

THE THREE-DIMENSIONAL SURFACE TOPOGRAPHIC CHARACTERISATION OF CONVENTIONAL AND SUPERABRASIVE GRINDING WHEELS

David L. Butler¹, John A. Webster², Liam A. Blunt³, and Ken J. Stout³

¹ School of Mechanical and Production Engineering, Nanyang Technology University, Singapore

² Unicorn International, United Kingdom (formerly University of Connecticut, Storrs, CT, USA)

³ Faculty of Engineering, University of Huddersfield, United Kingdom

Introduction

The final surface topography of a grinding wheel is determined by the particular trueing and dressing conditions it is subjected to; although it is the dressing operation which imparts the fine scale surface features to the grinding wheel. The actual topography arises from the process of grit fracture and/ or bond fracture. The wheel topography and the grinding parameters affect the kinematic interactions between the abrasive grains and the workpiece. The wheel topography and the conditions under which it is prepared have a profound influence upon the grinding performance as evidenced by the grinding forces, power consumption, cutting zone temperatures and surface finish of the components. Clearly a detailed understanding of the nature of the surface of the grinding wheel would enable improved control of the grinding process in general.

The work presented in this paper is part of ongoing research aimed at comprehensively characterising the grinding wheel topography. Parametric analysis is provided by the three-dimensional characterisation suite developed at the University of Birmingham and by additional bearing area parameters more recently developed at the University of Huddersfield.

For the purpose of this paper only the density of summits parameter S_{ds} , which is analogous to G_{Astat} (the number of active static cutting grains), will be presented and discussed. A number of conventional and super abrasive wheels were subjected to different machining conditions after dressing. The wheel topography was measured using a 3-D contact instrument both after dressing and at the end of the test.

Wheel Characterisation

The cutting edges of a grinding wheel are geometrically undefined in location and shape. As a result, generalisations or estimations are difficult to make with any degree of accuracy. Thus it has been necessary to develop a number of techniques for examining the wheel topography in order to ascertain quantitative measurements of cutting edges. The techniques employed have included scanning electron microscopy, acoustic emission, thermocouples, and thin blade coupons, a review of the different methods has been carried out by CIRP [1].

In order to differentiate between the total number of cutting edges (static) and those that actually do the work (dynamic), Verkerk *et al* [1] proposed a number of parameters. In addition, it was suggested that on one grain there is often more than one cutting edge so it is necessary to differentiate between the grains and cutting edges. Finally, in order to separate the 2-D measurement (linear) from the aerial (3D) the report recommended the use of subscripts *L* and *A* for linear and aerial respectively. *Table 1* lists the complete parameter set.

	Cutting Edges			Cutting Grains		
Linear (1/mm)	C_{Lstat}	C_{Ldvn}	C_{Lkin}	G_{Lstat}	G_{Ldvn}	G_{Lkin}
Aerial (1/mm ²)	C_{Astat}	C_{Advn}	C_{Akin}	G_{Astat}	G_{Advn}	G_{Akin}

Table 1. Parameters for designation of grinding wheel topography

Machining Conditions

A number of machining tests were carried out on a surface grinding machine using conventional aluminium oxide wheels, *table 2* summarises the conditions.

Wheel	Code	Dresser feed rate (s_d) mm/rev	Nominal downfeed (a) microns	Number of passes
1	A60I8V	0.05	25	200
2	A60K5V	0.05	25	200
3	A60H8V	0.05	25	125

Table 2. Summary of machining conditions

In addition, an electroplated CBN wheel was also used which had been subjected to extensive grinding tests on Inconel 718 (the actual machining conditions are not relevant to this research) was also analysed.

Measurement Strategy

A three-dimensional profilometry technique first proposed for grinding wheel measurement by Blunt and Ebdon [2] was employed. The measurement sampling strategy was based on the need to pass over each grain at least three times in order for the algorithm to register a summit. For conventional wheels the average grain size (d_g) is obtained by employing the formula suggested by Malkin [3].

$$d_g \text{ (mm)} = 28 * M^{-1.1} \quad \text{Equation 1}$$

where M is the grit number of the wheel.

