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A Note on Two Cooling Methods in Surface Grinding

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Abstract. This paper reviews two cooling methods for surface grinding. These include i) replacing the toxic coolant by a mixture of cold air and vegetable oil mist, and ii) minimising the use of coolant using a segmented grinding wheel system. The discussion concludes that the cold air-oil mist provides an environmentally conscious mean for surface grinding. However, due to the limit of its cooling capacity, it is more applicable for fine grinding. Using the segmented wheel system can minimise coolant consumption and can improve grindability.

Introduction

Precision grinding uses coolant that contains toxic and expensive additives. There have been investigations aiming to reduce coolant consumptions by designing nozzles that could focus coolant more accurately on a grinding zone [1]. However, the escape of coolant due to the high spinning speed of a wheel is typically at the rate of more than 90% of the total coolant quantity applied. This has made it difficult to reduce the quantity of coolant usage [2] when the surface integrity of a ground component is essential. Focusing the coolant jet makes little difference to the rate of coolant wastage. Another approach is to reduce the penetration of the grinding heating to the workpiece by using super-abrasives which have higher thermal conductivities. Diamond abrasives, in spite of their extreme hardness, are not suitable for grinding ferrous metals, because of their excessive wear caused by the chemical affinity between diamond and iron [3]. Feasible solutions will need a different approach. This paper reviews two cooling methods for less coolant consumption.

Application of mixture of cold air and vegetable oil mist

Experiment. A cold air-oil mist (CAOM) system was installed on a CNC surface grinder, as shown in Fig. 1. Compressed air (600kPa) was ejected through a vortex tube (Exair 3299) to generate cold air at -20^{o}C. To provide lubrication, olive oil mist at a small rate of 0.16cc/min generated from an atomiser was impinged onto the grinding point. For comparison, other cooling methods were also conducted, which were the uses of Noritake SA-02 coolant (concentration of 1:60), atmospheric dry air, and cold air at -20^{o}C. The grinding was conducted on 1045 steel with the wheel speed of 23m/s and table speed of 400mm/min.

Grindability. The use of cold air enabled the elimination of burning that occurred under dry air at the depth of cut of 10μm (Fig. 2a). Grinding with cold air provided good surface quality, comparable to that with Noritake SA-02 coolant (Figs. 2b and 2d). When the depth of cut became higher, 20 μm, however, cold air could not prevent the workpiece from surface burning. Unlike grinding with coolant where a large quantity of grinding heat could be carried away by liquid flow, the cooling by cold air is limited by its penetration into the grinding zone and by the low heat transfer capacity of air [4]. By adding a very small amount of vegetable oil in the cold air stream, it allowed higher depths of cut up to 20 μm to be ground. Chips were formed in the lamellar and leafy shapes (Fig. 2f), indicating a predominance of shearing in the chip formation. However, due to the poor cleaning capacity of the air stream, cutting could be disrupted due to the presence of the residual particle/chips (Fig. 2(e)), thus down-grading the surface finish.

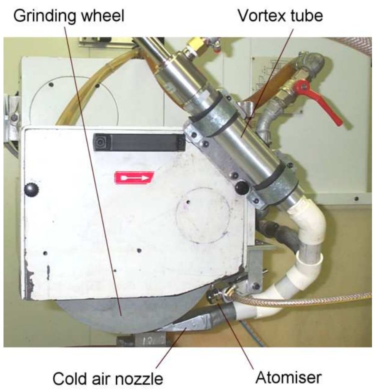


Fig. 1. The system for generating the cold air and oil mist mixture.

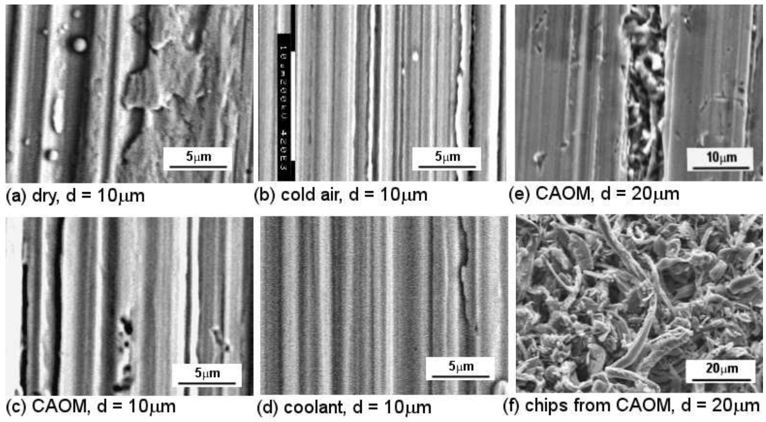


Fig. 2. Surface morphology and chips.

