Optimization and design of milling parameters for aluminum alloy thin-walled parts

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Abstract

The Thin-wall parts usually refer to parts with wall thickness less than 2mm. In general, the ratio of the maximum size to the minimum size of the contour of a thin-walled part is greater than that of 1:20. The aluminum alloy thin-walled parts are easily deformed during the processing, Seriously affecting processing quality.According to the deformation of Milling Thin-walled Aluminum Alloy problems, establish finite element model by ABAQUS software, set of orthogonal milling experiments, analysis of deformation under different milling parameters, milling and processing parameters to find the relationship between the deformation, and analysis of milling force effects on machining deformation

Keywords

Thin-wall parts, ABAQUS,Processing deformation quantity,Milling parameters.

1. The theoretical basis of the finite element model

Actually, milling is a very complex physical process, not only with the rotation of the tool and the feed movement of the workpiece, but also the load applied to the workpiece will periodically cut on the workpiece. Therefore, the use of finite element software reasonable simulation analysis for the whole milling process, not only can accurately predict cutting force size, cutting heat distribution, stress and strain change, deformation of workpiece, and also provided a data basis for the optimization of actual cutting parameters in the milling process. [1]ABAQUS is a powerful finite element analysis software. It can not only perform simple finite element analysis, but also be applied to engineering problems with huge complexity and high nonlinearity. The use of ABAQUS software is very convenient, and users can calculate and analyze the material properties, contact properties, boundary conditions and so on.

1.1 Finite element model of stress field

According to the Prandtl-Reuss theory, considering the total strain increment including elastic strain increment, plastic strain increment and temperature strain increment, the constitutive relation of thermo elastoplastic mechanics can be obtained.[2]

Elastic zone: $$d\{\sigma\}=[D](d\{\varepsilon\}-d\{\varepsilon\}_\theta) \tag{1}$$

Plastic zone: $$d\{\sigma\}=[D]_{ep}(d\{\varepsilon\}-d\{\varepsilon\}_\theta)+d\{\sigma\}_\theta \tag{2}$$

In these forms:

$$d\{\varepsilon\}_\theta=\left(\{a\}+\frac{d[D]^{-1}}{d\theta}\{\sigma\}\right)d\theta \text{ ;}$$

$$d\{\sigma\}\theta=\frac{[D]\frac{\partial\bar{\sigma}}{\partial\{\sigma\}}\frac{\partial H}{\partial\theta}d\theta}{\frac{\partial H}{\partial\varepsilon_p}+\left\{\frac{\partial\bar{\sigma}}{\partial\{\sigma\}}\right\}^\theta[D]\frac{\partial\bar{\sigma}}{\partial\{\sigma\}}} \text{ ;}$$

$\{\sigma\}$—Stress tensor;

$\{\varepsilon\}$—Strain tensor;

ε_p—Plastic strain;

$\{a\}$—Linear expansion coefficient vector of material;

$[D_e]$—Elastic matrix of materials;

$[D_{EP}]$—Plastic matrix of materials;

$\bar{\sigma}$—Equivalent stress of material;

H—The strengthening coefficient is determined by the characteristic curve of the material;

2. Finite element simulation of milling of thin wall parts

2.1 Workpiece geometric model

ABAQUS has independent CAD modules, which can carry out a simple 3D modeling and simulation design, but there are still many shortcomings compared with other 3D modeling software, and can not carry out more complex 3D modeling. Most of the complex model parts are simulated by PRO-E, SolidWorks and other three-dimensional software. Then, by modifying the name of the suffix to ABAQUS entry, the model is repaired by the repair function of ABAQUS, and then it is calculated and analyzed. This paper chooses the T parts commonly used on the space shuttle as the research object, that is, the T parts fixed on the three sides free. The workpiece structure is relatively simple, and it can be directly modeled in ABAQUS, and the workpiece size is 40mm * 25MM * 5mm. See fig 1.

