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Experimental Study of Factors Affecting the 7075 Aluminum Alloy Thin-walled Parts Milling Force

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Abstract

Taking 7075 aluminum alloy thin-walled part as the research object, with higher cutting parameters than the normal value selected, a four factors and four levels orthogonal experiment was carried out, in which we chose YG carbide cutting tools for the milling, intercepted the milling force stable section, selected ten peak values and took an average, conducted multiple linear regression analysis using Matlab numerical calculation software and established the milling force empirical formula of 7075 aluminum alloy thin-walled part to study the factors which have influence on its milling force. By range analysis of the experimental results, the cutting force change rule in the manufacturing process of aluminum alloy with the change of cutting parameter was revealed. It is found that the axial cutting depth had the greatest influence on the force perpendicular to the direction of cutting surface, and the radial cutting depth had the minimal impact. By comparative analysis on theoretical value and experimental value of milling forces, we found that the predicted value of the milling force F_x and F_y in theory were in good agreement with the experimental results with a relative error less than 8.7%. Under the experimental conditions, the optimal milling parameters are axial cutting depth of 2mm, radial cutting depth of 0.5mm, feed speed 95mm/min and cutting speed of 23.86m/min. It will provide data and experiment support for milling of thin-walled parts of similar materials, which will have important practical value and theoretical significance for engineering.

***Keywords**: 7075 Aluminum alloy; thin-walled parts; milling force*

1. Introduction

With the rapid development of science and technology, thin-walled structure has been widely used in key parts of ships, aircraft and other aerospace manufacturing. Because of thin-walled parts with the advantages of lighter weight and higher strength, it is widely used in many areas of mold, aerospace and other fields. But thin-walled parts have the features of complex structures, relatively low stiffness, great allowances, in the milling process, it can easily produce deformation and vibration, making the processing efficiency and accuracy reduce, not to meet quality requirements of the parts[1-2] .7075 aluminum alloy is a typical high-strength deformation aluminum alloy, belongs to Al-Zn-Mg-Cu alloys with high specific strength, widely used in aviation, aerospace and shipbuilding industry[3]. Milling force is an important quantities physical that comprehensively reflects the milling process[4]. For thin-walled parts, the process from the rough to the final shaping of the parts, the milling process is the main way to complete the whole process, so milling force becomes an important physical quantities. Milling force size has a direct impact on the stability of thin-walled structures milling, machining accuracy, machining quality and machining deformation, *etc*.. Therefore, it is important for the

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milling force to accurately calculate and predict. The 7075 aluminum alloy thin-walled parts as a research object in this experiment. By the milling experiment, study the milling force in this processing system and analyze the experiment factors that influence of milling force.

2. Milling Force Experiment

2.1 Test Tool and Equipment

When conventional milling of 7075 aluminum alloy thin-walled parts, because it belongs to the super-hard alloy, selected tool material should have the features of high hardness, well wear resistance and strong thermal deformability. Comprehensive consider to choose YG carbide cutting tools can meet the test requirements[5].

For the tool geometry parameters, the rake angle can not be too small, or when the chip flow resistance increases, increasing friction and cutting deformation, so that the rake face prone to wear. If the rake angle is too large, will also make a smaller heat dissipation volume of the tool, flank wear occurrence, considering the rake angle between 12^o-15^o as well. The size of relief angle relating the tool stiffness, increasing relief angle may reduce friction of flank, increase tool life, but it will reduce the stiffness of the blade, so considering 12^o. The number of cutter teeth also affect the milling force, the more teeth, the greater cutting force causes. At the same time increase the difficulty of chip removal. Too little teeth will reduce the stability of the cutting, resulting an increase in deformation and vibration of the cutting process, so choose 2-3 teeth[6]. A three-blade carbide end mill cutter used in the experiment for cutting aluminum alloy which produced by SOH. Cutter diameter is 8mm, spiral angle 55^o, rake angle 15^o, relief angle 12^o and the blade length is 25mm.

XA5032 milling machine for the experiment, the specific parameters is shown in Table 1.

Table 1. The Main Performance Parameters of XA5032 Milling Machine

Milling machine type	XA5032
Dimensions(mm)	2530×1890×2380
Main motor power(kW)	7.5
Fast moving speed of worktable(mm/min)	Longitudinal 2300 transverse 2300 vertical 770
Table feed range(mm/min)	Longitudinal 23.5～1180 transverse23.5～1180 vertical 8～394
Axially moving distance of spindle(mm)	85
Spindle speed(rpm)	30～1500/18 level

Model 9257B three-way KISTLER dynamometer, model 5070A KISTLER multi-channel charge-amplifier and PC-CARD-DAS16/16 data acquisition system are used in test system, as shown in Figure 1, The experiment working conditions are workshop temperature of 23 ℃, relative humidity of 52℃~55℃, tool surface integrity without any abrasion after cutting.

