

Ultrasonic Vibration-Assisted Cutting of Titanium Alloy

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INTRODUCTION

Titanium alloy has superior characteristics such as lightness, high strength and high corrosion resistance. These characteristics make titanium alloy highly suited for aircraft parts and medical implants. Although titanium is a very useful material and becoming more in demand, we are faced with difficulties in working the material to manufacture products. Especially, in the case of turning, titanium alloy is chemically active, therefore causing chips to adhere to the tool tip. Accordingly, when the adhesive chips separate from the tool tip, they take with them part of the tool material, causing severe wear. Another issue is that chips can become entangled between tool and workpiece. This results in damage to the surface of the workpiece and the surface roughness increases.

In this research, we have proposed the use of ultrasonic vibration-assisted cutting of titanium alloy in order to overcome these problems. By applying ultrasonic vibration to the tool tip, interrupted cutting, rather than continuous cutting, can be applied. This technology may enable us to prevent the adhesion and entanglement of chips, improving tool wear and surface roughness of the workpiece.

EXPERIMENTAL SETUP AND PROCEDURE

Fig. 1 shows the external view of the ultrasonic vibration cutting machine (Taga Electric, SB-50) used in this study. Fig. 2 shows a cross-sectional view of the same ultrasonic vibration unit. Ultrasonic vibrations generated by a bolted Langevin's element are transmitted to the cutting tool tip via the cone and horn. The frequency of the ultrasonic vibration is 19 kHz and the amplitude is 0.03 mm. The direction of the vibration is parallel to the cutting direction. A triangular tip (KENNAMETAL:TPGT110204K) is used as the cutting tool.

The face cutting of a titanium alloy (Ti-6Al-4V) was carried out by means of the ultrasonic vibration unit attached to the turret of a CNC lathe as shown in Fig. 3.

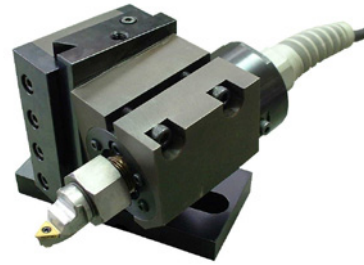


FIGURE 1. Ultrasonic vibration cutting machine

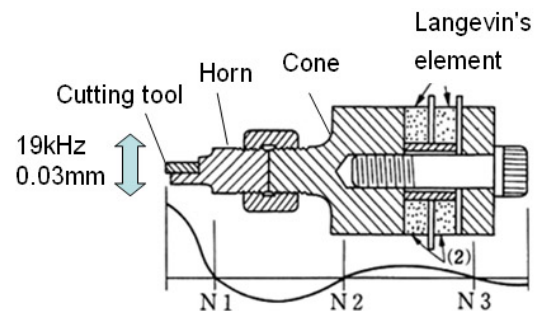


FIGURE 2. Cross-sectional view of ultrasonic vibration unit

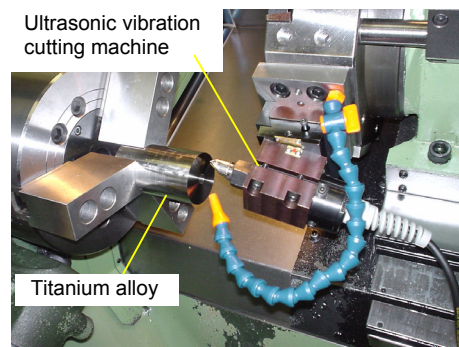


FIGURE 3. Experimental setup

EXPERIMENTAL RESULTS

Cutting Resistance

Fig. 4 shows the results of the measurements of the cutting resistance made using a force sensor (KISTLER:9257B). The results indicate that the cutting resistance in the ultrasonic vibration-assisted cutting process is between one-half to

one-third of that in the conventional cutting process without ultrasonic vibrations. Whereas the coefficient of friction, being defined by principal force F_z divided by thrust force F_y , in the case of conventional cutting gives a result of 0.84, in the case of ultrasonic vibration-assisted cutting this result is almost halved, to 0.44.

