Finite Element Modeling of Power Spinning of Thin-walled Ti_2AlNb Alloy Shell

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Abstract. A three-dimensional elastic-plastic FE(finite element) model of power spinning of thin-walled Ti_2AlNb alloy shell was established based on the dynamic, explicit module of FE software. The key technologies, including contact boundary, mesh, were dealt with reasonably. The reliability of model was validated by theoretical evaluation. To find a optimal combination of processing parameters, an $L_9(3^4)$ orthogonal test was adopted. The results showed that the feed velocity of roller had the most significant influence on the fracture trend, and the mandrel velocity on the wrinkle trend. The optimal processing parameters combination was $v_2n_1r_3t_3$. Based on this model, the distribution of strain of both sides of workpiece was obtained in order to research the reason of the fracture and wrinkle of workpiece. The strain of outer side was larger than that of inner side. The results conformed to the practical power spinning process.

Introduction

Ti_2AlNb orthorhombic alloy has exhibited great potential as high-temperature structural material due to its good creep resistance, high specific strength, and excellent oxidation resistance. It has an important significance for reducing the vehicle weight, improving the fuel efficiency and high temperature service performance in the fields of aeronautics, astronautics [1,2]. Commonly, due to high brittleness at room temperature, the deformation of Ti_2AlNb alloy is difficult to control, but it shows the excellent formability at elevated temperature. Thus, a structural component of Ti_2AlNb alloy usually is formed at elevated temperature in order to improve the deformation performances and avoid the cold forming defects. It is well known that spinning technology has been widely used in manufacture rotational symmetry components. Power spinning is a complicated plastic forming process and plays a key part in metal precision processing fields. It’s difficult to use analytic method and experimental method for studying the power spinning process. Therefore, more and more scholars put their eyes on the FE(finite element) numerical simulation method.

Ken-ichiro and Takayuki Nonaka[3] established a three-dimensional FE axisymmetric model under the FE software environment, simulated shear spinning forming process and compared with practical spinning process. Results showed that the model was reliable. Iman Soleimani Marghmaleki and Mohamadreza Abadyan[4] studied aluminium alloy disk blank spinning forming process, and analyzed the influence of temperature on forming process by FE analysis method. Finally, they obtained appropriatet parameters. Shimizu [5] discussed the movement of rollers in other spinning processes. These studies were focused on small or conical spun parts, which do not involve long computation times, complex roller trajectories, or serious springback. Xiaokai Zhao[6] simulated titanium alloy TA15 cylindrical part power spinning and stamping process, he studied the distribution of stress and strain during stamping process.The results provided theoretical basis for the design of workpiece. Wenjun Hu[7] established a three-dimensional FE model for the spinning process of thin-walled components with curved generatrix based on ANSYS/LS-DYNA and simulated the effects of the technological parameters(spindle rotation speed, the feed rate and the roundness radius of roller)on the quality of workpiece. The distribution and variation of stress-strain field were obtained. Whereas the amount of studies associated with the multi-pass spinning of high-temperature alloy is limited.

Thus, considering the characteristics of forming process, this study aimed to establish a three-dimensional elastic-plastic FE model of power spinning of Ti_2AlNb alloy based on the dynamic, explicit module of FE software. The reliability of the three-dimensional FE model was verified by theory evaluation. Based on the established model, the distribution of strain during this forming process was obtained. The spinning parameters were optimized by orthogonal test.

Establishment of Three-dimensional FE model of Power Spinning

The power spinning of thin-walled Ti_2AlNb alloy shell is a partial successive elastic-plastic forming process, and it is characterized by geometric, physical and boundary nonlinearities. Thus, a three-dimensional elastic-plastic FE model of thin-walled Ti_2AlNb alloy shell is established by the dynamic,explicit module of FE software, as shown in Fig.1. In this model, the blank is set as a three-dimensional deformable body, the mandrel and the rollers are set as analytical rigid bodies. One constraint type Tie is used between mandrel and blank to ensure that they can rotate together In order to simplify the forming process, Ti_2AlNb is defined isotropic.

