Experimental study on ultra-high speed grinding of Inconel 718

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Abstract. Ultra-high speed grinding is a promising machining technology for grinding hard-to-cut materials. In order to study the effect of improving the grinding speed on grinding effect, the ultra-high speed grinding experiments of Inconel 718 were carried out with CFRP grinding wheel under the maximum speed of 260 m/s. By increasing the grinding speed and the feedrate, the material removal rate per unit width can reach 8.4 mm^3/ (mm s), the grinding ratio increases by over 50%, and the value of surface roughness is smaller than *Ra* 0.4 μm. It is demonstrated that ultra-high speed grinding can significantly improve the machinability of Inconel 718. Besides, the machining efficiency, quality and life of the grinding wheel can be improved at the same time.

Introduction

Nickel-base superalloys have good thermal stability, fatigue resistance, corrosion resistance and high temperature strength under high temperature conditions. They are widely used in the aviation, aerospace, power and transportation fields[1]. However, excellent high-temperature performance also makes nickel-based superalloys a typical difficult-to-cut material, which has problems such as poor grinding performance, low accuracy, low efficiency, and high costs[2]. Therefore, enchancing the processing efficiency and processing quality of nickel-based superalloys is one of the key issues in improving the aerospace manufacturing technology[3].

In the recent years, with the development of grinding equipment, the application of ultra-high speed grinding technology to manufacture the structural parts of nickel-base superalloy has been paid more and more attention. Ultra-high speed grinding is an emerging technology that has been developed with the integration of modern advanced technologies. Dr.Konrad[4] called it as "The highest peak of modern grinding technology." The Institute of International Manufacturing Engineering considers high-speed grinding technology to be one of the important research directions facing the century[5].

Although a great deal of research has been done on grinding methods, the understanding of the grinding mechanism is not yet clear. The complexity of the grinding mechanism leads to the difficulty in establishing the basic mathematical model for describing the grinding process. The traditional mathematical model and grinding theory are not completely applicable to the ultra high speed grinding[6]. Therefore, how to establish the grinding theory under the condition of ultra high speed grinding is the key to the further development and application of ultra high speed grinding.

This paper aims to reveal the ultra high-speed grinding mechanism of nickel-based superalloys from the perspective of testing, and to demonstrate the advantages of ultra-high speed grinding technology in improving the grind ability of the material, and further explore the application potential of the ultra-high speed grinding process in simultaneously improving the machining efficiency, the quality and the wheel life of nickel-based superalloys.

Experimental setup

The grinding test was carried out on a self-innovated ultra-high speed grinding test equipment. The test equipment is shown in Figure 1. The cooling method is 5% water-based emulsion and the high-pressure jet cools. The workpiece material is a nickel-based superalloy Inconel 718 with a size of 50 mm × 40 mm ×5 mm.

The grinding wheel adopted is a self-innovated CFRP matrix CBN grinding wheel for ultra-high speed grinding. The main performance parameters are shown in Table 1.During the test, a four-channel piezoelectric dynamometer Kistler 9272 was used to measure the grinding force. The temperature of Inconel 718 was measured by the thermocouple detector. The corresponding grinding temperature [7] can be calculated based on the calibration curve formula (1-1) of Inconel 718

$$T = -0.0666U^2 + 20U + 12.78 \quad (1\text{-}1)$$

In this formula, T is the hot junction temperature (℃) and U is the thermoelectric potential (mV).

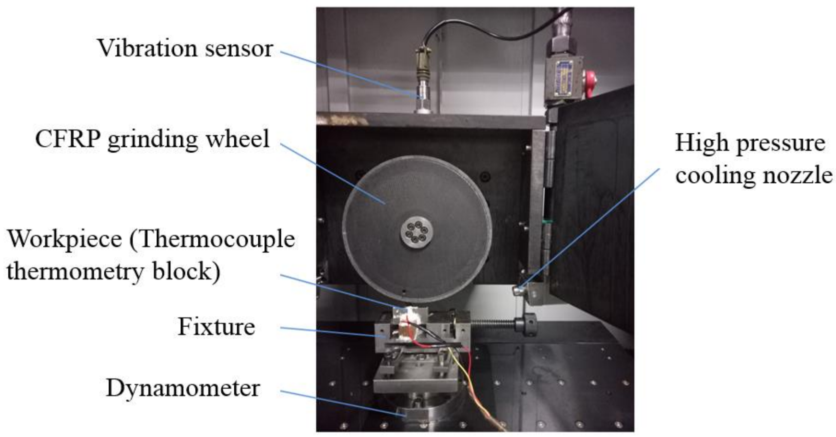


Fig.1 Grinding Test Program

Table.1 Grinding Wheel Parameter

Size	Φ240mm×10mm
Mass	1.186kg
Abrasive size	0.15-0.18mm
Bond of grinding wheel	Ceramic bond
Dynamic balance grade	G0.6

