Journal of Materials Processing Technology 243 (2016) 170–183

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Manufacturing of structured surfaces via grinding

E.J. Silva[a,*], B. Kirsch[b], A.C. Bottene[a], A. Simon[b], J.C. Aurich[b], J.F.G. Oliveira[a]

[a] University of Sao Paulo – USP, School of Engineering – Sao Carlos – EESC, Department of Production Engineering, Sao Carlos, SP, Brazil
[b] University of Kaiserslautern, Institute for Manufacturing Technology and Production Systems, P.O. Box 3049, 67653, Kaiserslautern, Germany

ARTICLE INFO

Article history:
Received 8 April 2016
Received in revised form 9 December 2016
Accepted 11 December 2016

Keywords:
Grinding
Structuring
Surface
Dressing
Tool development
Tribology

ABSTRACT

This paper presents the possibilities and limitations of structuring surfaces using special grinding wheels. Two methods were evaluated. Workpieces were structured using a patterned grinding wheel, specially conditioned during the dressing operation. The second method uses a grinding wheel with defined grain pattern to produce structured surfaces with micro features. The obtained results indicated the feasibility of the two methods.

1. Introduction

In the scenario of modern manufacturing, with the current demand for products and processes that require minimum consumption of resources and in a sustainable way, the performance of a machined component regarding energy performance is of high interest. In bearings, for instance, surface characteristics can highly influence the energy loss or load capacity. Surface characteristics can also play important roles in terms of energy or signal transmission by defining the mechanisms and the kinematics involved in this exchange phenomena in a micro and nano scale (Bruzzone et al., 2008). For example, tribological properties are highly influenced by the degree of interaction between two surfaces, leading to different results of friction, wear and/or lubrication conditions with a direct impact on energy consumption. As presented by Ibatan et al., surface texturing for increasing the tribological performance of sliding components is a very active research field, with several contributions over the last decades, in terms of production methods, analysis of the tribological enhancements and prediction of the obtained results by simulation (Ibatan et al., 2015). The importance of structured surfaces can be seen in other areas, with recent application examples in electronics (Wang et al., 2015), optics (Cho et al., 2013) and health (Zhang et al., 2015).

Structured surfaces are commonly produced by applying optical or X-ray lithography, etching and laser ablation. Hilgenberg and Steinhoff (2015) presented a new approach to produce deterministic structures in skin-pass rolls used in the final forming operation of metal sheets for automotive applications using pulsed laser dispersing. Costa and Hutchings (2009b) developed a maskless electrochemical method to produce textured surfaces in metallic workpieces, in which 100 holes of 220 μm in diameter, arranged in a 10 × 10 mm configuration were etched, achieving a maximum depth of 45 μm, with cycle time of 60 s. Zhang and Meng (2012) studied the surface texturing of mild carbon steel (ASTM 1020) using photochemical machining, which consisted of eight main steps, from cleaning to photoresist removal. Circles and triangles were produced at micrometric scale, with dimensions ranging from 20 to 200 μm and hypotenuse length from 18 to 600 μm, respectively, with maximum depth of around 55 μm, after 900 s etching time.

When compared to the previous approaches, grinding is a promising alternative for surface structuring, as no additional investments in machine tools or manufacturing steeps are needed. The present manufacturing chains of sliding components where structured surfaces can be used to improve tribological properties mostly already include grinding. In order to produce a structured ground surface, the desired pattern has to be generated in the wheel surface itself and subsequently transferred to the workpiece during grinding. Different methods have been researched to produced a structured grinding wheel, but leading to limitations on the achieved structured surfaces. In 1989, Stepién presented a method for the production of structures by grinding in which a conventional grinding wheel was dressed with deep single or double helical grooves in a combination of dressing passes (Stępień, 1989). The

* Corresponding author.
E-mail address: eraldojs@sc.usp.br (E.J. Silva).

http://dx.doi.org/10.1016/j.jmatprotec.2016.12.009
0924-0136/

regular surface textures were limited to three basic shapes, requiring one or two grinding cycles with preselected grinding conditions, being a combination of the nominal active surface of the wheel and the stochastic arrangements of the abrasive grains (Stępień, 2011). Denkena et al. applied grinding to generate riblet structures in turbine blades to enhance performance (Denkena et al., 2010). Wheel microprofile geometry was dressed using a diamond profile roller, requiring two consecutive plunge dressing cycles with axial shift to achieve the desired riblet structure, increasing dressing time. Uhlmann et al. used a kinematic modulation of the grinding process to produce microstructures in ball bearings (Uhlmann et al., 2013).

Aiming at achieving an increased flexibility in terms of production of structured surfaces via grinding in combination with functional surface parameters, two different texturing methods are presented here. The first includes specially dressed grinding wheels, structured using a combination of a high-speed dressing axis and a texturing software for production of macro features. The second uses grinding wheels with pre-defined grain pattern to produce micro features in which several texturing types can be obtained by reproducing target-grinding conditions previously calculated via simulation for flat surfaces.

The approaches were developed in a research project in the scope of the Brazilian-German Collaborative Research Initiative on Manufacturing (BRAGECRIM). By covering micro (German project) and macro (Brazilian project) features in this binational research project, the findings on manufacturing structured surfaces via grinding can be transferred to all workpiece geometries relevant for sliding components.