The optimum sample spacing (SS_{opt}) is achieved by employing the constraints given in *equation 2*.

$$\frac{d_g}{4} \quad SS_{opt} \quad \frac{d_g}{3} \quad \text{Equation 2}$$

By employing *equations 1* and *2* an optimum sample spacing for the conventional wheels of approximately 78 microns was chosen with a measurement area of 2mm by 2mm. For the superabrasive wheels a grit size of approximately 60 microns was used which resulted in an optimum sample spacing of 20 microns and a measurement area of 2mm by 2mm.

Analysis

Using the measurement conditions previously stated, each wheel was measured a number of times and analysed in terms of cutting grain density (c.g.d). For this analysis a cutting grain was defined as a peak on the three-dimensional map which protruded above a specified penetration level. The number of cutting grains was then analysed in terms of radial depth of penetration. This was achieved by truncating the surface map and counting the number of peaks intersecting the plane of truncation. A peak is defined, by convention, as a point in the data array which is higher than its eight nearest neighbours. The three-dimensional parameter S_{ds} [4] is indicative of the number of such peaks per mm^2 and can be used as a cumulative peak count. The values of G_{Astat} are related to the density of summits in such a way that G_{Astat} indicates the number of grains with the optimal sample spacing and therefore it can be assumed that $G_{Astat} = S_{ds}$.

Results

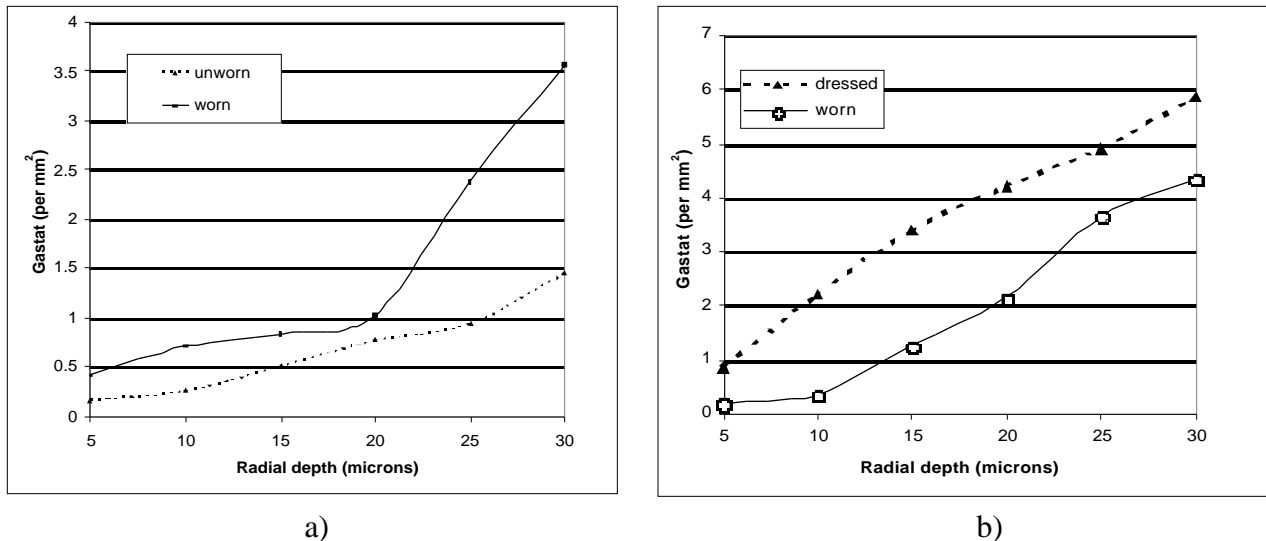


Figure 1. Graphs showing the variation in G_{Astat} against the radial depth of penetration for a) CBN and b) conventional wheels

Discussion

Both graphs (*figures 1a* and *1b*) show a general trend of the c.g.d increasing as the radial depth of truncation increases. This is because as the truncation depth increases, more grains are

exposed, thus the c.g.d increases. For the CBN wheels the G_{Astat} (*figure 1a*) is much lower for the unworn conditions (as would be expected) than for the worn wheel due to the reasons discussed in the following paragraph and illustrated in *figure 2a* and *2b*. For conventional wheels the results show (*figure 1b*) that the dressed wheels have a higher c.g.d than the worn wheels. This can be attributed to the wheel becoming dull with wear flats forming on the grains, furthermore, the gap between the grains may become filled with debris from the workpiece (a loading mechanism).