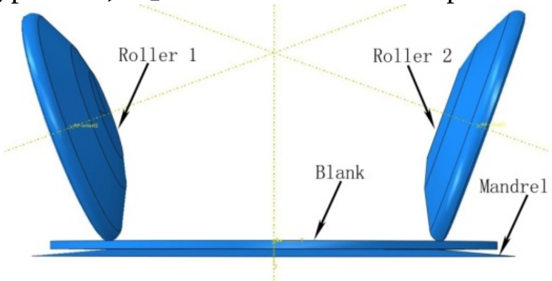

Fig.1 FE model of thin-walled Ti_2AlNb shell of power spinning

For improving the computing efficiency and accuracy, some key technologies for FE model, such as contact boundary, mesh[8,9]were dealt with reasonably.

Definition of Contact Boundary

For FE numerical simulation, many problems involing contact affect the accuracy and efficiency of simulation directly. The power spinning of thin-walled Ti2AlNb alloy shell belongs to a partial successive elastic-plastic forming process. During the forming process, contacts between rollers and blank, mandrel and blank are complicated and dynamic, and the spinning force focuses on one local area contacting with rollers.

Therefore, the classical Coulomb friction model and penalty function are adopted to describe the contact between rollers and blank. The friction between the contacing surfaces of mandrel and blank is neglected.

Determination of Mesh

The power spinning is a large deformation process, the number of elements, the elements type and elements shape have an important influence on the simulation results. Considering the linear element has lower sensitivity on distorted meshes than quadratic element, the former is adopted. For improving the accuracy of computing simulation, the blank is discreted by the three-dimensional linear reduction integration continuum element with eight nodes (C3D8R). Generally, the deformation degrees of blank are different at different zones during the power spinning. Thus, three zones are divided: the central zone (CZ), the large deformation zone(LDZ) and the uniform deformation zone(UDZ). The moderate mesh sizes are assigned in the LDZ and coarse mesh sizes are appointed in the UDZ. Compared with UDZ, the mesh sizes in the CZ are coarser. Fig 2 shows the meshes for a part of the blank.

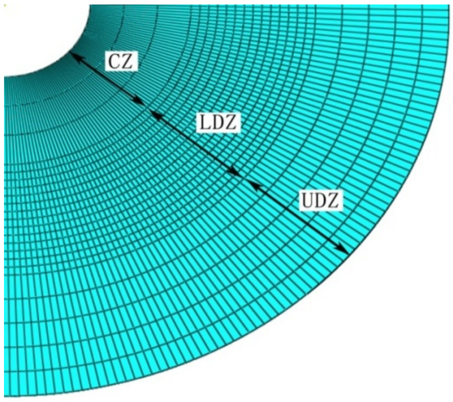

Fig.2 Meshes of a blank

During the forming process, it's easy to occur mesh distortion, which leads to reduce the accuracy of simulation. So,ALE adaptive meshing technology is adopted to solve this problem.

Evaluation of Model

Based on the key technologies above, a three-dimensional elastic-plastic FE model of thin-walled Ti2AlNb alloy shell is established, as shown in Fig 1. And it's necessary to evaluate the reliability of model.

Generally, there are two ways to evaluate the reliability of the model: theoretical evaluation and experimental vertification[10]. In this paper, the former is used.

In order to ensure the simulation results of FE model being a acceptable quasi-static solution, there is one criterion: kinetic energy of material during deformation process is no more than 10% of internal energy during most of simulation time[11]. The relative values between Kinetic energy (ALLKE) and Internal energy (ALLIE) during simulation time is shown in Fig 3. From Fig 3, the relative values between ALLKE and ALLIE is less than 5% in most of time, so it conforms to the criterion.

