International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 5 Issue 6 ǁ June. 2017 ǁ PP. 27-31

Investigations of Ultrasonic Vibration cutting of Ti-6Al-4V (TC4)

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Project number: 16KY0122

Abstract: *A wide variety of applications have shown that the ultrasonic vibration cutting is more effective than traditional cutting with lower cutting forces, less tool ware, better cutting stability and higher surface quality. Ultrasonic vibration machining is particularly advantageous in the surfacing of difficult-to-cut materials. This paper use the ABAQUS to simulate the cutting process of normal and vibration cutting. The effects of ultrasonic vibration on cutting force, chip shape and stress field are studied in this paper. The results show that the ultrasonic vibration cutting has some advantages in cutting Ti-6Al-4V (TC4).*

Keywords: *ultrasonic vibration cutting, ABAQUS, simulate, cutting force*

I. INTRODUCTION

Ultrasonic vibration machining is a method that applies a high frequency and small amplitude vibration to the moving tool to promote the discontinuous separation of chip and to suppress regenerative chatter in turning operation. Professor Kumabe[1,2,3] put forward the vibration cutting theory systematically fist. Subsequently, the theory was successfully applied to many machining fields, including: vehicle, milling, grinding, drilling,boring, hinge, and so on, and achieved good results. Amini[4] investigated the machinability of Al_2O_3 in vibration assisted turning using PCD tool. Bulla[5] utilized the ultrasonic assisted diamond turning of hardened steel for mould manufacturing. Xu[6] studied the mechanics and material removal mechanisms of vibration-assisted cutting of unidirectional fibrereinforced ploymer composites. Shimizu[7] studied the surface microtexture using vibration cutting. Maurotto[8] compared the machinability of Ti-15-3-3-3 and Ni-625 alloys in Ultrasonic assisted vibration cutting. Dong[9] made an experimental investigation on ultrasonic vibration-assisted turning of SiCp/Al composites. Xu[10] reported the elliptic vibration-assisted cutting of fibre-reinforced polymer composites: understanding the material removal mechanisms.

II. PRINCIPLE OF UV CUTTING AND SYSTEM DESIGN

Figure 1 shows a schematic illustration of the typical cutting process with adding the ultrasonic vibration on the cutting tool. The workpiece is fed at the nominal cutting speed in the positive x-direction and the cutting tool vibrates at the same time in the plane in the negative x-direction which is parallel to the uncut surface.

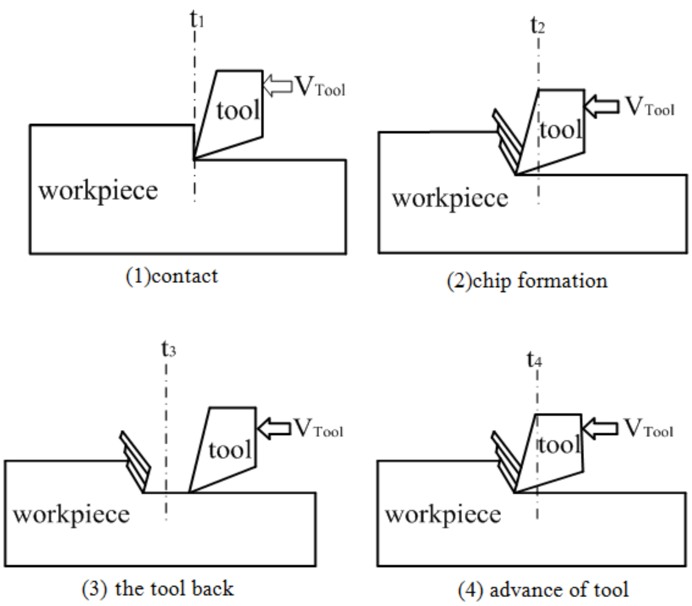


Fig. 1 Tangential ultrasonic vibration cutting

Suppose that the ultrasonic vibration trajectory of the cutting tool is described as follows:

$$\begin{cases} x_{Tool}(t) = A\cos(2\pi ft), \\ y_{Tool}(t) = B\sin(2\pi ft), \end{cases} \qquad (1)$$

where A and B are the vibration amplitudes in x-direction and y- directions,respectively,and f is the vibration frequency.

