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Two-dimensional Orthogonal Cutting Simulation of Aluminum Alloy Aerospace Structural Parts Based on ABAQUS

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Abstract. In this paper, the two-dimensional orthogonal cutting of aluminum alloy aerospace structural part is simulated in ABAQUS. It was found that the effect of chamfering is related to the pressing depth under recommended grinding speed and feed in the pre-conducted grinding test. The optimal cutting depth of the brush was determined by comparing the cutting quantity and geometric appearance of the edges and corners under five different cutting depths. The results show that the cutting amount increases with the increasing of preload depth, and when the preload depth is 0.8mm, the section removal effect is closest to R0.5 that meets the requirements. Finally, the test was carried out to verified the result of simulation—— under the preload depth of 1.0mm can meet the cutting requirements.

Keywords: Structural Parts, ABAQUS, Two-dimensional orthogonal simulation.

1. Introduction

Aviation structural parts with characteristic of light weight, high specific strength and specific stiffness are gradually replacing the traditional bolted and riveted aircraft assembly parts， which have a high material removal rate in the process of processing[1]. The grinding object studied in this paper is the integral wall structural parts with complex geometric structure. However the disadvantages are that the large overall size and low rigidity, thus the deformation is easy to occur in the machining process. Due to the difficult-to-process nature of structural parts, finite element simulation before machining has become one of the effective means to shorten the production cycle and improve production efficiency.

Zhang[2] studied the effects of cutting quantity on cutting force, fluctuation frequency and sawtooth shape by establishing a two-dimensional orthogonal model of high speed cutting Ti6Al4V using ABAQUS. The conclusion is that the average cutting force increases with the increasing of cutting depth, the frequency of cutting force fluctuation decreases with the increasing of cutting depth, and the degree of serration increases with the increasing of cutting speed and cutting depth. Deng[3] simulated the two-dimensional cutting of 45 steel with buried surfacing layer by using ABAQUS. The results show that the cutting force fluctuation of 45 steel with surfacing layer is more severe than that without surfacing layer. The cutting force, cutting temperature and intensity increase with the increasing of depth under the condition of constant cutting speed and feed. Liu[4] established a 3D milling model of titanium alloy in ABAQUS, and the cutting force values obtained by simulation were compared with the experimental results, which proved the referability of the milling force results obtained by simulation. Ma[5] used ABAQUS software to design and simulate the orthogonal experiment of three factors and four levels in cutting Ti6Al4V titanium alloy. By means of range analysis and variance analysis, the effects of cutting Angle and cutting depth on cutting force and cutting temperature were studied. The experimental results show that cutting depth has a great effect on cutting force, but no obvious effect on cutting temperature. The effects of cutting angle on cutting force and cutting temperature are highly significant. Kong used ABAQUS software to simulate the cutting of SiCp/Al composites. The simulation result shows that the cutting force increases with the increasing of the radius of the tool tip, and the volatility of the cutting force is positively correlated with the cutting speed. Li[6] carried out a finite element simulation study on 30CrMnSiA, a commonly used material manufacture aircraft load-bearing components, and analyzed the law of influence that the front angle of the tool and spindle speed on cutting force. The

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result shows that when the front angle of tool is 13°, the cutting force is minimum and the critical spindle speed is 2000r/min. Zhao[7] predicted the cutting force by building a 3D finite element cutting model which was combined with the method of BP neural network. The maximum deviation between the predicted cutting force and the force that obtained by simulation experiment was 9.48%. The accuracy of the BP neural network model was verified by the deviation results, and the simulation results also showed that the cutting force first increased and then decreased with the increasing of cutting speed. It increases with the increasing of cutting depth. Yin[8] simulated the cutting process of TC4 titanium alloy with ABAQUS software, studied the law of influence that the cutting parameters on cutting force and cutting temperature, and verified the simulation results with the conduction of experiments. The results of both have a considerable consistency which indicating that the results of simulation are reliable. Wang[9] studied the influence of cutting parameters on the machining deformation and residual stress of parts in small-bore deep-hole drilling by using Abaqus finite element simulation software. The results showed that reasonable cutting parameters could be selected according to the simulation results.The stimulation of cutting

Aiming at the milling problem of titanium alloy thin-walled parts, Yue[10] established a 3D milling model of titanium alloy thin-walled parts by using ABAQUS software, obtained the temperature field and milling force in milling, and verified the simulation results through experiments. The relative error between simulation and experiment is 12.3, and the simulation model can provide data basis for the subsequent work of milling parameters optimization. Li[11] used finite element analysis and orthogonal test to determine the optimal combination of milling parameters for circular thin-walled parts of titanium alloy.

