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Role of 3D topography of grinding wheel on its performance

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Abstract

Finish on ground surface depends largely on the topography of grinding wheel. In grinding wheel, the geometry of abrasive grain, bond, porosity and the state of wheel i.e. loaded or glazed wheel collectively make up the topography of a wheel. Wheel wear is a quasi-static process which is responsible for continuous change in topography of wheel. Topography and its variation during grinding have been mapped by several researchers using different methods which can be broadly classified into direct and indirect methods. Measurement of power, acoustic emission, vibration etc., account for indirect method of monitoring the condition of wheel whereas optical methods of characterization of wheel fall into direct method of wheel monitoring. While indirect methods give aggregate and instantaneous response, cumulative response is measured through wheel wear, wheel life and surface quality. It is well established and researched that topography of grinding wheel directly affects the performance of wheel. Hence, there exists a need to understand how to express topographical features of wheel and which surface parameters more accurately mark the variation in wheel performance. This work investigates the ability of confocal microscopy to effectively image wheel topography. Given the stochastic nature of abrasive grain distribution across the wheel surface, statistical parameters are more effective in representing cutting capability of wheel. These images are analyzed in accordance with ISO-25178 for S-parameters for obtaining standard characterization of topography and its effect on variation of wheel performance. 3-D Topographical variations are related to the performance of wheel in grinding.

Keywords: Grinding, 3-D Topography, Confocal Imaging.

1. INTRODUCTION

Grinding process is a well-established finishing operation in manufacturing industries. As close tolerances and better surface finish are important requirements on many engineering components, a continuing need to study this process is felt by many. The finish obtained on the work surface is a function of grinding wheel topography. This topography comprises of abrasive grit, bond, porosity and ground debris. The fact that these grits are geometrically undefined cutting edges [1] dispersed stochastically in the bond matrix, it is statistically possible to define the wheel surface. It is required to extract as much information from wheel surface as possible using various approaches and methods. With advances in optical imaging, it has become a favored method, among researchers, to capture wheel surface.

Extensive work has been done to understand the topography generated on wheel and to correlate it with performance in grinding. Primary focus has been on exploring various methodologies to characterize wheel surface topography. Early models to characterize wheel topography were of empirical nature which were a result of limited computational resources [2]. Doman et al. (2006) studied and presented a survey on grinding wheel where topography models were discussed under 1-D, 2-D and 3-D categories. Peklenik and Verkerk [2] focused on abrasive grain cutting edges as cited by Tönshoff [3]. This paved the way for the concept of static and kinematic cutting edge distinction. It was concluded by then that not all grains participate in cutting action [2]. Early 1-D parameters used for defining kinematic cutting density are cutting edge shape factor, speed ratio, depth of cut and grain size. In order to simplify wheel topography characterization with a single parameter, Liao (1995) developed fractal based model. Essentially, this model was based on fractal dimension '*D'* which was a function of profile length of trace and scale length of measurement [4].

Early 2-D topography measurement was done using mathematical and probabilistic models. Statistical 1-D model was subsequently extended to 2-D for obtaining 'average grain protrusion height' [5]. Chen and Rowe (1996) modeled the topography of wheel under the assumptions of spherical grain spaced uniformly in bond. To make it realistic, the locations of grit were randomized. The modeled topography was subjected to dressing, the contour path was given using periodic function [6]. Torrance and Badger (2000) included bond and grain fracture while generating topography model. The wheel surface is narrowed down to angled surfaces and a statistical average (rms) slope is used to characterize the surface [2]. In order to bring randomness associated with grain sizes, Hou and Komanduri (2003) brought in stochastic model which used normal distribution for grain size on wheel surface. However, this model did not consider dressing effects on topography generation [2].

The concept of effective profile was introduced by Radhakrishnan et al. [7]. This was among one of the first attempts to correlate wheel topography with work piece surface roughness. Multiple linear traces with simple stylus type instrument were taken across the wheel width and final superposed effective profile was generated which was stated as true cutting profile. In a different approach to capture wheel surface, capacitive sensor was used by Nowicki (1998). The method employed was capable of in-process surface roughness measurement, though with lower speeds. Using fringe field capacitive (FFC) method, Ra was calculated with an accuracy range of 10-20% [8].

