euspen's 21st International Conference & Exhibition, Copenhagen, DK, June 2021
www.euspen.eu

Effect of grinding fluid on the grinding characteristics of CMSX4

Tatsuki Ikari[1], Miyuri Honda[2], Takayuki Kitajima[1], and Akinori Yui[2]

[1]*Mechanical Systems Engineering, National Defence Academy, Japan*
[2]*Department of Mechanical Engineering, Kanagawa University, Japan*

Email: ikari@nda.ac.jp

Abstract
Ni-based heat-resistant alloys are widely used for turbine blades of gas-turbines engines. Due to the increase in the production of these engines all over the world, the demand for high-efficiency machining of Ni-based heat-resistant alloys is expected to rise. However, high-efficient grinding of Ni-based heat-resistant alloys is challenging because of its low thermal conductivity and thermal diffusivity, high chemical activity, large work hardening properties and high-temperature strength. The authors propose the high-efficient grinding using the high-speed-stroke grinding of Ni-based heat resistant alloys, and the goal of this study is clarifying the optimum grinding condition for the grinding method. In the experiment, the workpiece material is CMSX4 used in turbine blades, and Cubitron (precision-shaped ceramic grain) grinding wheel, and WA (white alumina grain) grinding wheel mounted on a linear motor-driven surface grinder have been used, and the grinding force, surface roughness and grinding ratio have been investigated. The rotational speed of the grinding wheel is set as constant. The grinding fluid was prepared in two types, solution and soluble. As a result, the wet grinding showed lower grinding force, smaller surface roughness, and a higher grinding ratio compare with dry-cut grinding. The improvement in the grinding ratio on the high-table speed was significant, and it was greater with the soluble type than the solution type.

Keywords: Grinding, Heat-resistant alloy, Creep-feed, Speed-stroke, Grinding fluid, Plunge grinding, Cubitron

1. Introduction

Demand for turbine blade's higher production volume is increasing; gas-turbine production volume had been increased till 2019, and maintenance parts volume for these engines is expected to reach the maximum in the past. As a result, high-efficient production of the turbine blade is required from the world. However, heat-resistant alloys are difficult to grind in high efficiency due to their low thermal conductivity and thermal diffusivity, high work hardenability, and high-temperature strength [1].

Historically, the Christmas-tree portion of the turbine blade had been machined by the creep-feed grinding, such as the continuous dressing grinding method [2]. Furthermore, the Cubitron grain grinding wheel, which uses ceramics grain and porous type grinding wheel, is also commercialized for heavy-duty grinding. Cubitron is a precision-shaped ceramic grain which bonded rigidly with white alumina grain; WA, using the vitrified bond.

The goal of this research is to achieve the high-efficient and high-speed-stroke grinding of heat resistant alloys. This experiment aims to investigate the effects of grinding fluid, grinding wheel, and other grinding conditions on the grinding characteristics and enable the selection of more efficient grinding conditions.

2. Experimental setup and grinding condition

The authors conducted surface grinding experiments on CMSX4, one of the significant turbine blade materials used for many kinds of aircraft engines, using a Cubitron + WA wheel and a WA wheel, and investigated the normal grinding force, surface roughness, and grinding ratio. The grinding machine used in this experiment is the UPZ315Li manufactured by Okamoto Machine Tools. The UPZ315Li is a grinding machine with a linear motor-driven table that realize a high feed rate and high-acceleration.

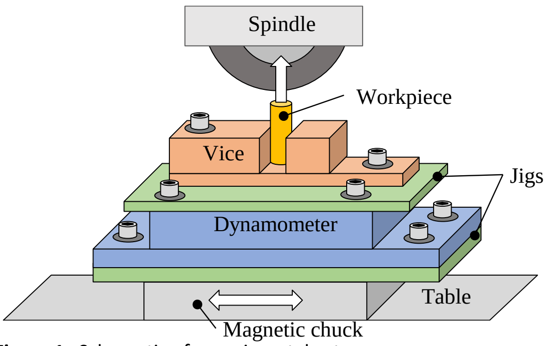

Figure 1. Schematic of experimental setup

As shown in Figure 1, a Kistler Type 9257 Quartz three-component dynamometer was fixed to the grinding machine's table. The workpiece was fixed using a vice, which set on the dynamometer.

The workpieces have a cylindrical shape with a diameter of 14 mm, and the circular cross-section side is ground in the experiments. CMSX4 is a typical difficult-to-cut material, which contains Cr: 6.4, Co: 9.3, Al: 5.5, Ti: 0.9, Mo: 6.3, Ta: 6.2, W: 6.2, Re: 2.8, Hf: 0.1 and Ni: bal.

The rotational speed of the grinding wheel was set constant in 1,590min^{-1} from the allowable peripheral speed of the wheel. The table speed was varied from 50 mm/s to 1000 mm/s from the performance of the grinding machine. The depth of cut was varied from 10 µm to 0.5 µm within a sufficiently safe for the current clamping method, and the removal rate was set at 0.5 $\text{mm}^3/\text{mm}\cdot\text{s}$. Two types of grind fluid were used in 5.2 vol.% diluted, solution and soluble type. For comparison, a WA grinding wheel was used in two grinding conditions, dry grinding and grinding using soluble type grinding fluid. The grinding conditions are shown in Table 1. Specifications of the grind wheels are shown in Table 2. Grinding experiments were performed once for each condition. The wear height and surface roughness were measured three times and averaged. The grinding ratio is measured by the transcription method using a thin carbon plate, as shown in Figure 2. In the method, the grinding ratio was calculated from the worn height of the grinding wheel on the centre of the worn part transferred on the carbon plate and the worn height of the workpiece on the centre of the grinding surface.

