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Experiential Formula of Cutting Force Established in Turning High Temperature Alloy

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Abstract

In order to study the experiential formula of cutting force and the influence of each cutting parameter for turning superalloy GH4169, the orthogonal experiment is applied to coated carbide tools turning high-temperature alloy GH4169, and got empirical formula of cutting force carbide using cutting tools for turning superalloy GH4169. The results show that: the greatest impact on the cutting force factor decreases in the order of the cutting depth, feed and cutting speed influence on the test results.

Keywords*: Superalloy; Turning; Cutting Force; Orthogonal Experiment; Experiential Formula*

1. Introduction

Workpiece material in this paper for Ni-base superalloy GH4169, a kind of difficult-to-cut materials and the relative machinability of only 5% to 15% of the 45 steel, is a typical of difficult to machine material. Its main characteristics can be summarized as [1], a high melting point, thermal strength properties, thermal fatigue properties, containing a high activation energy of alloying elements, stable organizational performance, anti-oxidation, hot corrosion and can resist high working temperature and pressure. Therefore, the result in the turning process are the strong cutting power, chilled severe deformation, high cutting temperature and serious tool wear. The relative machinability of superalloy is only about 10% in the manufacturing process of the engine blades. The main reason is the complex shape of the blade and high structural integrity requirements. Although the quality of parts are not big, needed total weight of blank are big. Most will are removed by chips, so the manufacturing efficiency is low. The key issue to limit the level of the aviation industry is how to improve the processing efficiency and machined surface quality in machining superalloy.

In the domestic, some studies have done on superalloy machinability, such as cutting process, cutting force, reasonable cutting amount, temperature distribution, surface quality and tool wear. Song Tingke [2]of the Dalian University of Technology studied experimentally turning of superalloy GH4169 by using PCBN tool in 2010. Obtained PCBN tool wear will be increased with the increase of cutting speed, at the same time increase of PCBN tool nose rounded can reduce amount of tool wear. Professor Liu Weiwei[3] of Northwestern Polytechnical University in 2012, who used coated carbide tool in turning superalloy GH4169, analyzed the machined surface roughness in the orthogonal experiment, established the prediction model of surface roughness, obtained the optimal range of cutting parameters. Professor Wu Xia [4], Northwestern Polytechnical University in 2012, studied the use of ceramic inserts for turning superalloy GH4169 by single factor test method and analyzed the influence of cutting parameters on cutting force, and got the key factor affecting cutting force being the feed. In this paper, studied the turning performance of superalloy GH4169 during the multiple orthogonal

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cutting tests, analyzed the influence rule of cutting parameters on cutting force, fit the empirical formula of cutting force and provided a basic theory for the actual machining.

2. Experimental Design

2.1. The Composition of Test System

In this paper, the experiment uses external turning superalloy GH4169 by ordinary horizontal lathe CA6140. Due to the outer surface of the purchase is not very smooth, using a dial indicator alignment clamping in the workpiece fixture and detecting workpiece center position. The central axis of the workpiece and machine tool spindle must be maintained a high coaxiality in order to enhance and ensure the machining accuracy of each test. Turning tool material is coated carbide KC5510, whose rake angle γ is 10°, relief angle α is 3°and corner radius r_{ε} is 0.4mm. Cutting force is measured by using Kistler 9257B dynamometer system which is shown in Figure 1. Turning testing field is shown in Figure 2.

In order to satisfy cutting tool installation, experimental system was set up. To ensure the cutting force can truly reflect on the dynamometer, need to install a fixture above the dynamometer to fix turning tool. When the fixture is designed, tools and dynamometer must be connected closely and steady. The structure of fixture was designed according to the dynamometer dimension and the actual structure characteristics of the lathe. The three views after assembly of dynamometer and fixture as shown in Figure 3.

