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Wear mechanism and morphologic space in ceramic honing process

R.A. Mezari [a,b,*], R.S.F. Pereira [a], F.J.P. Sousa [c], W.L. Weingaertner [d], M.C. Fredel [a]

[a] *Ceramic and Composite Materials Research Laboratories - CERMAT, Universidade Federal de Santa Catarina, Florianópolis/SC, Brazil*
[b] *SENAI Institute of Technology in Materials, Criciúma/SC, Brazil*
[c] *FBK – Fertigungstechnik und Betriebsorganisation Kaiserslautern, Technische Universität Kaiserslautern, Germany*
[d] *Laboratory of Mechanical Precision, Universidade Federal de Santa Catarina, Florianópolis/SC, Brazil*

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ABSTRACT

The aesthetic and mechanical properties of porcelain stoneware tiles have promoted their rise in the ceramic tile market. Great part of the aesthetic success is due to the gloss development, which occurs during the honing process. The present study, therefore, aims to focus on this stage of manufacturing process by clarifying the correlation among abrasive size, glossiness and roughness. A clearer interpretation of these parameters is offered, proposing a correction of the unit of measure which is being used in industry and the most of available literature for defining abrasive particle size. Herein, it is concluded that finer particles are those that most contribute to both surface roughness decrease and glossiness development. Not only is the roughness described as a function of the statistical parameters, namely kurtosis and skewness, but also a corresponding morphological space diagram is presented. This series of analyses results in the identification of changes in asperities' morphology taking place in the case of abrasives within a range of $17-23\ \mu m$, as a consequence of a transition in wear mechanisms.

1. Introduction

Porcelain stoneware is a product with higher technology degree than other ceramic tiles. However, their finishing process remains based on either the application of employees' expertise or empirical knowledge from other materials, such as ornamental stones and glass [1,2]. Moreover, up to 40% of the total production cost is due to the stage of the surface finishing [3]. High water consumption (20–40 l/m^2), tool wear (0.5 kg/m^2) and thickness losses, which occur through the product's thickness up to 10% [4], are factors leading to this high percentage of cost. There is a lack of scientific studies in this research field, which shows that there is a great opportunity to develop new technical and scientific knowledge providing possibilities to optimize the process.

Previous studies have been conducted in order to overcome the lack of knowledge in the field, thereby contributing to an increase of process efficiency. Sousa [5–7] used mathematical models describing the abrasive path in order to create a software tool, which is able to simulate the kinematics of flat honing with lapping kinematics process. Hutchings [8,9] replicated the process in laboratorial scale and studied the relation among abrasive particle size, surface roughness and glossiness. The results showed a greater glossiness increase for abrasive with particle size smaller than 400 mesh (37 μm); while a substantial reduction of surface roughness occurred for abrasives with larges particle size.

One of the subjects for optimizing and understanding this process is the identification of removal mechanisms during the process. Although ceramics are well-known as fragile materials, they may exhibit plastic or viscous flow [10,11] and crack propagation [12] under machining. These two different behaviors (brittle and plastic) give at least two different material removal micro-mechanisms: microcracking (brittle) and microplowing (plastic). The micro-mechanism prevailing in the process also has a great influence on the glossiness development and roughness of the piece. Sanchez [13] showed that abrasives particles smaller than 600 mesh (23 μm) result in grooves with characteristics of plastic flow.

Moreover, several studies have attempted to map the micro-mechanisms transitions in terms of specific parameters. Hsu [14], for example, studied the influence of lubrication and sliding speed for various materials. Hutchings [15] presented a map illustrating that microplowing is more likely to occur with decreasing abrasive particle size and low normal load. Most of these maps are applicable only to a specific tribological system, which limits its use and interpretations. However, Kato [16,17] and Adachi [18] proposed mappings taking into account dimensionless parameters, which were calculated based on toughness, hardness,

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[*] Corresponding author at: CERMAT/Centro Tecnológico – Universidade Federal de Santa Catarina, Caixa Postal 476 – Campus Universitário – Trindade 88040-900 – Florianópolis/SC – Brazil. Tel.: +55 48 96046075.
E-mail address: ramezari@hotmail.com (R.A. Mezari).

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friction and load. Using their methodology, it is possible to achieve maps predicting the wear behavior of a broad range of advanced ceramics.

The present study aims to address the geometrical changes of porcelain surface characteristics during the honing process (which is widely known as polishing). The goal is to correlate the active removal mechanism and a description of the surface morphology using parameters other than the usual average roughness, i.e. using higher order parameters like skewness and kurtosis. Through statistical analysis, the same collected data used for R_a calculation can be used in order to reach additional roughness parameters. Considering the measured surface heights as random events, a probability distribution curve may be achieved. The calculation of central moments based upon the resulting distribution curve leads to values describing e further characteristics of roughness.

The first central moment is the mean of distribution. It represents the asperities average heights, i.e. e. it is related to the average roughness R_a. The second central moment describes the variance [19].

The third central moment, skewness (R_{sk}), describes the curve asymmetry in terms of frequency of valley and peaks along the surface profile. This parameter presents the relation between the number of events above and below the mean line, or in other words, an indicative of the proportion between the amount of peaks and valleys. Profiles where the amount of peaks and valleys are equivalent result in values of $R_{sk}=0$. Profiles with removed peaks or with valley predominance have negative values for R_{sk}. When valleys are fulfilled, forming the pattern of plateau-peak, then R_{sk} becomes positive [19,20].