Supposed that the workpiece's speed is positive,the relative motion of tooltip to workpiece in UV cutting is :

$$\begin{cases} x(t) = vt + A\cos(2\pi ft), \\ y(t) = B\sin(2\pi ft), \end{cases} \quad \begin{pmatrix} 1DXUVcutting : A \neq 0, B = 0 \\ 1DYUVcutting : A = 0, B \neq 0 \\ 2DUVcutting : A \neq 0, B \neq 0 \end{pmatrix} \qquad (2)$$

The relative motion speed of tooltip to workpiece is:

$$\begin{cases} v_x(t) = v - 2\pi fA\sin(2\pi ft), \\ v_y(t) = 2\pi fB\cos(2\pi ft), \end{cases} \quad \begin{pmatrix} 1DXUVcutting : A \neq 0, B = 0 \\ 1DYUVcutting : A = 0, B \neq 0 \\ 2DUVcutting : A \neq 0, B \neq 0 \end{pmatrix} \qquad (3)$$

As summarized in the previous section, compared with a relevant traditional cutting process the UV cutting has shown its promising advantages in increasing tool life ,improving surface finish,reducing cutting forces and enhancing machining accuracy. Since then,it is clear that choosing an appropriate vibration parameters will be important to maximize advantages. An obvious criterion is that the maximum tooltip vibration speed in the cutting direction, $v_{x_{\max}}(=2\pi fa)$, should be higher than the tool feed rate[11,12,13],i.e, $v_{x_{\max}} > v$,as otherwise the vibration cannot play a role in cutting.Thus in the discussion in this paper, $v_{x_{\max}} > v$ will be a default assumption.

III. FINITE ELEMENT SIMULATION OF ULTRASONIC VIBRATION CUTTING

Vibration cutting is a new type of special cutting method, which is to give the tool (or the workpiece) in the appropriate direction, a certain frequency, amplitude of vibration, to improve the cutting efficiency of the pulse cutting method. Compared with ordinary cutting, the vibration cutting can reduce the cutting force and the cutting heat, improve the quality of the workpiece surface, cut chip easily, improve the tool endurance and machining stability, so it is considered to be a important development direction of machining study[14]. In order to acquire detailed results of process variables, such as stress, strain, strain rate and temperature which are extremely difficult to measure with current technology, it's important to apply the finite element method(FEM) and numerical simulation in the ultrasonic vibration cutting. This paper utilized a 2D ultrasonic vibration cutting model to simulate the cutting process, As shown in Fig 2. While the devices of ultrasonic vibration cutting include spindle, dynamometer, ultrasonic transducer and so on are shown in Fig.3

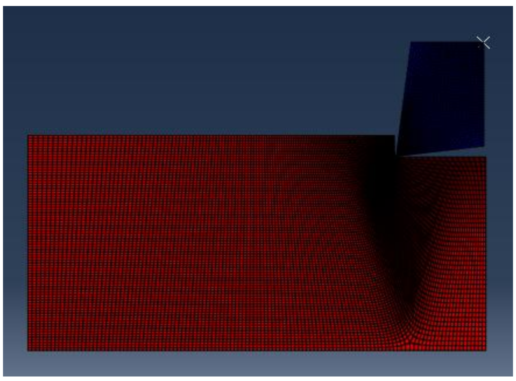


Fig.2 Contact between the workpiece and tool in ultrasonic vibration cutting model

