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Study on spinning process of thin-walled curvilinear generatrix parts based on variable thickness blanks

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Abstract: Large thinning ratio is a difficulty in spinning process of ellipsoid components**,** which needs to be solved to ensure the accuracy of parts. Based on the method of reverse deformation, two different variable thickness blanks were designed: (1) variable thickness blank based on thickness reduction of the conventional spinning process; (2) variable thickness blank based on sine rate of the shear spinning process. Then, the two methods were applied in the spinning simulation of ellipsoid thin-walled curvilinear parts with large diameter-thickness ratio. The results of simulation showed that variable thickness blank could significantly improve the forming quality of the forming parts.

1. Introduction

In spinning process of thin-walled curvilinear generatrix parts, the thinning ratio is different along generatrix, resulting in thickness nonuniformity of formed part and low accuracy of parts.

In order to obtain formed part of target shape, researches on the method of reverse deformation have been taken in nearly all metal forming process. Biglari[1] designed a preform model using backward deformation method in multistage forging processes with combination of a fuzzy decision making algorithm, then an axisymmetric disk forging was analyzed to demonstrate their approach. Wei[2] used the reverse deformation method in adjusting mould design of large-size turbine blade casting, which effectively solved the problem of size-of-tolerance.

The blank design methods of spinning process mostly focused on the algorithm design of diameter and thickness, while the research on design of variable thickness blank are hardly ever, for that the preforming process needs higher cost. After spinning process of uniform thickness blank, milling process is needed to ensure the thickness uniformity. Therefore, from the aspects of cost and material utilizatio, variable thickness blank is undoubtedly a better way. Yin[3] designed a preforming blank with thin center and thick margin for thin-walled abnormal shell, and investigated the forming precision and stress distribution. Tong[4][5] designed a variable thickness cone blank, and compared the results from different shapes of cross profile based on the FE spinning model of Yin, the result indicated that the initial variable thickness blank with straight outside generatrix lead to better uniformity of thickness. Jin group [6] designed two kinds of variable thickness blank for hemispherical thin-walled component based on conventional spinning and shear spinning, compared the triaxial strain of the two schemes with uniform thickness blank.

From above, the object parts in studies were almost conic, the thinning ratio of which varies little or simple, such as straight or circular line, during the process. In this study, variable thickness blank design of high diameter-thickness ratio part was carried out based on the methods of Jin group, and then we took discussion on the simulation results.

2. Design of variable thickness blank

2.1 introduction of research object

The thin-walled part researched in this section is ellipsoid, the length of major axis is 2250mm, minor axis 1602.9mm, and thickness 9mm shown in Fig. 1.

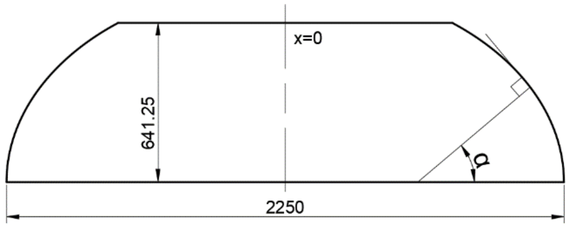


Fig. 1 Geometry of target part

2.2 Variable thickness blank design

2.2.1 Variable thickness blank based on conventional spinning process. The method we used drew on the method from Jin group [6], which is mainly a compensation on actual thickness of formed part from simulation. The details are as following: by using the non-linear implicit finite element code ABAQUS/Standard, the thickness variation of blank in conventional spinning process was obtained shown in Fig.2. The three-dimensional coordinates of the upper and lower surface nodes were extracted along the generatrix of the component. Then, these coordinates were changed to cylindrical coordinates for the calculation of thickness. The thickness was obtained through the relationship between the normal's slopes of lower nodes and the distance of upper and lower nodes, as shown in Fig. 3.

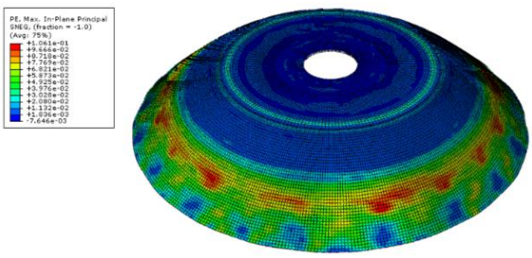


Fig.2 Thickness-direction strain distribution

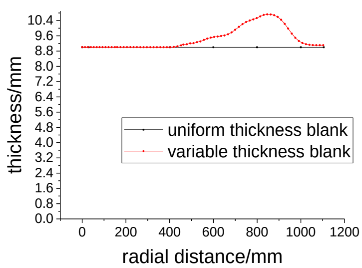


Fig. 3 Thickness distribution along radial distance

The main algorithm is as follows. The original thickness of lower nodes are *t*(1), *t*(2) ,…, *t*(n), and the deformed thickness are *t*'(1), *t*'(2) ,…, *t*'(n). Then the thinning ratio of each nodes is $\Psi(i)$=1- *t*'(*i*)/ *t*(*i*). Based on the reverse deformation method, the thickness of variable thickness blank is designed by equation:

$$T(i) = \frac{T}{1-\psi(i)} \tag{1}$$

where, *T*(*i*) is the thickness of designed blank, *T* is the target thickness of deformed blank.

