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Application of shallow circumferential grooved wheels to creep-feed grinding

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ABSTRACT

A single-point diamond dressing tool was used to cut shallow circumferential groove on aluminum oxide grinding wheels. Creep-feed grinding experiments were then carried out to compare the performance of these grooved wheels with a non-grooved wheel. The results showed that, for the conditions used in this research, a grooved wheel could remove twice as much material as a non-grooved wheel before workpiece burn occurred. The results also showed that a grooved wheel can improve grinding efficiency by reducing the consumed power by up to 61%. Although the use of grooved grinding wheels caused the workpiece surface roughness to increase slightly when compared to a non-grooved wheel, the grooved wheel enabled up to 37% more material to be removed while still maintaining workpiece surface roughness values below 0.3 μm ("fine quality" surface finish), and up to 120% more material to be removed while still maintaining workpiece surface roughness values below 1.6 μm ("average quality" surface finish).

1. Introduction

Creep-feed grinding is an important manufacturing process that is widely used in industries for its fine tolerances and smooth surface finishes. In comparison to conventional surface grinding, creep-feed grinding has higher material removal rates with slower workpiece velocities and larger depths of cut. Higher material removal rates result in higher grinding forces, power consumption and grinding temperatures – all of which have the potential to damage the workpiece. Creep-feed grinding is widely used to grind complex profiles in super-alloy components for aircrafts, gas turbines, petrochemical equipment, and other high-temperature applications. To help mitigate the risk of workpiece damage in the creep-feed grinding process, the present authors propose to add shallow circumferential grooves to a conventional abrasive grinding wheel.

The earliest published research investigating the use of a grooved grinding wheel is the work of Nakayama et al. (1977). In their work, a grooved grinding wheel was tested on the surface grinding process. Helical grooves, as depicted in Fig. 1(a), were formed on the surface of the grinding wheel using a screw-shaped crushing roll made of hardened carbon steel. The groove width was 2.5 mm. The authors reported a 30% reduction in the grinding forces and consumed energy when using this grooved wheel. Verkerk (1979) studied helically-grooved grinding wheels on the cylindrical grinding process. In addition to creating 1–1.2 mm wide grooves on the wheel using a crushed roll approach similar to Nakayama et al. (1977), Verkerk (1979) used a grinding wheel with premanufactured helical slots with width and depth of 3.5 mm and 65 mm, respectively. He recommended that the slots be narrow to avoid measurable traces of the slots on the workpiece surface, and that the slots be at an angle with the wheel axis to reduce grinding force fluctuations. Verkerk (1979) also introduced the term "groove factor" that can be used to describe the remaining non-grooved surface area of the grinding wheel after it has been grooved. For example, a grinding wheel with groove factor of 100% means that there are no grooves on the grinding wheel surface. The groove factor can be calculated using the following equation:

$$\eta = \frac{A_\circ - A_g}{A_\circ} \times 100\% \tag{1}$$

where η is the groove factor, A_o is the total wheel surface area (mm^2), and A_g is the total groove area (mm^2).

Okuyama et al. (1993) studied the effect of axially-grooved grinding wheels on the surface grinding process. As shown in Fig. 1(b), axial grooves are parallel to the wheel axis. The axial grooves studied by Okuyama et al. (1993) had a width and depth of 3.0 mm and 0.5 mm, respectively. These researchers examined the use of 4, 12, and 36 grooves around the periphery of the grinding wheel and reported that the maximum heat transfer coefficient increases with the number of grooves. In addition to this grooved-wheel research, Zheng and Gao (1994) developed a thermal model for slotted wheels, while Ngyyen and Zhang (2006) incorporated radial coolant jets into a segmented grinding wheel.

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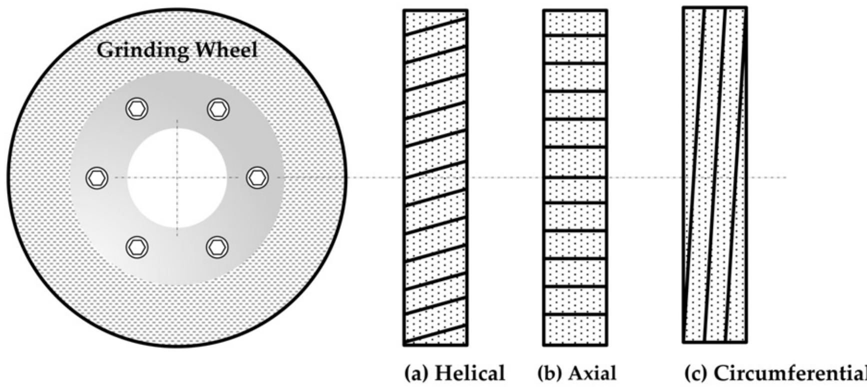

Fig. 1. Wheel grooving patterns.