The minimum cutting thickness of the material is an important basis for the selection of precision machining parameters. To solve the existence problems of the minimum cutting thickness, Zhou [12] established the minimum cutting thickness model to studied the estimation of the minimum cutting thickness. Wang[13] established a prediction model for the minimum cutting thickness of superalloy Inconel 718 by using the CEL cutting simulation technology of ABAQUS. The comprehensive simulation and test results show that the minimum cutting thickness range of Inconel 718 micro-cutting is 7~15μm.

Finite element means have been widely used in cutting simulation, and the main research were carried out to obtain parameters of processing such as force and temperature. However, there is less researches on the appearance of the workpiece to be cut. In this paper, the influence of different preload depths of the brush on the cutting geometry is analyzed by simulating the cutting of the simplified thin-walled model.

2. Establishment of Model

2.1 Tool &Workpiece

R knife, arc grinding wheel, machining center processing and other methods are usually used to process edge rounding of rectangular parts. Thin-walled parts are often handled manually with hand tools due to their low structural rigidity. In the process of manual filleting, a problem of unstable pressure control, resulting in unstable fillet size, difficult processing of corner and deformation of thin-walled structure. Difficult processing on the crossing thin-walled structure is also one of its shortcomes.

To solve such problems, this paper uses a ceramic fiber brush as a filleting tool, and its microstructure is a bundle of ceramic fiber, which has the following advantages compared with hand tool filleting:

During the relative movement of the bristle and thin-wall, the side of the bristle is in direct contact with thin wall of the workpiece, and the contact force that on the thin-wall is always maintained within a certain range due to the elasticity of the bristle. The contact force is less than the pressure of manual grinding;

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Fillet appearance consistency and surface finish are superior to manual filleting;
Crossing thin-wall can also be machined.

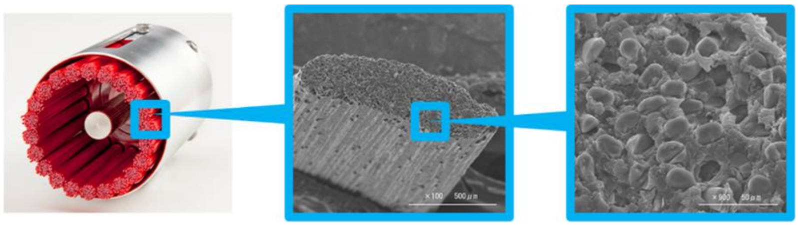

Fig1. Microstructure of ceramic fiber brush

2.1.1 Settings of thin-wall part:

The contact force of the fiber brush on the thin wall will not cause its deformation that affects the cutting result during the grinding process, so the upper grinding part of the thin wall is taken and the Encastre constraint is applied to its bottom border.

2.1.2 Settings of tool:

The analysis of the chamfering processing process shows that after the bristles are in contact with the thin wall, the bristles are bent and deformed, and the bristles are pulled by handles forward during the bending process. Finally, the bristles cut through the edges and corners to produce a chamfered arc. Thus in the analytical model, the bristles are simplified into a set of flexible rods that move towards a thin-walled section.

2.2 Parameter of Analysis

The workpiece material is aluminum alloy 6061, and the grid element is set to CPE4RT element type. The ceramic fiber brush is set as incompressible elastomer since it is almost loss-free during cutting. The tool workpiece model is shown in Fig 2. In the figure, the lower left corner is the upper part of the intercepted thin-walled section, and the strips arranged on the right are simplified brush models. In the initial state, the preload depth of the bristles and the thin-wall is 0.5mm. During the movement of the brush from right to left, the corners filleted. The same simulation process needs to be repeated under different preload depths which is shown in Table 1.

