Proceedings Paper:

Palmer, J., Curtis, D. orcid.org/0000-0001-6402-6996, Novovic, D. et al. (1 more author) (2018) The influence of abrasive grit morphology on wheel topography and grinding performance. In: Monostori, L., Stepan, G. and Bachrathy, D., (eds.) Procedia CIRP. 8th CIRP Conference on High Performance Cutting (HPC 2018), 25-27 Jun 2018, Budapest, Hungary. Elsevier , pp. 239-242.

https://doi.org/10.1016/j.procir.2018.09.005

Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 77 (2018) 239–242

www.elsevier.com/locate/procedia

8th CIRP Conference on High Performance Cutting (HPC 2018)

The Influence of Abrasive Grit Morphology on Wheel Topography and Grinding Performance

Jack Palmer[a,d*], David Curtis[b], Donka Novovic[c], Hassan Ghadbeigi[a]

[a]*Department of Mechanical Engineering, University of Sheffield, Sheffield, S1 3JD, UK*
[b]*Advanced Manufacturing Research Centre with Boeing, University of Sheffield, Rotherham S60 5TZ, UK*

[c]*Rolls-Royce plc, PO Box 31 Derby DE24 8BJ, UK*

[d]*Industrial Doctorate Centre in Machining Science, Advanced Manufacturing Research Centre with Boeing, University of Sheffield, Rotherham S60 5TZ, UK*

* Corresponding author. Tel.: +44-0114-215-8042; *E-mail address:* jack.palmer@amrc.co.uk

Abstract

Understanding and controlling the topography of an abrasive, vitreous-bonded grinding wheel is important for optimising performance of the grinding process used to machine advanced aerospace materials. The dressing process plays a critical role in ensuring grinding wheel form and topography is achieved prior to grinding, however the mechanisms of roller dressing for advanced engineered grit morphologies is not well understood. In this investigation, the impact of different dressing parameters on the topography of two vitreous-bonded abrasive wheels with engineered grit morphologies and resulting grinding performance was assessed and compared to a grinding wheel with conventional 'random' grit morphology. Continuous dressing grinding cuts were performed under a range of dressing parameters (two different infeed rates and three speed ratios) to determine the impact of dressing condition on grit fracturing and influence of resulting varying wheel topographies, whilst controlling wheel breakdown (wheel self-sharpening during grinding cuts). Constant grinding parameters were used for all grinding cuts and power consumption was monitored during the process. The generated grinding wheel surface morphology was characterised by using a range of surface roughness/topography parameters. In line with previous studies for conventional grit morphologies, results for all three wheel morphologies studied show that under aggressive dressing conditions grinding power is reduced, but so is ground surface quality. Scanning Electron Microscopy imaging of abrasive wheel sections revealed changing grit fracture mechanisms under different dressing parameters. Significant variation in dressing response between conventional and engineered grit morphologies was also observed. This work aims to enhance the fundamental understanding of the relationship between wheel topography and grinding performance using experimental data, and could influence dressing strategies used in industry.

Keywords: Grinding; Dressing; Topography; Grit shape

1. Introduction

The grinding process consists of the removal of workpiece material by contact with the abrasive grits (topography) of a grinding wheel. Therefore understanding and controlling the influence of this topography is vital to optimise component grinding by reducing consumable costs and process cycle times. Typically industrial grinding processes use grinding wheels with alumina (Al_2O_3) grits which are held together with a vitreous bond. The topography of these wheels is then controlled by dressing the wheel with a metal roller with a single layer of diamond particles impregnated into the surface (roller dressing).

There are three key parameters in dressing that control the topography of a grinding wheel, infeed rate, speed ratio and rotational direction [1]. Malkin and Murray [2] found that

10.1016/j.procir.2018.09.005

specific dressing energy is reduced by increasing the infeed rate due to a larger interference angle causing greater fracture of the abrasive grits. Finite element modelling of bonded wheel dressing by Klocke and Linke [3] indicated that high dressing forces weakens the wheel bonding and leads to increased grit breakout and wheel wear. Further wheel topography modelling work as a result of dressing has been conducted by Baseri et al. [4]. Work by Palmer et al. [5] indicated the influence of different dressing parameters on the topography of abrasive grinding wheels demonstrating that wheel roughness and peak density increase and decrease respectively, as the dressing power increases.

It is well known that wheel topography influences grinding performance and the influence of dressing conditions on grinding performance has been well studied. Research by Jiang et al. [6] created a workpiece topography model that accounted for dressing parameters, demonstrating the impact of dressing lead on grinding process quality. Saad et al. [7] also generated workpiece surface models which shows the relationship of interference angle on surface roughness. Shi et al. [8] performed surface grinding with a vitrified Cubic Boron Nitride grit wheel and showed that increasing speed ratio and dressing depth reduced grinding power and increased surface roughness. Baseri [9], [10] also found that increasing the speed ratio reduced the tangential force during grinding whilst increasing surface roughness with an alumina wheel.

