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Milling Experiment and Finite Element Simulation Analysis of Titanium Alloy Materials

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Abstract

In order to solve the machining difficulty of titanium alloy material, improve the machining surface quality and improve tool wear, orthogonal experimental design method was used to design the milling experiment to study the influence of cutting parameters on the machining effect of the material in the process of machining. In this paper, a prediction model of milling force in three directions was established. Finite element simulation analysis was carried out on two groups of specific experimental data by USING ABAQUS finite element simulation software and the chip morphology was compared with this group of experimental data. The results show that the milling depth and milling width have little influence on the milling force, and the three direction milling force has inflection point at different milling speed and feed. The results of finite element simulation show that chip shape changes with the change of machining conditions, and the condition of sudden change of chip shape is similar to the test.

Keywords

Titanium Alloy; Milling Processing; Cutting Parameters; Finite Element Simulation; Chip Morphology.

1. Introduction

In recent years, with the continuous in-depth development of China's aerospace engineering field, the performance requirements of aerospace components have been continuously improved[1]. Titanium alloy is a kind of lightweight high-strength alloy material widely used in the field of aerospace processing, with high strength, good corrosion resistance, strong thermal stability and other excellent performance[2]. Titanium alloy materials have adverse factors such as high processing temperature, high friction coefficient, high cutting stress per unit area and so on in mechanical processing, resulting in poor machinability, uneven surface quality and serious tool wear in mechanical processing[3][4]. In the process of machining, cutting force is sensitive to cutting parameters, and the exploration of cutting force provides appropriate cutting parameters for the actual production to a greater extent, which is convenient for the production and utilization of the material[5]. Because there are many unreliable factors in the machining process, a simple experimental study is not enough to explore all the properties of titanium alloy machining process. In this paper, two groups of specific experimental data were selected for finite element processing simulation analysis.

In this paper, titanium alloy TC4 material milling test processing and finite element simulation analysis, the test results show that: there are cutting speed critical point under different machining conditions, when the cutting speed is lower than the specific critical point, the change of cutting force with the cutting speed is positively correlated; When the cutting speed is higher than the critical point, the cutting force is negatively correlated with the cutting speed. At the same time, the results of the

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interaction of feed per tooth and milling speed on milling force are studied. Similar to the principle of cutting speed, there is a critical value of feed per tooth under different machining conditions. When the feed per tooth is less than this critical value, the change of milling force is negatively correlated with the milling speed. When the feed per tooth is greater than the critical value, the milling force is positively correlated with the milling speed. Milling depth and milling width have little effect on milling force.

In addition to the test study on the titanium alloy material, this paper selected the particular two groups of experimental data, the milling titanium alloy was built based on ABAQUS model. Finite element simulation analysis is effective way to research on material processing mechanism, and finite element simulation of the premise is to establish the correct material constitutive model. The dynamic solver module of ABAQUS was used to conduct finite element simulation on part of the tests to explore the processing performance of the material and its processing influence rule.

2. Experimental Study on Milling TC4 Material

2.1 TC4 Material Milling Test Scheme Design

Table 1. Design of orthogonal center compound test for milling plane of milling cutter with diameter of 6mm

Test number	Control factor			
	Milling speed ***vc*/(m/ min)**	Feed engagement ***fz*/(mm /z)**	Milling width ***ae*/mm**	Milling depth ***ap*/mm**
1	50	0.03	1	0.1
2	110	0.03	1	0.1
3	50	0.05	1	0.1
4	110	0.05	1	0.1
5	50	0.03	2.2	0.1
6	110	0.03	2.2	0.1
7	50	0.05	2.2	0.1
8	110	0.05	2.2	0.1
9	50	0.03	1	0.7
10	110	0.03	1	0.7
11	50	0.05	1	0.7
12	110	0.05	1	0.7
13	50	0.03	2.2	0.7
14	110	0.03	2.2	0.7
15	50	0.05	2.2	0.7
16	110	0.05	2.2	0.7
17	20	0.04	1.6	0.4
18	140	0.04	1.6	0.4
19	80	0.02	1.6	0.4
20	80	0.06	1.6	0.4