In the case of conventional cutting, chip adhesion was observed and tool wear became more apparent as shown in Fig.5(b). It is supposed that this is due to high cutting temperature. On the other hand, there was less tool wear and chip adhesion in the case of ultrasonic vibration-assisted cutting as shown in Fig.5(a).

TABLE 1. Cutting conditions

Workpiece	Ti-6Al-4V , $\phi 50$
Cutting tool	KENNAMETAL TPGT110208K
Depth of cut	0.1mm
Feed rate	0.15mm/rev
Cutting speed	30m/min
Ultrasonic Vibration	19kHz , 0.03mm
Coolant	Dry

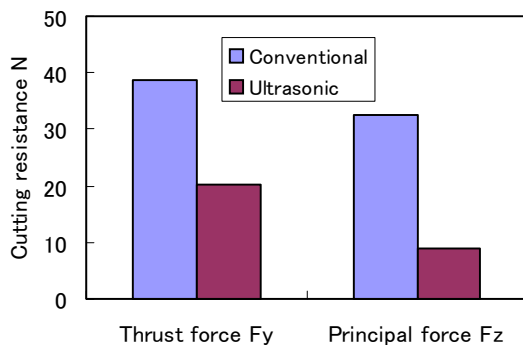
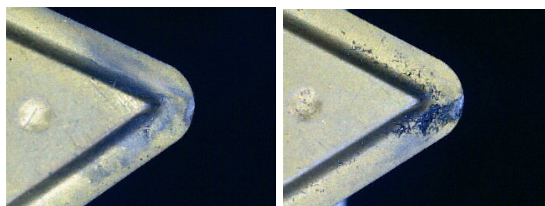


FIGURE 4. Cutting resistance



(a) Ultrasonic vibration (b) Conventional
FIGURE 5. Cutting tool tip images

Properties of Cutting Surface

Another issue of the conventional cutting of titanium alloy is that chips can become entangled between tool and workpiece. This results in damage to the surface of the workpiece and the surface roughness increases. Ultrasonic vibration-assisted cutting of Titanium

alloy shows more effective chip discharge in comparison to conventional cutting. Flow type chips were discharged and no entanglement was observed as shown in Fig.6.

Fig. 7 shows the difference in the properties of the cut surface with and without ultrasonic vibrations. In the ultrasonic vibration-assisted cutting process, the material is removed little by little, producing “fish scale-like” marks.

The surface roughness R_a was $1.37 \mu\text{m}$ in the conventional cutting process, and was improved to $0.55 \mu\text{m}$ in the ultrasonic vibration-assisted cutting process. In the ultrasonic vibration-assisted cutting process, the surface roughness is very close to the theoretical roughness.

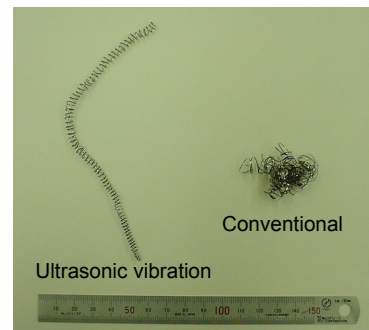
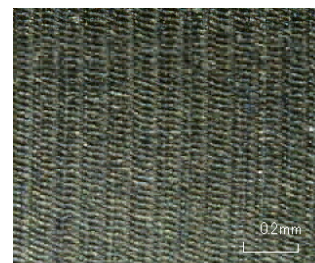
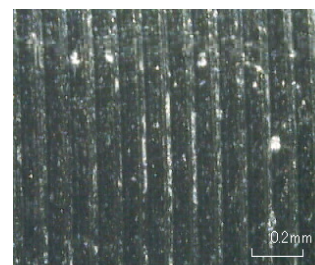


FIGURE 6. Chip comparison
(Cutting conditions: Depth of cut=0.2mm, Feed=0.1mm/rev, Cutting speed=20m/min)