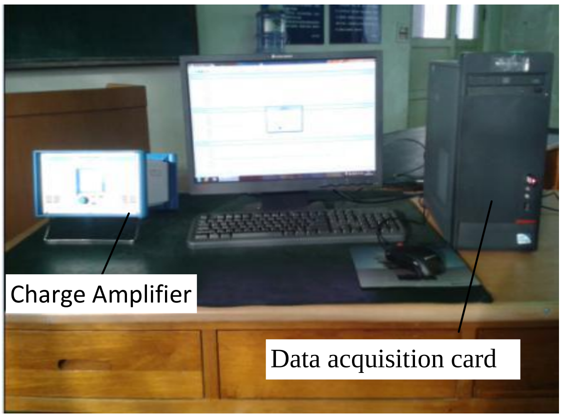

Figure 1. The Acquisition System of Cutting Force

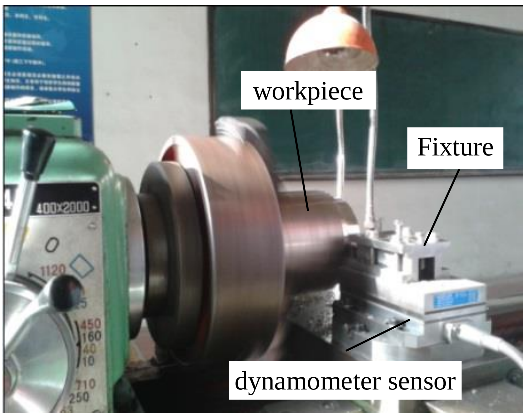

Figure 2. The Process of Cutting

2.2. Experiment Design

The experimental using the orthogonal tables of three factors and three levels(as shown in Table 1), three factors are selected for the cutting speed v_c, feed f and cutting depth a_p, cutting speed v_c (m/min) is respectively 70, 80, 90, feed f (mm/r) is respectively 0.1,0.15,0.2, cutting depth a_p (mm) is respectively0.2,0.3,0.4. When each experiment is over, kept cutting force test results, taken average before recorded. F_x, F_y and F_z (as shown in Table 2) represent feeding force F_f, back force F_p and the main cutting force F_c. The empirical formula of cutting force is established by the orthogonal cutting tests. Research the cutting variables influence on cutting force to analyze the result of the orthogonal experiments by the range analysis.

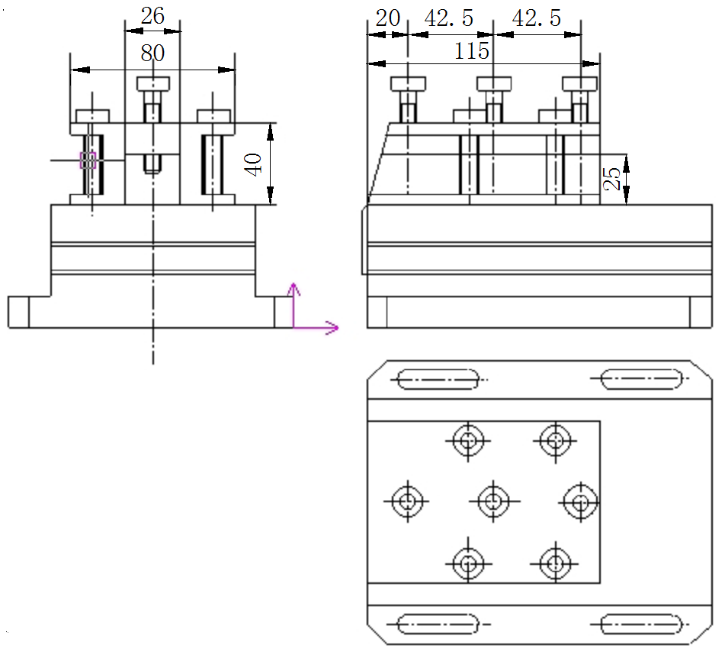

Figure 3. The Diagram of Fixture Assembly

Table 1. Orthogonal of Three Factors and Three Levels

Factors / Number	1	2	3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 2. Orthogonal Test Results of Three Factors and Three Levels

Factors / Number	v_c/(m/min）	f /(mm/r)	a_p/ mm	F_x/N	F_y/N	F_z /N	F /N

				5	8	1	1
1	70	0.1	0.2	1	8	12	51
2	70	0.15	0.3	8	1	1	2
3	70	0.2	0.4	0	06	87	29
				1	1	2	3
				14	25	91	37
				7	8	1	1
4	80	0.1	0.3	2	2	41	78
5	80	0.15	0.4	9	9	2	2
6	80	0.2	0.2	7	1	18	55
				4	9	1	1
				7	8	61	94
				9	9	1	2
7	90	0.1	0.4	4	3	84	27
8	90	0.15	0.2	5	1	1	1
9	90	0.2	0.3	6	14	45	93
				9	1	2	2
				1	55	36	97

3. Experimental Results and Analysis

3.1. Established Empirical Formula of Cutting Force

Exponential form empirical formula of cutting force is widely used, specific forms of expression as follows:

$$F_c = C_{F_c} \cdot a_p{}^{X_{F_c}} \cdot f^{Y_{F_c}} \cdot v^{Z_{F_c}}$$

$$F_f = C_{F_f} \cdot a_p{}^{X_{F_f}} \cdot f^{Y_{F_f}} \cdot v^{Z_{F_f}}$$

$$F_p = C_{F_p} \cdot a_p{}^{X_{F_p}} \cdot f^{Y_{F_p}} \cdot v^{Z_{F_p}}$$

where, F_c、F_f、F_p —main cutting force, feeding force, back force, N;

C_{Fc}、C_{Ff}、C_{FP} —coefficient, depend on workpiece material and cutting condition;

X_{Fc}、Y_{Fc}、Z_{Fc}、X_{Ff}、Y_{Ff}、Z_{Ff}、X_{Fp}、Y_{Fp}、Z_{Fp} —index.