The fourth central moment is known as kurtosis (R_{ku}) and it describes how distorted from normal the distribution curve is. When $R_{ku}=3$, the curve assumes a Gaussian shape; if $R_{ku} < 3$ it shows a thin form and it is called leptokurtic; whereas $R_{ku} > 3$, the distributions is flat and called platykurtic [19].

Physically, R_{ku}, gives guidance about the shape of asperities. Values below three indicate the presence of a few high peaks and deep valleys, higher values ($R_{ku} > 3$) indicates many low peaks and shallow valleys [20,21].

These two parameters (R_{sk} and R_{ku}) are so important that, if one draws a 2D diagram containing kurtosis and skewness as axes, the so called morphological space is created (Fig. 1). Since each entire distribution of peaks and valley in a given surface profile is represented by a single point, this diagram is an easy way to visualize the evolution of surface characteristics during a process. With it, is possible to distinguish different types of machining processes, as seen in Fig. 1, and also to identify changes in the removal mechanisms regime [22,23].

In the present paper, data obtained from literature and experiments (reproducing the industrial honing process of porcelain tiles on a laboratory scale) are confronted. Consequently, the relation among process parameters (abrasive size and number of contact between abrasive stone and porcelain), resulting properties (roughness and glossiness) and removal phenomena are clarified.

2. Materials and methods

2.1. Porcelain tiles

The porcelain tiles were acquired as sold, i.e. with their glossiness already developed. Then, the ceramic pieces were reprocessed using the first abrasive stone (36 mesh, 450 μm).

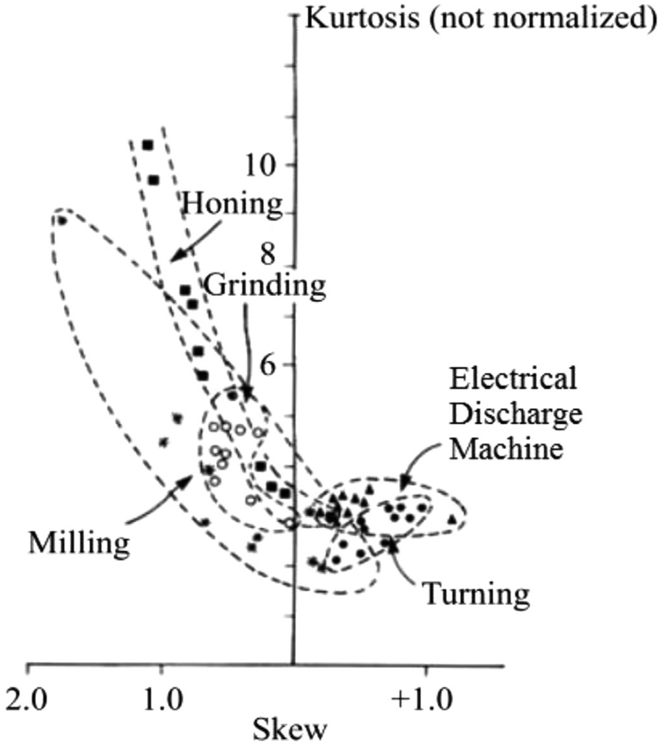

Fig. 1. Typical morphological space for several manufacturing process (adapted from [20]).

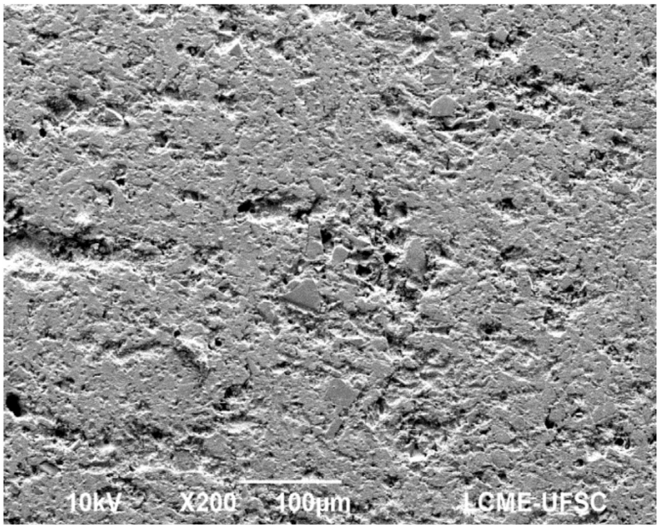

Fig. 2. Porcelain stoneware microstructure.

Table 1
Mechanical properties of porcelain tiles.

Hardness Vickers	Young modulus	Flexural strength	Weibull coefficient
639 HV	72 GPa	61 MPa	7

The porcelain microstructure is presented in Fig. 2. The sample was etched in a solution of hydrofluoric acid for 14 min. The image shows a glass matrix with disperse quartz crystals and pores.

Mechanical properties were measured and an overview is presented in Table 1. Hardness measurement was taken on 10 samples (5 points each) with a BUEHLER Vickers microhardness