Grinding Tools for Heat-Resistant Alloys

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Nickel-based heat-resistant alloys, widely used for aircraft jet engines and power plant gas turbines, are difficult-to-cut materials causing short tool life in the grinding process. To meet the market needs for extended tool life and increased machining efficiency, we have developed an innovative electroplated cubic boron nitride (CBN) grinding wheel, CB Master. CB Master demonstrated 5 times longer tool life in grinding jet engine parts, and 1.5 times higher efficiency in processing gas turbine parts than conventional wheels.

Keywords: grinding tool, electroplated wheel, difficult-to-cut material, gas turbine, high machining efficiency

1. Introduction

Grinding is a machining process used to finely remove unnecessary material from a workpiece by means of natural occurring or synthesized hard abrasive grains. In today's industry, shape form grinding is in wide use. For form grinding, grinding wheels have a large number of abrasive grains suitable for the intended finished shape of the workpiece. A.L.M.T. Corp. manufactures electroplated grinding wheels (hereinafter, the "electroplated wheels"). The electroplated wheel has diamond or cubic boron nitride (CBN)*1 abrasive grains bound on a steel body by nickel plating. Incidentally, diamond and CBN are the hardest and second-hardest known materials existing on the Earth. Electroplated wheels have an abrasive layer formed along the shape of the steel body. A feature of electroplated wheels is that it can be easily formed even complicated shape.

In recent years, commercial aircraft have been turning toward modern jet engines to improve fuel consumption, and demand has been growing for thermal power generation on a global scale. It is desired to develop a machining technology for high-efficiency grinding of heat-resistant alloys*2 such as nickel (Ni)-based alloys used in jet engines and power plant gas turbines. Meanwhile, heat-resistant alloys used in harsh thermal environments are difficult-to-cut materials[(1)] because of their high strength at elevated temperatures, causing abrasive grains to wear quickly.

To meet market needs, A.L.M.T. has developed a novel electroplated wheel named CB Master for machining heat-resistant alloys, which has longer life and higher machining efficiency. This paper reports on the development process and application examples of CB Master.

2. Formulation of Development Policy for CB Master

The electroplated wheel has a simple structure, with nickel plating acting as a bond between a steel body and abrasive grains (Fig. 1). Consequently, two important factors affecting tool life, grinding efficiency and other performance aspects of the electroplated wheel are: (1) Selection of suitable abrasive grains (grade and grain size) for specific applications and (2) Determination of grinding conditions for extended use of the abrasive grains with sharpness retained. Depending on these selections, the life of the electroplated wheel changes significantly.

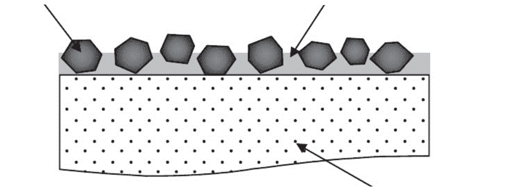
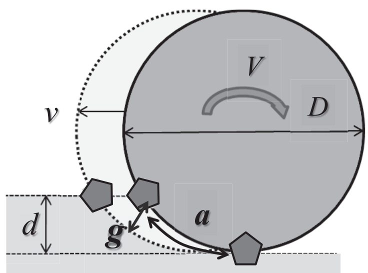


Fig. 1. Structure of an electroplated wheel (cross section)

For form grinding of heat-resistant alloys, CBN abrasive grains have been selected due to its superb sharpness attributable to its sharp crystal form. For the development of CB Master, we started a grinding evaluation for Inconel 718, which is a representative Ni-based heat-resistant alloy, using an electroplated wheel with standard CBN abrasive grains.

The grinding ratio (the ratio of tool wear in volume to the volume of material removed from the workpiece) is equivalent to tool life. Grinding ratios were rearranged with respect to grain depth of cut g,[(2)] which is a significant index used to express grinding conditions consisting of many



D	Wheel diameter
V	Wheel speed
d	Cutting depth
v	Feed rate
g	Grain depth of cut
a	Grain interval

Fig. 2. Schematic diagram of grinding

parameters. The grain depth of cut g expressed by the following equation corresponds to cutting by one grain into the workpiece (Fig. 2).

$$g = 2a \cdot v/V\sqrt{d/D} \quad \cdots\cdots (1)$$

Assuming that the grain interval a becomes a constant if the abrasive grain size is uniform, Equation (2) expresses the maximum grain depth of cut g/a, which is the quotient of the grain depth of cut g divided by the grain interval a.

$$g/a = 2 \cdot v/V\sqrt{d/D} \quad \cdots\cdots (2)$$

Equation (2) implies that the grinding force applied to the abrasive grain increases with increasing value of g/a. It also implies that improved grinding efficiency (material removal rate) requires increased maximum grain depth of cut g/a, resulting in an increased grinding force on the abrasive grain.