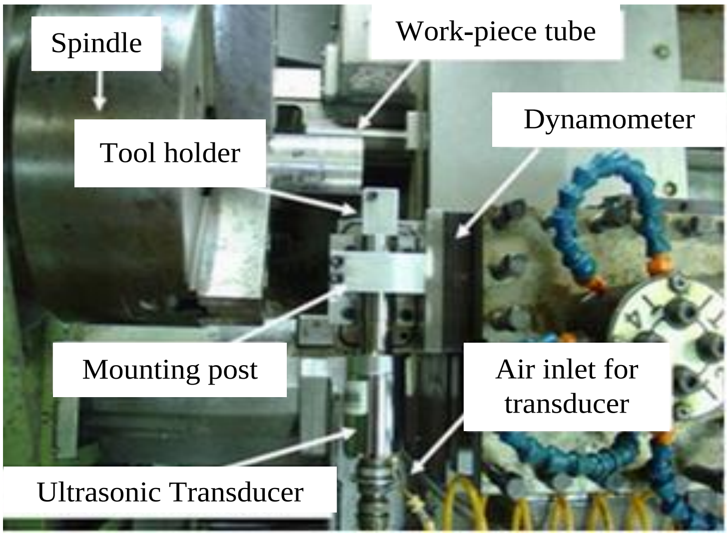
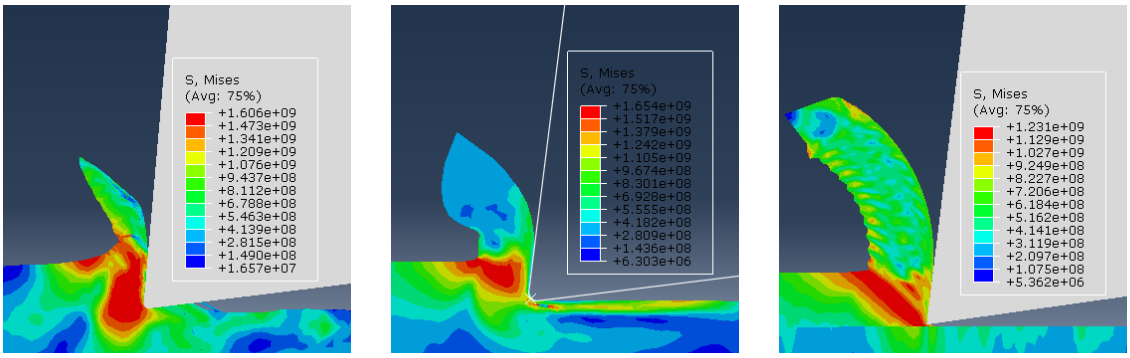


Fig.3 Ultrasonic vibration machining devices[15]

IV. SIMULATION RESULTS

4.1 Chip shape

By Fig 4 (a), (b), (c) it can be seen that vibration cutting shows the tendency of crimp compared with the ordinary cutting. The chip in the vibration cutting is not a serrated chip as in the ordinary cutting, but a strip, for the cutting speed is low in the vibration cutting and the cutting thickness is small. And with the increase of cutting speed, vibration cutting chip shape will tend to ordinary cutting form. Compared with the ordinary cutting, the thickness of vibration cutting is small for there is no squeezing on the workpiece, little intense friction between the tool-chip, lower cutting heat and smaller scraps of plastic deformation. Due to the impact, the shear angle in vibration cutting is bigger than in ordinary cutting and it's more advantageous to the chip separation.



(a)Vibration chip shape （b） strip chip （c） serrated chip

Fig.4. Chip shape

4.2 Cutting force

It can be seen from Fig 5 that the cutting force of ultrasonic vibration cutting is much smaller than normal cutting. The reason is that the ultrasonic vibration cutting is a process of constant contact and separation. There is quite a long time that the tool is separated from the chip in the process of ultrasonic vibration turning, and the friction is small when the tool is separated from the workpiece thus leading to a small cutting force. While in ordinary cutting, the cutting tool and the workpiece are always in contact, the cutting force is high and maintains the fluctuations in this value. It is obvious that the ultrasonic vibration turning can significantly reduce the cutting force.

