tile surfaces. The experimental results from the laboratory rig were then compared with data gathered from an industrial polishing line in order to validate the laboratory-scale simulation.

2. Analysis of a typical industrial polishing process for ceramic tiles

The information used in the following discussion was obtained from various industrial sources in Spain and Italy, and is considered to be typical of current European practice.

After initial flattening and rough grinding to correct the gross form and thickness of the product, often with diamond-impregnated fixed-abrasive tools, tiles are polished in a sequence of stages, most commonly with silicon carbide abrasive particles (ca. 10 wt.%) embedded in composite blocks formed with a magnesium oxychloride cement matrix.[2] The abrasive particle size in the composite is gradually reduced from each polishing stage to the next, progressing from an initial size of several hundred micrometres to a final size of a few micrometres, sometimes over more than 20 stages. A final, high quality polished tile surface typically has a surface roughness *Ra* of about 0.1 to 0.2 μm and optical gloss (measured at an angle of incidence β of 60°) up to about 80%.

Fig. 1 shows schematically the operation of a typical grinding tool in which six approximately rectangular composite blocks attached to a rotating head are pressed downwards against the tile surface. A swinging motion of each abrasive block is achieved by a mechanism inside the head. This swinging motion distributes the wear over a cylindrical surface on the block (with radius *R* indicated in Fig. 1b), and ensures that the local contact between the block and the tile occurs over a narrow strip along the surface of the block. The contact area is flooded with water, which removes heat and also flushes away the wear debris from both the block and the tile. The tool typically rotates about a vertical axis at a speed of 450 rpm (giving a mean peripheral speed of the blocks of ca. 8 m s^{-1}) while the tiles move linearly on a conveyor belt at a much slower speed (typically 75 mm s^{-1}) beneath the rotating tool. A normal load of 200 N is applied to each abrasive block, and the cylindrical radius *R* of the block surface (i.e. the radius of the swinging action) decreases from 130 mm (for a fresh block) to about 72 mm due to wear of the block during the polishing process.

During the industrial process, the contact length (in the direction of relative motion) between the abrasive block and the ceramic tile changes with the sliding time, and so does the contact pressure as wear causes the radius of the block surface to decrease. If, as a first approximation, it is assumed that the

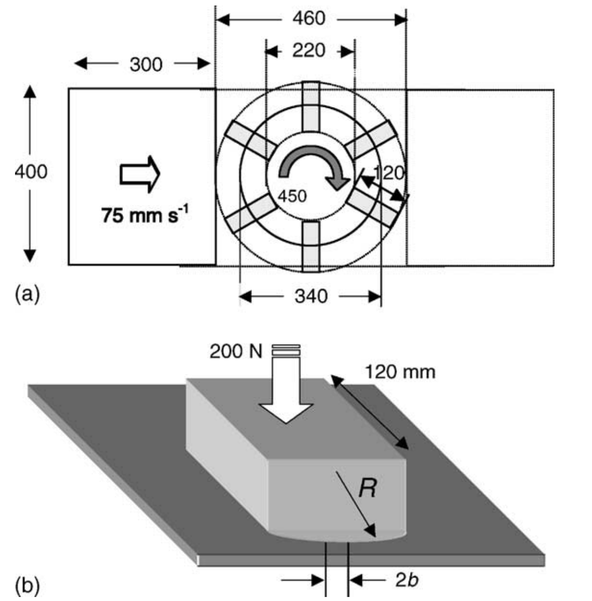

Fig. 1. Schematic diagrams of typical industrial polishing process: (a) a rotating head carries six abrasive blocks and the tiles are transported slowly beneath the head and (b) detail of a single abrasive block, which oscillates in a small arc with radius *R* about a horizontal axis while the whole polishing head rotates about a vertical axis.

contact between the block and the tile is elastic, then these two parameters can be estimated from the standard Hertz equations for elastic contact between isotropic bodies. The contact length 2*b* (as defined in Fig. 1b) is given by:

$$b^2 = \frac{4PR}{\pi E'} \tag{1}$$

where

$$\frac{1}{E'} = \frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2} \tag{2}$$

Here $P = W/L$, where W is the applied load and L is the length of the abrasive block; R is the radius of curvature of the abrasive block; and ν_1, E_1, ν_2 and E_2 are Poisson's ratio and Young's modulus respectively of the abrasive block and ceramic tile. The maximum contact pressure p is given by:

$$p = \frac{2P}{\pi b} \tag{3}$$

Fig. 2 shows the change in contact length 2*b* (according to Eq. (1)) and contact pressure *p* (from Eq. (3)) during the polishing process as a function of the radius *R* of the abrasive block. The broken vertical lines show the upper and lower limits of radius corresponding to the values for a fresh block and a fully worn block. As the radius of the abrasive block decreases from 130 to 72 mm due to wear, the contact pressure increases from 10 to 15 MPa, and the contact length decreases from 0.2 to 0.15 mm. These values, based on an elastic deformation model, should be treated as minimum values for contact length, and hence maximum values for pressure, since wear of the abrasive block occurring during