When grinding with cold air at a depth of cut below the critical burning depth, specific energy was lower than that when using coolant (Fig. 3). This may be due to the bonding effect – a re-welding between the chip particles between the particles and the work material. In dry air, this bonding is weak since the freshly ground steel is often coated with a thin layer of oxide [5]. By using coolant, however, atmospheric oxygen is minimised from the grinding zone, slowing down the oxidation process. In this sense, the application of cold air is advantageous at small depth of cut.

Fig. 4 shows the residual stresses induced on the ground surface in the directions of longitudinal and traverse to the grinding direction. Similar to the case with coolant, CAOM also provided a sufficient heat removal in which the deformation during grinding was predominantly mechanical, resulting beneficially compressive residual stresses on the ground surface. However, the mechanical cause was limited within a thin layer (about 50 µm) below which the residual stresses are dominantly generated by thermal deformation and were tensile, in particular in the traverse direction. This can be explained by the non-uniformity in lubrication provided by a conical flow of the oil mist which had a higher mist concentration at the middle part of the grinding width.

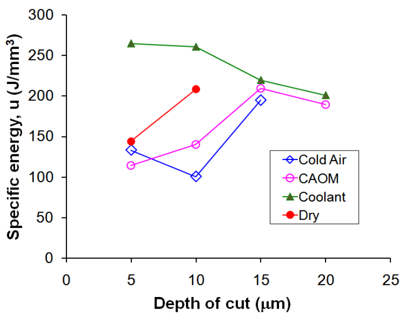


Fig. 3. Specific grinding energy.

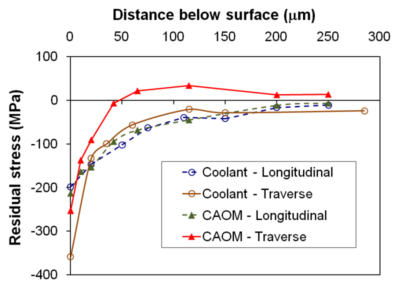


Fig. 4. Residual stresses (depth of cut = 15µm).

Segmented grinding wheel system

Experiment. Fig. 5 shows a segmented grinding wheel system [6-7]. The wheel body was built with perforated holes between the segments, allowing coolant to be squeezed through. A coolant chamber was machined to best fit to the wheel groove. The angular position of the chamber can be adjusted to direct the major coolant flow into the grinding zone. For comparison, a conventional wheel made of the same abrasive material as that of the segmented wheel was used and the cooling was provided by a nozzle of 10 mm in diameter. The workpiece material in this case was 4140 steel.

Machining performance. The segmented grinding wheel system enhanced the grindability and required less coolant, about 3 times lower than requirement by a conventional wheel. The specific energy was also about 6.6% to 23.5% lower.

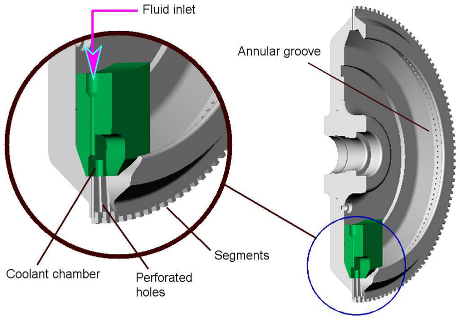


Fig. 5. The segmented grinding wheel system

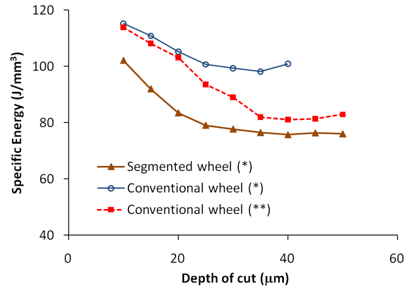


Fig. 6. Specific grinding energy (coolant flow rate: (*) 4.8 litres/min and (**) 14.5 litres/min).

The segmented wheel system effectively reduced the ploughing and rubbing in grinding. The material's side-flows due to abrasive ploughing which were obvious on the surface ground by the conventional wheel (Fig. 7a), did not seem to occur on that ground by the segmented wheel (Fig. 7b). The cross-section profiles in the traverse grinding direction showed that the segmented wheel produced numerous tiny 'peaks' on the ground surfaces, indicating that the sharpness of abrasive grits was retained during the grinding operation.