In a first, an extensive study to establish 3-D parameters was done by Stout and Blunt (1994) where a set of 14 numerical surface parameters were identified [9]. Using these parameters Blunt and Ebdon (1995) studied wheel surface. The surface data

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was captured using 3-D stylus method. A sampling criteria was proposed to get optimum results [10]. The introduction of these parameters allowed researchers to study grinding wheel topography in manner which was more relevant to grinding industry. Attempts have been made since then to identify simpler and efficient ways to capture wheel surface. 3-D profilometry was again used in a different research by Butler et al. (2002) to study the variation of these parameters with stock removal [11]. Nguyen et al. (2008) showed the correlation between various surface parameters [12].

Advances in the field of optical microscopy have been made in recent years which has resulted in better imaging systems to capture wheel surface. The reliability of surface parameter extraction from optical image depends on the quality of imaging system. Chromatic sensor has been used to capture 3-D topography by Warkentin et al. (2013) where the impact of dressing depth on wheel topography was discussed [13]. Confocal laser scanning microscope has been used by Liu et al. (2015) to extract grain geometry information. The rake angles were studied against shallow and higher depth of cuts [14]. A mathematical tool has been recently developed by Weiß et al. (2015) to extract characteristic parameters, namely, specific cutting areas in normal and tangential directions and mean cutting edge area, using tactile measurement for a better understanding of contact conditions. The study also states that as tactile measurement is time consuming, optical imaging system with higher resolution can help to speed up the procedure [15].

3-Dimensional topography characterization has been long sought research area with significant developments. The narrative needs a simpler and effective correlation between topography parameters and grinding performance. This research studies the variation of topography surface parameters and its effect on performance of the wheel.

2. TOPOGRAPHY CHARACTERISATION

Study of topography involves two interconnected parallels. First is capturing of wheel surface and second deals with choosing the right parameters which can act as process marker. Tactile measurement being time consuming [15], LEXT OLS 4000 Confocal laser scanning microscopy is used to capture surface data in this study. Although smaller wheel samples are needed for imaging, the method still provides with detailed surface data.

The surface parameters defined in International Standard ISO 25178 are discussed at length by Stout et al. [16, 17]. Franco and Sinatora (2015) provided and interesting insight towards understanding of functional parameter S_{pk}. Calculation of this parameter from Fig.1 is given by [18]:

$$\text{Shaded Hill Area} = \tfrac{1}{2}.S_{pk}.\,S_{mr1} \qquad (1)$$

S_{pk} represents the height of triangle whose area equals the area under hill region. Here normalized height is used to represent Y axis. For Abbot-Firestone curve without normalized height, S_q has to be divided to get normalized reduced peak height. This area, estimated by the equation (1), represents reduced peak height material volume which signifies abrasive material volume taking part in grinding action. Summit density, S_{ds}, is a spatial parameter which has been used already to characterize grinding performance [11].

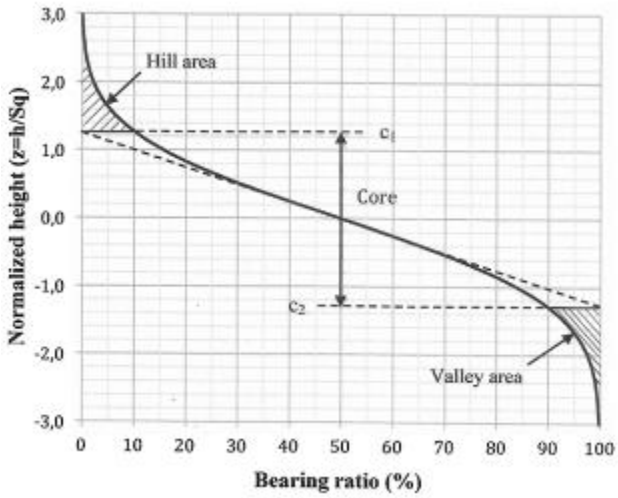

Fig. 1. Calculation of S_{pk}

To understand the correlation between these parameters and grinding performance, grinding experiments were carried out.

3. EXPERIMENT PROCEDURE

3.1 Experimental Details:

Table 1 : Process settings used in surface grinding

Machine Tool	CNC Surface Grinder
Work Material	EN8 Steel: 50mmx50mmx10mm
Wheel Specification	A60 K5 V
Dresser Specification	Single point diamond
Operation Type	Surface Grinding
Wheel Speed	1000 m/min
Wheel Dimension	180mm x 13mm x 31.75mm
Traverse Speed	7 m/min
Depth of Cut	10 µm/ pass
Grinding Width	10 mm

Table 2: Dressing/Truing Parameters

Radial In-feed	10µm/pass
Axial feed	100µm/rev

Three vitrified alumina grinding wheels of the same specification were reduced from 180mm to 179mm under medium dressing conditions in order to normalize the topography on all three wheels. Mild steel was used for grinding experiments. Only 10mm out of total 13mm of grinding width was employed for grinding (Fig. 2).

