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Study on optimization of texture parameters in micro-textured cutting of titanium alloy based on ABAQUS

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Abstract: *Tools with micro-textured surfaces can successfully lessen the primary cutting surfaces and decrease tool friction. To conduct additional research on the impact of microtexture parameters (depth, width, and spacing) on the cutting of titanium alloy. In this paper, a two-dimensional finite element simulation model for titanium alloy cutting using micro-textured tools is established by using Abaqus software, based on the response surface method, the influence of different microtexture parameters on the chief cutting surfaces and the interaction of microtexture depth, microtexture width,and microtexture spacing is obtained, it is concluded that the effect of the depth of microtexture on the chief cutting surfaces is the most significant, the microtexture spacing is the second, and the microtexture width is the weakest. The optimum parameters of the microtexture tool are microtexture depth 20μm, microtexture width 30μm, and microtexture spacing 80μm. The chief cutting surfaces is 208.26 N.*

Keywords: *Micro-textured tools, Response surface methodology, TC4*

1. Introduction

Because of its outstanding strength, outstanding resistance to corrosion and high heat resistance, titanium alloy is a critical alloy metal that is employed extensively in the aerospace, automotive, aircraft, and other industries. Due to its low deformation coefficient, however, the sliding friction path of the chip on the rake face is greatly increased, which accelerates tool wear. Therefore, a titanium alloy is considered as a typical hard-to-machine material. Many researchers have taken different approaches to mitigate this phenomenon.

Costa et al [1] have shown that parallel grooves are relatively good for improving tool-chip interface friction. Wu Ze [2] and others have conclude that the a reasonable surface microtexture can improve the cutting performance of the tool. The results show that the tool life can be extended by 20-25% by using the micro-texture tool. Ali Shafahat [3] et al obtained by orthogonal cutting experiments on AISI 630 stainless steel using different microgroove cutting tools that the cutting temperatures of rectangular and triangular microgroove cutting tools were reduced by about 10% and 7% ,respectively,the results show that the performance of rectangular micro-textured tools is relatively good. Kawasegi N [4] et al obtained lower cutting surfaces by using a microtexture tool in a cutting experiment. Patel [5] investigated the influence of different texture depths, texture width and texture spacing on cutting speed and feed rate by designing an orthogonal experiment, the effects of micro-groove parameters on specific cutting surfaces, the friction along the tool-chip contact and tool wear are achieved.

Reasonable surface microtextures can effectively reduce the friction of cutting tools, have the effect of lubrication, and can improve the quality of the workpieces. Based on Abaqus, a two-dimensional finite element simulation model for cutting titanium alloys with a micro-texture tool is created, and the response surface method is used to optimize the micro-texture combination and obtain the optimal combination of parameters.

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2. The finite element model of cutting surfaces is established

2.1 Geometric modeling

In this paper, Abaqus is used to construct the geometric model of two-dimensional right-angle cutting of titanium alloy, which is shown in Figure 1. To simplify the construction of the cutting model,the two-dimensional cutting model is usually used instead of the three-dimensional cutting process, and the two-dimensional rectangular section model is constructed to simulate the process of cutting titanium alloy TC4. Because of the difficult machining characteristics of titanium alloy, YG8 cemented carbide tool is used in this paper. The geometric dimension of the workpiece is 1.5mm × 0.8mm, the rake angle of the tool is 5°, the back angle is 7° and the radius of the cutting edge is 0.01mm. Figure. 1 is a geometric model of a two-dimensional perpendicular cut.

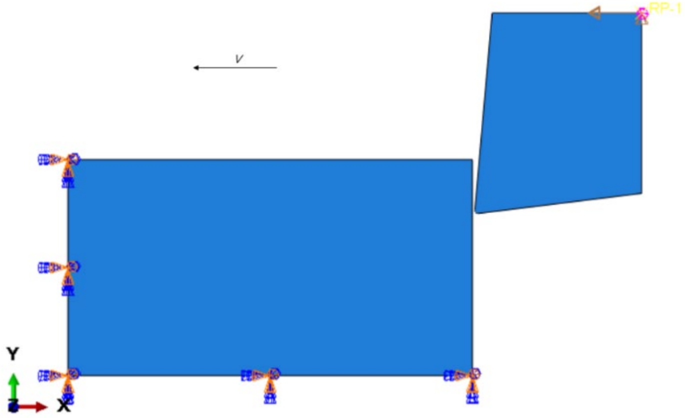

Figure 1: Two-dimensional right-angle cutting geometry model

To express the relationship between stress and strain and reflect the hyperelasticity and nonlinearity of materials, the constitutive model has been established. At present, there are many constitutive models, CT4 in the cutting process by cutting surfaces and cutting heat, resulting in large elastic-plastic strain. Therefore, the Jonson-Cook constitutive model is used to simulate the stress-strain relationship of CT4 during milling. The expression for this model can be written as follows:

