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To cite this article: Cao Xiang *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **538** 012017

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Research on High Efficiency and Low Destructive Manufacture Process of Complex Structure Honeycomb Core

Cao Xiang^{1,*}, Wang Yujie¹, Sun Chao¹, Shen Xin¹

¹CAC Chengdu Aircraft Industrial (Group) Co., Ltd., Chengdu 610092, China

*Corresponding author: 31635649@qq.com

Abstract. With the development of modern aircraft, complex structure honeycomb core parts are widely used. As a kind of difficult machining material, it's easy to destroy the surface quality of the parts during machining the honeycomb core parts because of the special structure. The article studies the technology to increase efficiency and reduce damage during the machining process of complex structure honeycomb core. The problem can be effectively solved by using proper clampings, proper cutting parameters and proper tool path interval.

1. Introduction

Honeycomb core is a kind of material with the properties of high specific strength, good heat resistance, impact resistance and good insulation etc., which is widely used in the aerospace field. For example, F22 fighter' honeycomb core ratio has reached 40%[1-3].

With the development of modern aircraft, the complex honeycomb are widely used. As a kind of difficult machining material, the processing of complex structure honeycomb parts are much more difficult than ruled surfaces honeycomb parts[4-6]. It's easy to damage the surface of the part and cause the part to be out of tolerance during machining the complex structure honeycomb parts, this reduces the performance and quality of the honeycomb core. To a certain extent, the application of honeycomb core in a wider range is limited[7-9]. For this reason, it's important to improve the manufacture process of complex structure honeycomb parts. Therefore, this paper analyzes the structural characteristics and processing difficulties of complex honeycomb parts. Designed the clamping scheme for complex honeycomb parts, solves the problem of reliable fixing. Combining with orthogonal test and analysis of single factor, the rules of influence on surface quality are obtained under different processing parameters. Based on constant scallop-height method, the tool path interval of direction-parallel machining is studied. The correctness of the research is verified by engineering application.

2. Characteristics Analysis of Complex Honeycomb Machining

2.1. Clamping Requirements

The structure of the parts is special, the profile is complex, and the material is made up of multiple honeycombs, which are easily deformed and the holding state is difficult to control. There are sharp corners, thin edges and chamfering edges at the edge of the part, as shown in Figure 1. In the processing, it is easy to pull up the parts, tearing and milling the edges of the parts, causing the parts to



be out of tolerance or even scrapped, and it also brings difficulties to the protection of the parts after the processing.

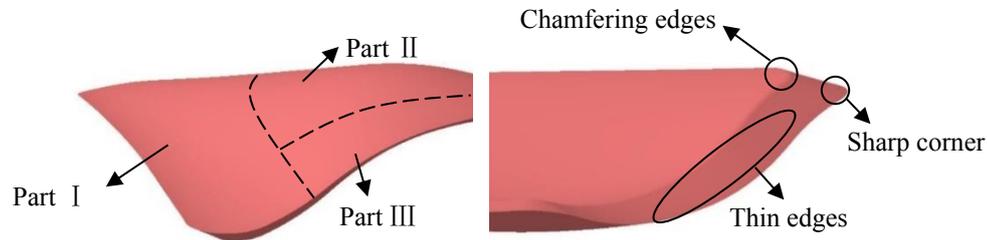


Figure 1. Structure of the typical honeycomb part.

Since the part has a double profile structure, the positioning of the second surface is mainly based on the machined surface of the first surface, the curvature of the two faces of the part is large, and the profile is a curved structure. Therefore, higher requirements are placed on the positioning of the parts.

2.2. Analysis of Cutting Parameters

In the actual machining process, the selection of milling processing parameters for complex honeycomb cores relies on empirical values, and the quality and precision of the machined surface are difficult to control, which is prone to problems such as the parts being entangled, the honeycomb structure being damaged, and the burrs being severe. In order to ensure better surface quality of the parts, it is often used to reduce the speed and small depth of cut, resulting in low processing efficiency. Faced with increasingly heavy production tasks, how to determine efficient processing parameters has become an urgent problem to be solved.

2.3. Tool Path Interval of Direction-Parallel Machining

The processing of complex curved surface of honeycomb core parts through multi-contoured and direction paralleled machining. The tool path interval is an important factor affecting part accuracy, efficiency and surface quality. It is easy to obtain better surface quality with lower tool path interval value, but the processing time increases and efficiency decreases. While the excessive tool path interval will increase the scallop height of the part surface and affect the accuracy of the part. Therefore, the tool path interval of direction-parallel machining must be reasonably determined, and the maximum value can be obtained under the premise of satisfying the processing precision requirement, thereby improving the processing efficiency.