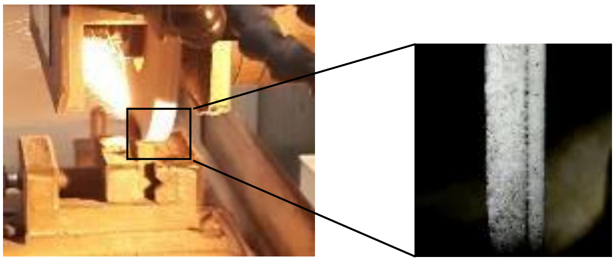

Fig. 2. Grinding experiment using CNC surface Grinder and used grinding width

Grinding was done on three mild steel specimens using three alumina wheels with total depth of cut 5mm, 10mm, and 15mm respectively. Forces were measured using Kistler dynamometer after every 50 passes.

3.2 Imaging Surface Topography:

Since the size of wheel is quite large to image it using Confocal laser scanning microscope, smaller pieces were prepared from all the three wheels. To remove the noise present in the images, Basic jagged filter was used. Fig 3 shows the filtered image of a 1280 mm x 1280 mm area.

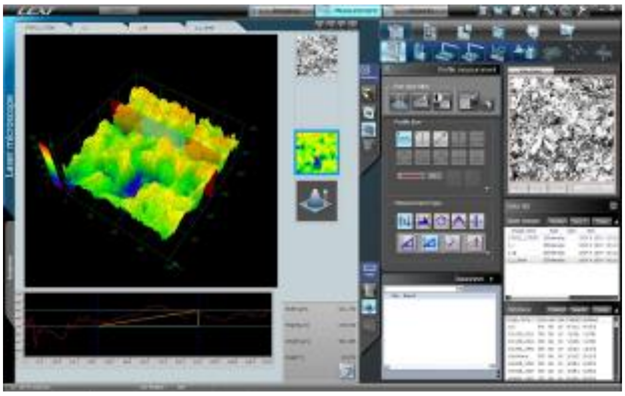

Fig. 3. Imaging with Confocal Laser scanning microscope

These images were subjected to a series of operations, shown in Fig.4, for estimating surface parameters. These parameters were extracted from these images using Mountains software.

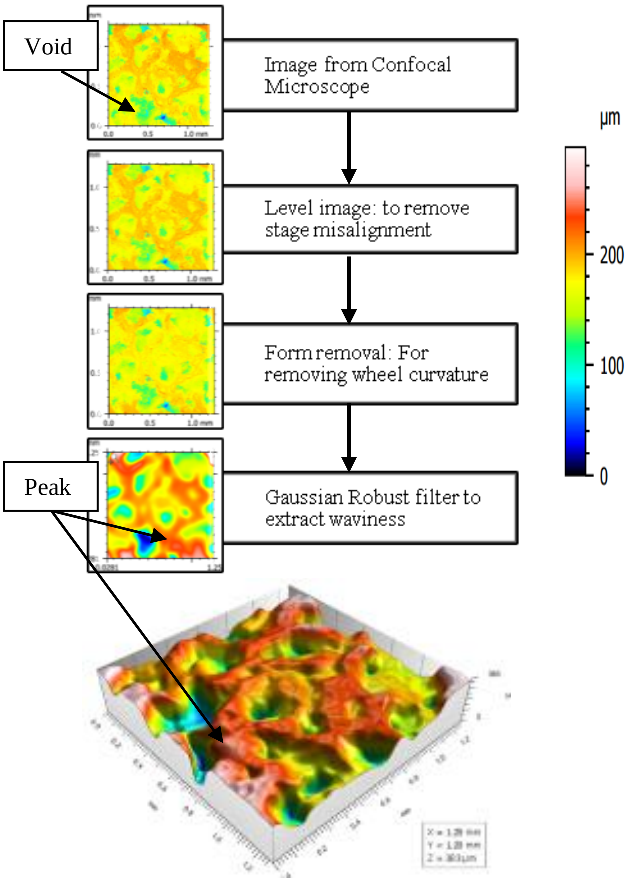

Fig. 4. Image operations before estimating Surface Parameters and 3D representation of topography

4. RESULTS AND DISCUSSION

4.1 S_{ds} vs Grinding Forces

From the results presented in Figure 5, it can be seen that S_{ds} has reduced with increasing number of grinding passes. Similarly forces have increased with increase in number of passes. The reduction in summit density with increase in grinding forces with increase in number of passes clearly shows that wheel has become blunt. Thus, this establishes a direct relation between summit density, S_{ds}, and grinding performance.