$$\sigma = (A + B \cdot \varepsilon^{n})\left(1 + C \cdot \ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_{n}}\right)\right)\left(1 - \left(\frac{T - T_{r}}{T_{m} - T_{r}}\right)^{m}\right) \quad (1)$$

Where A, B, C, M and n are the material constants, T is the parameter temperature, TM is the melting temperature, Tr is the room temperature and ε is the corresponding plastic strain. E is the corresponding plastic strain rate and ε0 is the reference strain rate. The corresponding JC constitutive model information is presented in Table .1.

Table 1: Constitutive JC model data from CT4 material

A	B	C	n	m	T_m	T_r
862MP	331MP	0.012	0.2	0.8	1560	250

The physical, mechanical and thermal parameters of the workpiece and tool materials are shown in Table. 2 and Table .3 respectively.

Table 2: Physical properties of cemented carbide materials [6]

Density	Young's Modulus	Poisson's Ratio	Specific Heat Capacity	Heat Transfer Coefficient
1.44 g/cm3	640 GPa	0.22	220 J/(kg·C)	75.4 W/(m·K)

Table 3: The physical properties of CT4 material [7]

Density	Young's Modulus	Poisson's Ratio
4.44 g/cm^3	108 GPa	0.34

Cutting is the process of removing material. In the element simulation, the deformation failure of the shear element and the fracture element are removed. Due to the constitutive model of JC, the corresponding failure and separation criteria use the Jonson-Cook damage development model. The

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principle of the model is to set incremental steps by iterative convergence of the finite element software to perform the damage evolution of the mesh element. When the damage parameter ω > 1, the element fails and is removed. The damage parameter ω can be calculated as follows:

$$\omega = \sum \frac{\Delta\varepsilon^{pl}}{\varepsilon_f^{pl}} \tag{2}$$

Δεpl is equivalent plastic strain increment, εplf is failure strain, and the failure strain formula defined by the Jonson-Cook damage evolution model can be expressed as:

$$\varepsilon_f^{pl} = \left[d_1 + d_2 exp d_3 \left(\frac{\sigma_m}{\bar{\sigma}}\right)\right]\left(1 + d_4 \ln \frac{\varepsilon^{pl}}{\dot{\varepsilon}_0}\right)\left[1 - d_5 \left(\frac{T - T_0}{T_{melt} - T_0}\right)\right] \tag{3}$$

Among them, d1、d2、d3、d4 ,and d5 are failure parameters of the material. The specific values are shown in Table.4.

Table 4: Failure parameters of materials [8]

d_1	d_2	d_3	d_4	d_5
-0.09	0.25	-0.5	0.014	3.87

3. Conclusions Central composite experiment

In this paper, the microtexture depth, microtexture width, and microtexture spacing are taken as the three factors of an orthogonal experiment, as shown in Figure 2, where x is the microtexture depth, y is the microtexture width and z is the microtexture spacing.

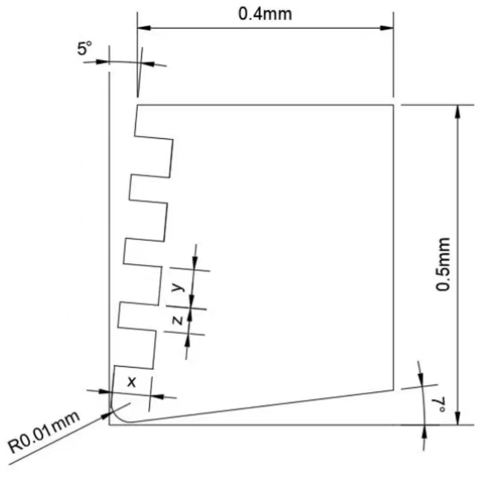

Figure 2: Microtexture morphology of cutting tool

In this paper, the experimental range of microtexture width is 25-35μm, the experimental range of microtexture distance is 75-85μm, and the experimental range of microtexture depth is 15-25μm. Therefore, three levels of each factor were selected for the experimental study, and the specific values are shown in Table .5.

