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Tool Flank Wear Experiment Study on High Speed Turning Nickel-based Superalloy Inconel 718

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Abstract

Based on the serious flank wear process in high speed cutting of nickel-based superalloy, the orthogonal experiment of turning is processed. The purpose is to research the effect of the cutting parameters on the superalloy Inconel 718 tool flank wear by using the ceramic tool on the condition of the high speed cutting. Replace the tool surface every cutting 25s. According to the variation of cutting parameters, observe the tool flank wear. The research results indicate that depth of cut has highly obvious influence on tool flank wear, followed by feed rate and cutting speed.

***Keyword**: Nickel-based superalloy; Flank wear; Cutting parameters; Turning*

1. Introduction

Nickel-based superalloy Inconel 718 is extensively used the aerospace industry in the hot sections of gas turbine engines. Its properties such as creep and corrosion resistance, as well as the abilities to maintain high strength-to-weight ratio, are vital for the economic exploitation of aerospace engines [1-4]. But due to peculiar characteristics such as higher cutting temperature, plastic deformation, work hardening *etc* makes it difficult to machine. The ceramic tool usually perform better in high speed machining and in machining of high hardness work piece materials as compared to high speed steel and carbide tools [5-7]. In high speed machining of nickel-based superalloy with ceramic tools can reduce machining costs and increase productivity. Cutting tool life was determined by flank wear, as a worn cutting tool may affect the surface quality [8]. The most well known flank wear type while cutting the Inconel 718 is notch wear at the depth of cut line. Notch wear at the depth of cut line is a kind of transfer-type wear generated by the adhesion of the work material to the tool [8-11]. Flank wear is an important factor to restrict the tool life [12-15].

In order to realize high speed and high efficient cutting of nickel-based superalloy, the tool flank wear mechanism on the turning process is studied emphasized.

In view of the above mentioned machining problems, the main objective of the paper is to study of the influence of different cutting parameters on tool flank wear. The Taguchi design approach is utilized for experimental planning during the turning of Ni-based superalloy Inconel 718. The results are analyzed to reduce flank wear. Mathematical models are developed by means of multiple linear regression analysis for optimal selection of machining parameters for minimum flank wear in turning Ni-based superalloy Inconel 718.

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2. Experimental Procedure

2.1. Workpiece Material, Cutting Tools and Equipment

The experiments were performed using an EMCO-Maxxturn 65 Turning Center having a maximum spindle speed of 5000 rpm. Cutting conditions is dry cutting. A nickel-based superalloy Inconel 718 bar was selected as the workpiece material for the experiment, of which heat treatment is solution and aging.

Hardness: 40 HRC; Workpiece size: $\phi 156mm \times 157mm$; Table 1 shown the chemical composition of the Nickel-based superalloy Inconel 718 used for the experimentation.

Table 1. Composition of Nickel-Based Superalloy Inconel 718 Used for Experiment Wt%

Composition	Content	Composition	Content	Composition	Content
C	≤0.08	Ti	0.75~1.15	Si	≤0.35
Cr	17.0~21.0	Nb	4.75~5.50	P	≤0.015
Ni	50.0~55.0	B	≤0.006	S	≤0.015
Mo	2.80~3.30	Mn	≤0.35	Cu	≤0.30
Al	0.30~0.70	Mg	≤0.01	Fe	~

Si_3N_4-Al_2O_3 ceramic (Sialon) blade KY1540 was selected as the main cutting tools in the experiment. The form of blade cutting edge is chamfered and chamfer width of 0.1mm, down angularity 20^o, The model equipped with a blade handle was a CRSNR 2525M12-MN4. After the cutting process, the tool flank wear values were measured under the use of Dino-Lite digital microscope.

2.2. Experimental Procedure and Operating Parameters

In order to study the relationship between flank wear of ceramic and the cutting parameters in tool durability experiment, flank wear will be studied. Measure flank wear every 25s, record the value of cutting tool flank wear and replace the tool. The experimental site is shown in Figure 1, and the experimental handle is shown in Figure 2.