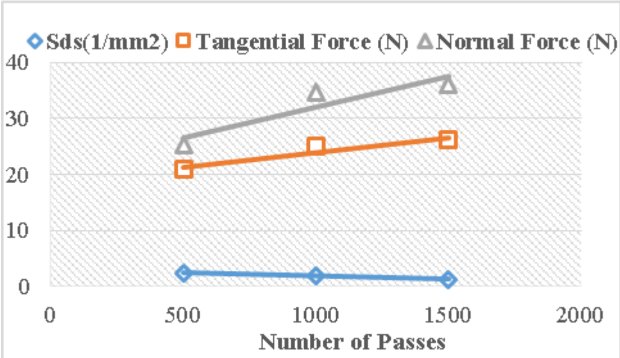

Fig. 5. Variation of Summit Density and Grinding Forces with number of passes

4.2 S_{ds} and Normalized Reduced Peak Height Area vs Specific Cutting Force and work piece surface finish

From the results presented in Figure 6, it can be seen that, with increasing number of passes, Normalized Reduced Peak height Area, along with S_{ds}, has reduced. With increasing number of passes, Specific Cutting Force shows an increasing trend. Roughness value, R_a, on work piece surface also increases with increasing number of passes. A reduction in Reduced Peak Height S_{pk} and Summit density S_{ds} with increase in Specific cutting force and work piece roughness value indicates a worn out wheel. Thus, these two parameters can be used as a measure to characterize grinding wheel topography and performance.

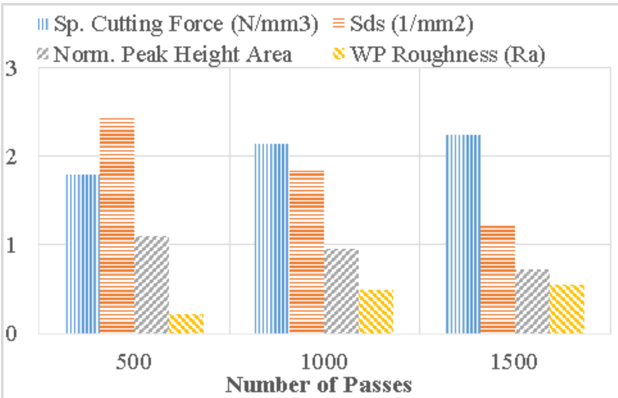

Fig. 6. Variation of Summit Density and Normalized Reduced Peak Height Area with Sp. Cutting Force and Work piece roughness

4.3 Abbot- Firestone Curve

Figure 7 presents a comparison of material ratio curve for three wheels used to remove 5mm, 10mm and 15mm total depth of cut from work piece respectively. The curve tends to become more flat as the wheel gets more and more worn out. This means reduced peak height parameter. It is interesting to note that with very less or almost no hill area in the curve, the wheel is blunt and hence the higher grinding forces stay justified.

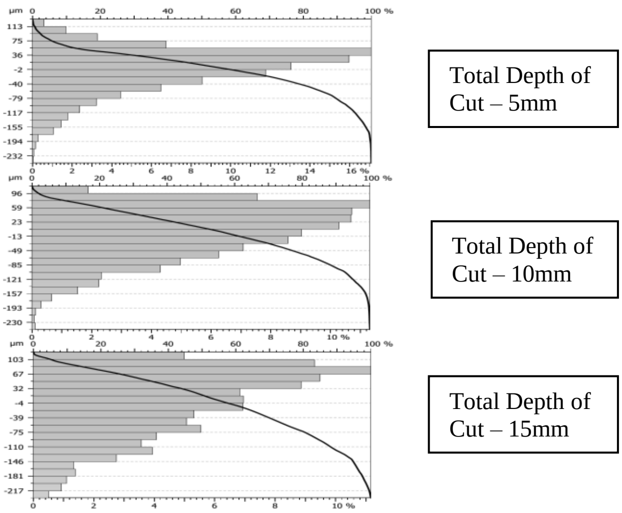

Fig. 7. Comparison of Material Ratio Curve for 3 wheels after grinding operation is performed.