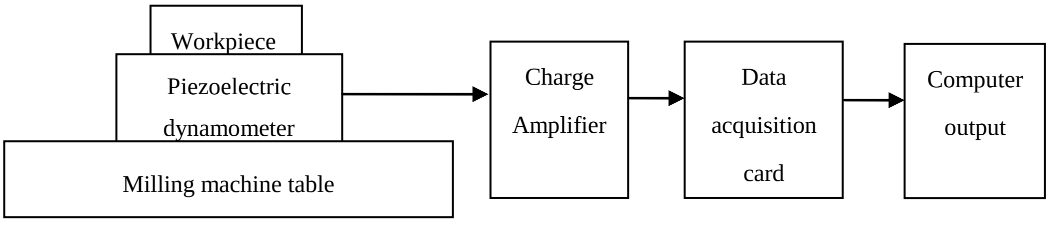

Figure 1. The Acquisition System of Cutting Force

2.2 Experimental Program

In the study on milling performance of 7075 aluminum alloy thin-walled parts, milling mode is down milling, and experiments select cutting parameters higher than conventional values. Milling program is four-factor four-level orthogonal experiment, as shown in Table 2. Cutting speed, feed rate, axial cutting depth and radial cutting depth are considered in the experiment. Through Kistler three-phase dynamometer, milling force of X, Y, Z directions is measured in each experiment, and the peak in stable segment is averaged and recorded into Table 3.

Table 2. Factor Levels Table

Factor / Level	A Cutting speed （m/min）	B Feed rate （mm/min）	C Axial cutting depth （mm）	D Radial cutting depth （mm）
1	15.07	95	1	0.2
2	23.86	118	2	0.3
3	29.64	150	3	0.4
4	37.68	190	4	0.5

Table 3. Orthogonal Experiment Table

No.	A Cutting speed （m/min）	B Feed rate （mm/min）	C Axial cutting depth （mm）	D Radial cutting depth （mm）	Fx （N）	Fy （N）	Fz （N）
1	15.07	95	1	0.2	30.10	40.74	31.49
2	15.07	118	2	0.3	31.23	26.06	30.33
3	15.07	150	3	0.4	34.03	47.18	30.76
4	15.07	190	4	0.5	20.02	39.22	25.82
5	23.86	95	2	0.4	48.54	61.25	34.42
6	23.86	118	1	0.5	28.07	37.32	33.75
7	23.86	150	4	0.2	38.52	36.01	33.76
8	23.86	190	3	0.3	43.87	39.67	29.18
9	29.64	95	3	0.5	56.08	82.04	30.82
10	29.64	118	4	0.4	48.30	45.07	30.27
11	29.64	150	1	0.3	33.54	81.31	33.14
12	29.64	190	2	0.2	33.31	87.13	29.91
13	37.68	95	4	0.3	60.81	84.45	32.71
14	37.68	118	3	0.2	28.89	81.74	34.23
15	37.68	150	2	0.5	33.47	91.54	39.89
16	37.68	190	1	0.4	33.36	85.67	32.83

3. Experimental Treatment

3.1 Orthogonal Experimental Results

The ranges of various factors are figured out respectively to make comprehensive comparison on the ranges value, and primary and secondary cases of various factors affecting the milling force are determined through analysis, then making optimal selection of better experiment parameters. The analysis results of range in Table 4 show that the various factors relationship to the F_X: axial cutting depth >feed speed >cutting rate>radial cutting depth. Hence, In the process of milling aluminum alloy 7075 thin-walled parts, the optimization solution of smaller F_X forces is $C_2B_1A_2D_4$, and corresponding milling parameters are axial cutting depth of 2mm, feed speed of 95mm/min, cutting speed of 23.86m/min and radial cutting depth of 0.5mm.

Table 4. F_x Range Analysis

	A Cutting speed (m/min)	B Feed rate (mm/min)	C Axial cutting depth(mm)	D Radial cutting depth(mm)
	j=1	j=2	j=3	j=4
T_{1j}	135.90	125.01	125.07	130.82
T_{2j}	126.48	126.49	124.03	139.45
T_{3j}	133.23	139.56	124.87	131.71
T_{4j}	136.53	141.08	158.17	130.16
R_j	10.05	16.07	33.01	9.29

The analysis results of range in Table 5 show that the various factors relationship to the F_Y are radial cutting depth>axial cutting depth >cutting rate>feed speed. Hence, in the process of milling aluminum alloy 7075 thin-walled parts, the optimization solution of smaller F_Y forces is $D_1C_1A_3B_1$, and corresponding milling parameters are radial cutting depth of 0.2mm, axial cutting depth of 1mm, cutting speed of 29.64m / min and feed rate 95mm / min.

Table 5. F_y Range Analysis

	A Cutting speed (m/min)	B Feed rate (mm/min)	C Axial cutting depth(mm)	D Radial cutting depth (mm)
	j=1	j=2	j=3	j=4
T_{1j}	175.23	135.77	130.37	120.94
T_{2j}	152.22	154.87	148.62	146.18
T_{3j}	139.55	156.04	154.63	167.14
T_{4j}	143.40	163.73	176.78	176.15
R_j	35.68	27.96	46.41	55.21

The analysis results of range in Table 6 show that the various factors relationship to the F_z are cutting rate>feed speed>axial cutting depth >radial cutting depth. Hence, in the process of milling aluminum alloy 7075 thin-walled parts, the optimization solution of smaller F_z forces is $A_1B_4C_4D_2$, and corresponding milling parameters are cutting speed of 15.07m/min and feed rate of 190mm/min, axial cutting depth of 4mm and radial cutting depth of 0.3mm.