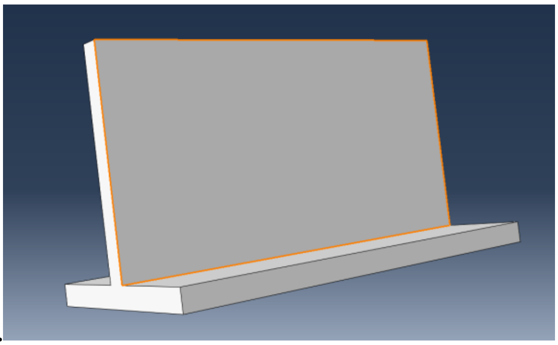

Fig. 1 Geometry model of T type workpiece

2.2 Workpiece geometric model

In this paper, a carbide cylindrical four tooth end milling cutter is selected as milling cutter for aluminum alloy thin-walled parts. The tool length is 20mm, the cutting length is 8mm, the tool diameter is 10mm, and the helix angle is 30 degrees. The 3D sketch of the tool parts is drawn by PRO-E, and the work piece is simulated by introducing ABAQUS into the IDG format.See fig 2.

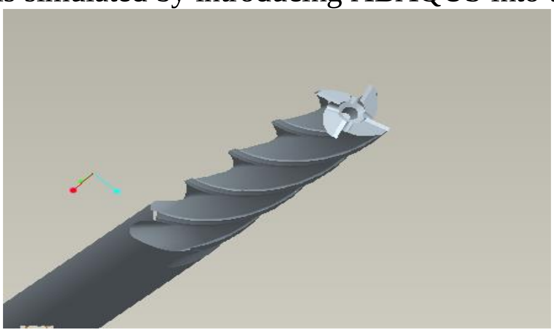

Fig. 2 Tool geometry model

2.3 Material model

The Johnson-Cook (J-C) shear failure model is an equivalent plastic model based on the integral point of the element. When the failure parameter of the material exceeds 1, the failure of the material is assumed. If all integral point material failure occurs, the unit will be removed from the grid. [3]The failure parameter W is defined as:

$$W = \sum \frac{\Delta \varepsilon^{pl}}{\varepsilon_f^{pl}} \tag{3}$$

In the form:

$\Delta \varepsilon^{pl}$ -Equivalent plastic strain increment;

ε_f^{pl} -Failure strain;

Constant and partial parameter values in J - C model of aluminum alloy 7050-T7451 material,see Table 1.

Table 1 Constant and partial parameter values in J - C model of aluminum alloy 7050-T7451 material

A	B	n	C	m	θ_{melt}	θ_r	$\dot{\varepsilon}_0$
490	206.9	0.344	0.005	1.8	600	20	0.001

2.4 Material properties

The chemical composition, thermal conductivity, specific heat capacity, [4]expansion coefficient and mechanical properties of the material see Table 2-8.[5]

Table 2 Nominal chemical composition of aluminum alloy 7050-T7451

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr
0.12	0.15	2.0-2.6	0.1	1.9-2.6	0.04	2.7-6.7	0.06	0.08-0.15

Table 3 Thermal conductivity of aluminum alloy 7050-T7451

θ，℃	50	100	125	200
λ，$W/(m\cdot℃)$	134	142	147	176

Table 4 Specific heat capacity of aluminum alloy 7050-T7451

θ，℃	50	100	150	204	260
$C, J(Kg \bullet ℃)$	888	904	988	1004	1047

Table 5 Coefficient of linear expansion of aluminum alloy 7050-T7451

θ，℃	20-100	20-125	20-150	20-200
$\alpha, 10^{-6} ℃^{-1}$	23.6	23.3	23.5	24

Table 6 Performance parameters of aluminum alloy 7050-T7451 (under the condition of 20 degrees at normal temperature)

Tensile Strength	Yield strength	Hardness	Tensile Strength	Modulus of elasticity
510MPa	455MPa	135MPa	517.671MPa	71.7GPa

Table 7 Physical and thermodynamic properties of cutting tools

Material Science	Young's modulus	Poisson ratio	Coefficient of linear expansion	Specific heat capacity
YG8	6.4X105	0.22	4.5	220

Table 8 Actual geometric parameters of cutting tool

Diameter(mm)	number of teeth	Helix angle	Rake angle	relief angle
10	4	30°	23.5°	14°

2.5 Assembly parts

Each component of the ABAQUS which are created in the independent coordinate system through separate rendering, in a relatively independent status in the module, the use of assembly function, can assemble various independent components through the constraints in the global coordinate system, to form a complete assembly. The tool and workpiece in the state of part are assembled through the assembly function (Asseblmy) in the ABAQUS.See fig 3.