Table 5: Microtexture parameter factor level table

Factor Level	Ax/ (μm)	By/ (μm)	Cz/ (μm)
1	15	25	75
2	20	30	80
3	25	35	85

Based on the experimental factors and levels, the Central Composite Composite Composite design method in Design-Export software is used to determine the combination of the microtexture parameters in the scope of the experiment. The cutting experiments of titanium alloy with different combinations of microtexture parameters were simulated by Abaqus simulation software and the results were recorded. In the process of the simulated cutting experiment, the cutting is divided into two stages. In the first stage, the cutting tool contacts the workpiece and cuts, the chief cutting surfaces rises rapidly, and in the second stage, the chief cutting surfaces enters the stable cutting state, and the chief cutting surfaces is relatively

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stable, therefore, the chief cutting surfaces can be obtained by cutting the second stage steady-state data and calculating the average value. The resulting experimental data are shown in Table 6.

When the tool has no micro-texture morphology, the simulation results show that the average chief cutting surfaces is 252N.

Table 6: Results of central composite experiment

Serial number	Depth/ (μm)	Width/ (μm)	Spacing/ (μm)	Force / (N)
1	20	25	80	235.29
2	15	35	85	234.50
3	25	35	80	236.50
4	25	25	85	229.03
5	20	30	85	209.35
6	25	35	80	236.50
7	20	30	85	209.35
8	20	25	80	235.29
9	20	30	85	239.34
10	15	25	75	231.58
11	25	30	80	230.17
12	20	25	80	209.10
13	20	35	75	227.66
14	15	25	85	216.43
15	20	30	80	232.42
16	15	30	80	230.99
17	20	30	75	217.54
18	20	30	80	208.26
19	20	35	80	226.83
20	25	30	75	231.41

From the above table, it can be concluded that the chief cutting surfaces of the tool with micro-texture is smaller than that of the tool without micro-texture in cutting titanium alloy, and the effect is obvious. According to Table 6, when the depth of the micro-texture is 20μm, the width is 30μm and the spacing is 80μm, the chief cutting surfaces is minimum, which is by the experimental hypothesis, the distribution of all data points is approximately a straight line, which shows that the model has good adaptability and the response surface method can fit the prediction model of the chief cutting surfaces well. The normal distribution probability of residuals is shown in Figure 3.

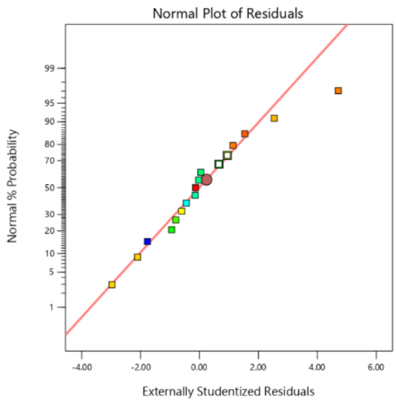

Figure 3: Normal probability distribution of residuals

4. Response surface analysis

From the response surface method to get visual graphics for analysis, and made the interaction of various factors of the response surface method. In this paper, the influence of the interaction of the other two factors on the chief cutting surfaces is investigated when one of the factors is fixed in the optimal value, response surface method can directly reflect the three factors of micro-texture on the chief cutting surfaces of the interaction. Figure 4-6 shows the effect of the interaction of variables on the chief cutting

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surfaces.

Figure. 4 shows the interaction of texture depth and width when the texture spacing is 80μm. It can be seen from the graph that when the width is constant, the variation of texture depth is larger, and the effect of depth on the chief cutting surfaces is larger. When the depth of the microtexture is 15μm, the lubrication effect of the microtexture can not be fully utilized because of the small depth. The chief cutting surfaces is the smallest at the depth of 20 μm, and then the cutting surfaces increases obviously with the increase of the depth, which is because the excessive depth will destroy the structure of the tool and the tool vibration will increase, the instability of cutting results in the increase of cutting surfaces.

