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Ultraprecision ultrasonic vibration polishing

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1. Introduction

In machining machine parts, internal gears and internal serrations cannot be ground or polished at high speed using a grinding wheel. Therefore, ultra-precise grinding is difficult. On the other hand, machining orientation notches of semiconductor substrates requires grinding or polishing with a small diameter wheel, so ultra-precise finishing is also difficult in this case.

Ultrasonic vibration polishing is effective for shapes and materials that cannot be machined with high surface accuracy using normal grinding and polishing methods.

The authors have been investigating ultrasonic vibration polishing using a grinding stone with uniform abrasive grain height. As a result, it has been revealed that a high polishing rate and ultra-precise polished surface can be obtained under low-speed polishing conditions[1)]. In this study, we report the results of an investigation into the polished surface accuracy when performing flat polishing on various metal materials.

2. Analysis of ultrasonic vibration polishing method

The principle of ultrasonic vibration polishing is shown in **Fig. 1**. In this polishing method, the grinding stone is subjected to longitudinal elastic vibration, and polishing is performed so that the vibration direction is perpendicular to the polishing direction. With conventional polishing methods, the polishing marks are oriented in the same direction as the polishing direction. In contrast, with ultrasonic vibration polishing, the trajectory of the polishing marks becomes a sine waveform in which the polishing speed and vibration speed are superimposed. The effects of ultrasonic vibration polishing include an increase in the polishing distance per unit time, an increase in the maximum polishing speed, and a constantly changing polishing direction. As a result, it has been shown that the polishing surface precision and polishing efficiency are improved[2,3)].

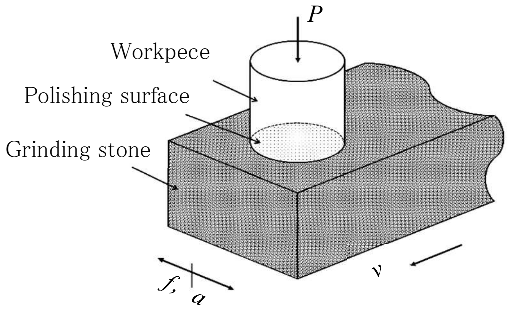


Fig. 1 Ultrasonic vibration polishing method

3. Analysis of ultrasonic vibration polishing method

An effective way of using ultrasonic vibration polishing is to make the grain height on the abrasive stone surface uniform. The truncation method for this purpose is shown in **Fig. 2**. Lapping is performed using a PCD lap and diamond slurry. This lapping selectively removes only the grains that are high on the abrasive stone surface, resulting in a uniform grain height.

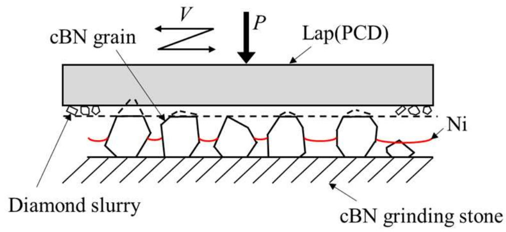
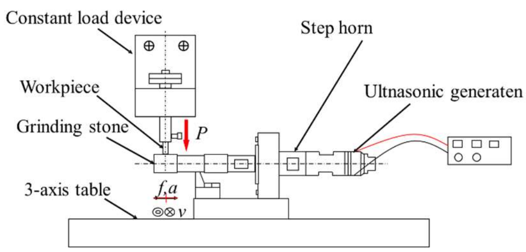


Fig. 2 Truncation method of grinding stone

4. Experimental setup and methods

The ultrasonic vibration polishing device is shown in **Fig. 3**. The polishing device was constructed on a tabletop three-axis stage (Takashima Sangyo, Multi Pro III). The grinding wheel was placed on the Y-axis table. Ultrasonic vibration was generated by a bolt-clamped Langevin



f: frequency, *a*: amplitude, *v*: polishing speed
P: polishing pressure
Fig. 3 Ultrasonic vibration polishing device

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transducer (BLT). A device for applying a constant load to the workpiece on the grinding stone surface was attached to the X-Z table surface. This constant load *P* was applied by a weight.