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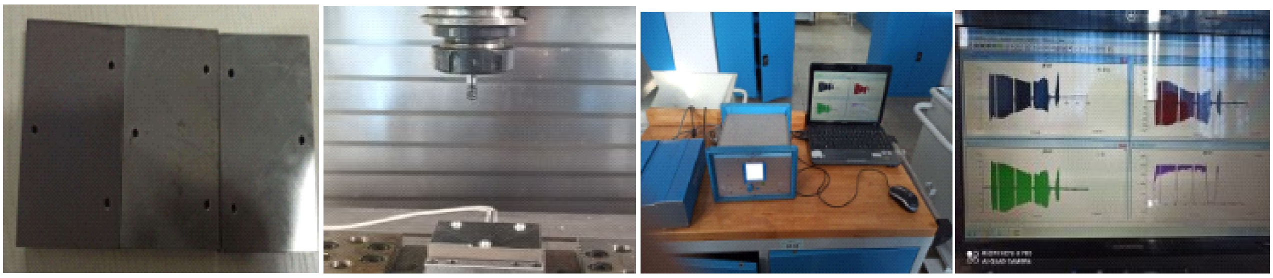
In this experiment, the orthogonal rotatable center composite test design scheme as shown in Table 1 was adopted. With response surface method, which the influence of cutting parameter interaction on cutting force in milling titanium alloy TC4 material was studied and analyzed.

2.2 Milling Test

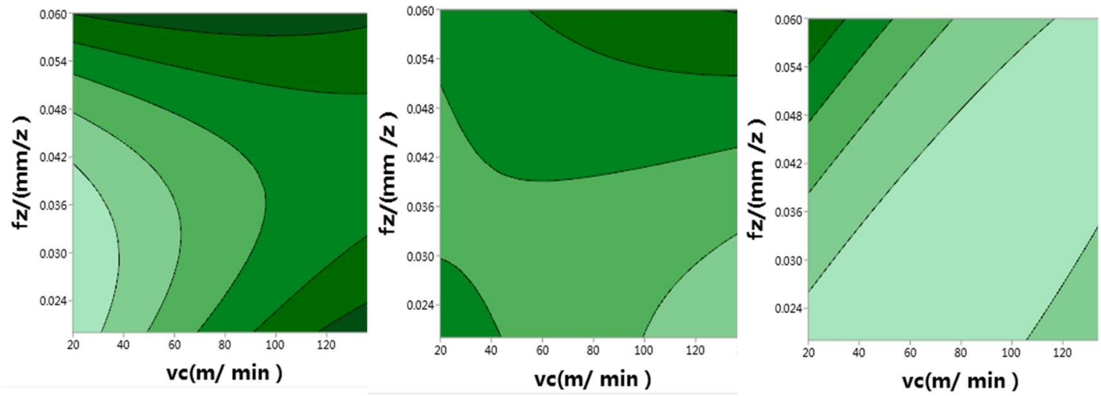
In this paper, a carbide tool with diameter of φ=6mm and TC4 sample with size of 78mm x54mm x15mm were used for vertical milling of the block titanium alloy with the harting NC turning milling center, as shown in Figure 1.a and Figure 1.b. Data were collected for the cutting force in the process by Kistler dynamometer, as shown in Figure 1.c. The workpiece was fixed with a fixture. Put on the dynamometer fixed on the working table of the machining center, the signal of the dynamometer is transmitted to the desk recorder through the data line for signal amplification, and then the test data is transmitted to the computer, and the cutting force signal is obtained as shown in Figure 1.d. The effects of different machining parameters on the cutting force are obtained through data processing.



(a) (b) (c) (d)

Figure 1. a.Test process drawing; b.Harting milling center clamping diagram; c.Kistler equipment; d.Signal test diagram of force.

2.3 Analysis of Milling Force



(a) (b) (c)

Figure 2. a.Diagram of interaction between feed per tooth and cutting line speed on X - direction milling force;b.Diagram of interaction between feed per tooth and cutting line speed on Y - direction milling force;c.Diagram of interaction between feed per tooth and cutting line speed on Z - direction milling force.

In order to clearly show the influence of interaction on cutting force, a two-dimensional contour map of interaction was drawn. In each set of figures, except for the two kinds of milling parameters studied, the other research parameters are taken as horizontal values.

