FEM Simulation of Elliptical Vibration Cutting

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Ultrasonic vibration cutting processes of inconel 738 are modeled and simulated in the present research, utilizing MSC-Marc FEM software. The vibration is applied to the cutting tool along the cutting velocity and the thrust directions denoted by elliptical vibration cutting (EVC). The cutting forces and the stresses developed within the workpiece during the vibration cutting processes are estimated and compared with those in the conventional cutting (CC) process. The influence of various parameters such as speed ratio (SR), amplitude and phase shift is subsequently investigated. It is partially concluded that though the cutting force fluctuates periodically in EVC, its average and instantaneous values are lower than those in CC. The shear angle increases and the cutting force decreases with a rise in SR in EVC process.

1. Introduction

Ultrasonic vibration cutting is an advanced machining in which high frequency vibration is superimposed on the movement of a cutting tool. The vibration may be applied to the cutting tool in one or two directions denoted by vibration cutting (VC) and elliptical vibration cutting (EVC), respectively.

In this paper, the authors studied cutting of Inconel 738 with the tool vibrating elliptically at ultrasonic frequency, using Msc-Marc. The engagement process between the workpiece and the tool was simulated, and cutting forces, stresses acting on the workpiece and shear angle during the processes were evaluated. Then, effects of speed ratio (SR), amplitudes and a phase shift on cutting force and shear angle were investigated.

2. Modeling of the orthogonal cutting process

The finite element model of the workpiece and the rigid tool insert are illustrated in Fig. 1. Msc-Marc has been employed in order to analyze the process, where the tool is considered to vibrate at an ultrasonic frequency of 36.16 kHz, amplitudes of 4 \( \mu \)m, and a phase shift of 90° in EVC. For comparison, machining force and stress in the conventional cutting (CC) have been analyzed. Cutting speed for CC is assumed to be 454 mm/s, which is equal to the vibration speed in EVC. Iconel 738 workpiece, which is 0.2 mm long and 0.05 mm high, has been employed for FE analysis. Undeformed chip thickness is assumed to be 4 \( \mu \)m. The rake and the clearance angles are assumed 0 and 7°, respectively. The above values are standard conditions, and the amplitudes, the phase shift and the cutting speed are changed to investigate their effects.

The boundary condition is assumed to be isothermal. An element type of Quad4 has been adopted for the analysis. The workpiece model initially contains 96 elements and 118 nodes. It should be mentioned that the number of elements and nodes change due to automatic remeshing during the analysis. This remeshing is needed for accurate simulation, since the deformation is large and the material is separated at the cutting edge. By applying the above conditions to the tool and the workpiece during ultrasonic vibration cutting processes, analysis of forces, stress and shear angle was performed.

3. Results and discussions

Relative positions of the tool and the workpiece and calculated stress distributions during the ultrasonic vibration cycle of EVC are illustrated in Fig. 2. The machining forces in CC and EVC are compared in Fig. 3. It is clear that the machining forces in EVC are significantly lower than those in CC, during the cutting period. As shown in Fig. 3, the machining forces (principal and thrust forces) are periodically exerted. In EVC, thrust force becomes negative in the latter part of
cutting period. This means that friction direction is reversed in this EVC process. This negative thrust force causes reduction in chip thickness and hence reduction in the principal force especially during the negative period.

Figure 4 shows the change of the maximum stress in the machining zone in processes. The maximum stress is almost the same in EVC and CC, since the same material is deformed in the cutting processes.

Effect of the SR on the machining forces in EVC is illustrated in Fig. 5, where SR is defined as a ratio of the maximum vibration speed in the cutting direction to the nominal cutting speed. SR is changed by changing cutting speed from the standard value. As shown in the figure, there is definite inverse correlation between the machining force and SR until it converges to a constant value. Also with an increase in S.R, duration of positive thrust force is decreased and duration of negative thrust force is increased.

Variations of the machining force against the vibration amplitudes $a$ and $b$ in EVC have also been analyzed. The results are shown in Fig. 6. Higher vertical amplitude $b$ causes smaller machining force, while the horizontal amplitude $a$ does not change the machining force so much. Generally in EVC, increasing amplitudes causes decreasing machining force, because the friction is reduced or reversed as the amplitudes are increased.

The shear angle is one of the most important parameters in metal cutting. It determines area of the shear deformation, cutting force, energy, heat generation, and so on. Therefore, it has also been analyzed, and influences of the machining parameters are investigated. The calculated shear angles in CC and EVC are summarized in Fig. 7, which also shows variations of the shear angle against the speed ratio SR in EVC. The shear angle in EVC is greater than that in CC. It is increased with an increase in SR, and then it converges to a constant value.

Variations of the shear angle against variations of the amplitudes $a$ and $b$ have also been analyzed. The results are shown in Fig. 8. When both of the horizontal and vertical amplitudes $a$ and $b$ are increased, the shear angle increases. However, increase of either amplitude has a little influence on the shear angle.

Fig. 9 shows influence of the phase shift on the shear angle. It indicates that the shear angle increases with an increase in the phase shift, and that it converges to a constant value.

4. Conclusions

The EVC and CC processes have been modeled and simulated by using the FEM software in this research. The results can be summarized as follows:

- The machining forces and the stress distribution within the workpiece vary periodically in EVC process, and the maximum force in EVC is significantly lower than that in CC.
- In EVC, the thrust force becomes negative in each vibration cycle.
- In EVC, the machining force depends heavily on SR and decreases with an increase in the S.R.
- The shear angle in EVC is greater than that in CC. In EVC, the shear angle increases with an increase in SR and then converges to a constant value.
- The shear angle in EVC increases with an increase in the vibration amplitudes or the phase shift.

REFERENCES