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Finite element study of two-dimensional ultrasonic vibration-assisted cutting

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Abstract

Recently, the ultrasonic vibration-assisted cutting (UVAC) becomes more attractive in academia due to several benefits compared to conventional cutting (CC), for example, decreasing cutting load, decreasing flank wear, and improving roughness. In this manuscript, the two-dimensional ultrasonic vibration-assisted cutting (2D-UVAC) was carried out through finite element (FE) in AdvantEdge software. The FE study becomes more sophisticated in the metal cutting process because of its ability to predict cutting output especially cutting forces. In this FE study, the ultrasonic vibration frequency of the cutting tool was adjusted from 16 to 32 kHz. Meanwhile, the maximum transient depth of cut (DOC_t), cutting speed (V_F), and vibration amplitude was set as a constant value. In the AdvantEdge, the adaptive re-meshing and the updated Lagrangian were embedded in the FE algorithm thus a large element distortion can be possibly avoided for the micro-cutting process. A two-dimensional orthogonal cutting was adopted in this FE study. The workpiece was set as SC45 and the tool material was set as cubic boron nitride (CBN). In this paper, both principal and thrust forces are the main objective of this study. The FE simulation results show that the cutting forces in the 2D-UVAC are periodically changing due to transient depth of cut. Based on comparison results, the cutting forces in the 2D-UAVC is averagely lower than that in the CC process. Based on the FE result, the average cutting forces are decreased by increasing vibration frequency in the 2D-UAVC.

Keywords: Cutting; Finite element method (FEM); Force; Ultrasonic.

1. Introduction

Finite element (FE) is a computation tool that can be utilized to examine an engineering problem. In metal cutting, the FE method has been proved as a sophisticated tool to manly solve cutting force, von Misses stress, cutting temperature, strain, strain rate in the main contact zone between tool and chip. The FE method has some benefits for solving complicated problems such as multi-coated tool analysis [1], textured cutting tool [2], tool wear and chip formation [3].

In the field of vibration-assisted cutting, a few FE studies [4,5] have been conducted to predict mainly cutting forces, cutting temperature and stress. The cutting force and stress in the vibration-assisted cutting is significantly lower than that in the conventional cutting [4], due to disengagement of the cutting tool from the main cutting zone. In conventional cutting, the cutting tool engages permanently with the deformed chip in the deformation zone during the entire cutting process. Meanwhile, in the vibration-assisted cutting, the cutting tool engages with the deformed chip about 40% of the 100% duty cycle [5].

The 2D-UAVC is different than the ordinary vibration assisted cutting. Wherein in the 2D-UVAC, the cutting tool is vibrated elliptically in two-directions: the thrust and cutting directions [6]. One of benefit using the 2D-UAVC is a lower roughness than that in conventional cutting [6].

In this short manuscript, the main aim of this FE study is to investigate the cutting forces during the 2D-UVAC process. The FE study was conducted by setting ultrasonic vibration in variable values from 16 to 32 kHz.

2. FE simulation setup

Table 1 shows the simulation parameter in the case of the ultrasonic vibration frequencies which were varied from 16 to 32 kHz. The cutting speed, maximum depth of cut, and vibration amplitude were set as constant. Figure 1 shows the FE simulation setup where a sliding constraint is set at the bottom. Table 2 shows the dimension and meshing parameter. The meshing parameter has been selected appropriately to save computation time without losing its accuracy.

Table 1 Simulation cutting parameter in the 2D-UVAC

Simulation parameter	Value
Cutting Speed (V_F)	1500 mm/min
Max Depth of Cut (DOC_{max})	10 µm
Frequency (*f*)	16 - 32 kHz
Amplitude x- and y-axis (*a and b*)	1 µm
Phase shift (θ)	45°
Length of cut	200 µm
Tool material	CBN
Workpiece material	AISI 1045

Table 2 Dimension and meshing parameter

Rake angle	0°	Node element	72000
Clearance angle	7°	Max size (µm)	10
Cutting edge radius	3 µm	Min size (µm)	1
Workpiece height	40 µm	Refinement factor	2
Workpiece length	200 µm	Coarsening factor	6