(a) Ultrasonic vibration cutting : $R_a=0.55 \mu\text{m}$



(b) Conventional cutting : $R_a=1.37 \mu\text{m}$

FIGURE 7. Cutting surface
(Cutting conditions: Depth of cut=0.1mm, Feed=0.1mm/rev, Cutting speed=30m/min)

Comparison of Cutting Fluid Supply Methods

In the ultrasonic vibration-assisted cutting of the titanium alloy, cutting experiments were carried out using three cutting fluid supply methods - dry, semi-dry and wet - to investigate the surface roughness and the tool wear under these conditions.

In the dry cutting process, no cutting fluid was used. In the semi-dry cutting process, a vegetable oil was supplied at a rate of 4 ml/h in the mist form. In the wet cutting process, a water-soluble cutting fluid was supplied at a rate of 10 l/min.

Fig. 8 shows the effects of the cutting fluid supply method on the surface roughness. The semi-dry method consistently resulted in low surface roughness. Fig. 9 shows the effects of the cutting fluid supply method on the flank wear of the tool. The tool wear was the smallest in the semi-dry cutting process. In the ultrasonic vibration-assisted cutting process, the lubricating ability of the semi-dry method was effective in reducing the surface roughness and the tool wear.

Fig. 10 shows images of the cutting face of the tool. The wear of the cutting edge of the tool was significant in the wet cutting process. In the ultrasonic vibration-assisted cutting process, the vibrating cutting edge of the tool intermittently cuts the workpiece. The temperature of the materials peaks when the cutting edge cuts into the workpiece, and drops down sharply when it is pulled back. In the wet cutting process, a large temperature difference occurs at the cutting edge repeatedly, causing a large thermal shock to the edge. Consequently, microchipping occurs at the cutting edge. Based on these results, in the ultrasonic vibration-assisted cutting of the titanium alloy, the semi-dry cutting process was the most suitable, surpassing the wet cutting process and dry cutting process. The semi-dry cutting process also has the advantage of being environmentally friendly.

TABLE 2. Cutting conditions

Workpiece	Ti-6Al-4V , $\phi 50$
Cutting tool	KENNAMETAL TPGT110208K
Depth of cut	0.1mm
Feed rate	0.1mm/rev
Cutting speed	20m/min
Ultrasonic Vibration	19kHz , 0.03mm
Coolant	Dry, Semi-dry, wet

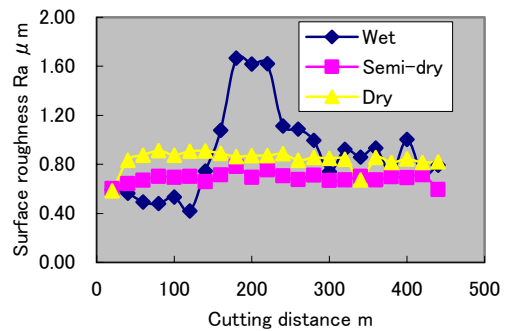


FIGURE 8. Surface roughness

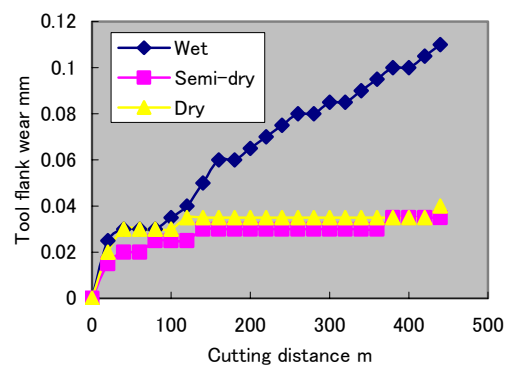
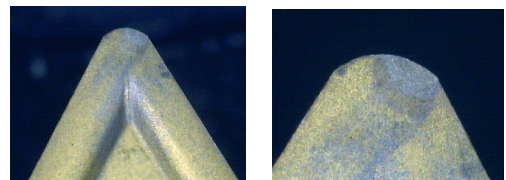
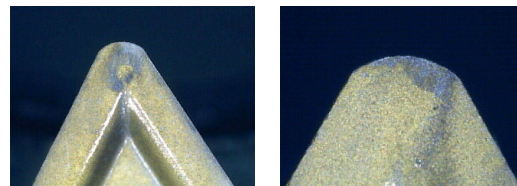