Although the importance and effects of dressing in the grinding process is relatively well studied the significance of the abrasive grit morphology is not thoroughly investigated. Most literature focuses on conventional abrasive grit shapes (random, assumed to be approximately spherical), but with the advent of new, engineered grit morphologies there is increased demand to further understand topography behaviour.

Aims of this research were to understand the influence of dressing engineered grains and how it impacts the performance of an abrasive wheel compared to conventional abrasive. This was achieved by conducting continuous dressing grinding (to remove wheel wear effects) on Ni-superalloy workpieces. The power consumption and produced surface roughness were measured for the conducted experiments and scanning electron microscopy performed on the wheels to determine sharpening mechanisms.

2. Experimental Design

Three different vitreous-bonded, alumina abrasive grinding wheels (A, B and C) were tested over two dressing infeed rates (0.0005 mm/rev and 0.002 mm/rev) and three speed ratios (-0.8, 0.4 and 0.8) in a full factorial experimental design. Each wheel had a medium porosity and manufacturers hardness grade H. They all consisted of grain sizes designed to give comparable performance to a fine #80 grit mesh size of conventional abrasive. The controlled variable was the abrasive grit morphology (see Fig. 1 with grit shapes of spheres, triangles and elongated grains respectively).

All grinding cuts were performed using a continuous dressing process ensuring that any wheel wear effects were removed. An initial continuously dressed grinding pass was performed in close proximity to the workpiece (using the dressing conditions determined by the factorial experimental design) in order to record background power consumption due to dressing and coolant application. This was followed by a grinding cut (using the same dressing conditions) in which workpiece material (Ni-superalloy CMSX-4) was removed and grinding spindle power consumption measured. Net power consumption was determined by removing the background power from the measured in-cut power. The process was then repeated under new dressing conditions. Grinding parameters were kept constant throughout at a mid-point between typical roughing and finishing conditions. Every grinding cut was repeated to increase the reliability of the data.

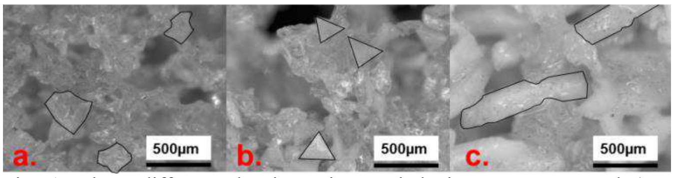

Fig. 1. Three different abrasive grit morphologies were compared (a - conventional, spherical grits, b – mixture of triangular engineered and conventional grits, c – 100% engineered, elongated grits).

Experimental grinding trials were conducted on a Makino A100 universal horizontal machining centre using the 5-axis VIPER grinding capability. The coolant was standard Hocut 768 (at a percentage of 6-8% and a pH of 8.5-9.5) applied during ahead of the cut at a pressure of 70 bar using a hook-in nozzle at 70° from the point of contact between the wheel and the workpiece. This was the only coolant source in the process.

After grinding, the surface roughness of every generated surface was measured using an optical focus variation microscope (Alicona InfiniteFocusSL). Each roughness measurement was conducted across the cutting direction (greatest height variation), for a minimum length of 4mm (as according to EN ISO 4287 & 4288) at 5 different positions along the length of the cut. The 5 measurements were averaged to give a final surface roughness reading for the cut.

Each abrasive wheel was also dressed at the extreme conditions (0.002 mm/rev infeed 0.8 speed ratio and 0.0005 mm/rev infeed -0.8 speed ratio) and examined under a Scanning Electron Microscope (SEM) to assess the fracture mechanisms of the different grit morphologies. Small sections were taken from each wheel, mounted and gold coated to enable imaging.

3. Results and Discussion

The results in Fig. 2 show the grinding spindle net power consumption (power during CD grinding – power during CD grinding without removing workpiece material).

There is a clear difference in the power for the different dressing infeed rates with the higher infeed rate (0.002 mm/rev) causing a reduction in the grinding power compared the low infeed rate (0.0005 mm/rev). This could be due to the higher infeed having a larger ‘crushing’ effect on the abrasive wheel. It has been shown in literature that crush dressing generates very aggressive wheel topographies [11] therefore when crushing is increased a more coarse topography is generated. This is because of increased fracturing of abrasive grains and the bond that generates sharp, cutting points (low negative rake angle) that cut the workpiece material rather than rubbing or ploughing.

