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Tool wear propagation in Ti6Al4V laser assisted micro milling using micro ball end mill

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ABSTRACT – This paper presents an experimental study of laser assisted micro milling of Ti6Al4V using micro ball end mill. Tool wear propagation was observed and compared between conventional and laser assisted micro milling to evaluate the effectiveness of laser assisted machining technique in Ti6Al4V micro machining. It is confirmed that laser assisted micro milling technique managed to improve the tool life even when using micro ball end mill tool. The maximum flank wear reduced for approximately 50 % at machining distance of 6000 mm when the laser pulse width is increased from 1 to 2 ms.

1. INTRODUCTION

It is well reported that laser heating is capable in improving the tool life by cutting force reduction. However, less has been discussed on laser assisted micro milling using micro ball end mill [1, 2]. The effectiveness of laser assisted micro milling (LAµMill) only can be achieved when the thermal softening gives dominant influence during the machining process compared to ductility and strain hardening effect [3, 4]. The appropriate heating temperature is one of the issue being argued among researchers. The most appropriate temperature were reported in different value which ranged from 150 to 500 °C [5-7]. Even though preheating the material managed to reduce chipping wear mechanism [6], the tools were still exposed to attrition, diffusion, and plastic deformation [8].

This study was conducted to investigate the effectiveness of LAµMill compared to conventional micro milling (Conv. µMill) in dry condition using micro ball end mill tool. Low power laser was used to avoid workpiece material properties changes during the machining process

2. METHODOLOGY

The experimental setup of laser assisted micro milling machine is shown in Figure 1 . TiAlN coated cemented carbide micro ball end mill with diameter of 0.3 mm was used to perform linear groove machining. Air bearing micro spindle was set with angle of 80° from X-Y plane to reduce the effect of rubbing. Linear grove machining of 25 mm/path was performed on Ti6Al4V with depth of cut (t_c) of 0.020 mm. The experiment was done in two stages. The first stage (1$^{st.}$ stage) was done to evaluate the influence of feed (f), cutting speed (v_c) and laser heating. The second stage (2nd. Stage) was done to further evaluate the influence of laser heating at lower cutting speed (3.0 m/min) and different pulse repetition rate (t_p =1 and 2 ms).

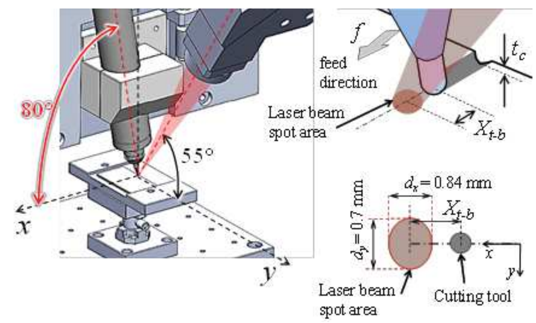

Figure 1 Laser assisted micro milling.

Table 1 Milling parameters.

Parameters	Value/ range
Depth of cut, t_c (mm)	0.020
Feed, $f \times 10^{-3}$ (mm/flute)	2.1, 3.0, 4.2
Cutting speed, v_c (m/min)	1$^{st.}$ stage : 7.6, 10.6 15.1 2$^{nd.}$ stage: 3.0

Table 2 Laser parameters.

Parameters	Value/ range
Laser focus diameter, (mm)	Elliptical, 0.70 × 0.84
Pulse repetition rate, f_p (Hz)	100
Pulse width, t_p (ms)	1 (1$^{st.}$ stage), 2 (2$^{nd.}$ stage only)

The milling parameters applied in this study are shown in Table 1. In LAµMill, the laser beam was focused with an angle of 55° from X-Y plane at distance (X_{t-b}) of 0.6 mm from the cutting tool and the detail lasing parameter is shown in Figure 1. The laser managed to heat the cutting area to approximately 130 °C to 165 °C.