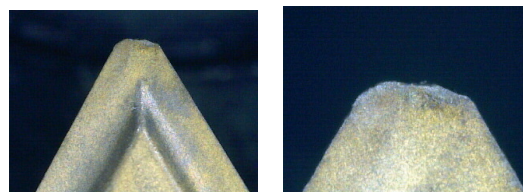
FIGURE 9. Tool wear



(a) Dry cutting with ultrasonic vibration



(b) Semi-dry cutting with ultrasonic vibration



(c) Wet cutting with ultrasonic vibration

FIGURE 10. Cutting tool tip images

Effect of Cutting Speed

Experiments with different speeds were tried to examine the effects of the cutting speed on the surface roughness of the workpiece and the flank wear of the tool, which are shown in Fig. 11. Both the surface roughness and the tool wear sharply increased at around a cutting speed of 30 m/min. The cutting speed of 30 m/min is about 30% of the maximum speed of the ultrasonic vibrating tool. Based on this, in order to achieve satisfactory cutting and a long tool life in the ultrasonic vibration-assisted cutting process, the cutting speed needs to be set at below 30% of the maximum speed of the ultrasonic vibrating tool.

TABLE 3. Cutting conditions

Workpiece	Ti-6Al-4V , ϕ 50
Cutting tool	KENNAMETAL TPGT110208K
Depth of cut	0.1mm
Feed rate	0.1mm/rev
Cutting speed	10 – 80 m/min
Ultrasonic Vibration	19kHz , 0.03mm
Coolant	Semi-dry

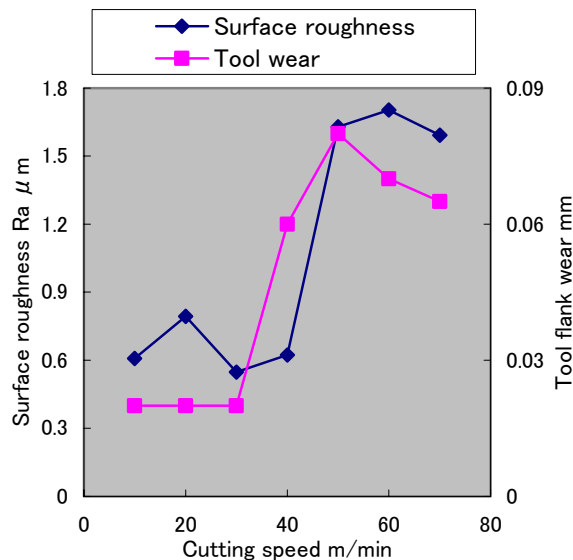


FIGURE 11. Effect of cutting speed

CONCLUSIONS

The effects of ultrasonic vibration-assisted cutting of titanium alloy were experimentally investigated. The results obtained are summarized as follows:

1. Using ultrasonic vibration-assisted cutting of titanium alloy, we succeeded in reducing the cutting resistance between one-half to one-third of that in conventional cutting.
2. Compared to conventional cutting, an improvement in surface roughness is observed in the case of ultrasonic vibration-assisted cutting of titanium alloy.
3. In regards to cutting fluid supply methods, comparisons were made of wet cutting, semi-dry cutting and dry cutting. We found that semi-dry cutting was the most suitable for ultrasonic vibration-assisted cutting of titanium alloy.
4. On investigating the effect of cutting speed in ultrasonic vibration-assisted cutting, we discovered that a cutting speed of 30 m/min showed the best performance. This speed is approximately 30 % of the maximum speed of the ultrasonic vibration at the tool tip.

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