The experimental conditions are listed in **Table 1**. The vibration frequency was 20.3 kHz, the amplitude was 10 μm (0-P), and the grinding stone was cBN#800. The polishing method was to move the workpiece back and forth on the grinding stone surface.

Table 1 Experimental conditions

Work material	High-speed tool steel (SKH51) Titanium alloy (Ti-6Al-4V) Aluminum (A1050) Stainless steel (SUS304) Brass (C3604) ※Diameter of all workpieces; 6mm
Frequency f	20.30kHz
Amplitude a (0-p)	10μm
Polishing velocity *v*	50mm/min
Constant load *P* (Work pressure)	10.6N(375kPa) , 15.9N(562.5kPa) , 21.2N(750kPa)
Abrasive grain (Grain size)	cBN(#800)
Polishing distance l	3000mm(12mm×250 times)
Polishing fluid	Insoluble cutting oil

4. Experimental results and discussion

4. 1 Characteristics of ultrasonic vibration polished surface

Fig. 4 shows the results of the polished surface properties with ultrasonic vibration. The workpiece is high-speed tool steel SKH51. With conventional polishing methods that do not apply ultrasonic vibration, polishing marks are generated in the same direction as the polishing direction *v*. Therefore, the surface roughness in the direction perpendicular to the polishing direction increases. The surface roughness was 0.109 μm*Ra*.

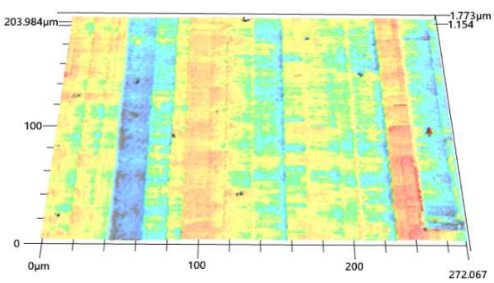

Fig. 4 Polished surface properties (SKH51, *P*:10.6N)

In contrast, with ultrasonic vibration polishing, the width of the polishing marks expands to about 20 μm. This is because both amplitudes of the ultrasonic vibration are 20 μm perpendicular to the polishing direction, resulting in polishing marks with a width equivalent to that amplitude. The surface roughness precision within the polishing marks is extremely good. The surface roughness of the polished surface was 0.015 μm*Ra*, a significant improvement compared to conventional polishing.

4.2 Relationship between polishing load and surface roughness in ultrasonic vibration polishing

Fig. 5 shows the relationship between polishing load and surface roughness. It can be seen that the surface roughness tends to increase as the load is increased. On the other hand, although the polishing efficiency has not yet been quantitatively measured, the results of observing the amount of chip removal show a clear tendency to increase. Furthermore, due to the effect of ultrasonic vibration, the chips do not clog the grinding stone surface.

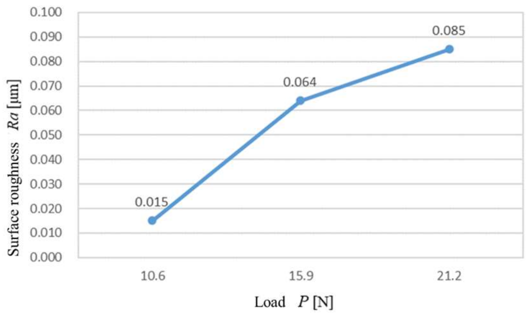

Fig. 5 Relationship between polishing load and surface roughness

5. Conclusion

In this study, we investigated the ultrasonic vibration polishing method, which applies ultrasonic vibrations to a polishing stone in a direction perpendicular to the polishing direction. We achieved a surface roughness of 15 nm*Ra* for high-speed tool steel SKH51, and also demonstrated the relationship between load and surface roughness.

Acknowledgment

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