Table 6. Fz Range Analysis

	A Cutting speed (m/min)	B Feed rate (mm/min)	C Axial depth of cut(mm)	D Radial depth of cut(mm)
	j=1	j=2	j=3	j=4
T_{1j}	118.40	129.45	131.22	129.38
T_{2j}	131.10	128.59	134.55	125.36
T_{3j}	124.15	137.54	124.99	128.29
T_{4j}	139.67	117.74	122.56	130.28
R_j	21.27	19.80	11.99	4.92

3.2 Establish Milling Force Empirical Formula

Milling Force classical model are:

$$F_X = C_{F_x} \cdot v_c^{X_{F_x}} \cdot v_f^{Y_{F_x}} \cdot \alpha_e^{M_{F_x}} \cdot \alpha_p^{N_{F_x}} \quad (1)$$

$$F_Y = C_{F_y} \cdot v_c^{X_{F_y}} \cdot v_f^{Y_{F_y}} \cdot \alpha_e^{M_{F_y}} \cdot \alpha_p^{N_{F_y}} \quad (2)$$

$$F_Z = C_{F_z} \cdot v_c^{X_{F_z}} \cdot v_f^{Y_{F_z}} \cdot \alpha_e^{M_{F_z}} \cdot \alpha_p^{N_{F_z}} \quad (3)$$

Which, F_X is the X-direction cutting force, perpendicular to the workpiece direction; F_Y is Y-direction cutting force, along the tool feed direction; F_Z is Z-direction cutting force, along the spindle direction. ***Error! No bookmark name given.***$_{Fx}$, ***Error! No bookmark name given.***$_{Fy}$, ***Error! No bookmark name given.***$_{Fz}$ are coefficient decided by the processed material and cutting conditions. ***Error! No bookmark name given.***$_{Fx}$, ***Error! No bookmark name given.***$_{Fx}$, ***Error! No bookmark name given.***$_{Fx}$, ***Error! No bookmark name given.***$_{Fx}$, ***Error! No bookmark name given.***$_{Fy}$, ***Error! No bookmark name given.***$_{Fy}$, ***Error! No bookmark name given.***$_{Fy}$, ***Error! No bookmark name given.***$_{Fy}$, X_{Fz}, Y_{Fz}, ***Error! No bookmark name given.***$_{Fz}$, ***Error! No bookmark name given.***$_{Fz}$ are index that used in the three component force formula for ***Error! No bookmark name given.***$_c$, v_f and a_e. Multiple linear regression analysis of the results in Table 3, linear fit exponential milling force formula obtained by Matlab.

$$\left.\begin{aligned} F_X &= 11.949 v_c^{0.1429} v_f^{0.1972} a_p^{0.2871} a_e^{0.1206} \\ F_Y &= 18.624 v_c^{0.1956} v_f^{0.1721} a_p^{0.2132} a_e^{0.2427} \\ F_Z &= 22.601 v_c^{0.1299} v_f^{0.1105} a_p^{0.0886} a_e^{0.0643} \end{aligned}\right\} \quad (4)$$

To verify the accuracy of the equation (4), four sets of data are selected for verification, the results are shown in Table 7. After calculation, the average relative error of F_x and F_Y is 8.07% and 8.625% respectively, and both are less than 10%, indicating that the theoretical formula predicted values of $F_{x,\ th}$ and $F_{y,\ th}$ accord with the experimental measurements well, and average relative error of 60.2% of F_z is caused by the limitations of experiment conditions and errors generated during the experiment, which has larger difference from predict value $F_{z,\ th}$ of formula, therefore, empirical formulas of milling force in x and y directions are suitable in the current processing conditions.

Table. 7 Cutting Force Comparative between Theoretical Value and Measured Results

No.	$F_{x,\ th}$/N	δ_x/%	$F_{y,\ th}$/N	δ_y/%	$F_{z,\ th}$/N	δ_z/%
1	35.59	18.2%	46.90	15.1%	47.97	17.7%
5	50.42	3.9%	70.38	14.9%	56.58	64.3%
9	59.38	5.9%	84.52	3.0%	61.20	98.6%
13	63.43	4.3%	83.21	1.5%	62.68	91.6%

4. Conclusion

(1) By orthogonal experiment, it has been found that the primary and secondary relationship affecting three-way force is different, but through the comprehensive analysis, the greatest impact is axial cutting depth, followed by the feed rate, cutting speed, and the smallest impact is radial cutting depth. The corresponding milling parameters of preselected optimization program for cutting force through experiments are axial cutting depth of 2mm, feed speed 95mm / min, cutting speed of 23.86m/min and radial cutting depth of 0.5mm.

(2) Milling force formula of 7075 aluminum alloy thin-walled parts is established, which has provided reliable theoretical support for accurate calculation of milling force in forming process of thin-walled parts with similar materials.

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