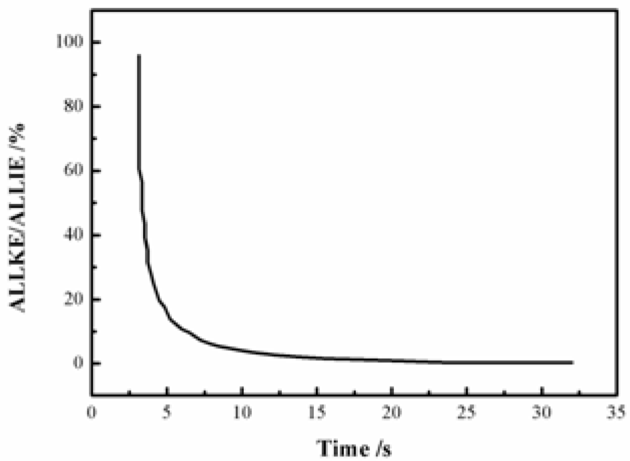

Fig.3 The relative values between kinetic energy and internal energy

Research methods

Based on the above established FE model, such a power spinning process is simulated. The main geometric parameters and the friction coefficient during the simulation process are listed in Table 1.

Table 1 Main geometric parameters and the friction coefficient

Parameters	Value
Initial diameter of Blank—D(mm)	474.0
Thickness of Blank—t_0(mm)	8
Diameter of Roller—D_0(mm)	260
Friction coefficient between Blank and Roller—μ	0.2

The first pass has an important influence on the power spinning of thin-walled Ti2AlNb alloy shell[12], therefore an orthogonal test is designed to obtain the optimal combination of processing parameters. The processing parameters include the feed velocity of roller, the rotary velocity of mandrel, the radius of corner of roller and the spinning temperature. The values of the processing parameters are chosen in Table 2. Each parameter has three levels indexed from 1 to 3, which denotes the chosen values of the processing parameters.

Table 2 Processing parameters chosen for an orthogonal analysis

Parameters	Levels		
	1	2	3
Feed velocity of roller—v(mm·s^{-1})	3	4	5
Rotary velocity of mandrel—n(rad·s^{-1})	20.94	26.18	32.99
Radius of corner of roller—r(mm)	6	12	16
Spinning temperature—t/°C	940	970	1000

The orthogonal table of $L_9(3^4)$, including four factors and three levels, is adopted to arrange nine cases. The simulation results are shown in Table 3. σ_1 represents the maximal pricipal stress and σ_3 represents the minimum principal stress. They can measure the effect of the processing parameters on the forming quality of thin-walled Ti_2AlNb alloy shell.

Table 3 Orthogonal table of $L_9(3^4)$ and the simulation results of the cases

Case	v(mm·s^{-1})	n(rad·s^{-1})	r(mm)	t(°C)	σ_1(Mpa)	$\|\sigma_3\|$(Mpa)
1	1	1	1	1	390.3	345.3
2	1	2	2	2	380.6	491.2
3	1	3	3	3	393.7	324.3
4	2	1	2	3	319.5	333.8
5	2	2	3	1	261.6	500.9
6	2	3	1	2	330.7	383.8
7	3	1	3	2	247.9	292.4
8	3	2	1	3	290.4	331.7
9	3	3	2	1	401.3	359.6

Results and Discussion

Orthogonal Analysis and Parameters Optimization

Table 4 presents the influences of the processing parameters on σ_1. σ_1 is mainly tensile stress and reflects the fracture trend of thin-walled shell to some extent. K_1 to K_3 represent different values of level 1 to 3, "Ra" represents significance level of the parameters. The parameter with a larger "Ra" has more important influence on σ_1 than other parameters according to the orthogonal test theory. Therefore, the effect order of parameters on the fracture trend is the feed velocity of roller, the radius of corner of roller, the mandrel velocity and the spinning temperature. The better processing parameters combination for decreasing fracture trend is $v_2n_2r_3t_2$.

Table 4 Analysis of the results for σ_1

Parameters	v(mm·s^{-1})	n(rad·s^{-1})	r(mm)	t(°C)
K_1(Mpa)	388.2	319.2	337.1	351.1
K_2(Mpa)	303.9	310.9	367.1	319.7
K_3(Mpa)	313.2	375.2	301.1	334.5
Ra(Mpa)	84.3	64.3	66.0	31.4

Table 5 presents the influences of the processing parameters on $|\sigma_3|$. σ_3 is mainly compressive stress and reflects wrinkle trend of thin-walled shell to some extent. The parameter with a larger "Ra" has more important influence on $|\sigma_3|$ than other parameters according to the orthogonal test theory. Hence, the effect order of parameters on the wrinkle trend is the mandrel velocity, the feed velocity of roller, the spinning temperature and the radius of corner of roller. The better processing parameters combination for decreasing wrikle trend is $v_3n_1r_1t_3$.