2. Production of macro features using a random grain distribution wheel, specially conditioned during the dressing operation

2.1. Method

The developed method consists of two basic steps: patterning an of-the-shelf grinding wheel during dressing and transferring the pattern to the workpiece during grinding. Full details on the developed method can be found in Oliveira et al. (2010) and Silva et al. (2013). For patterning the wheel, the dressing depth (a_d) is dynamically changed according to the desired feature to be produced (Fig. 1). A high-speed axis, perpendicular to the wheel surface, was added to the dressing tool and was used to perform the modified dressing operation. The patterning software is used to generate the control signals for the high-speed axis based on the texture to be produced. Dressing time is not affected by the developed technique when compared to a regular dressing operation, as dressing and patterning can be done simultaneously in the same dressing stroke. Once the wheel is patterned, the desired feature has to be transferred to the workpiece during grinding. An integer speed ratio between wheel (n_s) and workpiece (n_w) has to be selected in order to insure proper pattern transferring. If not, the pattern will be erased in the subsequent workpiece rotation. The number of patterns in the workpiece can be scaled up according to the selected value of the speed ratio. One important point in this process to be described is that there is no need for a synchronization control system to keep the phase angle between grinding wheel and workpiece during processing (Oliveira et al., 2010). This synchronization is automatically obtained, but would need relevant patterned area to be stable. It works like a gear engagement effect.

In order to verify the consistency of the pattern imprint in the wheel surface, the acoustic emission (AE) mapping of the wheel surface Oliveira and Dornfeld (2001) is used. Fig. 2a shows the output result of a dressing pattern operation, in terms of AE [V_{rms}] values,

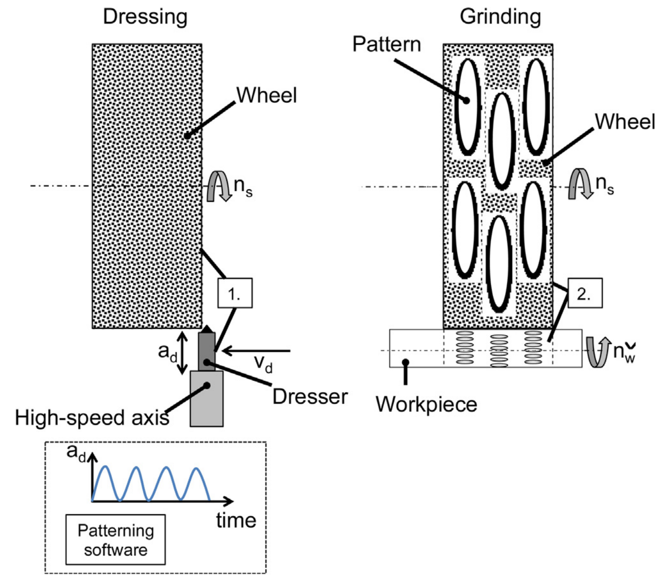

Fig. 1. Basic steps for manufacturing of structured surfaces via grinding using wheels conditioned during dressing: 1) patterning the wheel; 2) pattern transfer during grinding.

converted into a color intensity scale. The AE [V_{rms}] means the Root Mean Square value (in Volts) of the amplified signal. This value is correlated to the acoustic energy of the interaction between the dressing tool and the abrasive grains. The time constant used in the RMS calculation was of 0.2 microseconds. The vertical dimension represents the circumferential length of the grinding wheel and the horizontal one the wheel width. A pattern type "pockets" was inscribed into the wheel surface. The darker areas represent the lack of contact between the wheel and the dressing tool (pocket valleys). The brighter areas indicate the higher contact intensity regions (pocket peaks). For comparison, Fig. 2b presents an acoustic map of a non-patterned grinding wheel, indicating the homogeneity of contact interaction between dressing tool and grinding wheel.

The resulting macro features in the workpiece are strongly influenced by the process kinematics. Fig. 3 presents pattern transfer during grinding from the wheel to the workpiece, with emphasis on the resulting macro features dimensions:

As previously mentioned, to insure proper pattern transferring, an integer speed ratio between wheel and workpiece has to be selected. The feature width on the part (b_w) is not affected by the selected speed ratio, being equal to the feature width on the wheel (b_s). On the other hand, the feature length on the part (L_w) is depend on the adopted wheel and part velocities, according to Eq. (1)

$$\boldsymbol{L_w} = \frac{\boldsymbol{L_s * v_w}}{\boldsymbol{v_s}} \quad (1)$$

where: L_s is the feature length on the wheel, v_s is the wheel speed and v_w is the workpiece speed

The next important feature dimensions to be defined are the resulting feature profile in the part and the feature depth (h_k). Fig. 4 presents an extraction of a linear plot of a roundness trace for a cylindrical part, indicating the major features of a pocket-type profile.

The profile shape and depth depend on the process kinematics and the dimensions involved. Fig. 5 presents the schematic representation of the cutting path for an idealized structured grinding wheel (Silva et al., 2016).

For this kinematics representation, the wheel is modeled as a milling cutter with the abrasive grains representing the cutter teeth equally spaced at a distance L. The depth of cut is the dimension a and the feature depth is denoted as h_k. The wheel is dressed with