Figure 3 illustrates the grinding ratio of a conventional CBN electroplated wheel for grinding Inconel 718. The figure reveals that the conventional wheel is short-lived because when grinding a Ni-based super alloy, the grinding force increases with increasing g/a, resulting in the fracture of CBN grains. We deduced that CBN abrasive grains with improved strength would be required for grinding to reduce damage to wheels, based on our experience in the development of CBN cutting tools intended for heat-resistant alloys.[3]

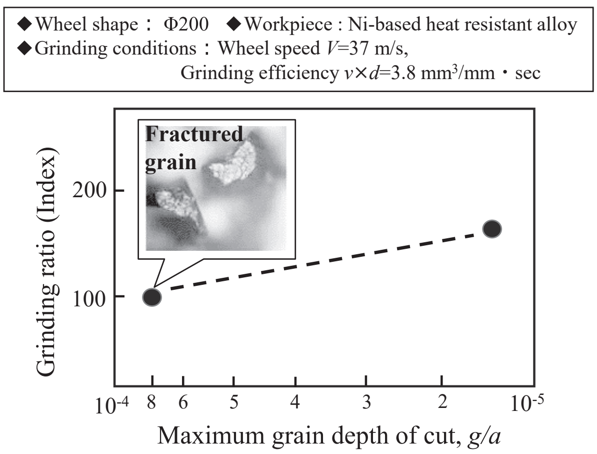


Fig. 3. Correlation between maximum grain depth of cut and grinding ratio for grinding of Ni-based super alloys by CBN abrasive grain

Consequently, for the development of CB Master, we have set the following two policies: ① Search for tough abrasive grains with excellent fracture toughness and ② Determination of grinding conditions for reducing the maximum grain depth of cut g/a, while fulfilling the required machining efficiency.

3. Establishment of CB Master through Application to the Ginding of Jet Engine Parts

In order to address the problem that conventional electroplated wheels were short-lived when applying them to the grooving of turbine blades used for aircraft jet engines (Fig. 4), we directed efforts toward improving tool life by developing CB Master.

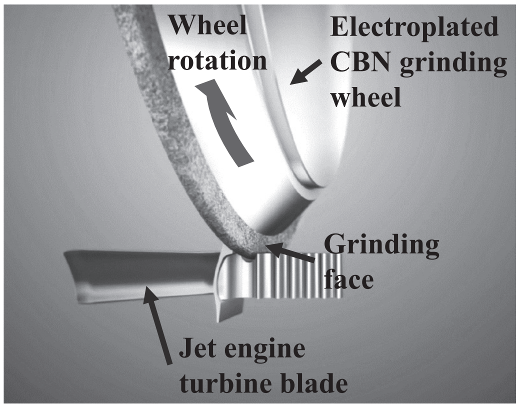


Fig. 4. Form grind of groove for turbine blade

More specifically, to increase the tool life, we used two approaches: ① Improvements of abrasive grain grade and ② Optimization of grinding conditions for reduced g/a.

For an improved abrasive grain grade (①), we focused on the development of CBN abrasive grain with increased toughness. A comparative evaluation of various commercially available CBN grades revealed that when grinding Ni-based heat-resistant alloys, a tough CBN grade exhibited less fracturing. We developed its proprietary CBN abrasive grain intended specifically for heat-resistant alloys, by controlling the CBN grain size with the aim of removing fine particles not contributing to grinding. Moreover, the plating technique used to bond the abrasive grain was innovated to ensure that the abrasive grain would have a uniform protrusion height to maximize the features of the newly developed abrasive grain (Fig. 5). This innovation enabled an ideal grinding face to be formed so that the grinding force incurred on the abrasive grain is dispersed during grinding.

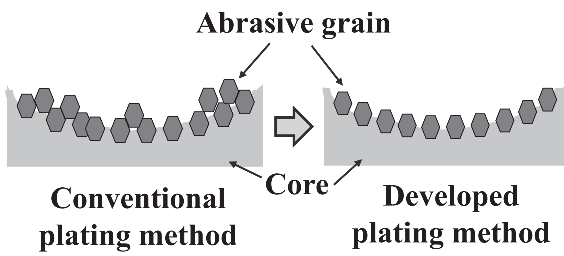


Fig. 5. Uniform protrusion of abrasive grain achieved through plating innovation

For optimizing the grinding conditions (②), Equation (2) indicates that the maximum grain depth of cut *g/a* can be reduced by raising the wheel speed *V*. Conventional grinding wheels are subject to usage restrictions including a maximum wheel speed *V* of 60 m/s. We explored specifications for them to be usable at higher wheel speeds. As a result, we developed a high-speed wheel usable up to a wheel speed of 100 m/s, made possible by strength enhancement of the body and to the optimized wheel structure.

Table 1 presents the results of a basic evaluation conducted on a conventional electroplated wheel and CB Master provided with the above-described improvements. CB Master with an improved abrasive grain (①) had only minimal abrasive grain fracture under the same grinding conditions as the conventional one, doubling the tool life. Additionally, when CB Master was constructed to a higher wheel speed specification (②), even under a condition of 1.5 times higher grinding efficiency, its tool life was eventually improved to five times in comparison with that of the conventional wheels owing to a 10% decrease in *g/a*.[4] Based on these evaluation results, CB Master demonstrated long tool life in the grinding of jet engine parts with improved machining efficiency at user.