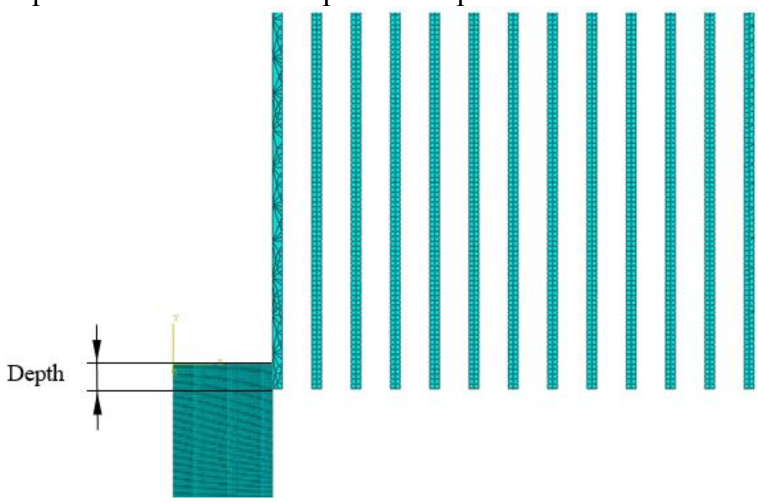

Fig2. The geometric model of simulation

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Table 1. The setting of brush

Speed(m/s)	Depth(mm)
5	0.5
5	0.7
5	0.9
5	1.1
5	1.3

3. Output and Analysis

The element on the upper right end deforms and falls off during cutting, forming a section with approximately fillet. The length between the intersection point of the two axes and that of the fillet and two axes are taken as x and y. the data is shown in Table 2. When the value of x is close to the value of y, the fillet shape is relatively ideal.

According to Fig 4 that summed up from table 2, the ideal fillet section can be obtained at the preload depth of 1.0mm.

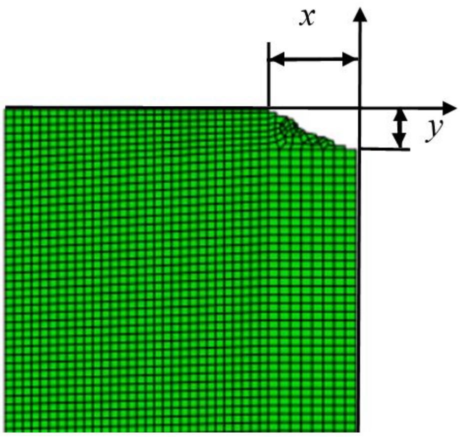

Fig3. Output of simulation

Table 2. Value of x&y

Depth(mm)	x(mm)	y(mm)
0.5	0.3	0.1
0.7	0.4	0.3
0.9	0.4	0.4
1.1	0.6	0.4
1.3	0.6	0.5

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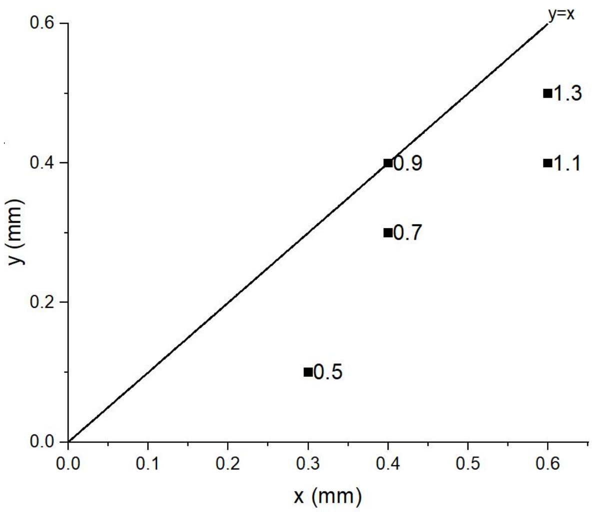

Fig 4. Comparison of X&Y coordinate

4. Testing Validation

The experimental platform is shown in Fig 5. The electro-spindle with ceramic fiber brush at the end is connected to the robot via an pneumatic force control device. Firstly, the position that is convenient for processing and measurement is determined to fix the aluminum alloy aviation structural parts, and the motion trajectory of the brush is edited by offline programming. Then set the offset distance so that the brush cuts the thin-wall of the aluminum alloy on a predetermined trajectory. The parameters set in the above procedure are as follows: the preload depth(that is offset distance) is 1.0mm, the feed speed is 20mm/s and the speed of electro-spindle is 2000rpm, the ideal filleting effect was obtained. As shown in Fig 6, the fillet of the thin-wall fits perfectly with the 0.5mm R ruler.

