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Sensitivity Analysis of The Influence of Milling Parameters on The Surface Residual Stress of Titanium Alloy TC11

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Abstract

In order to improve the surface integrity of titanium alloy, a mathematical model of residual stress in x and y direction is established by three factor and three level orthogonal test method. Based on this model, the influence of milling parameters on residual stress is analyzed by using the sensitivity analysis method. Test and analysis results show that the titanium alloy milling process, the residual stress increases with the increase of milling proecess parameters, but in x and y direction the degree of influence is different; The x direction residual stress on milling parameter sensitivity is higher than that of the residual stress in the y direction. x direction of surface residual stress is the most sensitive to change of the cutting speed and then is to the amount of feed per tooth, least sensitive to the cutting depth, y to the same conclusion.

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Keywords: Titanium Alloy；Residual Stress；Milling Parameter；Sensitivity

1. Introduction

Titanium alloy has the advantages of high strength, low density, good heat resistance, corrosion resistance and other advantages. It is widely used in aviation field. At present, the engine component, the skin, the skeleton, the fastener and undercarriage and so on are mostly the titanium alloy material. But,Titanium alloy has low elastic modulus, the large springback, strong chemical activity and poor thermal conductivity, which can cause a high cutting force and therefore cutting heat in the cutting process. Under the effect of thermal mechanical coupling, the surface layer of the workpiece will inevitably generate residual stress.The existence of residual stress can seriously affect the processing precision and dimensional stability, static strength, fatigue strength and corrosion cracking of the component. Especially in the bearing and rotating parts, the existence of residual stress is very easy to cause sudden destruction and the consequences are often very serious [1-3].Therefore, it is important to control the size of the residual stress by selecting the cutting parameters reasonably, which has important influence on the whole surface integrity and anti-fatigue property of the component. The influence of cutting parameters on residual stress has been studied by scholars both at home and abroad. Masmiati.N uses taguchi method to optimize the tilt angle, axial cutting depth, spindle speed and feed rate of the ball end milling cutter to achieve the purpose of controlling the surface integrity and residual stress [4]. Huang. X has established the prediction model of the residual stress of the side milling, the simulation results show that the side milling surface in the axial direction than in the feed direction showed a greater compressive stress[5]. Fergani. O presents an analytical algorithm for the prediction of the residual stress in the machining process based on orthogonal cutting. The method considers the change of the residual stress state caused by the muti-process and the hardening behavior of the material[6].Lutao.Liu simulats the cutting process of high speed cutting GH4169 by means of the finite

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element software.and adopts single factor method to study the cutting parameters and tool geometry parameters on distribution and magnitude of machined surface residual stress.Tianran.Huang carries out the low-speed disk milling titanium alloy milling parameters on machined surface residual. Experimental results show that machined surface residual stress is compressive stress, change of the milling speed is the most significant on the effect of stress, and the feed rate is second, and the depth of cutting is the least, in the selected range of cutting parameters. Longhui. Meng et al. analyze the influence of different cutting parameters and annealing treatment on the residual stress of the surface. The results show that the cutting speed, feed rate and cutting depth increase in the specified range, which leads to the increase of the compressive stress in the surface cutting and feed direction. The annealing treatment can reduce the residual stress in the 2 directions of the surface for the surface residual stress caused by Ti6Al4V pipe turning[9].Ye. Sun has studied about the effect of different cutting speed on the residual stress of cutting tool coating. The results show that the residual stress in the coating layer is greater with the increase of cutting speed. the residual stress in the surface layer is in a state of suppression in the axial and circumferential direction [10].

This paper has carried out the research on the influence law of cutting parameters on the residual by orthogonal experiment of the milling process parameters for the material of difficult machining of titanium alloy TC11.The purpose of this paper is to provide reasonable theoretical basis for aerospace parts machining process of cutting parameters.

2. Basic method of sensitivity analysis[11-15]

Sensitivity analysis refers to the optimal design target is sensitive to the change of the design variables, the purpose is to identify the objective function of optimization design in the design variables affect significantly on the weak link, in order to identified accurately and effectively the optimization variables to modify the optimization program.

2.1. Absolute sensitivity

Absolute sensitivity represents the target function for sensitivity of one cutting parameter. According to the mathematical definition of sensitivity, the absolute sensitivity for objective function of residual stress on cutting parameters (cutting speed, each tooth feed and cutting depth) in milling process is expressed as flows:

$$\begin{cases} S_\sigma^{v_c} = \dfrac{\partial \sigma(v_c, \overline{f}_z, \overline{a}_p, \overline{a}_e)}{\partial v_c} \\ S_\sigma^{f_z} = \dfrac{\partial \sigma(\overline{v}_c, f_z, \overline{a}_p, \overline{a}_e)}{\partial f_z} \\ S_\sigma^{a_p} = \dfrac{\partial \sigma(\overline{v}_c, \overline{f}_z, a_p, \overline{a}_e)}{\partial a_p} \end{cases} \quad (1)$$

Due to the objective function model $\sigma(x)$ is obtained by cutting experiments, the initial sets of cutting parameter combination are the discrete points. Therefore, in the respectively calculation of absolute sensitivity $S_\sigma^{v_c}$ 、 $S_\sigma^{f_z}$ 、 and $S_\sigma^{a_p}$, the other parameters are taken as the average values of the parameters obtained in the experiment f_z , a_p respectively take the average value of the parameters obtained from the experiment $\overline{f}_z$, $\overline{a}_p$ as calculated $S_\sigma^{v_c}$.

2.2. Relative sensitivity

Relative sensitivity method is one method to get rid of dimensional influence on sensitivity analysis, because of the cutting process of the objective function of the absolute sensitivity of different cutting parameters dimension is different, the cutting parameters can only reflect the influence degree of the change of the objective function itself. In order to overall comprehensive comparison of the process on the influence of surface residual stress. To deal with the dimensional absolute sensitivity $S_\sigma^{v_c}$ 、 $S_\sigma^{f_z}$ 、 $S_\sigma^{a_p}$ in formula 1, the relative sensitivity of objective function $\sigma(x)$ for cutting parameters as follows:

$$\begin{cases} S'^{v_c}_\sigma = S_\sigma^{v_c} \times \dfrac{v_c}{\sigma(v_c, \overline{f_z}, \overline{a_p})} \\ S'^{a_p}_\sigma = S_\sigma^{a_p} \times \dfrac{a_p}{\sigma(\overline{v_c}, \overline{f}_z, a_p)} \\ S'^{f_z}_\sigma = S_\sigma^{f_z} \times \dfrac{f_z}{\sigma(\overline{v_c}, f_z, \overline{a_p})} \end{cases} \quad (2)$$

Relative sensitivity is the comprehensive reflection of the objective function for the sensitive degree of the cutting parameters.

3. Experimental Scheme

3.1. Workpiece material

Material is TC11 titanium alloy, one α - β titanium alloy with high strength and high toughness. The main chemical compositions of the alloy (%) are given in table 1. The mechanical properties of TC11 in room temperature and 500 ° C are shown in table 2.

Table 1. Nominal chemical composition of the TC11 alloy

Element	Mo	Zr	S	C	O
%	3.29	1.79	0.23	0.025	0.006
Element	Al	Fe	N	H	Ti
%	6.42	0.077	0.004	0.003	balance

Table 2 Mechanical properties of TC11 alloy

	σ_b (MPa)	$\sigma_{0.2}$ (MPa)	δ (%)	Ψ (%)
25℃	1128	1030	12	35
	a_k (J·cm^{-2})	σ_b (MPa)	σ_{100} (MPa)	
500°C	44.1	765	667	