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Analysis of the optimization of tool geometric parameters for milling of Inconel718

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Abstract: Correct selection of cutting parameters is the most effective approaches to achieve optimum machining process. An attempt is made to investigate the machinability of Inconel718 based on the milling simulation and experimental study. The sub micron grain cemented carbide is used as the cutting tool, and the parameters such as milling force, milling temperature, tool wear and workpiece surface quality are investigated. Under the same cutting parameters and other cutter geometry parameters, the study analyzes the different helix angles, the milling force of rake angles in milling cutter, milling temperature, tool wear and workpiece surface roughness. The experimental results show that the smallest value of cutting force and cutting temperature, the best value for surface roughness, and the smallest tool wear value can be simultaneously achieved by optimization of cutting parameters, which is 45-degree helix angle and 12-degree rank angle. This study achieved the optimisation of tool geometric parameters for milling of Inconel718 using sub micron grain cemented carbide cutting tool.

1. Aims and Background

Ni-based superalloy has favorable high temperature mechanical properties, such as good anti-oxidation, corrosion resistance and thermal stability[1]. It is often used as the heat resistant material for discs and blades of aerospace engines and gas turbines. But it is difficult to machine and wore cutting tool severely, because it has low heat transfer coefficient, the high temperature strength, the high affinity of the workpiece and the cutting tool[2,3]. The blades and discs are mainly machined by milling process, with large material removal and high cutting tool cost. Cemented carbide, with high hardness, high strength, high elastic modulus, has been the most important tool material replacing high-speed steel in modern cutting tool material[4]. The cutting performance of the tool is mainly composed of three aspects: the tool material, the surface coating and the tool structure[5]. Among them, a good tool structure is the basis for giving full play to the tool cutting performance. The research report of the International Academy for Production Engineering (CIRP) has pointed out that tool life can be prolonged by nearly two times every ten years, due to the improvement of tool structure and geometric parameters[6]. It can be seen that the optimization design of tool structure is an effective way to improve the cutting performance of tools[7].

The domestic and foreign scholars have done a lot of researches on the influence of cutting parameters on the cutting performance of difficult machining materials. Yang Q. *et al*[8]have investigated the milling performance of powder metallurgy high temperature alloy by using coated cemented carbide tool. It is concluded that the reasonable selection of the front angle and the width of the back edge can enhance the strength of the cutting edge and improve the life of the cutter. Zhao B.Y. *et al*[9] have studied the tapping technology of GH4169. By optimizing the geometric parameters of the tap, the machining efficiency is improved by five times, and the service life is increased by three or four times. Han R.D.[10] have proposed that the selection of tool geometry parameters is the key point in the design of the cutting tool of difficult machining materials. Wang Q.D. *et al*[11] have studied the influence of tool geometric parameters on the milling force, which showed that the influence of tool geometric parameters on the milling force is comprehensive. The increase of helix angle can indirectly increase the number of working cutting edges, reduce the impact of cutting force, and suppress the deformation of tool and workpiece. However, at the same time, the maximum value of resultant force of cutting force becomes larger, which increases the tool chipping and the possibility of breakage. Huang C.Z. *et al*[12] have studied the cutting of GH4169 with cemented carbide cutter and ceramic. The results showe that, when the cutting speed is low, the K class cemented carbide is better than SiCw and SiCp reinforced Al_2O_3 + TiB_2 ceramic tool. However, when the cutting speed increases to v_c>100 m/min, the superiority. The rake face wear is caused by adhesion and diffusion, and the tool flank wear is due to abrasive wear. Narutaki N.[13] have investigated turning Inconel718 with Al_2O_3/SiCw ceramic tool, Si3N4 ceramic cutting tool and Al_2O_3+TiC ceramic tool in vc=500 m/min and 10 % aqueous cutting fluid. The wear form and wear degree of several tools are compared, cutting test was conducted with different geometrical angles of cutting tool. It is found that the sword sharp radius and mate angle tool can effectively reduce the groove wear of the ceramic cutting tool. In summary, there are a large number of studies on the cutting performance of Inconel718 and optimizing the geometric angle parameters of difficult machining materials. However, there is little study on the tool geometric parameters for milling of Inconel718, which is machined by the submicron grain cemented carbide milling cutter. This study focus on optimizing the tool geometric parameters for milling of Inconel718 using sub micron grain cemented carbide cutting tool.

