An Experimental Study for Lowering Surface Roughness in Grinding with Electroplated Superabrasive Wheels

Zhongde Shi[1,a*], Mouhab Meshreki[1,b], Jean-Michel Lamarre[2,c], Helmi Attia[1,d], and Maniya Aghasibeig[2,e]

[1]Aerospace Manufacturing Technology Center
National Research Council Canada,
5145 Avenue Decelles, Montreal, Quebec, H3T 2B2, Canada

[2]Automotive and Surface Transportation Research Center
National Research Council Canada,
75 Boulevard de Mortagne, Boucherville, Quebec, J4B 6Y4, Canada

[a]zhongde.shi@nrc.ca, [b]mouhab.meshreki@nrc.ca,
[c]jean-michel.lamarre@nrc.ca, [d]helmi.attia@nrc.ca, Maniya Aghasibeig@nrc.ca[e]
* Corresponding author

Keywords: Surface roughness, grinding, superabrasive grinding, electroplated wheel, wheel orientation, chromium carbide coating.

Abstract. This paper presents an experimental investigation for lowering surface roughness, or improving surface finish, in grinding with electroplated superabrasive wheels. The objective is to explore and evaluate a different grinding approach for lowering ground surface roughness other than the selections of grinding parameters and abrasive grain sizes. The approach is to orientate the wheel at an angle between the wheel speed and workspeed instead of aligning the two speeds as commonly used. Surface grinding experiments were conducted on chromium carbide HVOF-coated on flat surfaces of steel blocks with electroplated diamond wheels of diameter d_s = 101.6 and 9.5 mm. It was found that the orientation angle has a significant effect on lowering surface roughness. Under the tested conditions, the surface roughness was lowered effectively from R_a = 0.78 down to 0.30 μm by increasing the orientation angle from 0 to 60° in grinding with the 101.6 mm diameter wheel. The surface roughness was even lowered from R_a = 2.83 down to 0.32 μm at an orientation angle of 90° while grinding with the ball end of the 9.5 mm diameter wheel. The effects of spark-out grinding passes on surface roughness were also investigated with the large wheel for different workspeeds. It was revealed that the effectiveness of spark-out passes in lowering surface roughness increases with workspeeds.

Introduction

Electroplated superabrasive wheels, either diamond or cubic boron nitride (CBN), contain a single layer of superabrasive grains held on the wheel core by an electroplated nickel bond. These wheels are becoming widely used in aerospace, automotive, and mold/die industries [1]. Unlike resin-bonded or vitrified wheels, the topography of electroplated superabrasive wheels is not restored by periodic truing or dressing, which leads to transient nature of grinding performance. The grinding performance varies significantly as the electroplated wheel wears down [1 - 3].

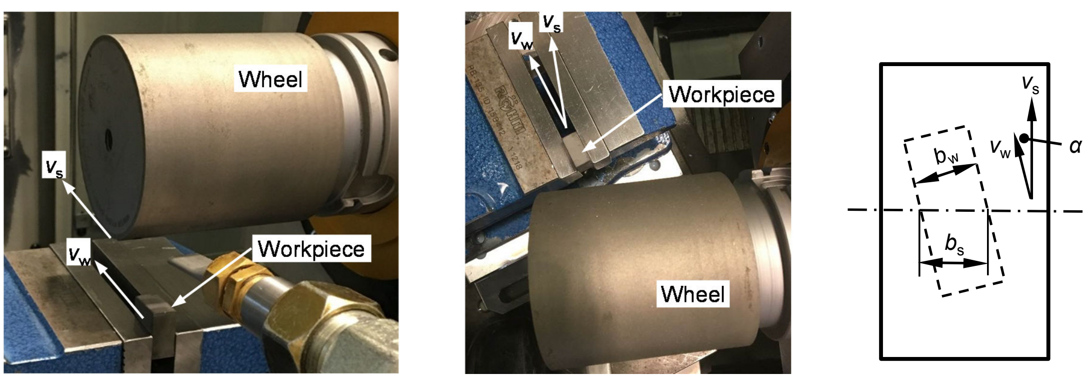
Surface roughness is one of the important parameters of grinding operations and ground surface quality. For grinding with resin-bonded or vitrified wheels, lower surface roughness can be obtained by applying finer wheel dressing conditions. Compared with dressing conditions, the size of abrasive grains has much less effects on surface roughness. For grinding with electroplated wheels, the surface roughness, however, was dominated mainly and affected significantly by the grain sizes since the wheels are not dressed periodically. It was also found that surface roughness produced in superabrasive grinding with all types of wheel bonds, resin-bonded, vitrified, or electroplated, is not very sensitive to grinding parameters of wheel speed, workspeed, and depth of cut due to the extreme wear resistance of superabrasive grains [4].

