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Experimental study of micro-dimple surface roughness by applying double-frequency elliptical vibration texturing

Rendi Kurniawan[1], Sung Jae Won[1] and Tae Jo Ko[1]

[1]Yeungnam University, South Korea

rendi@ynu.ac.kr, bluetjdwo@naver.com, tjko@yu.ac.kr

Abstract

This paper presents our experimental studies to improve the micro-dimple surface roughness by applying double-frequency elliptical vibration texturing (DFEVT) method. By adding an elliptical locus of the tip tool into the conventional texturing (CT) method, the DFEVT method is carried out possibly. In a few decade, the elliptical vibration (EV) method using diamond tool that has been known reduces the cutting forces and the surface roughness value. The DFEVT method has been carried out in the 3-axis CNC (computerized numerical control) milling machine. The ultrasonic elliptical vibrator that was used in these experiments is able to generate an elliptical locus that has vertical amplitude is about 0.6 µm and horizontal amplitude is about 1.2 µm, respectively, under ultrasonic frequency 23.1 kHz and phase shift is 90°. The amplitude of sinusoidal wave that was used in the CT method is approximately 8 µm. The micro-dimple pattern was successfully establish using the PCD tool on the SC45 workpiece, under low vibration frequencies are 10, 30, and 50 Hz with constant ultrasonic elliptical locus frequency is 23.1 kHz with phase shift is 90° and the texturing velocity was used is 500 mm/min. The results show that the micro-dimple surface roughness by applying the DFEVT method is reduced which is compared to the CT method depends on a texturing condition.

Keywords
Ultrasonic elliptical surface texturing, micro-dimple pattern, surface roughness

1. Introduction

This paper presents an experimental study of micro-dimple surface roughness comparison between the conventional texturing (CT) method and double-frequency elliptical vibration texturing (DFEVT) method. Shamoto claimed that surface roughness is reduced by applying the Elliptical Vibration Cutting (EVC) using diamond tool [1]. However, opposite results were reported by Kim, et.al. By using the EVC method, the surface roughness becomes increasing, although the side burr of the micro-groove is able to be removed significantly [2].

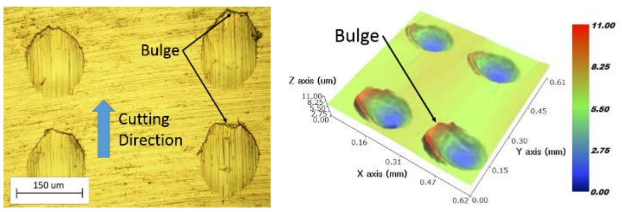


Figure 1. Bulge is formed by using CBN tool insert [3].

Based on the authors experiences, establishing the micro-dimple using a large edge tool radius (such as CBN tool) could form the bulge on the exit region as shown in Fig 1. A smaller edge radius is possible to avoid the bulge however sometimes, without expectations, it produces bad roughness of the bottom surface. By increasing the cutting speed, we can improve the surface roughness [4], however, there is a constraint that the computerized 3-axis machine has a maximum feed velocity no bigger than 1 m/min. Previous studies reported that cutting carbon steel using diamond tool is impossible due to rapid chemical wear of diamond tool [5]. Due to this reasons, a study of the DFEVT has been carried out to investigate a possibility enhancing the quality of a micro-dimple on the carbon steel surface using a PCD tool, especially reducing the roughness and removing the bulge on the exit region.

2. Double-frequency elliptical vibration texturing

Fig. 2 illustrates the DFEVT method in which the method is combination between low and ultrasonic vibration. The tool is able to rotate elliptically and penetrate the workpiece by a sinusoidal motion. The relative equation of tool motion in Cartesian coordinate can be described by Eq. 1 and 2. *a* and *b* is the minor and major amplitude of elliptical locus. φ is different phase. f_h and f_l is high frequency vibration and low frequency vibration, respectively. V_f is cutting velocity. *B* is amplitude of low sinusoidal motion. *t* is time.

$$x(t) = a \cdot \cos(2\pi f_h t + \varphi) + V_f \cdot t \tag{1}$$

$$y(t) = b \cdot \cos(2\pi f_h t) + B \cdot \cos(2\pi f_l t) \tag{2}$$

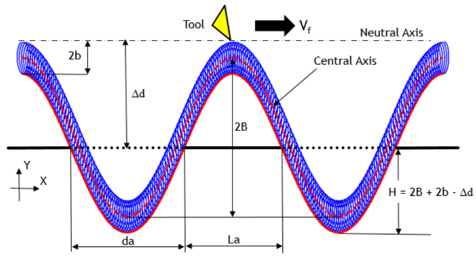


Figure 2. Illustration of DFEVT method.