2. Experimental part

Experiments were carried out on a Deckel Maho machining center (Deckel Maho DMC 70V Linear, max speed: 18000 r/min, position accuracy: 1μm) manufactured by Gildemeister. A piezoelectric dynamometer (Kistler dynamometer 9257B) was used to measure the milling force, and the DynoWare (Version 2.4.3.2) processing software was adopted to perform the data acquisition. Fig.1A shows the view of the experimental set-up. The workpiece material used in this work was Inconel718, which was shaped in the form of 50 mm×40 mm×30 mm blocks. The chemical components and mechanical properties of Inconel718 are showed in table 1 and table 2.

Table 1 The chemical components of Inconel718

Workpiece Material	Chemical components（W_t）%				
	Ni	Cr	Nb	Mo	Ti
Inconel718	51.75	17	5.15	2.93	1.07
Workpiece Material	C	Si	Mn	B	Fe
Inconel718	0.042	0.21	0.03	0.006	21.812

The sub micron grain cemented carbide was used as the cutting tool in the study, rod type raw materials were provided by IMC company and processed by Harbin Dong´an Lifeng Cutter Co., Ltd. The geometric parameters of cutting tool were four teeth flat endmill and diameter of 8 mm, meanwhile other geometric parameters are shown in table 3. The image of the cutting tools is shown in

Fig.1D.

Table 2 The mechanical properties of Inconel718

Workpiece Material	density ρ (kg/m^3)	yield strength $\sigma_{0.2}$ (MPa)	tensile strength σ_b (MPa)
Inconel718	8280	1260	1430
Workpiece Material	elongationδ_5 (%)	shrinkageψ (%)	impact toughness a_k (J/cm^2)
Inconel718	24	40	40

Table 3 The geometric parameters of milling tools

Tool number	Total toll length L_1 (mm)	Cutting edges length L_0 (mm)	helix angle β (°)	rake angles (°)	B_w (°)
1	60	20	30	9	14
2	60	20	38	9	14
3	60	20	45	9	14
4	60	20	30	12	14
5	60	20	38	12	14
6	60	20	45	12	14
7	60	20	30	15	14
8	60	20	38	15	14
9	60	20	45	15	14

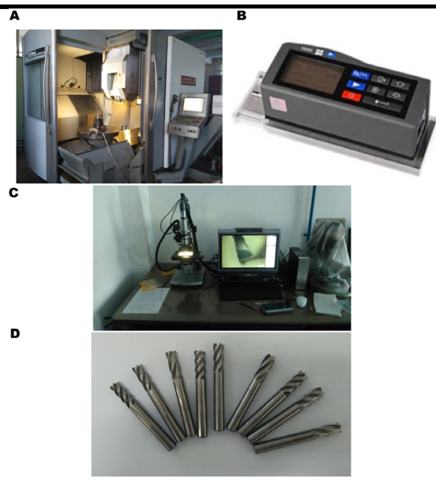

Fig. 1 A view of the processing equipment and milling cutter.
(A) A view of the experimental set-up. (B) TR200portable surface roughness tester. (C) Super depth of field microscopy.(D) Images of the milling cutter.

The Third Wave Systems Advantedge FEM software was used to carry out the milling simulation. The TR200 portable surface roughness tester was used to measure the workpiece surface roughness (Fig.1B), and the super depth of field microscopy was used to assess the degree of tool wear (Fig.1C).

The vertical milling merhord was used to machine the side surface, and cutting parameters are showed as follow: machining side surface, cutting speed Vc=50m/min, ap=0.2, f=0.05mm/Z, ae=5mm,

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100mm of machining length by using the vertical milling machining method

3. Results and Discussions

The cutting parameters, the value of the cutting force, the level and distribution of cutting temperature and the type of tool wear form, are some important basis for judging the matching of cutting tool and workpiece. This study comprehensively evaluates the matching of sub micron grain cemented carbide cutter and Inconel718 workpiece through milling simulation and experimental study, and achieves the optimisation of tool geometric parameters for milling of Inconel718 using sub micron grain cemented carbide cutting tool.

3.1 Analysis of the influences of helix angles on the milling performance

When milling difficult-to-cut materials, the selection of helix angles of tool has a decisive effect on the milling performance. Suitable selection of helix angles of tool can effectively improve service life of cutters and surface quality of workpiece. Under the same cutting parameters and other cutter geometry parameters, with different rake angle, the influence of helical angle on milling force, milling temperature, workpiece surface roughness and tool wear was analyzed in this paper.