Table 1 Grinding condition

Table feed rate	Depth of cut	Removal rate
50 mm/s	0.01 mm	0.5 mm³/mm·s
100 mm/s	0.005 mm	
200 mm/s	0.0025 mm	
1000 mm/s	0.0005 mm	

Table 2 Specifications of grinding wheel

Type	93DA60 /80FISVPH901W	WA60KV35
Abrasive grain type	Cubitron(250μm)30% +WA(500μm)70%	WA (250μm)
Bond type	Vitrified (Low-strength type)	Vitrified
Porosity	Polus type	Normal type
Wheel Size	205x20x50.8	205x19x50.8
Manufacture	3M	Noritake

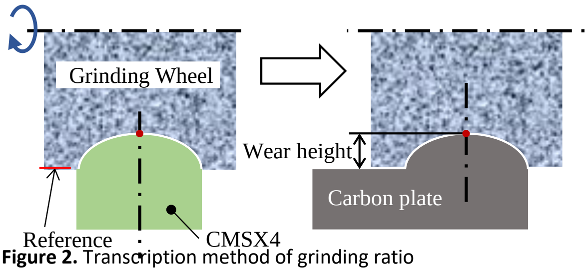

Figure 2. Transcription method of grinding ratio

3. Experimental result

Figure 3 shows the normal grinding force, and Figure 4 shows the grinding ratio, and Figure 5 shows the surface roughness of the workpiece.

The apparent depth of cut of Dry condition increased due to thermal expansion of the workpiece. In the WA/soluble condition, the grinding force is much higher at the creep-feed grinding side. However, the surface roughness is slightly improved. Also, the WA wheel has a higher bond strength than the Cubitron wheel, resulting in glazing caused by the wearing of abrasive grain on WA/dry.

In the WA/soluble, the grinding ratio decreased when the table speed was 1000 mm/s. That is due to the higher porosity of the Cubitron wheel and the more pronounced effect of the grinding fluid. Cubitron/soluble shows a better grinding ratio than Cubitron/solution on the speed-stroke side. The result indicates that in the high table speed range, the soluble type with better lubrication and permeability is more advantageous in improving the grinding ratio than the solution type with better cooling.

Surface roughness was improved for both Cubitron and WA with the grinding fluid compared to the dry condition. However, there was no notable effect on the surface roughness caused by the grinding fluid type difference. The Cubitron/Soluble condition showed improved surface roughness in the speed-stroke grinding side compared to the other conditions.

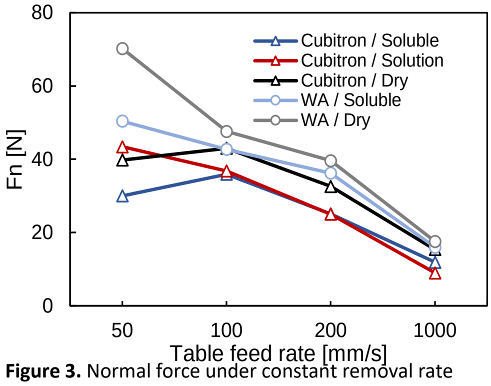

Figure 3. Normal force under constant removal rate

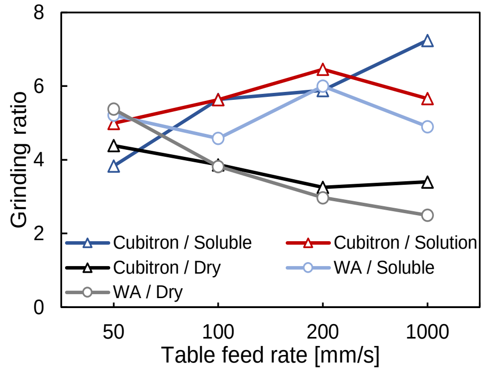

Figure 4. Grinding ratio under constant removal rate

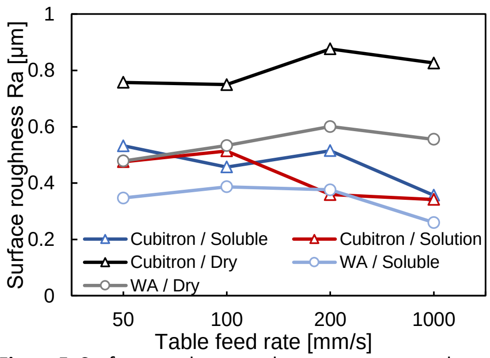

Figure 5. Surface roughness under constant removal rate

4. Summary

On the creep-feed grinding side, the result shows the tendency of glazing wear with the WA wheel. As the table speed increased, dry showed the opposite trend to the other conditions because the apparent depth of cut of Dry condition increased due to thermal expansion of workpiece. At the highest table speed, the grinding ratio of the soluble type grinding fluid is much higher than the solution type. This result indicates that permeability is a key property of the grinding fluid in improving the grinding ratio at the speed-stroke grinding side. Since this was a foundational experiment using a small workpiece, further study is needed to apply the results to the actual products.

Acknowledgement

This work is supported by Yushiro Chemical Co. LTD.

References

[1] e.g. E.O. Ezugwu, Key improvements in the machining of difficult-to-cut aerospace superalloys, Int. J. of Machine Tools and Manufacture, Vol. 45, Issues 12–13, 2005, pp. 1353-1367
[2] F. Klocke, S. L. Soo, B. Karpuschewski, J. A. Webster, D. Novovic, A. Elfizy, D. A. Axinte, S. Tönissen, Abrasive machining of advanced aerospace alloys and composites, CIRP Annals, Volume 64, Issue 2, 2015, pp. 581-604