Wheel life of electroplated wheels is closely related to the grain size. Coarser grains provide a thicker electroplated abrasive layer and hence a longer wheel life than finer ones. Extending wheel life by the usage of coarser grains, however, is limited by increased surface roughness. As noted above, coarser grains lead to higher surface roughness and the surface roughness cannot be improved significantly by adjusting grinding parameters. Therefore, it is of importance to investigate how to reduce surface roughness other than by adjusting grinding parameters. The solution will allow the usage of coarser grains for achieving reduced surface roughness without compromising the wheel life.

The present investigation was undertaken to explore a different grinding approach to improving the surface roughness in grinding with electroplated superabrasive wheels. This paper presents the approach and its application in grinding chromium carbide coatings with electroplated diamond wheels.

Description of Approach

The approach is illustrated in Fig. 1 through an example of flat surface grinding operations with a cylindrical grinding wheel. For comparison purpose, the commonly used conventional approach is also included in the figure. In the conventional approach as shown in Fig. 1 (a), the wheel speed v_s is aligned with the workspeed v_w. Depending on the grinding mode, up or down grinding, the wheel speed and workspeed are opposite to each other or in the same direction. In the approach studied in this paper, the wheel speed and workspeed form an angle or the wheel speed is orientated at an angle to the workspeed as illustrated in Fig. 1 (b). Such a configuration and the corresponding grinding kinematics can be easily realized with multi-axis NC grinding machines.



(a) v_s aligned with v_w (b) v_s orientated at an angle to v_w (c) b_s versus b_w

Fig. 1 Relationship between the directions of wheel speed and workspeed

The idea of reducing surface roughness by orientating the wheel speed at an angle to the workspeed was motivated by increasing the number of cutting edges per unit grinding width, or packing density, of the workpiece. It has been well realized that increasing the packing density has a significant smoothing effect on ground surfaces [4]. The cutting edge density applies to resin-bonded or vitrified wheels. For electroplated superabrasive wheels, the grain packing density, instead of cutting edge density, is used since such wheels are not dressed. The effect of wheel orientation on the packing density can be explained by the relationship between the grinding width of the workpiece b_w and the corresponding wheel width b_s. As shown in Fig.

1 (c), the width b_s is larger than b_w ($b_w = b_s / \cos\alpha$) due to the orientation angle α. This means that more grains distributed within the b_s take the cutting actions and generate the ground surface with the wheel speed orientated at an angle than aligned with the workspeed for grinding the same workpiece width b_w. This leads to increased packing density and hence smoother ground surfaces of the approach.

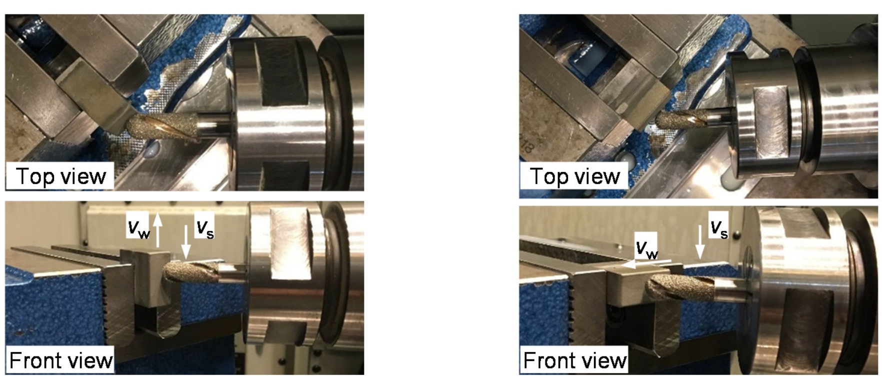
Experiments

The workpieces were rectangular AlSI 1538 steel blocks of 12.7×25.4×25.4 mm^3. One of the 12.7×25.4 mm^2 surfaces of each block was coated with a layer of chromium carbide of about 0.4 mm thick and hardness of HRC55. Coatings were deposited using a Diamond Jet HVOF (high-velocity oxy-fuel) torch and Woka 7102 (Cr_3C_2-20(Ni20Cr)) powder both from Oerlikon-Metco. Hydrogen was used as the fuel gas and a 3 to 1.75 to 1 hydrogen to air to oxygen ratio was maintained during the process. A spray distance of 20 cm and a robot movement speed of 760 mm/s were used.