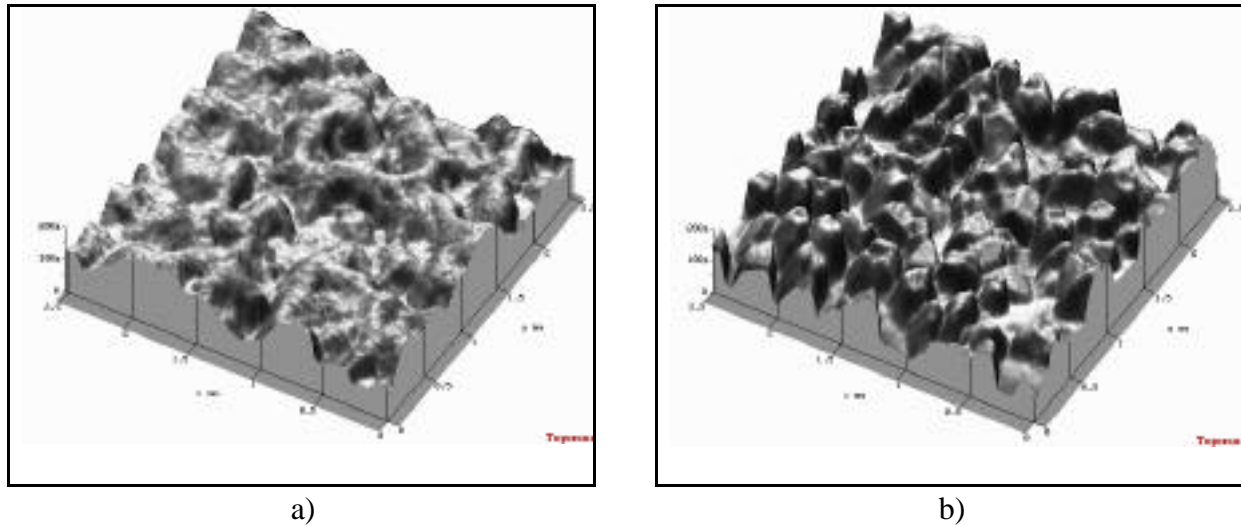


Figure 2. Axionometric plots of the electroplated CBN wheel a) unworn and b) after the removal of material from the workpiece

The unworn CBN wheel gives a lower G_{Astat} for the original (untruncated) surface ($S_{ds} = 16.5$) than after material removal has occurred ($S_{ds} = 22.1$). *Figure 2a* is an axionometric plot of the unworn wheel with very few grains clearly visible due to overplating. The G_{Astat} values for the untruncated wheel increase as the workpiece is ground. This could be attributed to the erosion of the bond material thereby exposing additional grains [3]. *Figure 2b* is a plot of the wheel after the wheel had been worn - it can be clearly seen that more cutting grains are now available and that some wear flats have developed due to attritious wear mechanisms.

Conclusion

- Three-dimensional stylus profilometry has been demonstrated to be a useful tool in evaluating the topographic characteristics of the grinding wheel to provide both a qualitative and quantitative meaning.
- The recently developed 3-D parameter S_{ds} has been shown to be analogous to G_{Astat} and is able to quantify the number of cutting grains per unit cm^2 .
- For the electroplated CBN wheel, more cutting grains become available after the wheel is worn – this has been demonstrated both visually and quantitatively while for conventional wheels the opposite is true as grains break off, wear flats develop, and debris makes grain identification more difficult.

References

- [1] J. Verkerk *et al*, *Final report concerning CIRP cooperative work on grinding wheel topography*. Ann. CIRP 26/2, 1975
- [2] L.Blunt and S.Ebdon, *The application of three-dimensional surface measurement technique to characterising grinding wheel topography*. Int. J. Mach Tools Manufact., Vol 36, no 11, pp 1207-1226, 1996
- [3] S.Malkin, *Grinding Technology; Theory and Applications of Machining with Abrasives*, Ellis Horwood, 1989
- [4] K.J. Stout *et al*, *The development of methods for the characterisation of roughness in three dimensions*, European Commission, ISBN 0-7044-13132 (1993)