3. Experimental Setup

Table. 1 shows the trial setup of experiment. The experiment were conducted by using 3 different low vibration frequencies f_l: 10, 30, and 50 Hz. So that, the dimension of micro-dimple is appropriate for friction reduction application (range of 100 – 300 µm in length). The cutting speed was used constant at low about 0.5 m/min, so that the velocity vibration was maintained bigger than the cutting speed. A micro-groove experiments were also established in order to see the effect of removing side burr of the ultrasonic elliptical vibration (UEV) method.

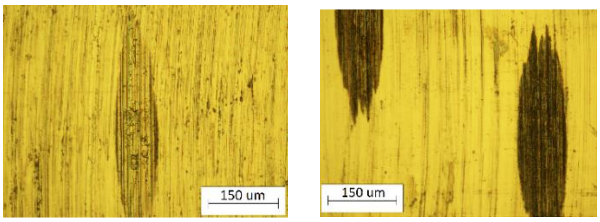
Table 1. Texturing parameters.

Texturing parameters	Material: AISI 1045 (H_RC: 30)
Low vibration frequency, f_l	10, 30, 50 Hz
Cutting velocity (micro-dimple), V_f	0.5 m/min
Cutting velocity (micro-groove), V_f	1000, 500, 100 mm/min
High vibration frequency, f_h	23.1 kHz
Phase shift, φ	90°
Minor amplitude, a	0.3 µm
Major amplitude, b	0.6 µm
Low vibration amplitude, 2B	8 µm

4. Experimental Results

4.1 Micro-dimple results

The micro-dimple was established on the medium steel alloy using PCD tool insert. Based on Fig. 3, the bulge on the exit region does not exist for both CT and DFEVT. Thus, using sharp cutting edge radius such as PCD tool can eliminate occurrence of the bulge. It was observed that in case CT method, a rough surface was produced at the bottom of micro-dimple, as shown in Fig. 3. This rough surface occurs because the friction between the flank face and micro-dimple surface at low cutting speed condition. On the other hand, by using the DFEVT method, the surface roughness is typically distributed uniform. Fundamentally, the DFEVT method increases the relative cutting velocity during cutting process. Fig. 4 shows the summary of comparison the arithmetic roughness between CT and DFEVT. In case of f_l=50 Hz, it shows that the roughness using CT is lower than compared to DFEVT method.



(a) ***(b)***

Figure 3. Micro-dimple at f_l: 10 Hz, f_h: 23.1 kHz and V_f: 500 mm/min **(a)** CT method, ***(b)*** DFEVT method.

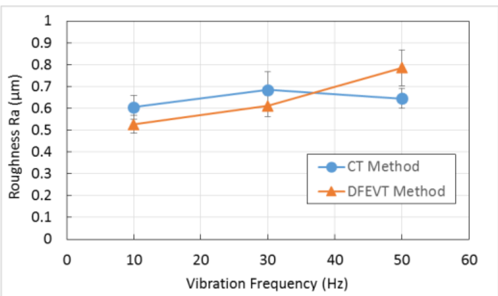
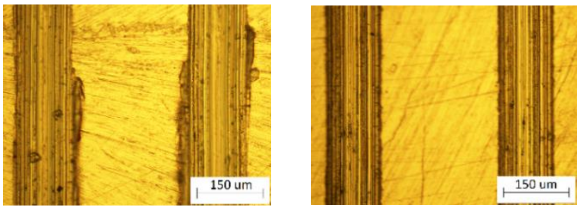


Figure 4. Surface roughness *Ra* comparison without and with DFEVT.

4.2 Micro-groove results

The micro-grooves were conducted in order to investigate the effect of removing side burr of the UEV method. As seen in Fig. 5, the side burr of the micro-groove is removed by using UEV method due to the effect the ultrasonic tool locus motion. In conventional method, a specific cutting energy increases due to the size effect at small cutting depth of cut, yielding plastic deformation and burrs at cutting regions. Due to intermittent cutting in the UEV method, the UEV method reduces significantly the frictional force between the tool edge and chip, yielding the specific cutting energy reduces and removing the burr occurrences. Surface roughness of the micro-groove was measured and compared which shows in Fig. 6. The roughness of micro-groove using UEV has better value compared to conventional method.



(a) ***(b)***

Figure 5. Micro-groove at f_h: 23.1 kHz and V_f: 1000 mm/min ***(a)*** conventional grooving, ***(b)*** using UEV method.

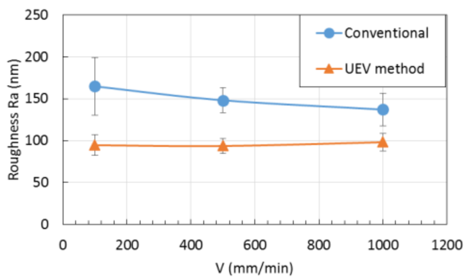


Figure 6. Surface roughness comparison between conventional grooving and UEV method using different cutting velocity.

5. Conclusion

The roughness of micro-dimple is reduced by using the DFEVT, depends on the texturing parameter is used. The side burr of micro-groove can be removed by applying UEV method.

Acknowledgement

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