3. RESULTS AND DISCUSSION

Laser heating has shown the most effect when the f was 3.0 × 10^{-3} mm/flute (Figure 2). All v_c values has shown approximately the same tool wear rate. At f of 4.2 × 10^{-3} mm/flute, v_c of 7.6 m/min has shown the best machining performance with the lowest maximum flank wear (VB_{MAX}) increment. It is suggested that laser heating has managed to give further softening effect which could significantly increase the workpiece deformability. Consequently, the tool managed to preserve the cutting edges initial geometry longer with minimum VB_{MAX} increment.

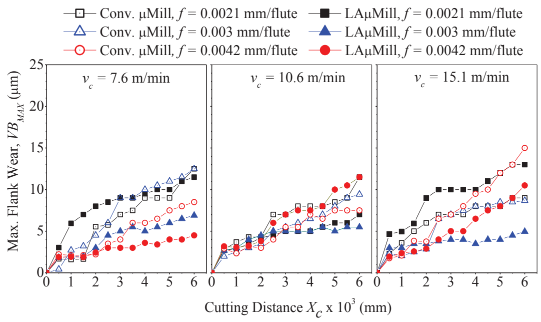

Figure 2 Comparison on maximum flank wear (VB_{MAX}) propagation between different feed (f) and machining method at t_c of 0.02 mm.

The effect of laser heating using different pulse width (t_p) can be observed form Figure 3. When the workpiece is heated up, the VB_{MAX} propagated with different rate and characteristics. In the case of LAµMill 1 which applied 1 ms for the t_p, machining using f of 2.1 × 10^{-3} mm/flute has failed to show any improvement initiated by laser heating. The tool worn out even slightly faster than Conv. µMill. Laser heating has promoted the workpiece ductility and plasticity behavior. The machining performance at f of 2.1 × 10^{-3} mm/flute become worse when the workpiece become softer and more ductile.

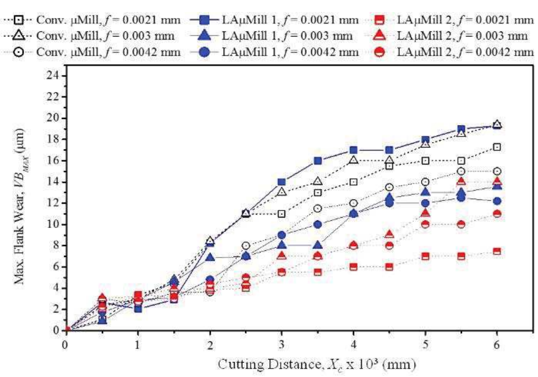

Figure 3 Flank wear increment comparison between Conv. µMill, LAµMill 1 and LAµMill 2.

Generally, observation on the VB_{MAX} has shown that LAµMill 2 performs better than Conv. Mill and even better than LAµMill 1 with approximately 30 % of VB_{MAX} reduction at X_c of 6000 mm. The increment of t_p from 1 to 2 ms has successfully gave significant influence to the machining performance. In LAµMill 2, the workpiece was heated up to a higher temperature compared to LAµMill 1. The workpiece became softer during the machining process compared to the LAµMill 1 and Conv. µMill.

4. CONCLUSIONS

From the maximum flank wear observation, the next conclusions are derived:

(a) Feed at 3.0 × 10^{-3} mm/flute gives the lowest tool wear rate in LAµMill 1. Low and considerably equal tool wear rate were observed at all cutting speed.

(b) Laser heating using pulse width of 1 ms managed to reduce the tool wear rate but not at feed of 2.1 × 10^{-3} mm/flute. Increasing the pulse width to 2 ms has successfully further improve the laser assisted micro milling efficiency. The tool wear in LAµMill 2 recorded approximately 50 % lower than LAµMill 1.

(c) LAµMill 2 which were performed at 50 °C higher temperature than LAµMill 1 managed to give significant tool wear rate decrement. Heating temperature of approximately 200 °C and above is essential to obtain good machining performance.

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