Grinding experiments were conducted on a Makino A88E high-speed (18,000 rpm) and high-power (50 kW) 5-axis machining center. Two electroplated diamond wheels were used. One wheel had a diameter of d_s = 101.6 mm and was electroplated with 270-grit (nominal grain diameter d_g = 54 μm) blocky mono-crystal synthetic diamond grains. The other wheel was a ball-end grinding wheel of d_s = 9.5 mm with 100-grit (d_g = 151 μm) grains of the same type diamond.

The wheels and workpiece materials were selected for applications in grinding chromium carbide coatings of mold for high pressure die casting of aluminum components. The large wheel was used for grinding surfaces without constraints of accessibility. Finer 270-grit diamond grains were selected for this wheel in order to obtain lower surface roughness. The small wheel was used for grinding fillet surfaces with the ball-end. Coarser 100-grit diamond grains were used to compensate for the shorter life due to the smaller diameter of the wheel. A 7% solution of soluble oil was used as the grinding fluid.

The setup pictures with the larger wheel were the same ones as given in Fig. 1. The pictures with the small wheel are presented in Fig. 2. The grinding was conducted with the ball-end of the wheel. Fig. 2 (a) shows the configuration with the wheel speed and workspeed aligned, and Fig. 2 (b) shows the configuration at a 90° orientation, in which the wheel speed is normal to the workspeed. In both configurations, the wheel axis was inclined and formed a 45° angle with the ground surface to avoid grinding with the tool tip where the wheel speed was zero.



(a) v_s aligned with v_w (b) v_s perpendicular to v_w

Fig. 2 Setup pictures of the small wheel

The tests with the large wheel were conducted at a wheel speed v_s = 30 m/s, and workspeeds v_w = 20 – 160 mm/s. The wheel orientation angle was varied from 0 to 60°. For the tests with the small wheel, the wheel speed was v_s = 8 m/s, workspeed v_w = 20 mm/s, and wheel orientation angle α = 0 and 90°. The depth of cut was fixed at a = 0.01 mm in all the tests. Surface roughness R_a was measured across grinding passes for all the tests. The curved surfaces ground with the ball-end of the small wheel were also observed with a microscope.

Results and Discussions

The effects of workspeed on surface roughness R_a for grinding with the large wheel is presented in Fig. 3, showing the surface roughness measured following the grinding pass and the 3rd spark-out pass of each test condition. It can be seen from this figure that the surface roughness decreased slightly from about R_a = 0.78 down to 0.75 µm for a wide range of v_w = 20 to 160 mm/s. This was consistent with previous findings [4] and further confirmed that the surface roughness was not sensitive to grinding parameters with superabrasive wheels. This figure also shows that the spark-out pass had a smoothing effect on ground surfaces and the effects increased with increasing workspeed.

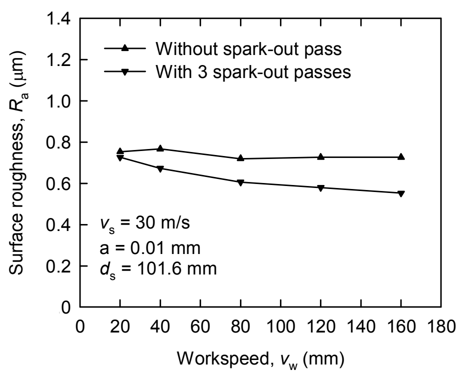


Fig. 3 Effects of workspeed on R_a

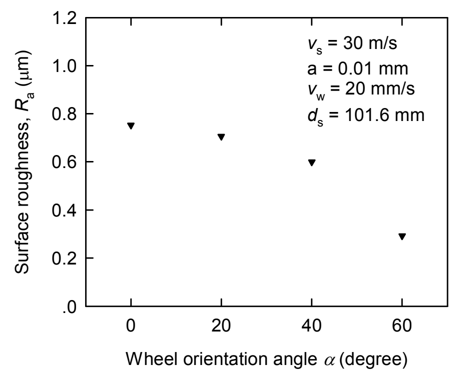
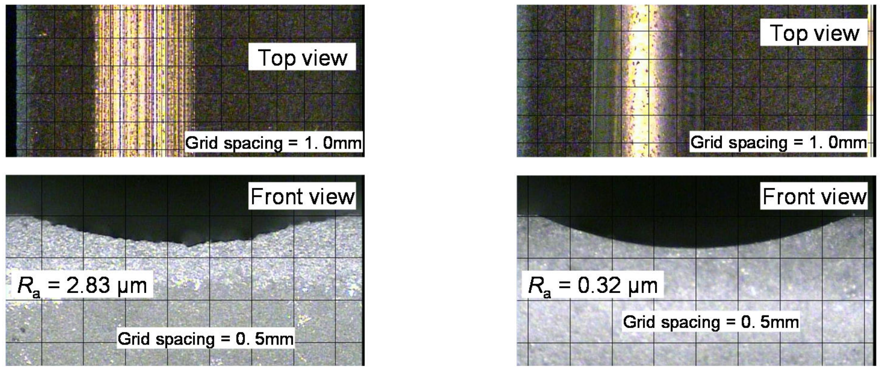