5. CONCLUSIONS

The importance and effectiveness of 3-D parameters has been discussed. Grinding was carried out in order to capture and compare topography of 3 alumina wheels. Imaging is done using confocal microscopy which essentially images highly detailed 3-dimensional images. These images were further analyzed using imaging software. After processing and filtering out form and surface roughness, waviness is extracted and surface parameters are calculated. Reduced Peak Height Parameter, S_{pk}, is related to Normalized reduced peak height area. It gives a clear distinction between various phases of worn out wheel. The variation in Summit Density (S_{ds}) significantly corroborate the data. These variations in Surface parameters have been studied against the grinding performance for which specific cutting energy and work piece roughness were selected. The study clearly establishes a relation between selected surface parameters and grinding wheel performance.

References

[1] Klocke F., Manufacturing Processes, *Springer-RWTH Edition*, Aachen, Germany, 2008.

[2] Doman D A., Warkentin A., and Bauer R., A survey of recent grinding wheel topography models, *International Journal of Machine Tools and Manufacture*, **46** (2006) 343-352.

[3] Tönshoff H K., Modelling and simulation of grinding processes, *Annals of CIRP*, **41** (1992) 677-678.

[4] Liao T W., Fractal and DDS characterization of diamond wheel profiles, *Journal of Materials Processing Technology,* **53 (3-4)** (1995) 567-581.

[5] Koshy P., Jain V K., and Lal G K., A model for the topography of diamond grinding wheels, *Wear*, **169(2)** (1993) 237 – 242.

[6] Chen X., and Rowe W B., Analysis and simulation of grinding process. Part I: generation of grinding wheel surface, *International Journal of Machine Tools and Manufacture*, **36(8)** (1996) 871 – 882.

[7] Sathiamoorthy P., Radhakrishnan V., and Raman J F., *Precision Engineering,* **1(1)** (1979) 31-32.

[8] Nowicki B., and Jarkiewicz A., The in-process surface roughness measurement using fringe field capacitive FFC) method, *International Journal of Machine Tools and Manufacture*, **38(5-6)** (1998) 725 – 732.

[9] Stout K J., Sullivan P J., Dong W P., Mainsah E., Luo N., Mathia T., and Zahouani H., The developments of methods for the characterization of roughness in three dimensions, *Commission of European Communities*, Birmingham, UK, 1994.

[10] Blunt L., and Ebdon S., The application of three-dimensional surface measurement techniques to characterizing grinding wheel topography, *International Journal of Machine Tools and Manufacture,* **36(11)** (1995) 1207-1226.

[11] Butler D L., Blunt L A., See B K., Webster J A., and Stout K J., *Journal of Materials Processing Technology*, **127** (2002) 234-237.

[12] Nguyen A T., and Butler D L., Correlation of grinding wheel topography and grinding performance: A study from a viewpoint of three-dimensional surface characterization, *Journal of Materials Processing Technology,* **208** (2008) 14-23.

[13] Darafon A., Warkentin A., and Bauer R., Characterization of grinding wheel topography using white chromatic sensor, *International Journal of Machine Tools and Manufacture*, **70** (2013) 22-31.

[14] Tahvilian A M., Liu Z., Champliaud H., and Hazel B., Characterization of grinding wheel grain topography under different robotic grinding conditions using confocal microscope. *International Journal of Advanced Manufacturing Technology,* **80** (2015) 1159-1171.

[15] Weiß M., Klocke F., Barth S., Rasim M., and Mattfeld P., Detailed analysis and description of grinding wheel topographies, *Proceedings of the ASME: International Manufacturing Science and Engineering Conference,* 2015.

[16] Dong W P., Sullivan P J., and Stout K J., Comprehensive study of parameters for characterizing three-dimensional surface topography III: Parameters for characterizing amplitude and some functional properties. *Wear,* **178** (1994) 29-43.

[17] Dong W P., Sullivan P J., and Stout K J., Comprehensive study of parameters for characterizing three-dimensional surface topography IV: Parameters for characterizing spatial and hybrid properties. *Wear,* **178** (1994) 45-60.

[18] Franco L A., and Sinatora A., 3D Surface parameters (ISO 25178:2): Actual meaning of S_{pk} and its relationship to V_{mp}, *Precision Engineering,* **40** (2015), 106-111.