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Drastic reduction of grinding fluid flow in cylindrical plunge grinding by means of contact-type flexible brush-nozzle

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ABSTRACT

This study aims to drastically reduce grinding fluid usage in cylindrical plunge grinding of 34CrMo4 steel using a vitrified CBN wheel. A newly proposed flexible brush-nozzle is placed in contact with the wheel surface in order to apply a fluid film to the wheel surface while simultaneously scraping the 'air belt'. This innovative brush-nozzle makes it possible for the grinding fluid to adhere to the wheel surface by the 'Coandă effect', and it reduces grinding fluid consumption to below 0.04 L/(min mm) without causing any thermal damage to the ground surface. Even with such extremely small amount of grinding fluid, the grinding force, surface roughness, and grinding temperature are nearly the same as those in the case of conventional wet grinding.

1. Introduction

Grinding is one of the most important machining processes in the production of high-precision and high-quality mechanical and optical components [1]. Owing to the interactions between the fine abrasive grains and the workpiece material, such as sliding, plastic deformation, plowing, and cutting, the specific grinding energy becomes extremely large, resulting in high grinding zone temperature [2]. The generated grinding heat causes deterioration of surface finishing and reduces dimensional accuracy. Therefore, grinding fluids are generally used as coolants. However, the boundary layer of air that co-rotates with the wheel surface, i.e., 'air belt', prevents the ingress of grinding fluid into the wheel-work contact zone. Hence, some special techniques and a large amount of grinding fluid are used to eliminate this air belt [3,4]. Consequently, a considerable amount of energy and effort is required for fluid circulation and liquid waste disposal. At present, there is an urgent need to reduce the usage of grinding fluid. Some attempts have been made toward this end [5].

A comprehensive review of the cooling and lubricating effects of grinding fluids was presented by Brinksmeier et al. [6], who evaluated the grinding fluid type and grinding fluid supply method from a tribological viewpoint. An air scraper is well known as an effective tool for eliminating the air belt around the wheel surface, and it has been employed in practical production sites [7]. However, in many cases, the scraper is primarily used to maintain the cooling effect while reducing grinding fluid usage.

Many attempts have been made to effectively supply the grinding fluid [8] using a suitable nozzle design. One of the most popular designs is the coherent jet nozzle [9], which shows superior performance in creep feed grinding. Shoe nozzle, spray nozzle, and internal supply have also been shown to be effective [6,10]. Ninomiya et al. [11] developed a floating nozzle characterized by a narrow gap between the wheel and the nozzle, thereby succeeding in improving the grinding performance. Suzuki et al. [12] incorporated a megasonic transducer in the above-mentioned floating nozzle and achieved further improvement in the grinding performance for hard materials. However, such composite nozzles require a specific device, and the applicable grinding style or configuration is limited. The original purpose of these methods was mainly to promote the cooling and lubricating effects of the grinding fluid, not to reduce grinding fluid consumption.

In this study, a new contact-type flexible brush-nozzle is developed in order to achieve considerable reduction in grinding fluid consumption, especially in thermally unopened grinding configurations such as crank shaft or gear, as shown in Fig. 1. The availability of this innovative nozzle is examined in the case of cylindrical plunge grinding. In addition, the effect of the scraper on air flow around the wheel surface is analyzed using computational fluid dynamics (CFD) in order to theoretically support the action of the proposed brush-nozzle.

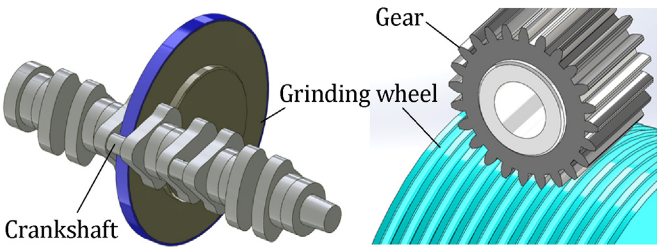

Fig. 1. Typical thermally unopened grinding of crankshaft and gear.

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2. Numerical analysis of air flow around wheel surface

2.1. Computational fluid dynamics (CFD) model

This section describes the numerical analysis of turbulent air flow around the rotating wheel, which is conducted using the CFD software package ANSYS FLUENT0® 13.0 with the k–ε turbulence model [13]. In this model, the wheel (d_s = 305 mm, b_s = 26 mm) with a certain surface irregularity rotates at a peripheral speed of 45 m/s in air, and the effect of the air scraper on the boundary layer of air is analyzed. Here, d_s and b_s denote the wheel diameter and width, respectively. In this CFD model, structured non-uniform hexahedral grids are generated.

2.2. Air flow around the periphery of a rotating grinding wheel

Fig. 2 shows the CFD simulation results of the air-belt around the rotating wheel surface for some scraper-wheel gaps δ when the wheel has surface irregularities of 125 μm corresponding to the #120-wheel. From Fig. 2, the air belt is generally eliminated by the scraper, especially δ = 0, but it remains through the gap when the scraper gaps are 1 and 2 mm. Even at δ = 0, it appears again quickly. This means that the scraper gap should be zero and immediate or simultaneous grinding fluid supply is required.

Fig. 3 shows the velocity distribution of the air belt in the radial direction y when the surface irregularity h is changed, where the nondimensional velocity v_θ/v_s (v_s denotes the peripheral wheel speed) at the rotational position θ = 18° from the scraper is plotted. As is obvious from the figure, the scraper becomes more effective as h decreases, where v_θ/v_s approaches 0 as y/d_s decreases. This suggests that it is difficult to eliminate the air belt completely on the actual grinding wheel rough surface.