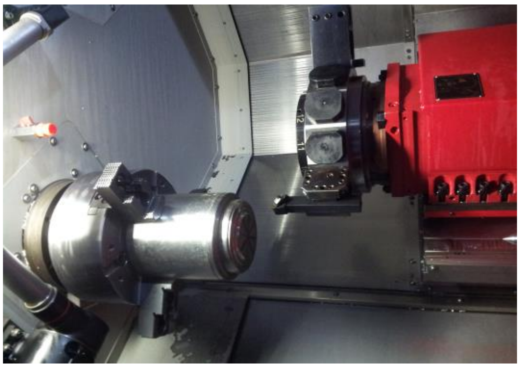

Figure 1. Experimental Site

Figure 2. Experimental Handle

Taguchi method is a unique and powerful statistical experimental design technique, which greatly improves the engineering productivity [6,16].According to Taguchi method-based robust design and an $L_{16}(4^4)$ orthogonal array are employed for the experimentation. Three machining parameters are considered as controlling factors (depth of cut, cutting speed and feed rate) and each parameter has four levels, denoted by 1, 2 and 3. Table 2 shows the cutting parameters and their levels as considered for the experimentation.

Table 2. Cutting Parameters and Their Levels

Sl. no.	Machining parameters	Level 1	2	3	4
1	A: depth of cut. mm	0.6	0.8	1	1.2
2	B: feed rate. mm/r	0.1	0.15	0.2	0.25
3	C: cutting speed. m/min	200	250	300	350

The result for flank wear was presented in Figure 3.

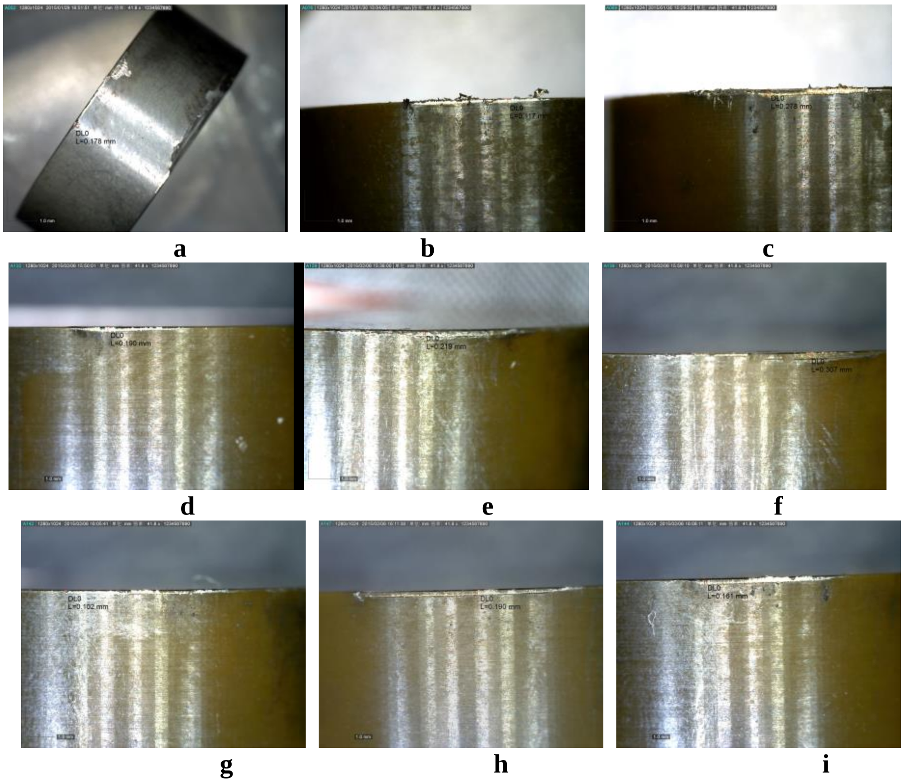

Figure 3. Flank Wear Observed On Ceramic Tool At Different Cutting Parameters

a) v_c=200m/min, f_z=0.1 mm/r and a_p=0.6 mm.(b) v_c=250m/min, f_z=0.15 mm/r and a_p=0.6 mm. (c) v_c=350m/min, f_z=0.25 mm/r and a_p=0.6 mm.(d) v_c=200m/min, f_z=0.2 mm/r and a_p=1 mm. (e) v_c=200m/min, f_z=0.25 mm/r and a_p=1.2 mm.(f) v_c=250m/min, f_z=0.25 mm/r and a_p=1 mm. (g) v_c=250m/min, f_z=0.1 mm/r and a_p=0.8 mm.(h) v_c=300m/min, f_z=0.1 mm/r and a_p=1 mm.