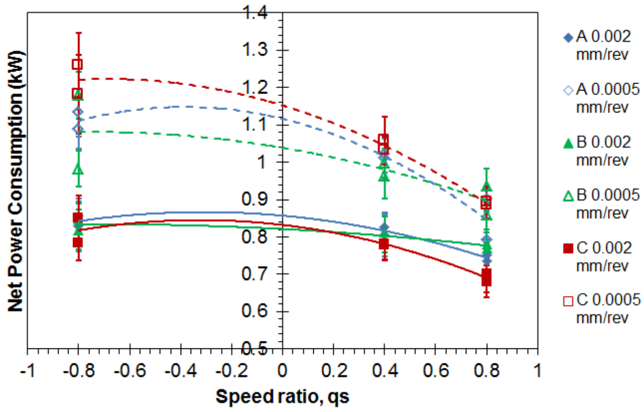

Fig. 2. Net power consumption of abrasive wheel spindle during grinding.

Not only this but a higher infeed rate results in a steeper interference angle (angle of the trochoidal path of a diamond on the dresser relative to the grinding wheel edge [2]). Therefore the forces from the collisions between the abrasive grains and the dresser diamonds impact deeper into the wheel causing fracturing that creates sharp cutting points. The variation in the power for low infeed rates is much higher compared to the higher infeed. This suggests that when crush dressing effects are reduced, the speed ratio becomes more influential at lower infeed rates (steeper interference angle).

A general linear model was constructed using the data in Fig. 2 and showed that despite a similar response between wheel types the influence of grit morphology is significant. Wheel B (triangular grits) demonstrated the least variation, potentially due to its micro-fracturing capability, as shown in Fig. 4c–d.

The results in Fig. 3 demonstrate the measured surface roughness of the ground surface as a function of the measured net power consumption.

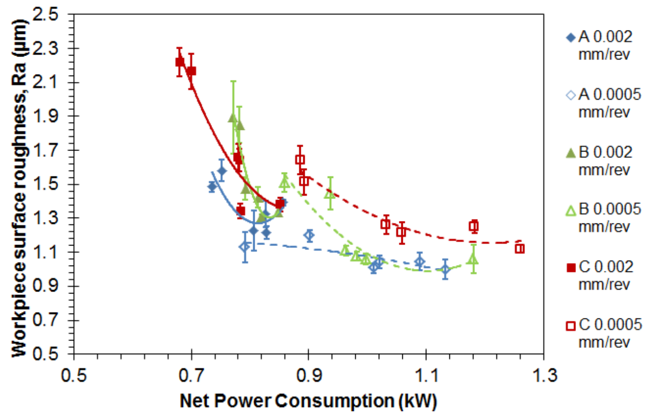

Fig. 3. Workpiece surface roughness as a function of net power consumption.

As can be seen in Fig. 3, the surface roughness variation is reduced for the low infeed rate compared to the high infeed rate. This is due to the dulling of the cutting edges on the wheel. As demonstrated in work by Palmer et al. [5], at low infeed rates there is diminished change in the topography of a grinding wheel over a range of speed ratios. The topography is also duller, resulting in less number of active cutting grits that leads to increased ploughing and rubbing action on the surface of the workpiece material and producing a lower surface roughness. The generated surfaces are rougher for high infeed rates as the interference angle of the dresser diamonds on the abrasive wheel is steeper causing grit fracture and generating sharp cutting points [2].

It is clear that wheel C generated the roughest workpiece surface. As the abrasive grains are large and elongated, the protruding grains can penetrate deeper into the workpiece surface. This creates deeper cut channels on the surface, increasing the surface roughness. This was consistent for both 0.002 mm/rev and 0.0005 mm/rev infeed rates. Wheel A showed a different rate of change in the surface roughness over a net power consumption change between the infeed rates. This could be due to a different dressing mechanism in each condition. Under less aggressive dressing parameters (low infeed rate, low speed ratio), the collisions between the dresser diamonds and the abrasive grits are of low velocity. Therefore macro-fracturing and whole grain pull out is limited and micro-fracturing of the grains (see Fig. 4) dominates. This means the number of cutting points per unit area is high, therefore undeformed chip thickness is very low (as shown by the equation from Malkin & Guo [12]) hence surface roughness is reduced. As the dressing becomes more aggressive (high infeed rates, high speed ratios) the dresser diamond-abrasive grit collision velocities and forces increase and so there is increased macro fracture of the grits as well as whole-grain pull out [13]. This creates well-spaced, sharper cutting points [5], so greater undeformed chip thickness and a higher surface roughness. Less cutting points also reduces the grinding power, as shown by Chen et al. [14]. However, for wheel B, due to the triangular grits, microfracturing increases with macrofracturing in aggressive dressing conditions. Therefore although the cutting points are shaper, the total number of points does not change as much as wheel A. Hence for wheel B there is a large variation in surface roughness over a very small power difference (see Fig. 4 c-d).

