CHARACTERIZATION OF THE TOOL WEAR DUE TO THE POLISHING OF CERAMIC TILES UNDER DUCTILE REGIME USING MORPHOLOGICAL SPACE

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ABSTRACT

Polished ceramic tiles cost up to 40 % more than similar unpolished tiles. This is to a great extend due to the wear of the abrasive tools, industrially known as fickerts. The present work intends to extend the validity of using morphological space to quantify the wear of fine abrasive fickerts during the industrial polishing process. In such space, the horizontal and vertical axes are respectively the skewness and the kurtosis of the distribution of heights taken from the surface profile. This enables the sequence of geometrical changes suffered by the fickert’s surface to be evaluated by the resulting curve registred in the morphological space. The experimental points obtained were nearly aligned and with a negative slope, just as expected for abrasive wear. Unplausibly, the results for fine abrasive fickerts was much more scattered than for those with coarse abrasive particles found in literature.

Keywords: Abrasives; Silicon carbide; Morphological Space; Surface characterization; Polishing process

INTRODUCTION

The polishing process of ceramic tiles has high demand for energy, water and abrasive tools (1)(2), which together with a low level of efficiency associated to the process (3)(4) result in polished products costing up to 40% more than unpolished products. According to Hutchings (1), the consumption of abrasive tools, colloquially known as fickerts, is ca. 0.5 kilos per square meter of final polished product. A typical fickert is composed by a matrix of magnesium oxychloride cement containing silicon-carbide particles dispersed as abrasives. Fig. 1 illustrates such fickerts, together with
the swinging they perform in order to assure a uniform wear and also a condition of linear contact between them and the tile surface.

Figure 1 – (a) Typical abrasive tool tile polishing (b) and its operational details

Although many fruitful studies focused on the tile surface have been reported (2)(5)(6)(7), investigations focused on the surface of the abrasive blocks are still very sparse in literature. In a previous work from the authors (8), the viability of using morphological space to evaluate the geometrical changes suffered by the fickert surface during the polishing process in quantitative terms was verified considering embedded abrasive particles of ca. 325 µm up to 400 µm in diameter (#100).

The main goal of the present paper is to expand this viability by analyzing a fickert containing a much smaller range of abrasive size, from 10 µm up to 20 µm in diameter (#600). Thus, other than before, the ductile removal mode of the tile surface is expected to prevail (8). For this purpose, the evolution of the wear of a #600 fickert was analyzed in situ during laboratorial polishing and plotted into the morphological space, defined at next. Important to notice is that the removal mode taking place on the surface of the fickert may differ from that occurring on the tile surface.

MORPHOLOGICAL SPACE

Admitting the distribution of heights taken along the abrasive surface of a fickert, given by \( p(z) \), with mean \( \mu \) and standard deviation \( \sigma \) and where \( z \) is height of a single ordinary point, the skewness \( S_K \) and the kurtosis \( \text{K} \) are expressed as:

\[
S_K = \frac{1}{\sigma^3} \int_{-\infty}^{+\infty} (z - \mu)^3 \cdot p(z) \, dz
\]

(A)
Variations in these both parameters can be simultaneously represented using the morphological space, whereby the skewness lies along the x-axis and the kurtosis lies along y-axis composing a 2D space. Fig. 2a considers the morphological changes of the abrasives during wear. An example of morphological space can be seen in Fig. 2b. Surface alterations during adhesive wear are expected to be yield values of skewness nearly to zero, either small positive or small negative, whereas a surface after successive abrasion tends to present a constantly decreasing skewness with points nearly aligned.

\[
K = \frac{1}{\sigma^4} \int_{-\infty}^{+\infty} (z - \mu)^4 \cdot p(z) \, dz
\]  

Figure 2 – Examples of morphological space. (a) Evolution of abrasive and adhesive wear is cast irons (adapted from Mello 1985 (9)). Typical variations in the surface profiles and their corresponding distributions of heights during abrasive wear.

The common term \((z-\mu)\) present in both equations indicates that \(S_K\) and \(K\) are not totally independent. Therefore, two regions can be distinguished in the morphological space: the impossible zone and the improbable zone. Furthermore, the exponent limits the kurtosis to positive values. By definition, surfaces whose distribution of heights follows an idealized Gaussian curve have \(S_K = 0\) and \(K = 3\).

METHOD

The abrasive tool used in this experiment was composed by two small abrasive blocks made out of the same commercially available fickerts, which was gently provided by the company Fabras Química do Brasil, in Urusanga-SC, Brazil. Each small abrasive block was 10 mm wide and 30 mm long, and the size of the
abrasive particles embedded into them was around 10 µm up to 20 µm in diameter (mesh #600). The abrasive tool and its tool holder are presented in Fig. 3. A swinging mechanism in the abrasive tool imposes a small curvature into the abrasive blocks so that a linear condition of contact is maintained upon an area of 0.2 mm x 30 mm between each abrasive block and the tile surface, as usual in industrial lines.

Figure 3 – Details on (a) the Abrasive tool and (b) the abrasive blocks (fickerts), and (c) the region under investigation

The parameters used during all polishing tests are: forward speed of the fickert of 10 mm/s, spindle rotation of 1800 rpm, normal load of 102 N, and distances between tool center and innermost abrasive of 55 mm and between peripheral abrasive of 115 mm. The surface to be polished was a porcelain stoneware tile of 296 mm x 150 mm and 7 mm thick. Abundant tap water was used as lubricant.