(i) v_c=350m/min, f_z=0.2 mm/r and a_p=0.8 mm.

3. Experimental Details

Table 3 shows the turning experimental results of tool life. Table 4 shows the result of the analysis of variance (ANOVA) for flank wear.

Using the Taguchi method can reduce the test and improve product quality [17]. The S/N ratio is used to measure the quality characteristic. Based on statistical analysis of various test schemes, the best parameter level combination of strong anti-interference ability, good adjustment, stable performance is identified.

Taguchi uses the S/N ratio to measure the quality characteristic which deviates from a desired value. The S/N ratio characteristics can be divided into three categories; nominal the better, smaller the better and higher the better when the quality characteristics is continuous [18].the aim of this test is to minimize flank wear within optimal cutting parameters, the smaller flank wear is selected and is given as

$$\eta = 10\lg \frac{1}{\frac{1}{N}\sum_{i=1}^{n} Y_i^2} = -10\lg(\frac{1}{N}\sum_{i=1}^{n} Y_i^2) \quad (1)$$

In Equation (1), Y_i is the value of flank wear for the i th test, n is the number of tests, and N is the total number of data points.

Table 3. Experimental Results For V_B

Exp.no.	A cutting speed v_c (m/min)	B feed rate f_z (mm/r)	C depth of cut a_p (mm)	Test results	
				V_B (mm)	S/N (dB)
1	200	0.1	0.6	0.178	14.99
2	200	0.15	0.8	0.189	14.47
3	200	0.2	1	0.190	14.42
4	200	0.25	1.2	0.219	13.19
5	250	0.1	0.8	0.102	19.82
6	250	0.15	0.6	0.117	18.63
7	250	0.2	1.2	0.175	15.14
8	250	0.25	1	0.307	10.26
9	300	0.1	1	0.190	14.42
10	300	0.15	1.2	0.263	11.60
11	300	0.2	0.6	0.102	19.83
12	300	0.25	0.8	0.102	19.83
13	350	0.1	1.2	0.190	14.42
14	350	0.15	1	0.321	9.87
15	350	0.2	0.8	0.161	15.86
16	350	0.25	0.6	0.278	11.12

The calculation results as shown in Table 4. It is easy to determine the effect of each factor on the response effect.

Once the optimal level of the design parameters have been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of the design parameters [4, 11].The following just take the method of range analysis to study the influence of various factors and the collocation of the optimal combination of factors.

In order to analyze the effect of each factor index, calculate each column Ⅰ ^{j}, Ⅱ ^{j} and Ⅲ ^{j} (j = 1&2, mean respectively corresponding factors) according to 16 groups of test results. The V_B response table for each level of the process parameters (cutting speed, feed rate, and depth of cut) was created in an integrated manner the V_B response results are given in Table 4. On the other hand, the same S/N results are listed in Table 5.

Table 4. V_B Response Table for Flank Wear

levels	cutting speed v_c (m/min)	feed rate f_z（mm/r）	depth of cut a_p (mm)
Ⅰ $_j$	0.776	0.666	0.675
Ⅱ $_j$	0.701	0.889	0.554
Ⅲ $_j$	0.657	0.628	1.008
Ⅳ $_j$	0.95	0.906	0.847
△max-min	0.293	0.378	0.454

Table 5. S/N Response Table For V_B

levels	cutting speed v_c (m/min)	feed rate f_z（mm/r）	depth of cut a_p (mm)
Ⅰ $_j$	57.07	63.65	64.57
Ⅱ $_j$	63.65	54.57	69.98
Ⅲ $_j$	65.68	65.25	48.97
Ⅳ $_j$	61.27	54.4	55.07
△max-min	8.61	9.25	21.01