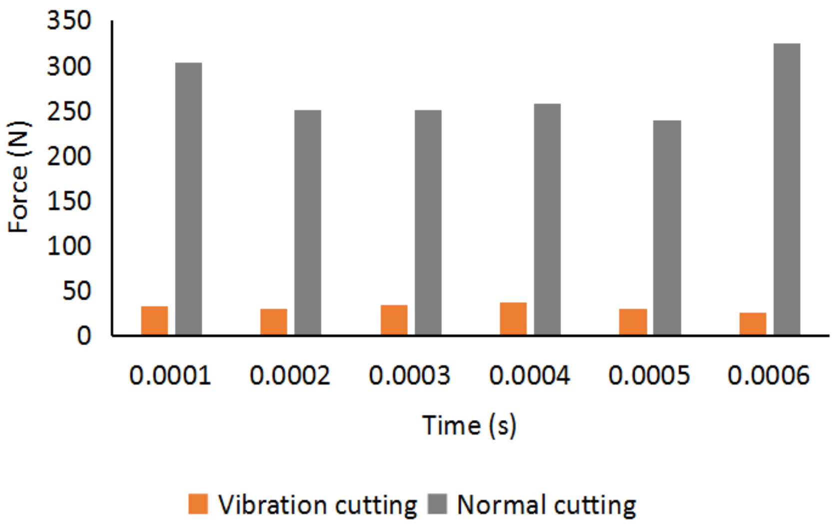


Fig.5. Cutting force

4.3 Cutting stress

In ultrasonic vibration turning, there is mainly compressive stress between the tool tip and the workpiece and tensile stress between the contact area of the flank face and the workpiece. In the process of ultrasonic vibration turning tool-chip is a process of continuous contact separation. Therefore, there is quite a long time that the tool-chip is in the separation state in the process of ultrasonic vibration turning, meaning that there is no extrusion between the tool and the chip. The average stress in the ultrasonic vibration turning is smaller than the ordinary cutting, as shown in Fig.6.

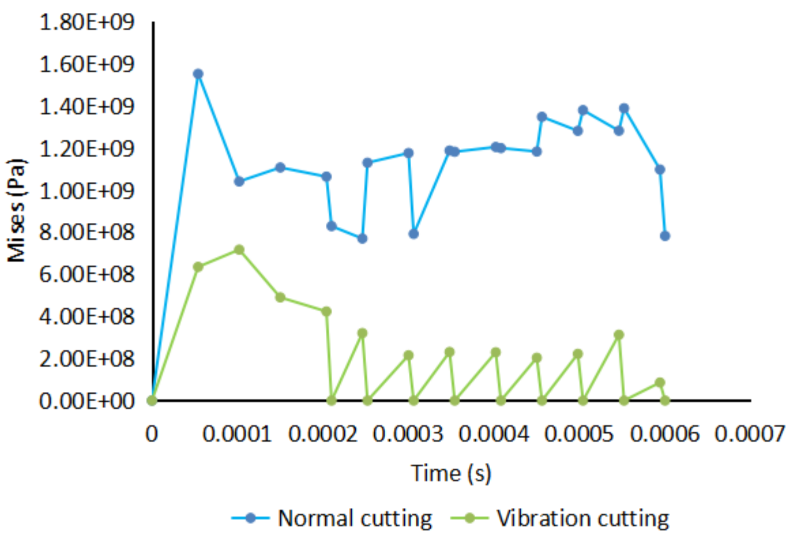


Fig.6. The stress of normal cutting and vibration cutting

V. CONCLUSION

The ordinary unsteady cutting model and ultrasonic vibration cutting model was proposed to comparatively analyze the impact of ultrasonic vibration on the chip shape, cutting force and stress field in the metal cutting based on TC4 as the research object. The results show that the ultrasonic vibration cutting can significantly reduce the cutting force and the value of stress. It also can improve the quality of machining surface and reduce the tool wear.

ACKNOWLEDGEMENT

This project is sponsored by Shanghai University of Engineering Science Innovation Fund for Graduate Students (No. 16KY0122).

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