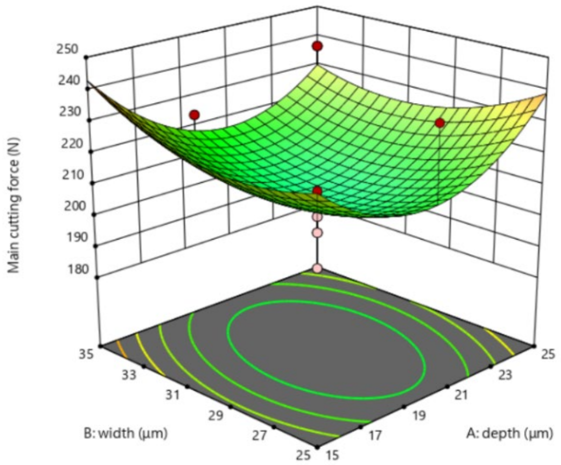

Figure 4: Interaction of microtexture depth and width on the chief cutting surfaces

Figure 5 shows the interaction between the width of the microtexture and the spacing when the depth of the microtexture is 20 μm. It can be seen from the graph that when the width of the microtexture is constant, the value of the chief cutting surfaces changes greatly with the decrease of the spacing, the influence of the spacing on the chief cutting surfaces is greater than the width.

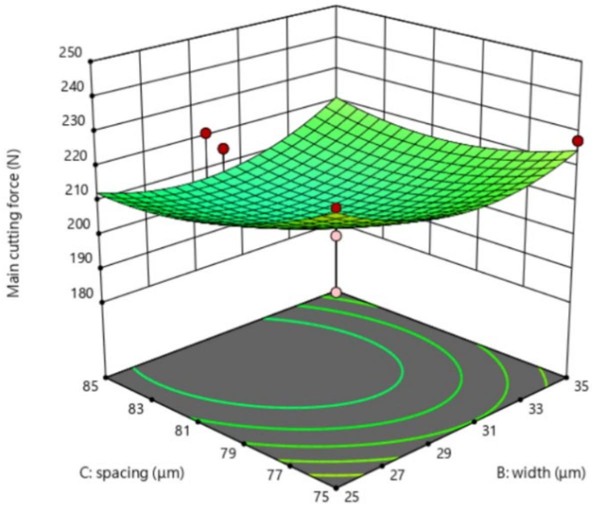

Figure 5: Interaction of microtexture width and spacing on the chief cutting surfaces

Figure 6 shows the interaction between the width and the spacing of the micro-texture when the width of the micro-texture is 30μm. From the figure, it can be seen that when the spacing of the micro-texture is unchanged, the variation of the value of the chief cutting surfaces is larger with the decrease of the depth, and the range of variation is greater than that of the chief cutting surfaces with the decrease of the spacing when the depth is constant.

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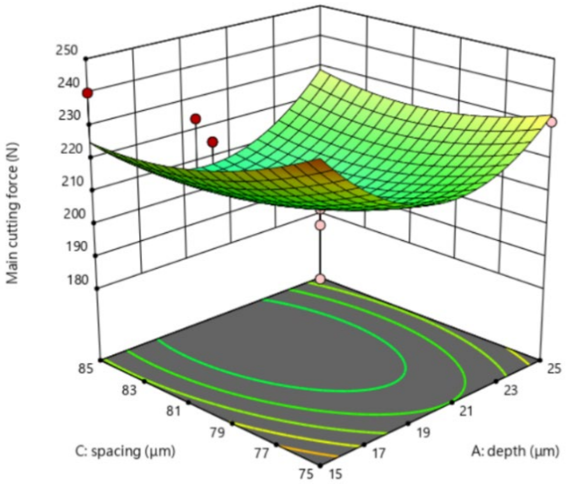

Figure 6: Interaction of microtexture depth and spacing on the chief cutting surfaces

5. Conclusions

In this paper, the finite element model of cutting titanium alloy with a micro-texture tool is established by using Abaqus software, taking the micro-texture parameters (depth, width, and spacing) as variables, based on the model, the central composite experiment is carried out and the response surface is obtained:

(1) The existence of the microtexture can obviously reduce the chief cutting surfaces and the tool friction.

(2) From the response surface, it can be concluded that in the range of test data, the effect of microtexture depth on the chief cutting surfaces is the most significant, the microtexture spacing is the second, and the microtexture width is the weakest.

(3) The optimum parameters of the microtexture tool are microtexture depth 20μm, microtexture width 30μm, microtexture spacing 80μm, and chief cutting surfaces 208.26 N.

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