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Surface Quality Controlling Research on High Speed Milling Nickel-Based Superalloy Inconel 718

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Abstract

Nickel based superalloy Inconel 718 is difficult to machine as a material. The prediction model of surface roughness in high speed milling of Nickel-based Superalloy Inconel 718 was developed based on multiple regression analysis. The model is established from the experiments conducted on a XH714D matching center. The predicted results by using this model agree very well with those obtained from experiments, and the Prediction model of surface roughness of nickel based superalloy can provide a foundation to optimize cutting parameters and control surface quality.

Keyword: *Nickel-based superalloy; Surface roughness; Cutting parameters*

1. Introduction

Nickel-based superalloy are widely used in aerospace applications due to their excellent mechanical properties maintained at high temperature and their corrosion resistance. [1] However, Nickel-base super alloy Inconel 718 is well known to be one of the most difficult materials to machine because of its high hardness, high strength at high temperatures [2]. Surface roughness on Inconel 718 is contributed by tool geometry and material properties, cutting kinematics and cutting conditions [3].

The surface roughness in the machining is mainly due to the surface roughness caused by geometrical factors, which is mainly affected by the residual area height. In addition, during the milling process, the chip peeling, Built-up edge and the vibration of the machine tool can affect the surface of the processing. Therefore, the factors affecting the surface roughness is very complex in high speed machining which mainly manifest in the following four points [4-6].

1) Tool factors. In the process of milling, tool material, tool rake angle and back angle, nose radius, tool wear and so on will influence on the surface roughness produced.

2) Influence of workpiece factors. In the workpiece material properties, the strength, hardness, plasticity and toughness of the workpiece material, the microstructure of the workpiece material will have an impact on the surface roughness. In the process, the plastic of the workpiece material determines the formation of the built-up edge and scale.

3) Influence of milling parameters. The milling parameters mainly include the milling speed, milling depth, feed rate and milling method. These parameters affect the surface roughness in high speed machining, and often lead to the change of milling force, vibration of machine tool and milling temperature.

4) Influence of milling process factors. Mainly refers to the influence of milling force, milling temperature and machine tool vibration on the surface roughness in high speed machining.

The influence factors of surface roughness are mainly divided into two categories, one is geometric factor, and the other is non geometrical factor. In terms of geometric factors,

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the milling model can be simplified to the cutting edge relative to the workpiece for small linear motion, as shown in Figure 1.

From Figure1, h is the surface of the processed surface of the residual area height. Residual area height h is mainly governed by the tool of main angle k_r, tool angle k_r', feed per tooth f_z and tool radius r. These can be collectively referred to as the influence of geometric factors.

On the other hand, in the process of the emergence of the scale, machine vibration, built-up edge, the wearing of tool and whether the use of cutting fluid will have an impact on the surface roughness. These can be referred to as non geometrical factors.

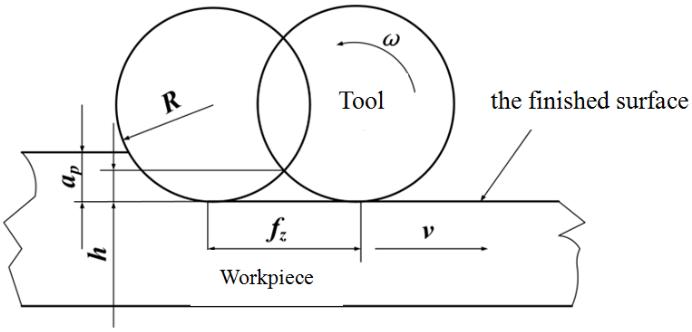


Figure 1. Milling Workpiece

Through the analysis of the geometric factors, the formation of residual area height of h will occur three cases after machining, as follows.

1) The intersection region between cutting tool and two straight line cutting edge. As shown in Figure 2.

2) Tool position intersects in straight line and arc. As shown in Figure 3.

3) Tool position intersects in arc. As shown in Figure 4.

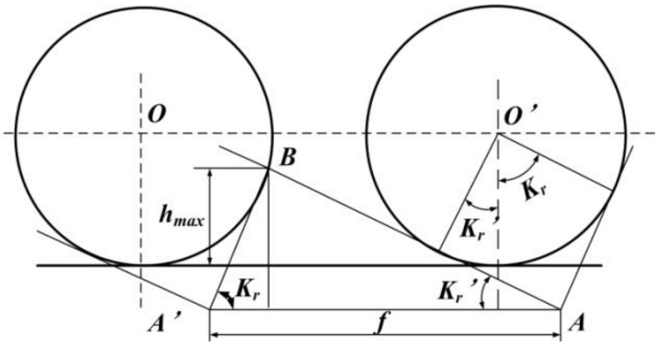


Figure 2. Tool Position Intersects in Straight Line

When the first case occurs, that is $f > r\left[\frac{1-\cos(k_r + k_r')}{\sin k_r'}\right]$,

$$h = \frac{f}{\cot k_r + \cot k_r'} - r\left[\frac{\cos\frac{k_r - k_r'}{2}}{\cos\frac{k_r + k_r'}{2}} - 1\right] \tag{1}$$