Table 5. Shows That the Cutting Speed, Feed Rate and Depth of Cut Are Equally Responsible and Have a Great Influence on Flank Wear V_B (Mm)

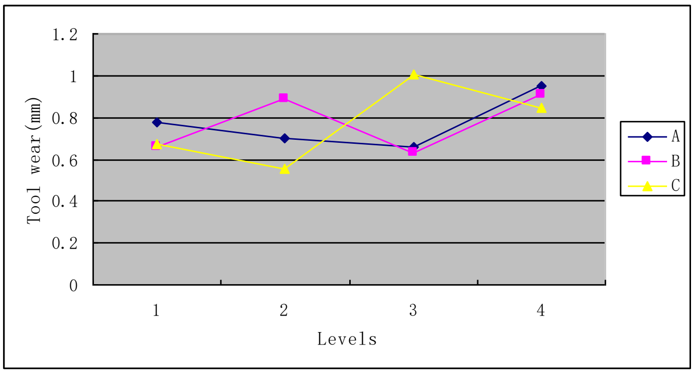

Figure 4. Main Effects Plot For V_B

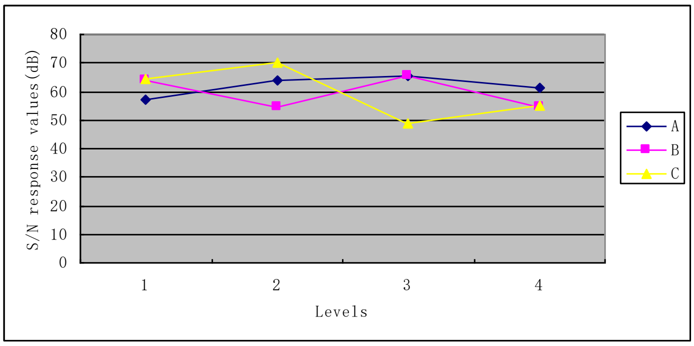

Figure 5. Main Effects Plot For S/N

The effects of process parameters resulting from the optimization process are plotted in Figure 4 and Figure 5. The V_B and S/N response tables for flank wear in order to find the optimal levels of the three parameters. In Figure 4, it is shown that the maximum S/N response value at each level produces the lowest flank wear.

As you can see from Figure 4, the effect of various factors on the impact of S/N is different. Depth of cut is one of the most important impact factors. The trend of S/N increased with increase in depth of cut. The average flank wear reduced when the depth of cut increased from 0.6 to 1 mm.

1. The factors influence on the index (flank wear) of primary and secondary.

Table 5 shows the third column value is the maximum and the first column is the minimum. This reflects when factors (depth of cut) C level changes, the index fluctuations are maximum, and the factors of A (cutting speed) level changes, the index fluctuations are minimum.

2. Better production conditions

It can be seen from Table 3 and 4 that the better production conditions are cutting speed for 300 mm/min, feed rate for 0.2 mm/r and depth (factors) of cut for 0.8 mm. Obtained by the flank wear value of the minimum, the optimal combination is the fifteenth orthogonal experiment test. Flank wear as shown in Figure 3 (i).

4. Conclusions

In this study, the Taguchi optimization method was applied to find the influence regular pattern of cutting speed, feed rate and depth of cut which minimize flank wear during high speed machining Inconel 718. The following conclusions can be drawn from the theoretical and experimental results of this study：

1. The experiment studied the influence factors of flank wear in high speed turning and proposes an optimal process plan to reduce the effect of tool flank wear. It provides an experimental basis for the optimization of high speed turning system.

2. Analysis of variance suggests that depth of cut is the significant influencing factor in case of flank wear. Based on the optimization result, the minimum flank wear is 0.161 mm in experimental measurements.

3. For minimum flank wear, the recommended setting value of cutting speed is 300m/min, feed rate is 0.2 mm/r and depth of cut is 0.8 mm for turning Inconel 718 processing in high speed machining center.

Acknowledgements

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