The purpose of the test is the analysis on the orthogonal test result using multiple linear regression , and obtain the empirical formula index and coefficient by linear fitting.

First, the exponential formula into the linear forms by getting the logarithm of the formulas.The linear formulas as following:

$$\lg F_c = \lg C_{F_c} + X_{F_c} \lg a_p + Y_{F_c} \lg f + Z_{F_c} \lg v \quad (1)$$

$$\lg F_f = \lg C_{F_f} + X_{F_f} \lg a_p + Y_{F_f} \lg f + Z_{F_f} \lg v \text{ z} \quad (2)$$

$$\lg F_p = \lg C_{F_p} + X_{F_p} \lg a_p + Y_{F_p} \lg f + Z_{F_p} \lg v \quad (3)$$

In the formula (1), Y_c= lgC_{Fc}, X_1=lga_p, X_2=lg f, X_3=lg$v$, C_c=lgC_{Fc}, and the formulas (2) and (3) are the same. The simplified equations are obtained:

$$Y_c = C_c + X_{F_c} X_1 + Y_{F_c} X_2 + Z_{F_c} X_3$$

$$Y_f = C_f + X_{F_f} X_1 + Y_{F_f} X_2 + Z_{F_f} X_3$$

$$Y_p = C_p + X_{F_p} X_1 + Y_{F_p} X_2 + Z_{F_p} X_3$$

Based on orthogonal test results, the mathematical software of MATLAB is used for multiple linear regression analysis. And obtain empirical formulas of cutting force for turning of superalloy:

$$F_c = 1325.867 \cdot a_p{}^{0.7194} \cdot f^{0.6395} v^{0.0299}$$

$$F_f = 331.742 \cdot a_p{}^{0.9933} \cdot f^{0.1676} \cdot v^{0.0160}$$

$$F_p = 46.004 \cdot a_p{}^{0.0501} \cdot f^{0.4944} \cdot v^{0.4189}$$

3.2. Effects of Cutting Parameters on Cutting Force

Analyze the cutting force data from orthogonal tests by range analysis, the range of cutting variable factor is lager, the influence of the factor on cutting force is more prominent, and vice versa.

The result of the analysis of the total cutting force F is shown in Table 3. Range analysis results of feed f is 272mm/r, cutting depth is 281mm and cutting speed is 90m/min. Through the analysis of orthogonal test results, obtain that the influence of cutting variables for total cutting force F is $a_p > f > v$.

Table 3. *F* Range Analysis

	v/(m/min)	f/(mm/r)	a_p/mm
K_1	717	556	538
K_2	627	677	704
K_3	717	828	819
Range R	90	272	281
Primary-Secondary	$a_p > f > v$		

Analyze the result of the feeding force F_f is shown in Table 4. Range analysis results of feed is 35mm/r, cutting depth is 151 mm and cutting speed is 29m/min. The analysis of orthogonal test results show that the influence of cutting variables for total cutting force F is $a_p > f > v$.

Table 4. F_f Range Analysis

	v/(m/min)	f/(mm/r)	a_p/mm
K_1	245	217	154
K_2	216	233	243
K_3	241	252	305
Range R	29	35	151
Primary-Secondary	$a_p > f > v$		

Analyze the result of the back force F_p is shown in Table 5. Range analysis results of feedis 115mm/r, cutting depth is 43 mm and cutting speed is 91m/min. The analysis of orthogonal test results show that the influence of cutting variables for back force F_p is $f > v > a_p$.

Table 5. F_p Range Analysis

	v/(m/min)	f/(mm/r)	a_p/mm
K_1	319	263	300
K_2	271	311	343
K_3	362	378	309
Range R	91	115	43
Primary-Secondary	$f > v > a_p$		

Analyze the result of the main cutting force F_c is shown in Table 6. Range analysis results of feed is 251mm/r, cutting depth is 281mm and cutting speed is 70m/min. The analysis of orthogonal test results show that the influence of cutting variables for the main cutting force F_c is $a_p > f > v$.

Table 6. F_c Range Analysis

	v/(m/min)	f/(mm/r)	a_p/mm
K_1	590	437	538
K_2	520	550	704
K_3	565	688	819
Range R	70	251	281
Primary-Secondary	$a_p > f > v$		

4. Conclusion

In this paper, the empirical formulas of cutting force was established by orthogonal test. Research the influence of cutting variables on cutting force and using the range analysis to analyze the result of the orthogonal experiments. Study on the influence of a_p, f and v for F_f, F_c and F, obtain the primary and secondary relation of the three variables is: $a_p > f > v$ and the influence degree of a_p, f and v for F_p is $f > v > a_p$. Therefore, when using coated carbide tool to machine superalloy, increasing the cutting speed and reducing feed and the cutting depth are considered.

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