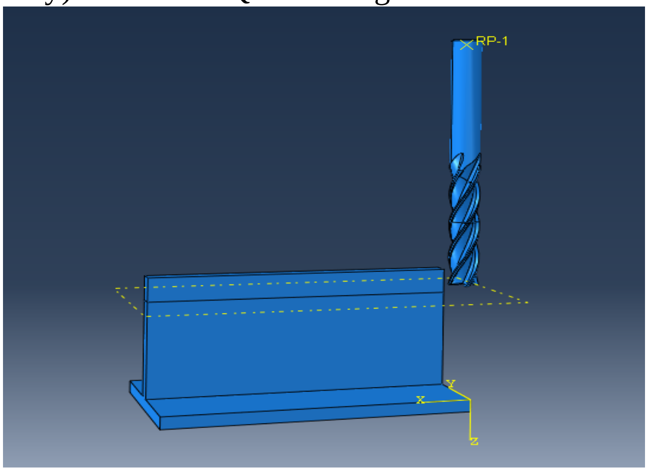

Fig 3 Assembly drawing of workpiece and tool

2.6 Orthogonal experiment

In the actual milling process, when the workpiece and the tool are determined, the influence of the milling force in the process is better than that in the process.The main factors are spindle speed n, feed per tooth f_z, axial cutting depth a_p and radial cutting depth a_e. In order to further study milling force variation and workpiece deformation under different processing parameters, orthogonal experiments were designed, and four factors were selected, each factor taking three levels to carry out orthogonal simulation experiment.See table 9.

Table 9 Orthogonal experiment milling parameter design table

number	Spindle speed n(r/min)	Feed per tooth f_z	Radial cutting depth a_e (mm)	Axial cutting depth a_p (mm)
1	4000	0.1	0.5	1
2	4000	0.15	0.75	1.5
3	4000	0.2	1	2
4	6000	0.1	0.5	1
5	6000	0.15	0.75	1.5
6	6000	0.2	1	2
7	8000	0.1	0.5	1
8	8000	0.15	0.75	1.5
9	8000	0.2	1	2

3. Conclusion

In the milling process of thin-walled Aluminum Alloy in milling process is a discontinuous cutting process, without considering the vibration conditions in contact with the cutting edge and the workpiece part stress will be much bigger than the other parts, after a period of time in the milling of thin-walled parts, edge stress is large. At the same time the stress concentrated phenomenon is not very obvious. In the whole milling process, the stress is mainly concentrated in the direction of X and Y, and the stress change in the direction of Z is not particularly obvious.See fig 4-12.