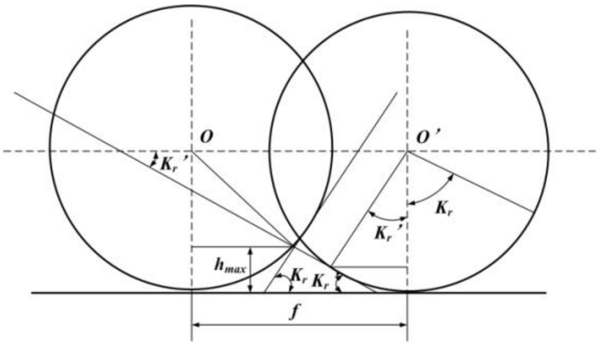


Figure 3. Tool Position Intersects in Straight Line and Arc

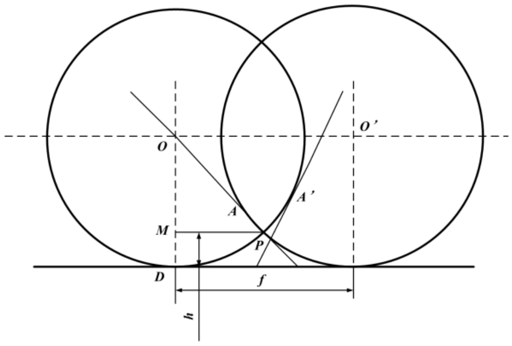


Figure 4. Tool Position Intersects in Arc

When the second case occurs, that is $r\left[\frac{1-\cos(k_r+k_r')}{\sin k_r'}\right] \geq f \geq 2r\cdot\sin k_r'$,

$$h = r(1-\cos k_r') + \frac{f}{2}\sin 2k_r' - \sin\sqrt{f\cdot\sin k_r'(2r - f\cdot\sin k_r')} \qquad (2)$$

When the third case occurs, that is $f \leq 2r\cdot\sin k_r'$,

$$h = r - r\sqrt{r^2 - (\frac{f}{2})^2} \qquad (3)$$

With $f \leq 2r\cdot\sin k_r'$, The formula (3-3) Can be simplified:

$$h = \frac{f^2}{8r} \qquad (4)$$

Where h is residual area height, r is corner radius and f is feed rate. According to the actual measurement experience, the theoretical surface roughness is $Ra \approx 0.2h$.

2. Experimental Procedure

2.1. Workpiece Material and Cutting Tool

The experiments were performed using an XH714D vertical machining Center. A nickel-based superalloy Inconel 718 was selected as the workpiece material for the experiment, of which heat treatment is solution and aging.

Hardness: 40 HRC; Workpiece size: 80mm×40mm×25mm; 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	~

Ceramic blade KYHS10 was selected as the main cutting tools in the experiment. Roughness measurement using LINKS 2207 type surface roughness measuring instrument, as shown in Figure5.

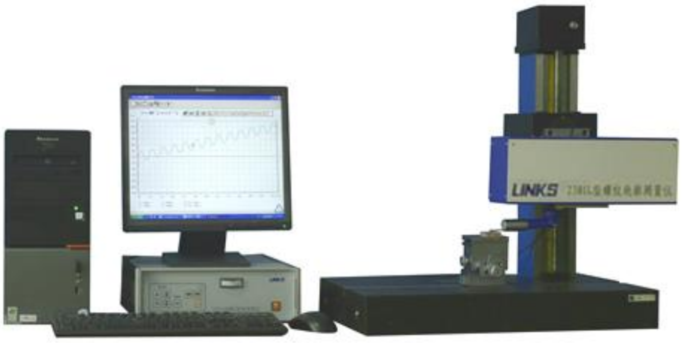


Figure 5. LINKS 2207 Surface Roughness Measuring Instrument

2.2. Experimental Design

Taguchi method is a unique and powerful statistical experimental design technique, which greatly improves the engineering productivity [7,16].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 (Milling speed, feed per tooth and depth of cut) and each parameter has four levels, denoted by 1, 2 and 3. Table 2 shows the milling parameters and their levels as considered for the experimentation.

Through the analysis of the experimental results, using MATLAB software to fit the experimental data and obtained the mathematical model of surface roughness, find the influence rule of milling parameters on the surface roughness. Provide theoretical basis for selection of cutting parameters.

Table 2. Milling Parameters and Their Levels

Sl.no.	Machining parameters	Level			
		1	2	3	4
1	Milling speed v (m/min)	300	350	400	450
2	feed per tooth f_z (mm/z)	0.05	0.07	0.09	0.1
3	depth of cut a_p (mm)	0.7	0.9	1.2	1.5

3. Experimental Details

After the end of the milling experiments take the workpiece. In order to prevent the workpiece surface adhesion, the tiny chips and dust, the machined surface of high voltage jet and oil processing. This will help to accurately measured the surface roughness value.

