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ORIGINAL ARTICLE

Investigation on using high-pressure fluid jet in grinding process for less wheel loaded areas

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Abstract Wheel loading entails chip accumulation in porosities between grains or welding to the top of cutting grains. It is considered one of the most prevalent problems in grinding nickel-based super alloys. Utilizing separate jet cleaning systems can significantly reduce wheel loading. In this study, a separate high-pressure coolant was supplied through a nozzle towards the wheel surface to flush out the chips. The effects of various wheel cleaning parameters on the loaded area to wheel surface ratio in relation to grinding performance were examined. It was observed that the lowest wheel loading was achieved at a nozzle standoff distance of 70 mm from the wheel's surface. Nozzle stream direction had no significant effect. Increasing flow rate and jet speed led to a significant decrease in wheel loading and corresponding specific energy until a threshold value was reached. Furthermore, the loaded area to wheel surface ratio was reduced by 100 % and the corresponding specific energy by up to 30 % when the wheel cleaning system was employed.

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1 Introduction

The properties of difficult-to-cut materials render grinding among the most effective machining methods for superalloys [1–3]. In the grinding course of such materials, frequently detaching chips may adhere to porosities between abrasive grains or weld to the top of cutting grains—a process known as wheel loading [4, 5]. This phenomenon leads to dull wheel grains, resulting in excessive rubbing and vibration. It also increases cutting force and temperature and reduces wheel life [6]. Recent works in the analysis of CBN grinding wheel operations prove the continued interest in the wheel loading phenomenon as well as means to counteract its development [7–10]. CBN vitrified grinding wheels are an ideal solution in several applications due to the possibility of controlling the wheel's porosity and structure in vitreous bonds [7, 11]. However, this type of wheel is prone to wheel loading, particularly when grinding superalloys [5].

Grinding fluid helps transport chips, clean the grinding wheel, and provide corrosion protection for newly ground surfaces. Grinding fluid is generally regarded as having two primary roles: lubrication and cooling [12]. The conditions in which a wheel clogs up are not well understood. Therefore, developing a method towards a stable cutting process is of high interest in the industrial and technological fields. Employing a high-porosity, open wheel structure and frequent dressings are the two most common methods of overcoming the loading issue [5, 6]. The first technique is detrimental to wheel strength while the second increases cost. It has been revealed that applying a secondary nozzle for wheel cleansing can considerably enhance grinding performance [6, 13, 14]. Cameron et al. [6] found that a critical specific material removal rate of up to 100 % when grinding with an aluminum

oxide wheel could be achieved by applying the wheel cleaning system. Heinzel and Antsupov [14] examined four different nozzle types and observed that the highest cleaning effect can be attained with flat fan nozzles. Sinot et al. [13] experimentally simulated the efficiency of a wheel cleaning system. Observations showed that fluid temperature has no significant effect but the air boundary layer is important.

Nevertheless, it remains unclear what influence different parameters have on achieving efficient grinding wheel cleaning. In this paper, the effects of nozzle standoff distance, stream direction, flow rate, and jet speed on the loaded area to wheel surface ratio and corresponding specific grinding energy were investigated with respect to grinding nickel-based superalloys using CBN vitrified wheels.

2 Cleaning nozzle flow properties

2.1 The impact of liquid jets on solid surfaces

Figure 1 shows the stream structure of a high-speed fluid jet as well as the collision between a liquid droplet and a solid surface. The initial shock in the contact zone leads to a lateral jetting tangent towards the surface where strong shear stress will occur, with the potential for surface damage by erosion [15]. The effect of water nozzle standoff distance from the surface on mass removal, droplet diameter, and droplet impact frequency at the surface are also schematically shown in [15]. The maximum mass removal rates were observed for a certain standoff distance (SOD) at all water pressures [15]. Mass removal rates diminished for either a shorter or longer standoff distance. The complex dynamics of large droplets as a result of the interaction between the fluid jet and air, along with the resulting turbulences, lead to a higher mass removing effect of the fluid jet at a particular nozzle distance from the target surface (SOD is illustrated in Fig. 1).

2.2 Nozzle flow characteristics

The nozzle flow schematic is portrayed in Fig. 2. The Bernoulli law was utilized to calculate the discharge flow rate from a given nozzle, indicating that liquid flow energy remains unchanged throughout all sections of flow. Friction and turbulence loss was neglected, which is reasonable since the nozzle's input and output sections are not far from each other. The Bernoulli law can be written as follows:

$$P+\frac{1}{2}\rho\cdot V^2+\rho\cdot g\cdot z=C \tag{1}$$

where P is the pressure energy, ρ is the density of the liquid, V is flow speed, g is gravitational acceleration, z is the height, and C is a constant value. Therefore, if two sections (A and B) as in Fig. 2 are considered, the law can be written as:

$$P_A+\frac{1}{2}\rho\cdot V_A^2+\rho\cdot g\cdot z_A=P_B+\frac{1}{2}\rho\cdot V_B^2+\rho\cdot g\cdot z_B \tag{2}$$

If the two above sections are read immediately in front of, and behind, the nozzle outlet orifice, we have:

$$\begin{aligned} z_A &= z_B \\ P_B &= 0 \\ V_A &\cong 0 \end{aligned} \tag{3}$$

Due to the fact that P_A is a differential pressure energy referring to atmospheric pressure, V_A is negligible compared to V_B (orifice diameter is much smaller than the input pipe diameter). By substituting these in Eq. (2), the exit velocity from the nozzle is:

$$V=K\cdot\sqrt{P} \tag{4}$$

where $K=\sqrt{\frac{2}{\rho}}$, which is a constant value for a given fluid. Because fluid turbulence and friction loss are neglected, in a real condition some deviation from the theory is expected.

3 Experimental method

The experiments were performed on a Hauni-Blohm HFS 204 Surface Grinder. Grinding conditions and wheel specifications are given in Table 1. The workpiece material was Inconel 738 with hardness of 400Vickers after age hardening. The schematic setup is shown in Fig. 3. The quantitative amounts of wheel loading were evaluated using an image processing technique [16–18]. A Dino-Lite digital microscope captured images along the wheel's circumference, after which the images were analyzed in MATLAB Toolbox. A typical processed image is illustrated in Fig. 4. The white region represents the loaded area and its percentage can be calculated from:

$$\textit{Loaded area ratio}=\frac{\text{Number of white pixels}}{\text{Number of (white + black) pixels}}\times 100 \tag{5}$$

Preliminary grinding tests were conducted to determine the optimum number of pictures necessary to be captured around the wheel's circumference in order to obtain the loaded area to wheel surface ratio. After capturing eight locations, the standard deviation of loading percentage remained constant. Four images were needed to cover the wheel's entire width. Therefore, eight locations from the circumference and four images for each location in the wheel's width direction were selected to