3. Manufacture Process of Complex Structure Honeycomb Core

3.1. Clamping Scheme

The fixing and positioning method of honeycomb parts is different from metal parts because of the different properties of honeycomb materials than metallic materials, honeycomb parts through double-faced adhesive tape to achieve fast fixing. The part blank is a V-shaped spliced honeycomb with a V-angle of 120°-160°. Since the blank state is difficult to control, it is easy to appear that the blank surface can not fully fit the tooling surface because of the deformation of the blank or the incorrect geometric size. If the blank is clamped and fixed to the tooling by forced pressing, it is easy to cause the parts to rebound and deform during the machining process, resulting in the scrapping of the parts. In order to solve this problem, the repairing tooling is designed, as shown in Figure 2, and the blank surface with the correct geometrical dimensions is milled by the workpiece, and then the parts are clamped to ensure that the bottom surface of the part and the tooling surface are completely fitted.

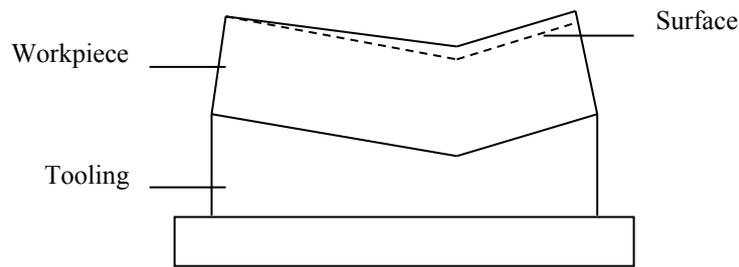


Figure 2. Repairing tooling.

In addition, since the width of the contour surface of the part is extremely small, it can be simplified into a curved structure, and it is difficult to locate by aligning the edge of the part with the contour of the tooling when the clamping is fixed. Therefore, a special tooling with a positioning stop as shown in Figure 3 is designed to realize quick positioning and clamping of the parts.

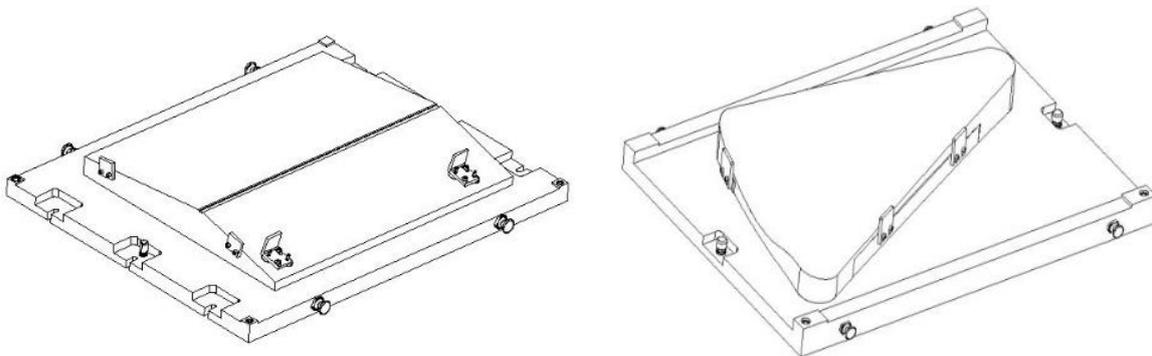


Figure 3. Structure of special tooling.

3.2. Surface Quality Analysis Based on Cutting Parameters

In order to analyze the influence of cutting parameters on the surface quality of honeycomb parts, a set of orthogonal experiments of honeycomb processing are designed. This experiments use climb milling and dry cutting to machining nomex honeycomb core on the five-axis CNC machine tool, the experimental tool is a typical honeycomb milling cutter with tool diameter 45mm. Because the honeycomb is a porous structure, it is difficult to measure surface roughness with a surface roughness meter like the metal part. Therefore, according to the situation that the surface quality of parts in actual production often occurs to dividing the quality grade, as shown in table 1.

Table 1. Honeycomb surface quality grade.

Number	Surface quality	Quality grade
1	Structure damage	0
2	Burrs in surface	5
3	Structural integrity and excellent surface	10

In this paper, four-factor four-level orthogonal test is carried out to obtain the surface quality. The four-factor include cutting depth, cutting width, feed rate and spindle speed. The cutting parameters and experimental results are shown in table 2.

Table 2. Experimental parameters and surface quality results.