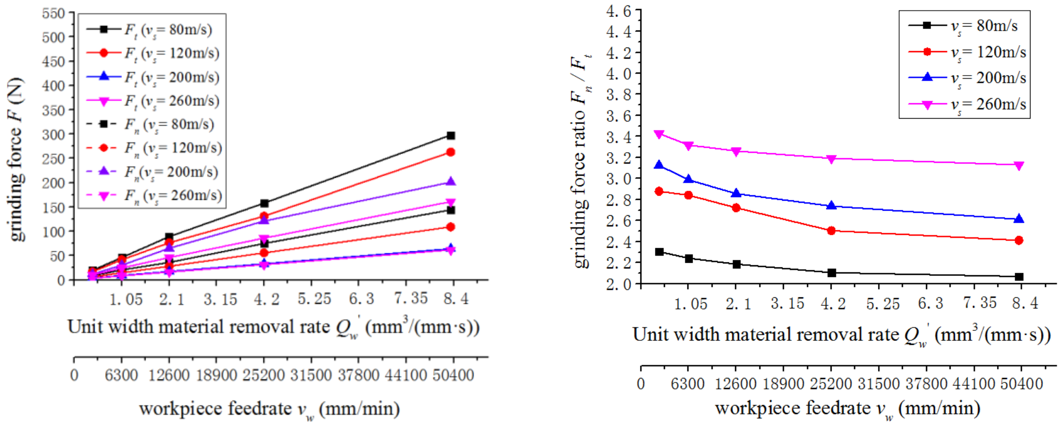
In order to study the ultra high-speed grinding mechanism of Inconel 718 and improve its grinding ability, this test plan intends to explore the high material removal rate of Inconel 718 by controlling the grinding wheel velocity v_s, workpiece feedrate v_w, and grinding depth a_p. The machined surface quality analysis was performed by measuring the surface roughness and micro hardness.

Table.2 Process Parameters

v_s（m/s）	v_w（mm/min）	a_p（mm）	a_{gmax}（μm）	Q_w'（mm³/(mm s)）
40～260	6300～50400	0.01	0.29～2.4	1.05～8.4

Results and discussion

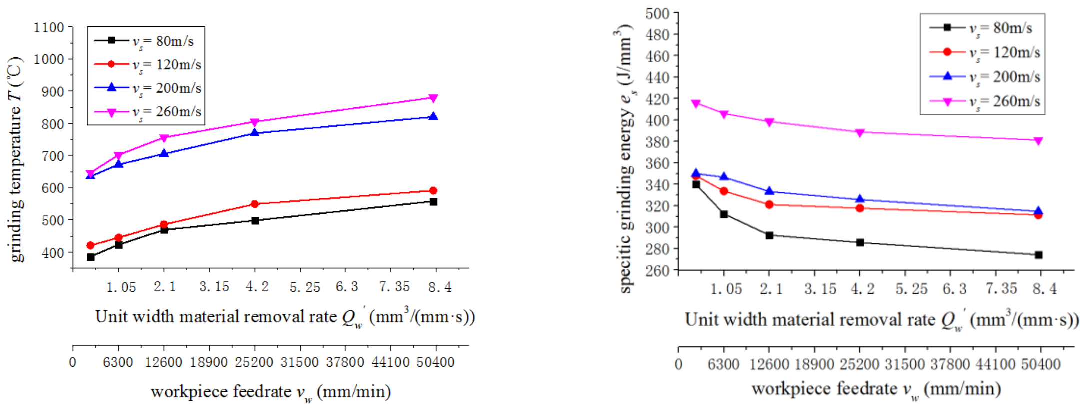
Grinding force ratio: The effect of material removal rate per unit width on the amount of grinding force is shown in Figure 2. It can be seen from Figures 2(a) and 2(b) that when the unit width material removal rate Qw' increased from 0.4mm^3/(mm s) to 8.4mm^3/(mm s), both the normal grinding force and the normal grinding force increase significantly, but the grinding force ratio decreased. In the same material removal rate per unit width conditions, the increase of the grinding speed can effectively reduce the grinding force while increasing the grinding force ratio. This is mainly due to the fact that as the material removal rate increases exponentially, the abrasive grain undergoes a sharp increase in the grinding load, resulting in a marked increase in the tangential grinding force and the normal grinding force. What's more, the abrasive particles become dull, making the grinding force ratio lower. It is shown that in the grinding process where a higher material removal rate is obtained by increasing the workpiece feed rate, the use of a higher grinding speed can effectively reduce the high grinding force at high material removal rates and increase the grinding force ratio.



（a）grinding force　　　　（b）grinding force ratio

Fig.2　Effect of material removal rate per unit width on grinding force and grinding force ratio

Specific grinding energy: From the results of the grinding temperature study (Fig 3(a)), it can be seen that the grinding temperature increased with the increase of the material removal rate per unit width, the higher the grinding speed, the higher the grinding temperature. The results of grinding specific energy study (Fig. 3(b)) showed that with the increase of the removal rate per unit width of material, that is, the increase of the workpiece feed rate, the maximum thickness of a single abrasive grain increases, and the thermal softening effect increases. The effects of shear flow stress and strain rate are weakened, resulting in a decrease in grinding specific energy. Increasing the grinding speed makes the maximum thickness of the single abrasive grain smaller, and the shear flow stress and strain rate of the material increase, resulting in an increase in the grinding ratio.