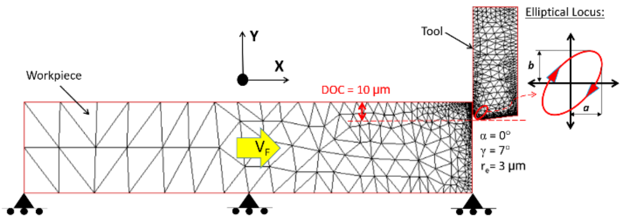

Figure 1. Simulation setup for the 2D-UAVC process

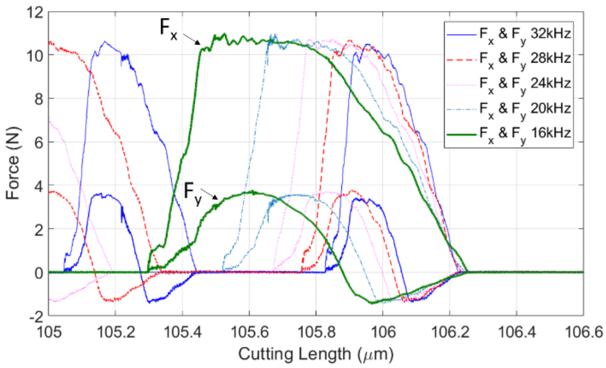

Figure 2. Cutting force F_x and F_y with different ultrasonic frequencies

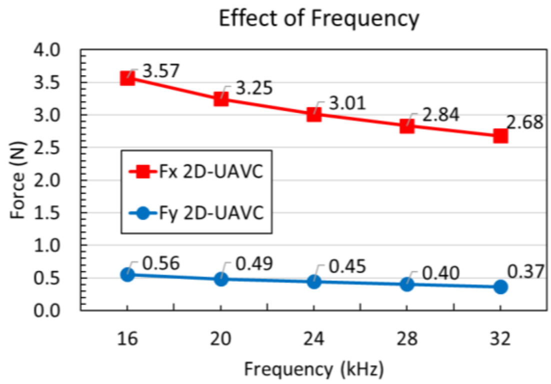

Figure 3. The trend of the cutting force F_x and F_y with different ultrasonic frequencies

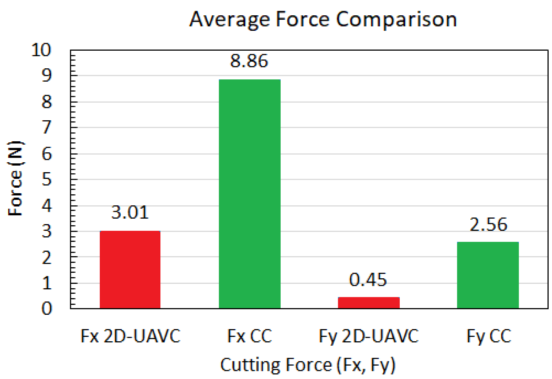

Figure 4. Comparison of the average cutting force F_x and F_y

3. FE simulation results

3.1. Effect of vibration frequency

Figure 2 shows the cutting force F_x and F_y shape when the ultrasonic vibration frequencies are varied. In the case of the principal cutting force F_x, the force starts to climb due to an increase in the depth of cut. And then F_x achieves maximum when the depth of cut is maximum. Finally, F_x decreases as the depth of cut decreases. In the case of the thrust cutting force F_y, while Fx decreases, the F_y also decreases up to the negative value in which the friction reversal effect occurs. The friction reversal occurs due to the tool slides upward to the deformed chip instead of a cutting process. Both F_x and F_y are equal to zero because the cutting tool disengages from the main cutting zone.

The effect of increasing vibration frequency makes a substantial benefit. Both F_x and F_y decrease as the vibration frequency increases as shown in Figure 3. It is acknowledged that by increasing vibration frequency, it leads to a decrease in cutting contact length between tool and workpiece during cutting (see Figure 2). In other words, the contact period between tool and workpiece decreases when the vibration frequency increases.

3.2. Comparison to CC process

In the comparison process, the ultrasonic vibration frequency was set at 24 kHz in the 2D-UAVC case. Meanwhile, the cutting speed and depth of cut was set similar for both methods at 1500 mm/min and 10 µm, respectively.

Figure 4 shows a comparison of the cutting force F_x and F_y between the 2D-UAVC and the CC process where the cutting force in the 2D-UAVC process is less than that in the CC process. It can be understood clearly that in the CC process, the cutting tool and the deformed chip always contact during the entire cutting process. Meanwhile, in the 2D-UAVC process, the cutting tool disengages periodically from the main cutting zone, it yields a reduction of the average cutting force.

4. Conclusion

Based on the FE results, the principal (F_x) and thrust (F_y) cutting force decreases by increasing the ultrasonic vibration frequency in the 2D-UAVC. The FE result also shows that the average cutting forces in the 2D-UVAC are significantly lower than that in the CC process due to the disengage effect of the cutting tool.

Acknowledgment

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