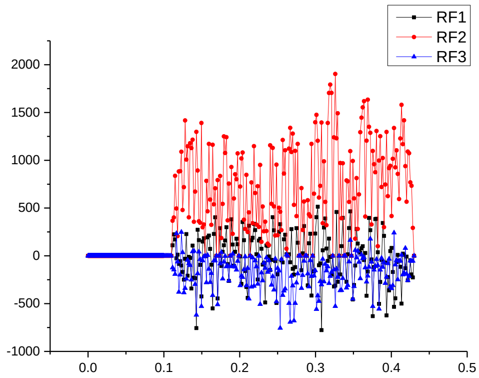

Fig 4 Simulation stress of one groups of milling experiments

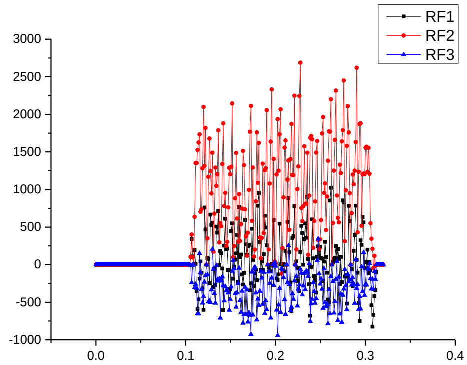

Fig 5 Simulation stress of second groups of milling experiments

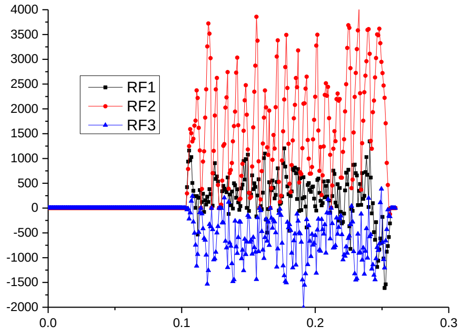

Fig 6 Simulation stress of third groups of milling experiments

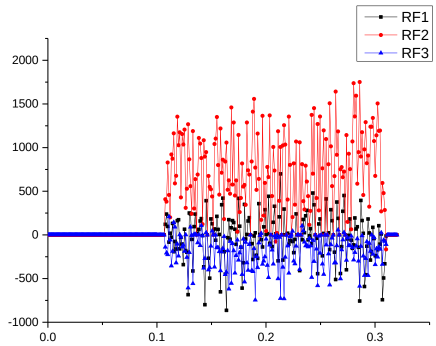

Fig 7 Simulation stress of fouth groups of milling experiments

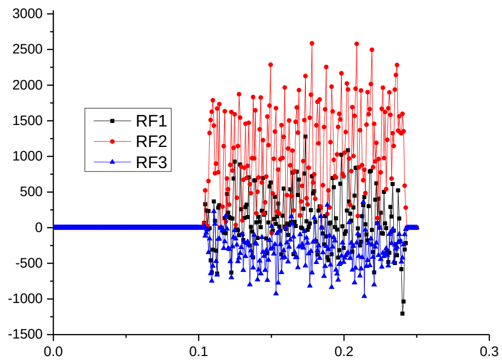

Fig 8 Simulation stress of five groups of milling experiments

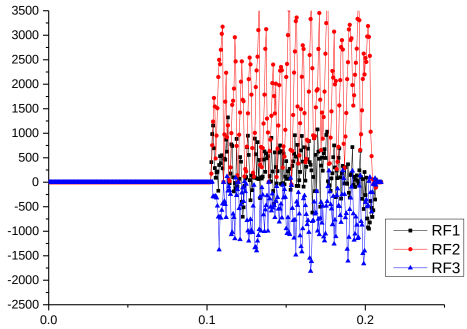

Fig 9 Simulation stress of six groups of milling experiments

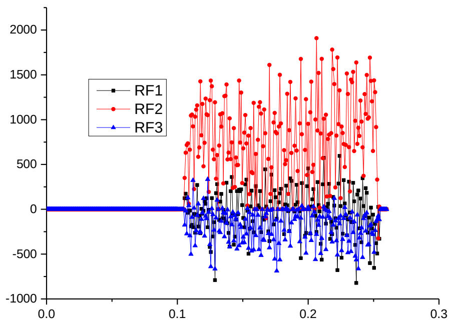

Fig 10 Simulation stress of seven groups of milling experiments

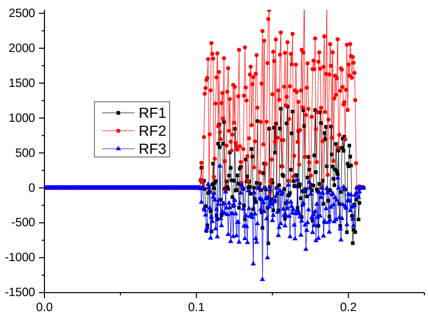

Fig 11 Simulation stress of eight groups of milling experiments

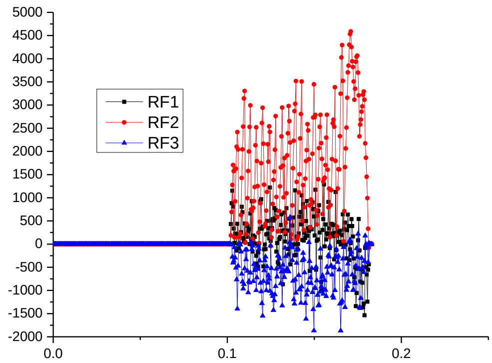

Fig 12 Simulation stress of nine groups of milling experiments

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