Fig. 4 demonstrates the influence of dressing extremes from very aggressive (0.002 mm/rev, 0.8 qs) to gentle (0.0005 mm/rev, -0.8 qs) conditions. Extensive whole grain fracture with macro-cracks were observed for wheel A under aggressive dressing conditions, as highlighted in Fig. 4a. the interference angle in the less aggressive dressing condition is 36 times shallower than the former condition when it is calculated using equation by Murray & Malkin [2]. This results in the formation of more flat regions by fracturing protruding cutting points in a ‘skimming’ effect, as highlighted by Fig. 4b.

There is also evidence of macro-fracturing of the abrasive grits, including the engineered grains, in wheel B under aggressive conditions (high net power consumption). This leads to the formation of sharp cutting points that generate a rough surface. There is also substantial microfracturing on the tips of the engineered triangular grits (highlighted in Fig. 4c), explaining the substantial surface roughness changes over a small net power difference. Gentle dressing parameters however result in very little fracturing as most of the visible engineered grains have retained their triangular shape (Fig. 4d). This suggests that most fracturing occurs in the conventional grains in wheel B when the dressing conditions are not very aggressive, and supports the theory of a different dressing mechanism between wheels A and B. For wheel C, in aggressive dressing conditions (Fig. 4e), the interference angle is steep (36 times steeper than the gentle dressing conditions) and so the elongated grains fracture in a way that generates sharp cutting points, as shown in the encircled region of Fig. 4e. The interference angle is reduced under gentle dressing which produces grits with much duller peaks (Fig. 4f). Hence generating a machined workpiece with an average 46% lower surface roughness.

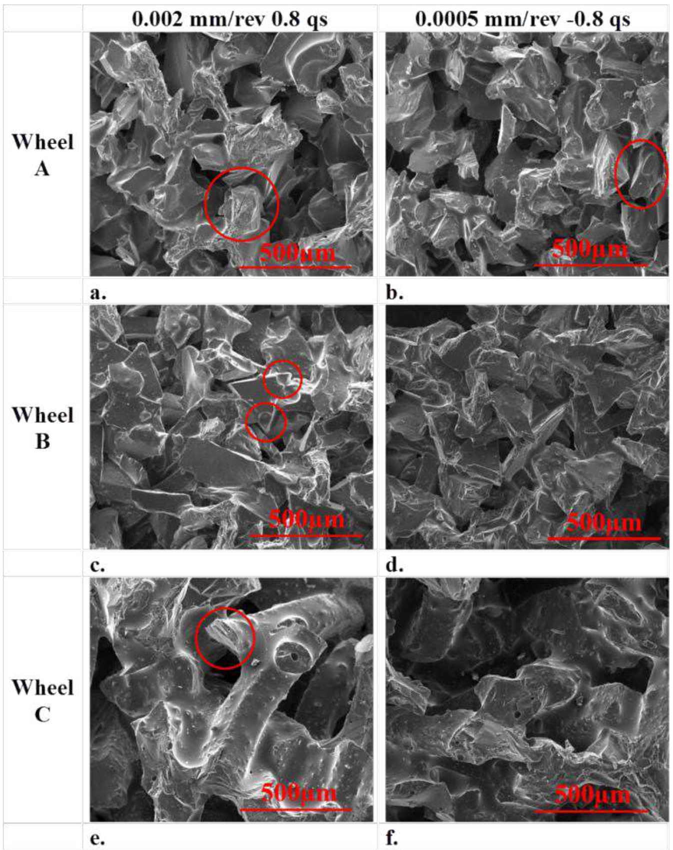

Fig. 4. SEM. Images of each abrasive wheel dressed under different parameters.

4. Conclusions

This research investigated the grinding performance of different abrasive grit morphologies and assessed the difference in response under various roller dressing parameters. The conclusions that can be drawn are:

- The lowest grinding power and highest workpiece surface roughness is achieved under high dressing infeed rates and high, synchronous speed ratios for all wheel morphologies. The high interference angle causes macro-fracturing of the abrasive grits and generates sharp cutting points due to the steep angle of approach.
- The infeed rate is the most influential dressing parameter for all abrasive grit morphologies. The higher the infeed rate the greater the crush dressing effects of the dressing process resulting in increased grain and bond fracture.
- Elongated abrasive grits generated the roughest workpiece surface roughness due to the large grain size increasing the penetration depth. Wheel B containing the triangular grits showed the most workpiece surface variation over the grinding power range suggesting a change in the dressed topography due to different dressing mechanisms becoming more dominant.

Acknowledgements

All work was supported by Rolls-Royce and EPSRC (grant EP/I01800X/1).

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