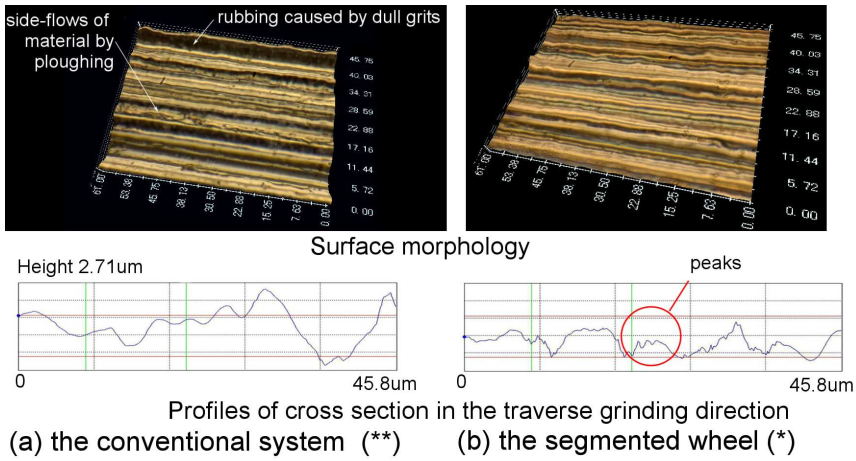
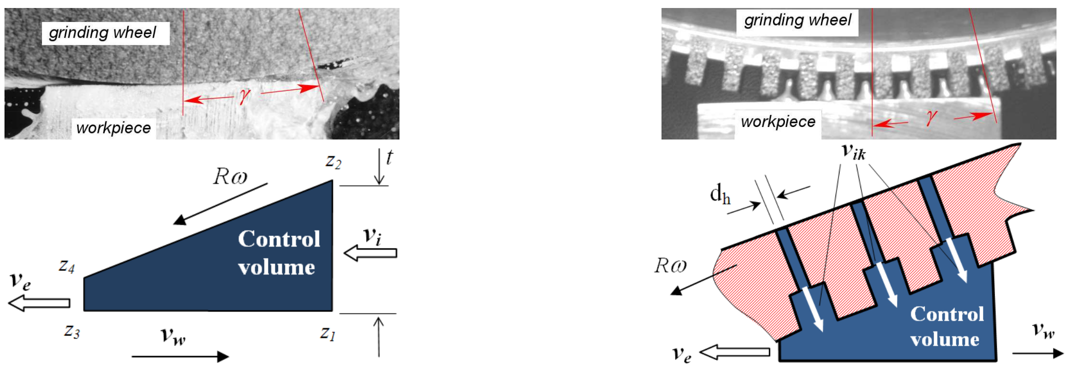


Fig. 7. Ground surface morphology (depth of cut = 35μm; coolant flow rate: (*) 4.8 litres/min and (**) 14.5 litres/min).

Coolant penetration. The effectiveness of cooling depends largely on the amount of coolant penetrating into the grinding zone, and hence relies on the pumping power of a coolant supply system.



(a) the conventional system (b) the segmented wheel

Fig. 8. Analytical control volume.

By applying the equations of momentum for a steady flow and continuity to the control volumes shown in Fig. 8, the power of pumping action enforcing the coolant into the grinding zone (P) can be determined [8-9] as

$$\begin{cases} P = \left(\frac{1}{2}\rho R\omega\right) C_s \left(\sum_{k=1}^{n_{cv}} v_{ik}\right)^2 \\ C_s = \frac{1}{bR}\left(\frac{\pi d_h^{\ 2}}{4}\right)^2\left(\frac{2R}{h}-1\right) \end{cases} \quad \text{(the segmented grinding wheel system)} \tag{1}$$

$$\begin{cases} P = \left(\frac{1}{2}\rho R\omega\right) C_c v_i^2 \\ C_c = Rb\left[\frac{1}{2}\sin 2\gamma \sin\gamma + (1-\cos\gamma)^2\left(\frac{2R}{h}-1\right)\right] \end{cases} \quad \text{(conventional coolant supply system)} \tag{2}$$

where ρ is the coolant density, b is the wheel width and other symbols are defined in Fig. 8.

Further analysis on the effect of coolant splash [8] gives:

$$\frac{\partial P}{\partial \omega} = \frac{1}{2}\rho R C_s\left[\left(\sum_{k=1}^{n_{cv}} v_{ik}\right)^2 + \omega\sum_{k=1}^{n_{cv}}\frac{\partial v_{ik}}{\partial \omega}\right] > 0 \quad \text{(segmented grinding wheel system)} \tag{3}$$

$$\frac{\partial P}{\partial \omega} \approx \frac{1}{4}\rho R^2 b v_j^2 \gamma\left[3 + \left(1-4\gamma^2\right)^{1/2}\right]\frac{\partial \gamma}{\partial \omega} < 0 \quad \text{(conventional coolant supply system)} \tag{4}$$

These indicate that the pumping power is enhanced with the wheel speed using the segmented wheel, in contrast with the decrease that occurs in a conventional coolant supply system.

Conclusions

Cold air is environmentally conscious for grinding to provide good surface quality. However, due to its limit in cooling capacity compared to the coolant, it is more applicable for fine grinding. With the addition of a small amount of vegetable oil mist, a higher depth of cut can be achieved, although the uniformity of the lubrication needs to be further developed.

The segmented wheel system is feasible to minimize coolant consumption in surface grinding. The grindability can be improved.

Acknowledgement

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