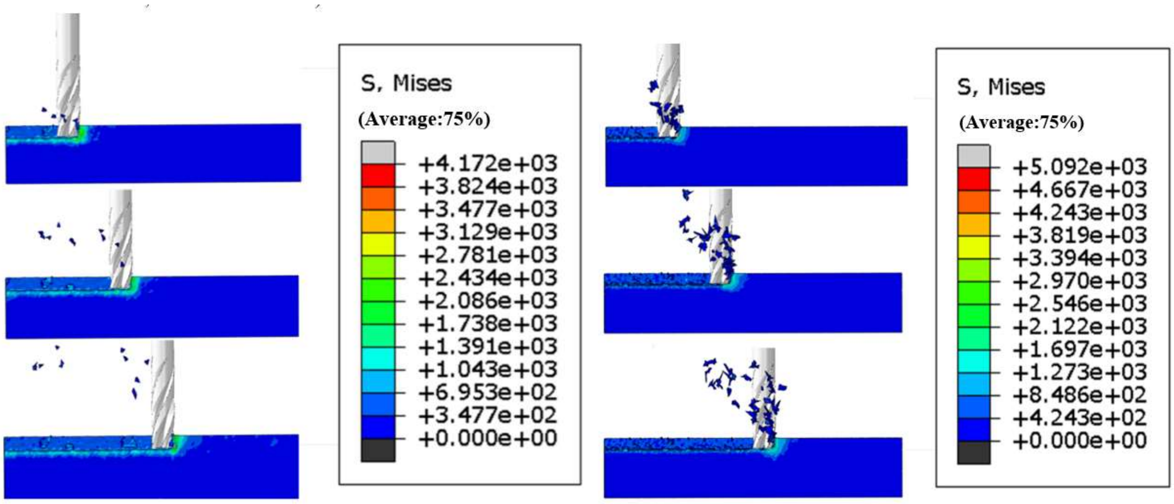
It can be seen from Figure 2.a. that when the linear speed is lower than 90mm/min, the cutting force in the X direction is positively correlated with the change of feed quantity. When the linear speed is higher than 90mm/min, the cutting force increases first and then decreases with the increase of feed quantity. An inflection point appears at the feed quantity per tooth is 0.045mm/z.

It can be seen from Figure 2.b. that when the linear velocity is lower than 45mm/min, the cutting force in y direction decreases first and then increases with the increase of feed. When the linear velocity is higher than 45 mm/min, the cutting force in Y direction increases with the increase of feed per tooth. When the feed per tooth is less than 0.04mm/z, the cutting force in y direction increases with the increase of feed.

It can be seen from Figure 2.c. that when the linear velocity is lower than 105mm/min, the cutting force in the Z direction increases with the increase of the feed. When the linear velocity is higher than 105mm/min, it decreases with the increase of feed. When the feed per tooth is less than 0.036mm/z, the cutting force in the Z direction decreases with the increase of linear velocity. When the feed per tooth is higher than 0.036mm/z, it increases with the increase of linear velocity.

3. Finite Element Simulation of TC4 Milling Test

In the simulation cutting process, we choose the same tool size and test conditions consistent with the establishment of three-dimensional milling finite element simulation model. Figure 3.a and Figure 3.b shows the Mises stress results at the finite element simulation time of milling (T1=4.3004 E-03, T2= 7.5006 E-03, T3= 1.0000 E-02).



(a) (b)

Figure 3. a.The stress cloud image at three moments of milling simulation with cutting parameters of (a_p=0.7mm, a_e=2.2mm,v_c =50 m/min, f_z= 0.03mm/z);

b.The stress cloud image at three moments of milling simulation with cutting parameters of (a_p=0.7mm, a_e=2.2mm,v_c =110 m/min, f_z= 0.03mm/z);.

4. Conclusion

In this paper, the following conclusions are drawn by studying the cutting test and simulation of cutting parameters on titanium alloy, a difficult material to be machined:

The results show that the milling speed and feed per tooth are the main factors affecting the machining quality of titanium alloy. When the milling speed is lower than the critical value of 90mm/min, the milling force in X direction is positively correlated with the feed per tooth, when the milling speed is higher than the critical value of 90mm/min, the milling force is negatively correlated with the feed per tooth. The milling force in Y direction is negatively correlated with the feed per tooth when the milling speed is less than 45mm/min, when the milling speed is higher than the critical value of 45mm/min, the milling force is positively correlated with the feed per tooth, and when the feed per tooth is less than 0.04mm/z, the milling force is positively correlated with the feed per tooth. When the milling speed is lower than the critical value of milling speed 105mm/min, the milling force in Z

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direction is positively correlated with the feed per tooth, when the milling speed is higher than the critical value, the milling force is negatively correlated with the feed per tooth, when the feed per tooth is lower than the critical value 0.036mm/z, the milling force is negatively correlated with the milling speed, when the feed per tooth is higher than 0.036mm/z, the milling force is positively correlated with the milling speed.

The finite element analysis can be summarized as follows:

1) When milling titanium alloy which is difficult to machine at a relatively low speed, the chip shape is broken sheet, and the processed surface quality is poor;

2) When titanium alloy is processed at a relatively appropriate milling speed, the chip shape is zigzag, and the simulation results are consistent with the actual situation.

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