Table 5 Analysis of the results for $|\sigma_3|$

Parameters	v(mm·s^{-1})	n(rad·s^{-1})	r(mm)	t(°C)
K_1(Mpa)	386.9	323.8	353.6	401.9
K_2(Mpa)	406.2	441.3	384.9	389.1
K_3(Mpa)	327.9	355.9	372.5	329.9
Ra(Mpa)	78.3	117.5	31.3	72.0

Variations of σ_1 and $|\sigma_3|$ for different processing parameters are presented in Fig 4 and Fig 5. It shows that one parameter has different influence on σ_1 and $|\sigma_3|$. On the premise of making comprehensive consideration for the fracture trend and wrinkle trend, $v_2n_1r_3t_3$ is considered as the optimal processing parameters combination.

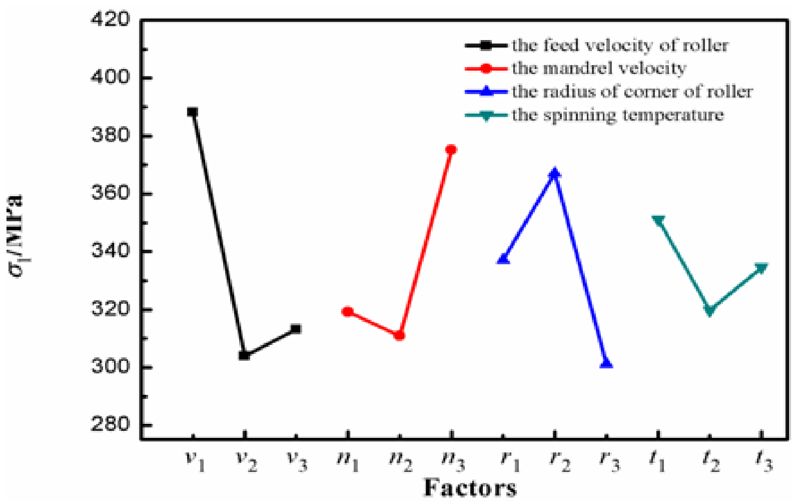

Fig.4 Profiles of σ_1 for different processing parameters

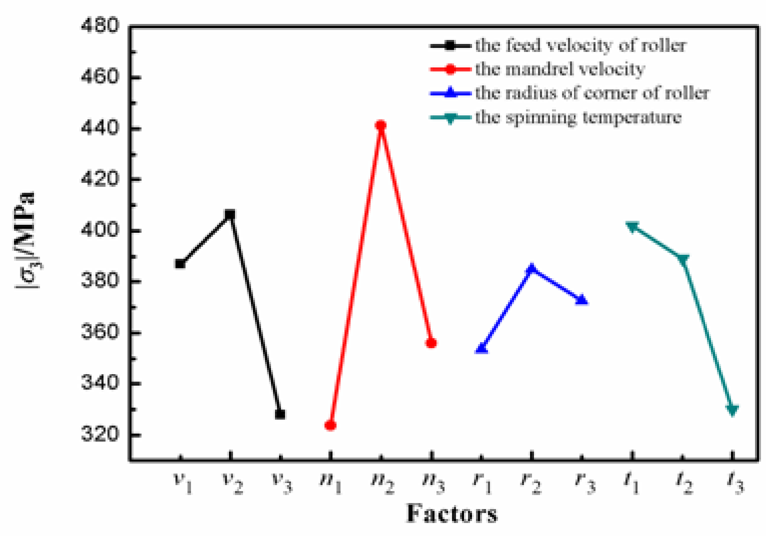

Fig.5 Profiles of $|\sigma_3|$ for different processing parameters

Distribution of Strain

In fact, the distribution of strain has significant influence on the quality of thin-walled shell. The deformation of blank is center symmetric during power spinning process, so the section plane of thin-walled shell after the first pass of spinning process is chosen, as shown in Fig 6. The line AB and CD represent the nodes of the section plane . The strain of the nodes and the strain changing curves along the distance that has been normalized are obtained.

