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Design and experimental study of a micro-groove grinding wheel with spray cooling effect

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Abstract The effectiveness of grinding fluid supply has a crucial impact on grinding quality and efficiency in high speed grinding. In order to improve the cooling and lubrication, through in-depth research of self-inhaling internal cooling method and intermittent grinding mechanism, a new spray cooling method used in high speed grinding is proposed. By referring to the structure of bowl-shaped dispersion disk, the grinding wheel matrix with atomization ability is designed; through studying heat transfer of droplet collision and the influence of micro-groove on the boiling heat transfer, grinding segment with micro-groove is designed to enhance the heat flux of coolant and achieve maximum heat transfer between droplets and grinding contact zone. High-speed grinding experiments on GH4169 with the developed grinding wheel are carried out. The results show that with the micro-groove grinding wheel just 5.4% of pump outlet flow rate and 0.5% of spindle energy is needed to reduce the grinding temperature to 200 °C, which means the developed grinding wheel makes cooling high efficient and low energy consuming.

1. Introduction

Grinding generates a large amount of heat because of the internal and external friction. Moreover, most of the heat flows into the workpiece and results in concentration of high temperature at the tool-piece interface. So in the process of grinding, such problems as high temperature at abrasive grinding points, grinding burn, cracks and part distortion will easily occur. To avoid thermal damage, a grinding fluid is almost always employed as it plays a vital role through lubrication and cooling.[1] In fact, lubrication and cooling is more crucial when pursuing higher grinding efficiency and environmentally friendly processing.[2]

Conventionally, the cooling lubricant with very high flow rates and pressures is supplied by external nozzles, because of the difficulty to penetrate the surrounding air layer and reach contact zone between the grinding wheel and the workpiece. Therefore, internal cooling method that allows coolant to supply into the contact zone directly was developed to avoid influence by the surrounding air layer.[3] Moreover, internal cooling method applied to the grinding wheel with channels to achieve intermittent grinding has been proven to be more effective.[4,5] Furthermore, the increasing need for environmentally friendly production techniques and the rapid growth of

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cooling fluid disposal costs have confirmed the demand for a substitute to machining processes using large amount of coolant. Therefore, minimum quantity lubricant (MQL) machining has become the focus of attention of researchers and technicians in the field of machining as a substitute for traditional coolant supply method. Some new cooling lubrication technologies have been developed, such as liquid-nitrogen cooling, steam cooling, and spray cooling.[6] Of the above cooling technologies, spray cooling is characterized by phase transformation, high heat transfer coefficient and small fluid inventory.

However, along with eliminating cooling fluid, its positive influence on machining is also lost since cooling fluid is an important technological parameter in machining. Drastic reduction or even complete elimination will undoubtedly lead to increased temperature in processes, decline in cutting tool performance, loss of dimensional precision and geometry of the parts, and variation in the machine's thermal behavior.[7]

This paper will give a new cooling method which combines the advantages of internal cooling, intermittent grinding and spray cooling in high efficiency grinding. By studying the structure of centrifugal atomization nozzle and the trajectory of the droplets when there is collision on wall surface above the Leidenfrost temperature, a grinding wheel with microgroove and spray cooling effect is reasonably designed. The result of high-speed grinding experiments on superalloy GH4169 with the developed grinding wheel shows that just using a small amount of coolant can achieve a good cooling effect. That means the developed grinding wheel can help achieve green grinding and low consumption cooling.

2. Wheel structural design

2.1. Wheel matrix design

As mentioned before, the design idea is combination of the wheel and the atomizing nozzle to enable grinding and spray cooling simultaneously. Common atomizers are divided into the following kinds: pressure atomizer, air-atomizer and centrifugal atomizer. Considering the similarity of grinding wheel's high-speed rotational movement and centrifugal atomizer dispersed disk's atomization method, it is natural to design the grinding wheel with reference to the centrifugal atomizer structure. Moreover, main types of the centrifugal atomizer dispersed disk contain leafy dispersion disk, bowl-shaped dispersion disk, cup-shaped dispersion disc.[8] Since the laboratory wheel diameter is 80 mm, the wheel matrix is designed as Fig. 1, which refers to the bowl-shaped dispersion disk. Meanwhile, to achieve self-inhaling and enhance the atomization effect, the grinding wheel is machined with chutes, which is similar to the structure of enclosed impeller, as shown in Fig. 2.

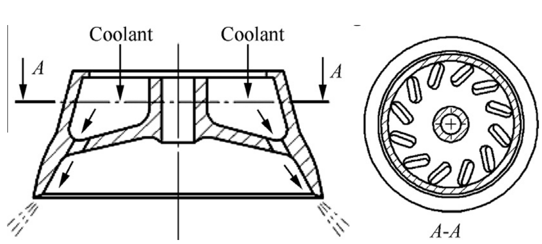

Fig. 1 Bowl-shaped dispersion disk.

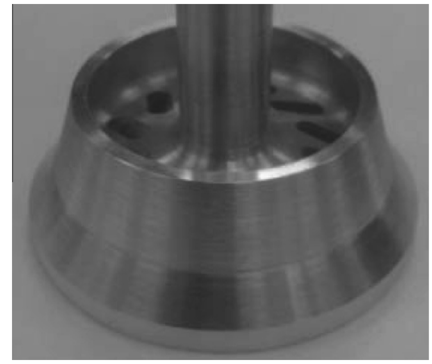
Fig. 2 Grinding wheel matrix.

2.2. Parameters design of grinding segment

2.2.1. Intermittent grinding design

Performance of intermittent grinding mainly depends on two parameters, intermittent grinding ratio η and slot number N. Base on moving heat source model, researchers draw the following conclusions: slot number $N \in [16,32]$ is appropriate,[4] intermittent grinding ratio $\eta \in [0.5,0.7]$ is appropriate.[5] Considering the grinding ratio, structural strength and easiness to process (If too many slots are processed, the grinding wheel has low strength and will wear quickly. Otherwise, cooling effect is not satisfactory), so η takes 0.6 and N takes 18. And the structure of wheel is shown in Fig. 3. As wheel diameter d is 80 mm, slot width b is expressed as

$$b = \frac{\pi d}{N}(1 - \eta) = 5.5 \ \text{mm}$$

In this paper, the grinding segment material is cubic boron nitride (CBN), grain size is 100#, concentration is 125%, and grinding segment height is 5 mm.

2.2.2. Micro-groove design

Micro groove decides the way droplets impact on grinding contact zone, and is the most important structure that influences heat transfer. In order to achieve the best effect of heat transfer, it is necessary to study temperature field of the grinding surface and the movement of a single droplet after colliding on hot surfaces.

According to the most credible triangle moving heat source distribution model,[9–12] grinding temperature field was

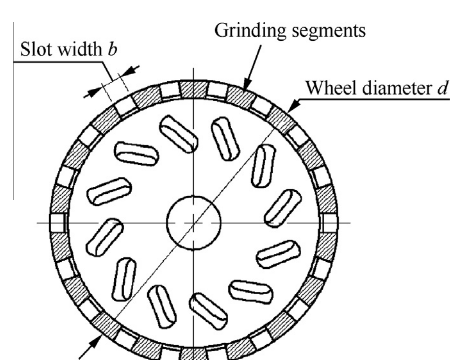

Fig. 3 Intermittent grinding design.