Experiment number	Spindle speed (r/min)	Feed rate (mm/min)	Cutting width (mm)	Cutting depth (mm)	Surface quality grade
1	6000	800	1	3	0
2	6000	2000	2	5	0
3	6000	5000	10	15	0
4	6000	8000	20	20	0
5	10000	800	1	3	5
6	10000	2000	2	5	5
7	10000	5000	10	15	0
8	10000	8000	20	20	0
9	14000	800	1	3	10
10	14000	2000	2	5	5
11	14000	5000	10	15	0
12	14000	8000	20	20	0
13	18000	800	1	3	10
14	18000	2000	2	5	10
15	18000	5000	10	15	5
16	18000	8000	20	20	0

In order to obtain the influence of cutting parameters on surface quality, analyze the experimental results by single factor analysis. The surface quality is represented by W , cutting parameters are represented by A_i , B_i , C_i and D_i , i is parameter level of orthogonal test. Add the surface quality grade of the same parameter level, and then calculate the average, as shown in the following equation:

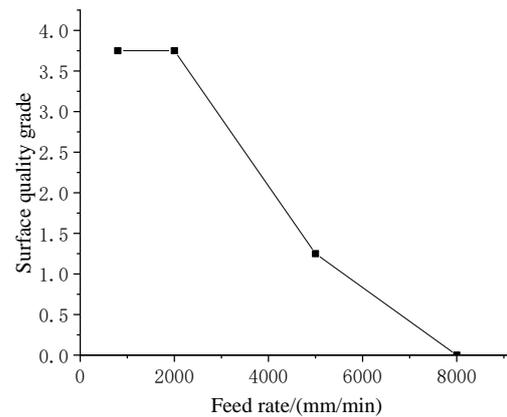
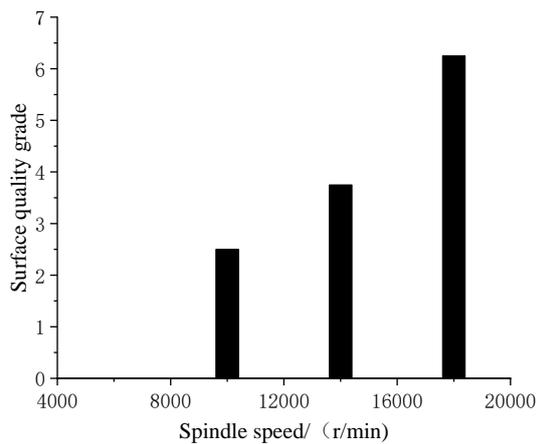
$$W_{A_i} = \frac{\sum_{i=1}^n W_{A_i B_i C_i D_i}}{m}, i = 1, 2, 3, \dots, n-1, n \quad (1)$$

Where m is the amount of surface quality result corresponding to A_i , n represents the amount of parameter level of orthogonal test. The W_{A_2} , W_{A_3} and W_{A_4} can be obtained in the same principle. Then use the same calculation for other parameters, the results are shown in table 3.

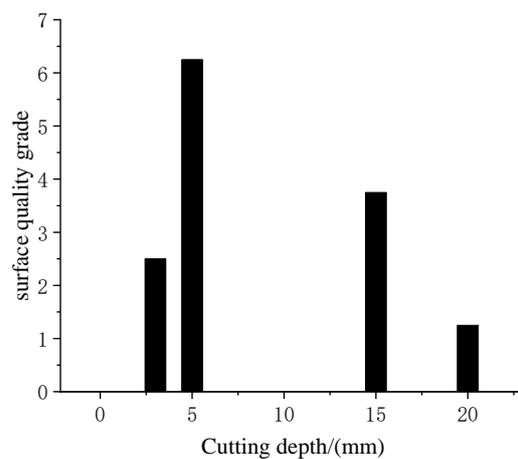
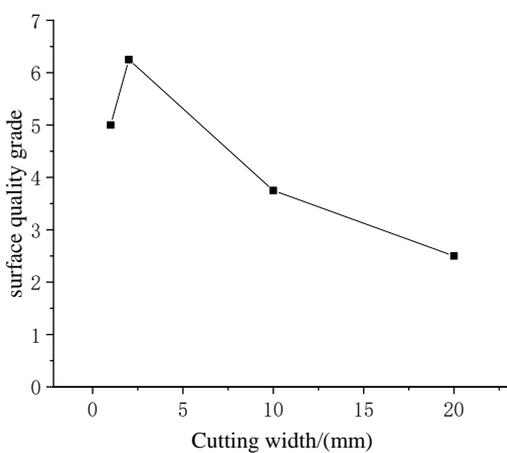
Table 3. Surface quality results of single factor.