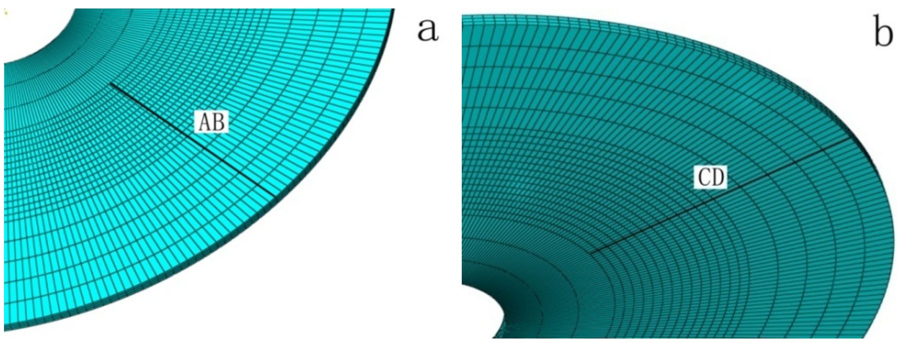

Fig.6 The nodes of (a) inner side and (b) outer side of the workpiece

The variations of strain with path are shown in Fig 7. According to Fig 7, The starting point of x axis is the node of thin-walled shell that is close to central zone. The end point of x axis is the node of the flange of thin-walled shell. Obviously, the variations of strain-path of both sides of thin-walled shell are different. The strain in inner side of surface of blank is smaller, while the strain in outer side of surface of blank is larger. The variation of strain-path of outer side of surface of blank is divided into two stages, including the former stage in which nodal strain increases rapidly and the amplitude is large, and the latter stage in which nodal strain gradually falls. Meanwhile, the nodal strain of inner side of surface of blank changes little. The larger is the difference between the strain of both sides of thin-walled shell, the easier the workpiece cracks and wrinkles. The results conform to the practical power spinning process.

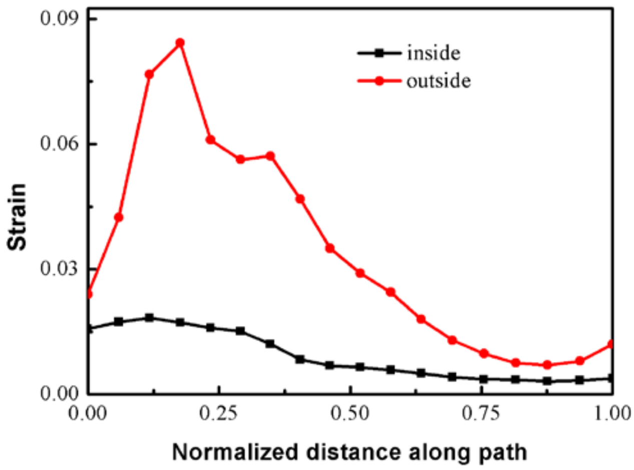

Fig.7 The variations of strain with path

Conclusions

(1)A three-dimensional elastic-plastic FE model of power spinning of thin-walled Ti_2AlNb alloy shell is established based on the dynamic, explicit module of FE software, and the key technologies, including contact boundary, mesh, are dealt with reasonably. The reliability of model is validated by theoretical evaluation.
(2)Influence of the processing parameters on the power spinning of thin-walled Ti_2AlNb alloy shell is studied by the orthogonal test, and the following conclusions are obtained. The effect order of parameters on the fracture trend is the feed velocity of roller, the radius of corner of roller, the mandrel velocity and the spinning temperature. The effect order of parameters on the wrinkle trend is the mandrel velocity, the feed velocity of roller, the spinning temperature and the radius of corner of roller. The optimal processing parameters combination is $v_2n_1r_3t_3$.
(3)During the process of power spinning, the distribution of strain of both sides of workpiece are different. The strain of outer side is larger than that of inner side. This may lead to the fracture and wrinkle of workpiece.

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