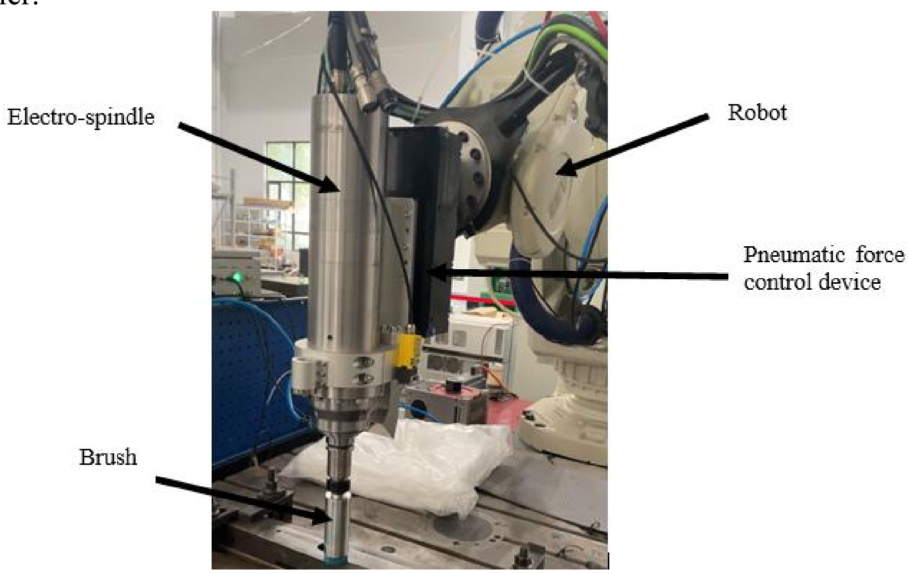

Fig 5. Experimental Platform

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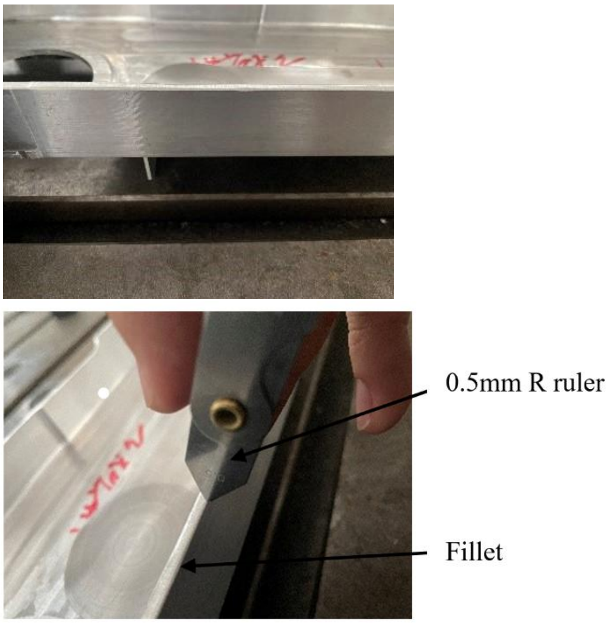

Fig 6. Cutting effect

5. Conclusion

In this paper, the cutting model is simplified after the machining characteristics of the part fillet are analyzed, and a two-dimensional orthogonal model is established for simulation. It is concluded that under the parameters of speed and feed that the ceramic fiber brush recommends, the downward preload depth of 1.0mm can obtain a more ideal fillet of R0.5 .After the processing test carried out on the experimental platform, the ideal filleting effect was obtained in the preload depth of 1.0mm.

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