Fig. 4 Effects of orientation angle on R_a

The results of surface roughness versus wheel orientation angle are summarized in Fig. 4 for the workspeed v_w = 20 mm/s. The R_a was for the grinding passes. Surface roughness decreased from about R_a = 0.78 down to 0.30 µm with an increasing rate when the orientation angle was increased from 0 to 60°. This was expected as discussed above for the effect of wheel orientation on grain packing density. Such a low surface roughness R_a = 0.30 µm has never been reported for conventional grinding approaches with electroplated wheels. It is worth noting that the surface roughness decreased faster with the orientation angle. This trend is consistent with that of the cosine value of the orientation angle. The faster decrease of cosine of the angle might lead to the faster increase of the b_s, the grain density, and the faster decrease of surface roughness.

The surface roughness obtained with the small wheel was R_a = 2.83 µm when the wheel speed and the workspeed were aligned. After the wheel was orientated at an angle of 90°, the R_a was reduced down to 0.32 µm, representing an 89% improvement. It should be noted that 100-grit diamond grains were used for the small wheel and 270-grit for the large wheel. But the surface roughness produced with the small wheel at the 90° orientation angle was much lower than that obtained with the large wheel without wheel orientation. This implies that diamond grains much finer than 270-grit would be needed for producing R_a = 0.32 µm without wheel orientating.

The microscopic pictures of the grooves ground with the ball end of the small wheel are presented in Fig. 5. The front view pictures were taken on the workpiece end surfaces along the workspeed direction and the top view pictures normal to the ground surfaces. Please note that different magnifications were used for the top view and front view pictures. A lower magnification was used in order to get a better focus of grooves for the top view. The smoothing effect by orientating the wheel at an angle can be seen from the ground surfaces. Grinding scratches are clearly seen in Fig. 5 (a). The surface shown in Fig. 5 (b) is much smoother.



(a) v_s aligned with v_w (b) v_s perpendicular to v_w

Fig. 5 Microscopic pictures of ground grooves

Concluding Remarks

Orientating grinding wheel at angle between the wheel speed and workspeed for lowering surface roughness was discussed and experimentally investigated. It was found that the orientation angle has a significant effect on lowering surface roughness. The surface roughness decreases at an increasing rate with orientation angle. Surface roughness was reduced from R_a = 0.78 down to 0.30 μm, or a 60% improvement by applying a 60° orientation in flat surface grinding tests. The surface roughness was even lowered from R_a = 2.83 down to 0.32 μm at 90° orientation. It is obvious from the discussion that the effectiveness of the approach is not restricted to specific workpiece materials and types of grinding wheels although the experiments were carried out on carbide coatings with electroplated diamond wheels. The approach, however, is more useful for electroplated wheels since these wheels cannot be dressed for surface roughness improvements.

Acknowledgments

The authors would like to acknowledge the National Research Council Canada for funding this investigation and allowing us to publish this paper.

References

[1] Z. Shi, and S. Malkin. An Investigation of Grinding with Electroplated CBN Wheels. Annals of the CIRP 2003, Vol. 52(1), p. 267-270.

[2] R. P. Upadhyaya, and S. Malkin. Thermal Aspects of Grinding with Electroplated CBN Wheels. ASME J. of Manufacturing Science and Engineering 2004, Vol. 126, p. 107-114.

[3] T. W. Hwang, C. J. Evans, and S. Malkin. High Speed Grinding of Silicon Nitride with Electroplated Diamond Wheels, Parts I and II. ASME Journal of Manufacturing Science and Engineering 2000, Vol. 122, p. 32-50.

[4] S. Malkin: *Grinding Technology*: *Theory and Applications of Machining with Abrasives.* Ellis Horwood Ltd, Chichester, and John Wiley & Sons, New York, (1989).