During the experiment, the abrasive tool performed a sequence of nine polishing steps lasting one second each. The roughness profile resulting on the abrasive block was then measured after each polishing step, so that the evolution of the wear occurred on the surface of the fickerts could be evaluated. The spindle rotates clockwise for the first five steps and counterclockwise for the four last steps.

To assure a complementary interpretation of the results regarding the surface morphology, both optical and (Olympus, model BX41M) confocal (Nano Focus, model µsurf Explorer) microscopy were used to carry out the surface analyses. The former technique provides the materials microstructure whereas the later technique provides the surface topography. The region under investigation was always confined to an area of 1.5 mm x 1.5 mm located as indicated in Fig. 3c. A mechanical mask (stencil), also seen in Fig. 3c, was employed to assure that all characterizations were done at the same surface. Once the initial abrasive particle was selected, the morphological variations suffered by the surface of the abrasive block during each
one of the nine polishing steps are then evaluated through their corresponding roughness profiles.

RESULTS AND DISCUSSION

Fig. 4a assembles the evolution of the wear occurred on the fickert’s surface in terms of morphological space during the nine polishing steps. The points were plotted and numerated directly following the sequence of polishing steps. Results similarly obtained for coarse abrasives (#100) and collected from literature (8) are found imposed together in Fig. 4b for comparison purpose.

Figure 4 – Morphological space: (a) experimental results for a fickert containing #600 abrasives, and from literature (b) containing #100 abrasives for comparison (8).

Considering first the experimental results presented in Fig. 4a, a general trend can be observed. The points lay nearly aligned along reasonable thick line with a negative slope. This behavior are typical for abrasive wear (8)(9), and it can be explained in view of four basic mechanisms: dulling of the edges of the abrasive particles, sudden detachment of entire abrasives previously anchored on the fickert’s surface, sudden generation of new sharp edges due to the partial breakage of the abrasives, and gradual wear of the bounded matrix. The two first and two last mechanisms are typical observed in fickerts with strong and weak matrices, respectively.
Negative values of skewness indicates the prevalence of valleys against a few but prominent peaks. Remounting to the distribution of heights, this would represent a curve asymmetrically biased to the left. The more negative the skewness, the more seldom and prominent the peaks are. On the contrary, surfaces presenting a few deep valleys surrounded by large plateaus have therefore positive values of skewness, and their distributions of heights are asymmetrically distributed to the right. In both cases, the kurtosis increases when the contrast between extreme values and those close to the mean is increased.

Besides the reasonable agreement between a straight line and the trajectory representing the wear of the abrasive blocks, it was possible to notice that the sequence of the points exhibited in Fig. 4a was far from monotonic. Although the general alignment was nearly kept, in several occasions the trajectory suddenly changed or became even totally inverted.

Bearing in mind the four basic mechanisms exposed above, sequences like those from the points 3 to 4 and 7 to 8, both indicating tremendous geometrical changes, can be explained by the sudden breakage of abrasive particles, as the skewness values became suddenly more negative while their kurtoses increase, due to the emergence of new and more contrasting peaks. On the other hand, sequences like points 5 to 6 and 7 are more likely to represent the progressive wear of the existing edges, so that the predominance of peaks and their contrasts decreases monotonically. Worthy to recall is that, as expressed in Eq. (A) and Eq. (B), these both parameters are very sensitive and depend on the core value \( z - \mu \) powered by 3 and 4, respectively.

Sometimes however, such modifications were minimal, and limited to the enlargement of the crater previously formed. Such enlargement basically deepens the position of the average line, i.e. reduces the value of \( \mu \), so that the intensity of both values \( S_K \) and \( K \) is directly reduced.

When compared with the results from coarse abrasives (#100), a similar behavior can be observed, especially regarding the slope. The prevalence of ductile regime on the surface of the ceramic tile during polishing seems not to affect the geometrical changes of the fickerts. However, the scattering from the alignment found for the fine abrasive fickert (#600) was much higher. A possible explanation would be the impact of any geometrical variation is accordingly higher on the surface.
with smaller roughness, i.d. that from the fine abrasives fickert, as the presence of extreme deep valleys remains due to either porosity or new holes left by removed abrasives.

More research including different abrasive sizes may enable further generalizations on this issue. So far the morphological space seems to be a useful statistical tool for characterizing the evolution of wear on the abrasive tool during the polishing process of porcelain stoneware tiles.

CONCLUSIONS

Based on the results obtained, the following conclusions can be drawn:

- Apart from the very beginning of tests, all topographical modifications at the surface of the fickert with fine abrasives (#600) abrasives were plotted in the negative side of the morphological space and along a nearly straight alignment. Such fitting was found to be worse than that found in literature for fickerts with #100 abrasives.

- The prevalence of ductile regime on the surface of the ceramic tile during polishing seems not to affect the geometrical changes of the fickerts. However, a much higher scattering from the alignment was found for the fickert with fine abrasives.

Finally, the morphological space seems to be a useful statistical tool for characterizing the evolution of wear on the abrasive tool during the polishing process of porcelain stoneware tiles.

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