Parameter level	Spindle speed (r/min)	Surface quality results	Parameter level	Feed rate (mm/min)	Surface quality grade
1	6000	0	1	800	3.75
2	10000	2.5	2	2000	3.75
3	14000	3.75	3	5000	1.25
4	18000	6.25	4	8000	0
Parameter level	Cutting width (mm)	Surface quality results	Parameter level	Cutting depth (mm)	Surface quality grade
1	1	5	1	3	2.5
2	2	6.25	2	5	6.25
3	10	3.75	3	15	3.75
4	20	2.5	4	20	1.25

Through the analysis of the surface quality results of single factor, the influence of various processing parameters on the surface quality is obtained, as shown in Figure 4. The higher surface quality grade, the better surface quality can be obtained, it can be seen that the high spindle speed and low feed rate cutting scheme is adopted in the honeycomb processing, and the great processing effect is more easily obtained. Therefore, in order to improve the processing efficiency under the premise of ensuring the processing quality of parts, it is necessary to consider the comprehensive effect of spindle speed, feed rate, cutting depth and cutting width.



(a) The influence of spindle speed on surface quality (b) The influence of feed rate on surface quality



(c) The influence of cutting width on surface quality

(d) The influence of cutting depth on surface quality

Figure 4. Effect of single factor on surface quality.

3.3. Tool Path Interval Analysis Based on Constant Scallop-Height Method

The processing of complex curved surface of honeycomb core parts through multi-contoured and direction paralleled machining. The tool path interval is an important factor affecting part accuracy and efficiency. The front inclination angle of honeycomb milling cutter is required when direction paralleled machining, and projection from the tool feed direction an ellipse can be obtained. And the direction paralleled machining is as shown in Figure 5.

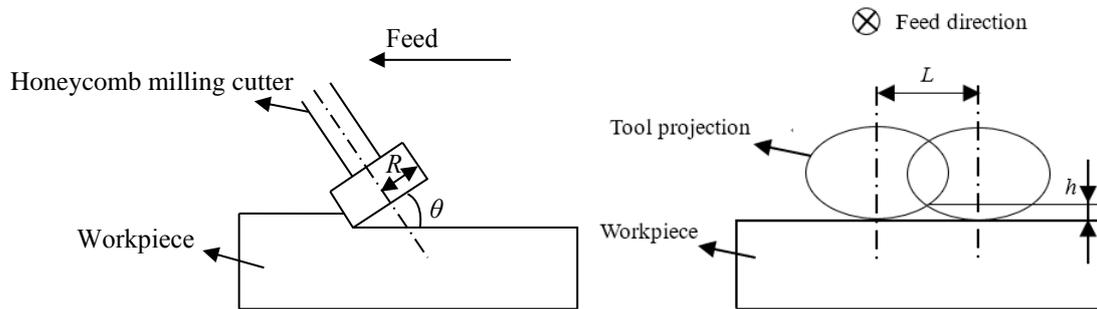


Figure 5. Schematic diagram of direction paralleled machining.

From the geometric relationship on the graph, the tool path interval of direction-parallel machining can be obtained as equation (2):

$$L = \sqrt{4R^2 - \frac{4(R \sin \theta - h)^2}{\sin^2 \theta}} \tag{2}$$

Where R is the tool radius and θ is the tool front inclination angle, the scallop height of machining surface is h . Therefore, determining the tool radius, the tool front inclination angle and the scallop height, the optimum tool path interval of direction parallel machining can be obtained.

4. Practical Application Verification

In the production process of the parts, the complex honeycombs machining was carried out by using the key technologies proposed in this paper, the cutting parameters and verification results are shown in table 4.

Table 4. Practical application verification results.

Cutting method	Spindle speed (r/min)	Feed rate (mm/min)	Cutting width (mm)	Cutting depth (mm)	Surface quality grade
Climb milling and dry cutting	18000	2500	5	8	10
Cutting method	front inclination angle (°)		Tool path interval (mm)	Efficiency Improved (%)	
Direction paralleled machining	15		8.25	27	
	25		6.53		
	30		5.98		
	40		5.29		

The machining results show that the machining time is shortened about 27% while the machining stability and quality are ensured, the precision of the part surface is $\pm 0.1\text{mm}$ and the contour accuracy is $\pm 1\text{mm}$, which satisfaction the manufacturing requirements. The surface quality of the parts is excellent, and there are no burrs or broken edges.

5. Conclusions

In this paper, the characteristics of complex honeycomb structure and processing difficulties are analyzed in depth, and the corresponding NC processing scheme is formulated. The effects of cutting parameters on the surface quality and processing efficiency of the parts were studied, and the

calculation method of the tool path interval was analyzed by the constant scallop-height method. This solution enables efficient, high-quality machining of complex structure honeycomb core.

Acknowledgments

The results presented in this paper were outcome of the research project funded by the National Natural Science Foundation of China (No. 51761145103).

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