（a）grinding temperature　　　　（b）specific grinding energy

Fig.3　Effect of material removal rate per unit width on specific grinding energy

Surface roughness: It can be seen from the influence of the removal rate per unit width of material on the surface roughness of the grinding workpiece (Figure 4). With the increase of the workpiece feedrate, the maximum thickness of the abrasive grain increased, and the load of each abrasive particle increased, resulting in an increase in the surface roughness of the workpiece. At the same time, increasing the grinding speed can significantly reduce the surface roughness value. In general, with the removal rate per unit width increased from 0.4 mm^3/(mm s) to 8.4 mm^3/(mm s), the surface roughness values at different grinding speeds ranged from 0.15 μm to 0.322

μm. When Q_w'=8.4 mm^3/(mm s), the surface roughness of 260 m/s was 22% smaller than that of 80 m/s. Therefore, a higher grinding speed should be used while improving the removal rate of the workpiece material, so that a better surface quality of the ground workpiece can be obtained.

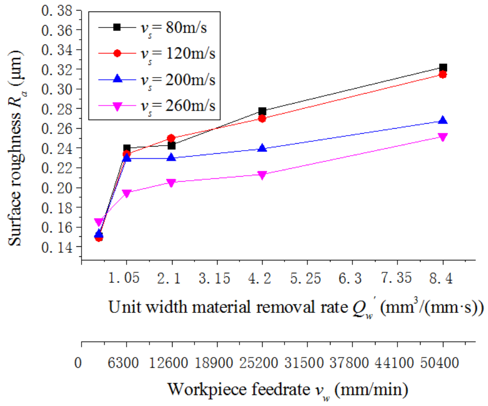


Fig.4 Effect of material removal rate per unit width on surface roughness of grinding workpiece

Microhardness: In order to minimize the influence of the interference between the measuring points and reduce the secondary work hardening of the surrounding materials by using the measuring points, the microhardness test was selected to measure diagonally, and the increment between adjacent measurement points was 5μm, as shown in Figure 5.

Under different grinding speed conditions, the microhardness change of the ground workpiece is shown in Figure 6. As the grinding speed increases, the microhardness of the workpiece surface decreases, and the depth of the hardened layer also decreases. This shows that with the increase of the grinding speed, the maximum thickness of the single abrasive grain is reduced, and the formation time of a single wear debris is very short. Under the combined effect of strain rate effect and thermal softening effect, the plastic deformation layer on the surface of the workpiece becomes shallow and the area becomes smaller. As a result, the hardening tendency of the surface layer of the workpiece is reduced, the maximum microhardness value is reduced, and the depth of the hardened layer becomes shallow, thereby facilitating a better surface quality of the grinding quality.

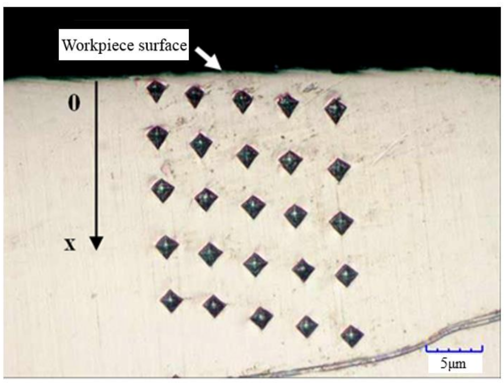


Fig.5 Microhardness measuring point

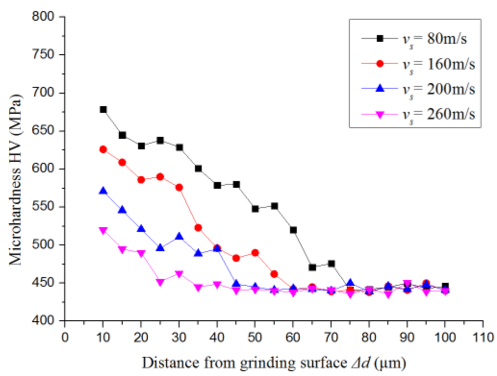


Fig.6 Microhardness distribution on the surface of grinding workpiece

Summary

(1) High material removal rate can be achieved by increasing the grinding speed and the workpiece feedrate. Under the premise of no significant processing burn, the processing efficiency of Inconel 718 can reach $Q_w{}'=8.4\ mm^3/(mm\ s)$.

(2) With the increase of material removal rate, although the grinding force increases and the grinding temperature increases, the grinding force ratio and the grinding ratio can be significantly reduced.

(3) With the increase of grinding speed, the surface roughness of the grinding workpiece and the hardening of the surface layer have become better and R_a can be realized at 0.15-0.32μm. It verifies that ultra-high speed grinding can simultaneously improve workpiece machining efficiency, machining quality, and wheel life at the same time.

Acknowledgements

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