After the pretreatment, the workpiece is placed on the platform of LINKS 2207 type surface roughness measuring instrument. Each set of parameters measured 6 ~ 8 points, and Then the average value of these points is recorded in Table 3.

Extreme difference analytical method was used to find the optimum combination of the best milling parameters for surface roughness. Surface roughness range analysis table as shown in Table 4.

Table 3. Roughness in Different Milling Parameter

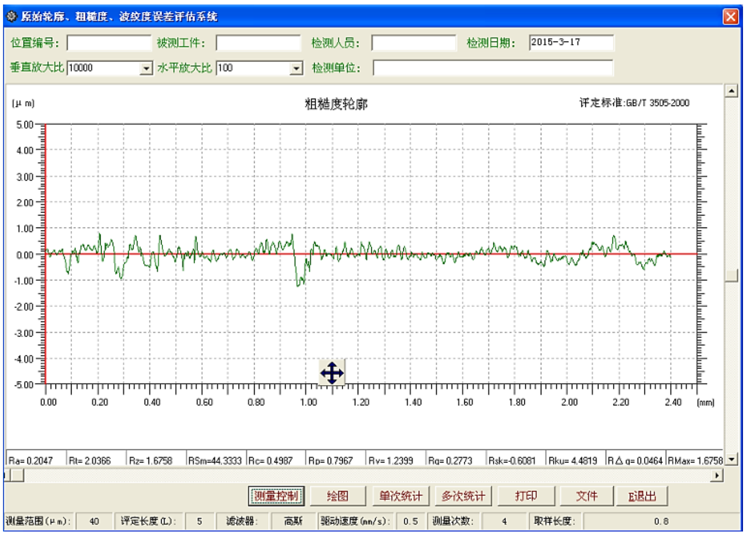
Sl.no.	Milling speed v(m/min)	Depth of cut a_p(mm)	Feed per tooth f_z(mm/z)	Roughness R_a(μm)
1	300	1.5	0.05	0.212
2	300	1.2	0.07	0.379
3	300	0.9	0.09	0.366
4	300	0.7	0.1	0.645
5	350	1.5	0.07	0.343
6	350	1.2	0.05	0.270
7	350	0.9	0.1	0.290
8	350	0.7	0.09	0.596
9	400	1.5	0.09	0.383
10	400	1.2	0.1	0.581
11	400	0.9	0.05	0.530
12	400	0.7	0.07	2.324
13	450	1.5	0.1	0.392
14	450	1.2	0.09	0.738
15	450	0.9	0.07	0.529
16	450	0.7	0.05	0.980

In the same way, the range value of the depth of cut a_p and the range value of feed per tooth f_z can be obtained. From Table 4, it is found that the effect of depth of cut is the most influence, the second is the milling speed, and the last is the feed per tooth.

Table 4. Range Analysis of Finish Surface Roughness

levels	Milling speed	Depth of cut	Feed per tooth
K1	0. 401	0. 333	0. 498
K2	0. 375	0. 492	0. 894
K3	0. 954	0. 429	0. 521
K4	0. 66	1. 136	0. 477
R	0. 58	0. 804	0. 417

From the analysis reference table for S/N ratio, the response suggests that choosing milling speed 350m/min, depth of cut 0.7mm and depth of cut 0.1mm/z results in lower surface roughness within the range of experiments based on smaller the better characteristics. The surface roughness measured in the optimal milling parameters is shown in Figure6.



原始轮廓、粗糙度、波纹度误差评估系统

位置编号：
被测工件：
检测人员：
检测日期： 2015-3-17
垂直放大比 10000
水平放大比 100
检测单位：

评定标准:GB/T 3505-2000

Ra= 0.2047 | Rt= 2.0366 | Rz= 1.6758 | RSm=44.3333 | Rc= 0.4987 | Rp= 0.7967 | Rv= 1.2399 | Rq= 0.2773 | Rsk=-0.6081 | Rku= 4.4819 | RΔq= 0.0464 | RMax= 1.6758

测量范围(μm): 40
评定长度(L): 5
滤波器: 高斯
驱动速度(mm/s): 0.5
测量次数: 4
取样长度: 0.8

Figure 6. Finish Surface Roughness

4. Conclusions

In this study, the Taguchi optimization method was applied to find the effect of milling speed, depth of cut and depth of cut on surface roughness in finish milling of Inconel 718. It is found from the result that good surface finish are obtained using ceramic tool when finish milling Inconel 718 at small depth of cut. The optimal milling condition for good surface finish is milling speed 350m/min, depth of cut 0.7mm and depth of cut 0.1mm/z. The experiment studied the influence factors of surface roughness in high speed milling and proposes an optimal process plan to control surface quality.

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