Table 1. Grinding efficiency and tool life improvements by CB Master

Conditions, Performances	Conventional wheel	CB Master	
		① Abrasive improvement	**② Condition optimization**
Wheel diameter D (mm)	Φ 200		
Abrasive grain	Standard CBN	① **Tough CBN**	
Wheel speed V (m/sec)	60		② **100**
Maximum grain depth of cut g/a (Index)	100		**90**
Gridning efficiency $v \times d$ (Index)	100		**150 (1.5 times v)**
Tool life (Grinding ratio, Index)	100 (Large fracture)	**200 (Small fracture)**	**500 (Sharpness)**

4. Exploring the Uses of CB Master at the Customer Solution Center

To explore the uses of CB Master completed through the process of grinding jet engine parts, we have used it for the grinding efficiency improvements of power plant gas turbine blades constructed similarly from Ni-based heat-resistant alloys.

The first step was to optimize the grinding conditions at the Customer Solution Center (CSC), which is the evaluation department of A.L.M.T., to improve the grinding efficiency to 1.5 times that of conventional electroplated wheels, thereby responding to user needs. CSC possesses various testing machines and analyzers. It is tasked by A.L.M.T. to provide customer services, with its dedicated staff collaborating with users to solve various user needs (Photo 1).

Figure 6 shows the grinding ratios of a conventional wheel and CB Master, evaluated at the conditions with an increasing grinding efficiency. To improve the efficiency to 1.5 times, it is necessary to apply a higher feed rate *v* or a greater depth of cut *d* than the ones used under conventional grinding conditions. Using harsh grinding conditions, conventional electroplated wheels would encounter increased fracture of CBN abrasive grains, resulting in a reduced grinding ratio compared with that observed under conventional grinding conditions.

In contrast, CB Master made of tough CBN abrasive grains exhibited a higher grinding ratio than the conventional electroplated wheel. Moreover, the optimization of grinding conditions (low feed rate × great depth of cut) with reduced *g/a* was found to extend the tool life, being longer than under conventional grinding conditions. Observation with a microscope of the abrasive layer of CB Master after grinding revealed reduced fracture of CBN abrasive grains, with retention of its sharpness.

For the purpose of expanding application, CB Master proved itself to offer a suitable tool life and grinding efficiency for user needs, using the grinding conditions determined through evaluation at CSC.

Photo 1. Evaluation conducted at CSC with customer

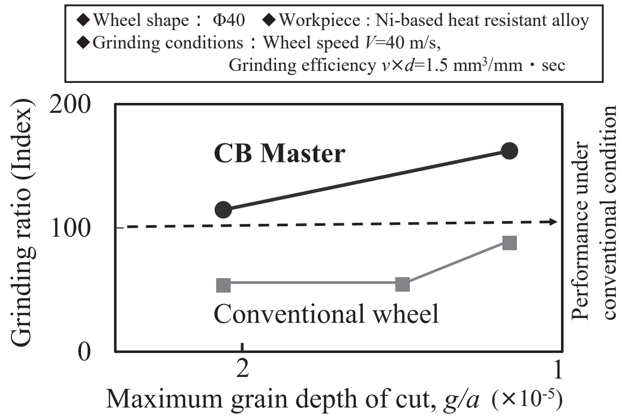


Fig. 6. Grinding performance of CB Master

5. Future Approaches

In the field of metallurgy, ceaseless efforts are being made to enhance the high-temperature strength of heat-resistant alloys with the aim of improving the thermal efficiency of jet engines and gas turbines. This means that heat-resistant alloys will be increasingly difficult to cut.

For the purpose of additionally improving the performance of CB Master, A.L.M.T. is working on performance innovation of CBN abrasive grains as it is critical to the performance of electroplated wheels. We have newly developed CBN abrasive grains with extremely favorable wear resistance in collaboration with the Advanced Materials R&D Laboratories of Sumitomo Electric Industries, Ltd. Combining this effort with the CBN abrasive grain reported in this article is expected to bring about an even better grinding performances. We intend to commercialize new CBN in 2021 for use in next-generation electroplated wheels.

6. Conclusion

Aircraft jet engines and power plant gas turbines use heat-resistant alloys for their structural components. In heat-resistant alloy grinding applications, user needs include extended tool life and increased machining efficiency. A.L.M.T. has developed the electroplated wheel CB Master to meet such needs. Going forward, we intend to contribute to the industrial world by further improving the performance of electroplated wheels.

Technical Terms

*1 CBN: Cubic boron nitride is the second-hardest known material, next to diamond. It has been commercialized as a material for cutting tools and abrasive grains for grinding wheels due to its low reactivity with steel and cast iron.

*2 Ni-based heat-resistant alloy: A nickel-based super alloy with superb high-temperature strength, developed as a result of advances in metallurgy. Many variations have been developed, differing in alloy composition and manufacturing process. Inconel is a type of Ni-based heat-resistant alloy and is a trademark or registered trademark of Huntington Alloys Corporation.

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