As shown in the simulated curve and experimental curve (Fig.2A, 2B), under the same rake angles, the simulation values and experimental data of milling force decrease gradually when the helix angles increase, and the smallest value of milling force is gotten with 45-degree helix angle. There is certain difference in the numerical value between the measured values and software simulation, however， the influence of the helix angles on the milling force shows the same change trend and the theoretical analysis is in agreement with experimental results. The reasons is analyzed, when the helix angle increases， it indirectly increases the number of working cutting edges and reduces impact force on the tool, therefore, the milling force shows a downward trend.

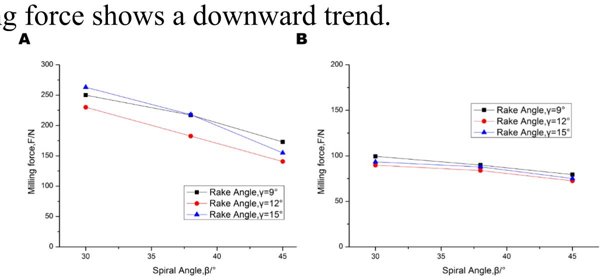

Fig. 2 The cueves for the influences of helix angles on the milling force. (A) The simulated curves. (B) The experimental curve.

From the simulation curve of Fig.3, it can be found that the temperature decreases with the increase of helix angle at the same rake angles. When the helix angle increases, the cutting time on a single cutting edge of a tool is reduced, resulting in the reduction of the cutting heat. From the experimental data of Fig.4A, at the same rake angle, the roughness value decreases with the increase of the helix angle. When the helix angle is 45 degree, the roughness value is the smallest. The reason for the condition is that the helix angle increases, the milling force and milling temperature decrease, leading to improve the surface quality of the workpiece and reduce the roughness value. The experimental data of Fig.4B can be seen, under the same rake angle, with the increase of helix angle, the tool wear VB value increases gradually. With the 45 degree helix angle, VB value is the largest. However, it can be seen from the curve trend, the tool wear tends to be gentle with the increase of helix angle. The reason for the situation, when the helix angle increases, it is the transition from the right angle cutting to the oblique cutting, the cutting edge intensity decreases, the wear value increases from the cutting principle. When the helix angle increases to a certain value, the influence gradually decreases.

To sum up, from the above five results, increasing the helix angle can reduce the milling force and milling temperature, meanwhile improve the quality of the workpiece surface processing. However, it will increase tool wear. When the helix angle is greater than 45 degree, the maximum value of the cutting resultant force will become larger, increasing the possibility of the tool tipping and damage.

Thus, it is not carried out in the experiment which helix angle is greater than 45 degree.Tool rake angle of cutter is an important variable which affectes the cutting process. It will greatly affect the cutting force, cutting temperature and surface machining quality. Under the same cutting parameters and tool geometry parameters, with different helix angle, the influence of rake angle on milling force, milling temperature, surface roughness and tool wear was investigated in this paper.

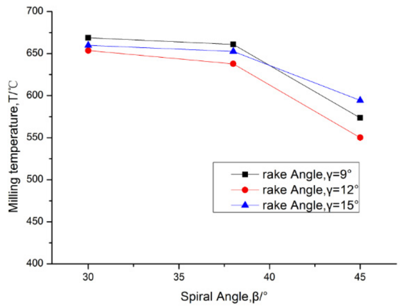

Fig. 3 The simulatd curves for the influences of helix angles on the milling temperature.

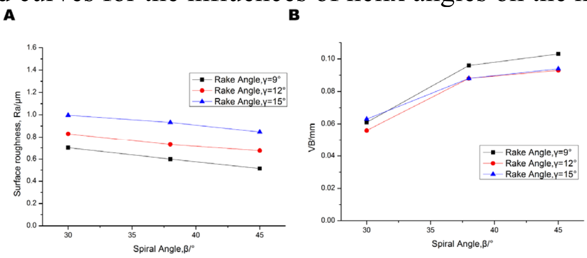

Fig. 4 The experimental curve for the influences of helix angles on the workpiece surface roughness and tool wear.

(A) The influences of helix angles on the workpiece surface roughness. (B) The influences of helix angles on the tool wear.