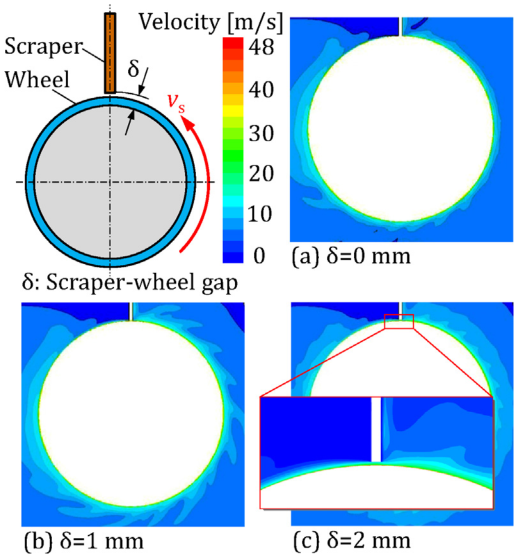

Fig. 2. Effect of air scraper on air-belt around rotating wheel.

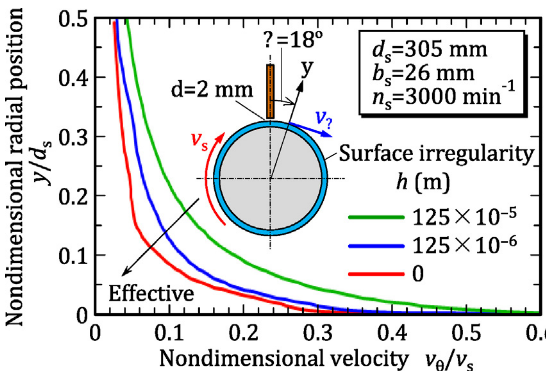

Fig. 3. Influence of surface irregularity of wheel surface on velocity distribution of air-belt.

The above results indicate that it is necessary to develop a novel gapless scraper for the rotating irregular wheel surface and an appropriate coolant nozzle in order to reduce grinding fluid consumption.

3. Contact-type flexible brush-nozzle

Fig. 4 shows two versions of the newly proposed contact-type flexible grinding fluid brush-nozzle. They are simple structures consisting of a nylon brush and plastic oil pool. In the case of the internal supply nozzle (Fig. 4(a)), the grinding fluid is supplied along the brush to the wheel surface such that it flows through the interspace of the brush fiber bundles. On the other hand, the grinding fluid streams along the lateral face of the brush in the case of the external supply nozzle (Fig. 4(b)). The diameters of the brush fibers are 0.29 mm and 0.20 mm, respectively. Based on the analytical results presented in Section 2, these nozzles are designed so as to eliminate the air belt and supply the grinding fluid on the wheel surface nearly simultaneously. The flexible brush can completely fit an irregular wheel surface while rotating; thus, it acts as an ideal air scraper.

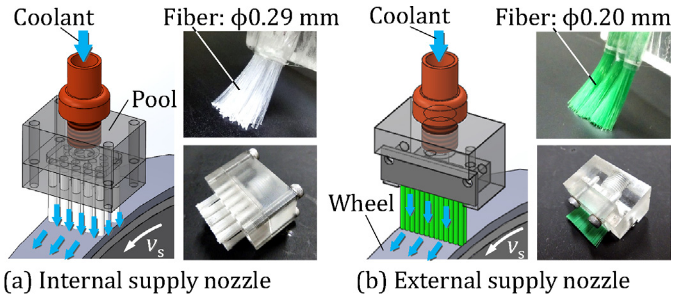

Fig. 4. Two versions of contact-type flexible grinding fluid brush-nozzle.

The insets in Fig. 5 show the formation of a grinding fluid stream accompanying the rotating grinding wheel these flexible brush-nozzles are placed in contact with the wheel surface. It is obvious from the figure that this innovative brush-nozzle makes it possible for the grinding fluid to adhere to the wheel surface by the 'Coandă effect' even when the flow rate of the grinding fluid is at most 0.7 L/min (flow rate per unit wheel width, q = 0.028 L/(min mm)), whereas the grinding fluid is peeled from the wheel in the case of the scraper (δ = 0.1 mm).

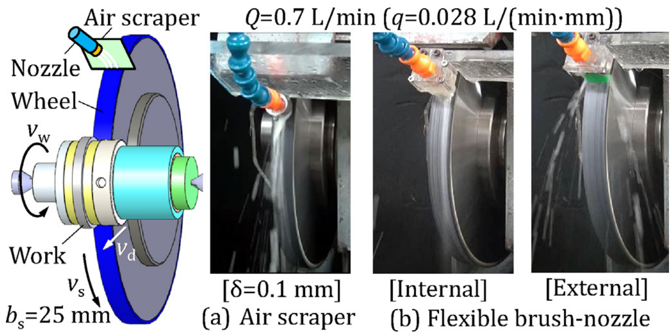

Fig. 5. Experimental arrangement and formation of grinding fluid stream by contact-type brush-nozzle in comparison to air scraper.

4. Cylindrical plunge grinding

4.1. Experimental setup and procedure

Cylindrical plunge grinding is carried out with OKUMA GPO 10-30, a commonly used cylindrical grinding machine. This machine tool has a 7.5-kW spindle motor that allows deep and high-speed grinding. The schematic structure of the work-holding apparatus is also shown in Fig. 5. The hollow disk-shaped workpiece is fixed tightly by a set of holders; this detachable structure makes it possible to measure the surface roughness of the workpiece after