In this paper, a novel, inexpensive and straightforward method to create grooves in a grinding wheel is presented using a single-point diamond dresser. The groove pattern in this work increases the angle of the helical groove geometry used by Nakayama et al. (1977) and Verkerk (1979) to produce a spiral-shaped groove around the wheel surface, as depicted in Fig. 1(c). This circumferential groove geometry has not been previously investigated in the literature and is applied to the creep-feed grinding process in this research. The proposed circumferential groove geometry satisfies Verkerk's (1979) recommendation of having narrow grooves at an angle relative to the wheel axis. Furthermore, the maximum groove depth performed in this study was only 0.2 mm which is shallower than all of the previous studies found in the literature.

2. Experimental setup

To study the performance of these circumferentially-grooved wheels, creep-feed grinding experiments were conducted on a Blohm-Planomat 408 creep-feed grinding machine utilizing an annealed AISI 4140 steel workpiece (152.4 mm × 6.23 mm × 30 mm) with surface hardness of 46 HRC and an aluminum oxide (Al_2O_3) wheel (Radiac Abrasives WRA 60-J5-V1). The feed rate and wheel speed were held constant for all experiments and set to 1.7 mm/s and 22.4 m/s, respectively. Prior to each creep-feed grinding experiment, the grinding wheel was dressed using a single-point diamond dresser having addressing feed of 0.04 mm/rev and a dressing depth of 0.01 mm.

Grinding forces were measured using a Kistler 9275B three-component quartz force dynamometer with a 5019B charge amplifier, while the grinding power was measured using a Load Controls Inc. PH-3A power transducer. The measured power was collected via a National Instruments BNC 2120 connector block which was linked to a National Instruments PCI-MIO-16XE-10 data acquisition board. The resulting grinding forces and consumed power were measured at a sampling frequency of 500 Hz. The arithmetic mean surface roughness R_a of the ground workpiece was measured directly using a MahrFedral Inc. Pocket Surf. The cutting-fluid concentration of 5.1% CIMTECH 310 was maintained at 20 °C and was monitored prior to each creep-feed grinding experiment. This cutting-fluid was delivered to the grinding zone at 50.4 L/min.

A novel approach was used to cut circumferential grooves in a conventional aluminum oxide grinding wheel. As illustrated schematically in Fig. 2, a single-point diamond dressing tool was used to generate the spiral-shaped groove on the working surface of the grinding wheel with a groove depth of a_g and groove width of b_g.

Experiments were initially carried out using a regular (non-grooved) grinding wheel in order to establish a benchmark for comparing the performance of the grooved wheels. Referred to throughout this paper as Case 1, these benchmark creep-feed grinding experiments gradually increased the depth of cut from 0.75 mm until either workpiece burn or grinding wheel breakdown occurred. The onset of workpiece burn could clearly be seen as a sudden spike in the measured power and the resulting burn was always visible on the workpiece surface.

Similar experiments were then carried out with three circumferentially-grooved wheels, referred to in this paper as Cases 2, 3 and 4, to compare their performance against this benchmark. As

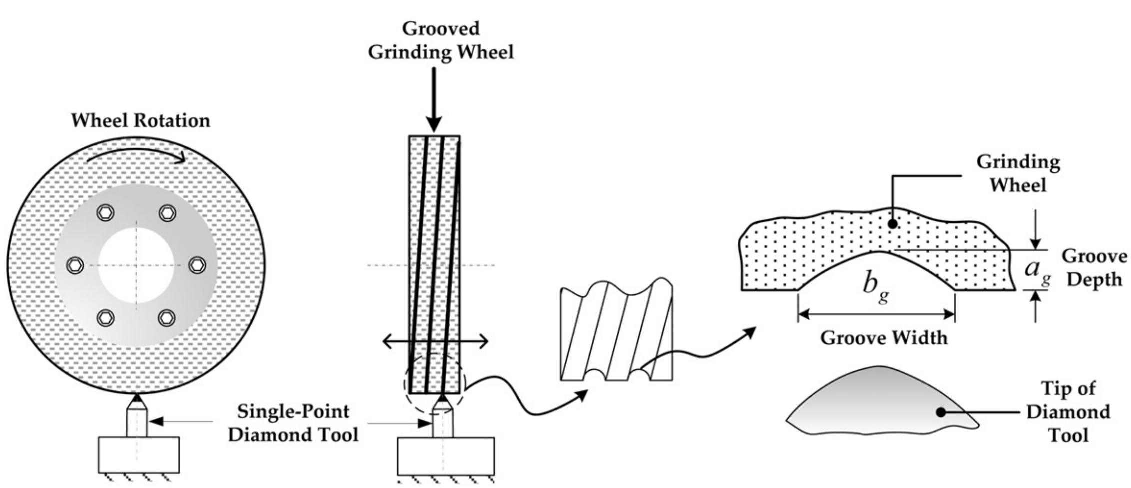

Fig. 2. Grooving procedure, groove pattern and geometry.