As shown in the simulated curve and experimental curve (Fig.5A, 5B), in the experimental and simulation conditions, with the same helix angle, the milling force is the smallest when rake angle is 12 degree. From the simulation curve Fig.6, under the same helix angle, the milling temperature is the lowest when the rake angle is 12 degree. The results of Fig.7A showed that, under the same helix angle, with the increase of the rake angle, the surface roughness value of the material is gradually increasing. The roughness value is the smallest when the rake angle is 9 degree, while it is the maximum when the rake angle is increased to15 degree. As shown in Fig.7B, under the same helix angle, the tool wear VB value is minimum when rake angle is 12 degree.

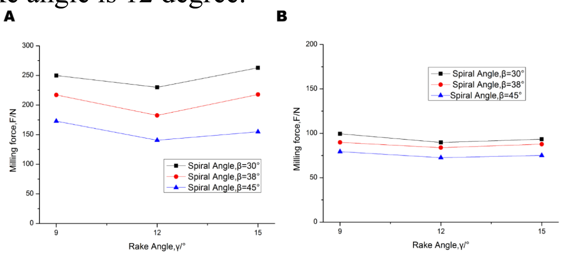

Fig. 5 The cueves for the influences of rake angles on the milling force. (A) The simulated curves. (B) The experimental curve.

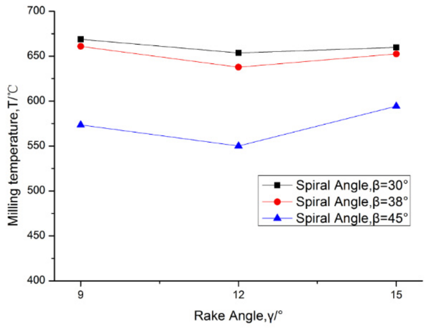

Fig. 6 The Simulated curves for the influences of rake angles on the milling temperature.

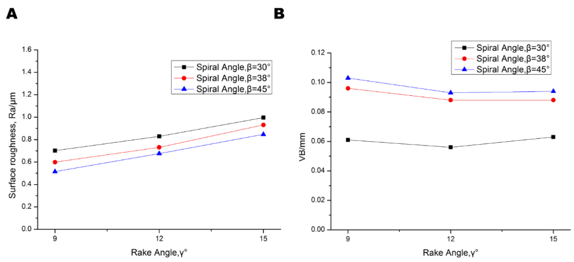

Fig. 7 The experimental curve for the influences of rake angles on the workpiece surface roughness and tool wear. (A) The influences of rake angles on the workpiece surface roughness. (B) The influences of rake angles on the tool wear.

The reasons are analyzed, the appropriate increase in the rake angle of the tool can improve the degree of sharp edges, however, an unduly large rake angle will reduce the strength of the blade. Therefore, when the tool rake angle increased from 9 degree to 12 degree, the simulation and measured values of the milling force, milling temperature are in a decreasing trend. When the rake angle is 15 degree, the milling force, the milling temperature and the measured value are all increased. When the milling force is small and the milling temperature is low, the value of tool wear reduced. Thus, when the front angle is 12 degree, the VB value is minimum, and the surface roughness value of the workpiece show tendency to ascend with the increase of front angle. Along with the increase of the front angle, the contact distance between the cutter back angle and the surface of the work piece raises, which result in the increased roughness.

4. Conclusions

Through the vertical milling simulation and machining experiments in different helix angles and rake angle, furthermore, followed by analysis of the milling force, milling temperature, workpiece surface roughness and tool wear, the best helix angle and rake angle value of the sub micron grain cemented carbide milling cutter in machining Inconel 718 were got.

By analyzing the results, the influence of tool geometric parameters on milling force is comprehensive. When the cutter helix angle increases, the difference between maximum value and the minimum value of each resultant and component force becomes smaller. The impact force on the tool is reduced and the cutting process is more stable, which can suppress the vibration of the tool and workpiece system and improve the surface quality. The increase of helix angle can indirectly raise the number of working cutting edges, and reduce the cutting force and deformation of the tool and workpiece. However, when the helix angle is too large, the tool wear will increase. The increase of rake angle will increase the sharpness of cutter, while the rake angle is too large, tool wear, cutting force and the surface roughness will increase. According to the comprehensive analysis of the above factors, 45 degree helix angle and 12 degree rake angle is the best-optimized parameters for milling of Inconel 718 with sub micron grain cemented carbide cutter.

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