2.2.2Variable thickness blank based on sine rate of the shear spinning process. The method in this section is also mainly a compensation algorithm, but the thickness was obtained theoretically. The thickness of blank in shear spinning stage follows the law of sine：

$$t = t_0 - t_0 \cdot sin\alpha \tag{2}$$

where t is the thickness of deformed blank, t_0 is the original thickness, α is the half-cone angle in shear spinning stage.

In the spinning process of ellipsoid thin-walled parts, the angles of α follows the equation:

$$\alpha = \arctan\left(\frac{bx}{a\sqrt{a^2 - x^2}}\right) \tag{3}$$

where, a and b are the major axis radius and the minor axis radius of the ellipse respectively.

The thickness of clamped part remains unchanged during all the process, so that the initial blank is designed as following

$$f(x) = \begin{cases} \text{H} & x < x_0 \\ \dfrac{\text{H}}{\sin\alpha} & x_0 \le x < x_1 \\ \dfrac{\text{H}}{\sin 40^\circ} & x_1 \le x < \text{L} \end{cases} \tag{4}$$

$$x_1 = a^2 \tan 40^\circ (b^2 + a^2 \tan^2 40^\circ)^{-0.5} \tag{5}$$

where, x is the distance from center, x_0 is the abscissa value of where spinning begins. L is the maximum radius of original blank, x_1 is the abscissa value of the end of shear spinning stage.

As mentioned above, lower α could result in lager thinning ratio, for which the minimum value of α was designed 40° in this paper. So, when $x_1 \le x <$ L, the thickness is changed as the same as where α =40°, as shown in Fig.4.

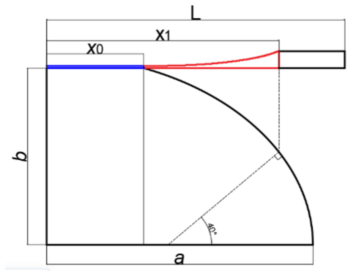
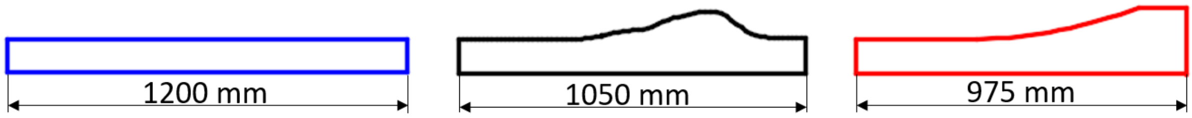


Fig.4 Method for variable thickness blank

2.3 Schemes of spinning process

In this paper, three schemes based on three kinds initial blanks were designed. The thickness of original blank used in traditional spinning process is uniform, of which diameter is 2400mm, thickness 9mm. In this section, two kinds variable thickness blank and uniform thickness blank were simulated and compared to explore the best process route. For the sake of simplicity, 1 represents uniform thickness blank, 2 represents the variable thickness blank based on conventional spinning process and 3 represents the variable thickness blank based on shear spinning process at all figures and text in this section.



Scheme 1 Scheme 2 Scheme 3

Fig. 5 Cross-profile shape of three initial blanks

All the initial blank design is shown in Fig. 5. Thickness distribution in scheme 2 is based on the simulation result of scheme 1, the thickness of each node was calculated by equation (1), then the shape of cross profile was obtained by curve fitting method. Thickness distribution in scheme 3 was obtained from equation (4), and the total length of each initial blank is obtained by the method of identical volume.

3. **Simulation and discussion**

The material is AA 2219, mechanical properties of which are listed in Table 1:

Table 1. Mechanical properties of AA 2219

Density /Kg·m^{-3}	Elastic modulus/GPa	Hardening exponent/%	Yield strength /MPa	Elongation rate	Poisson ratio
2.78e3	73	0.31	170	17%	0.33

For that the shape is ellipsoid, the mandrel could but be set discrete rigid, as well as be meshed in mesh module. In order to enhance the stability in spinning process of large radius-thickness ratio component, two symmetrically distributed rollers and multi-pass strategy was used in the simulation.

The parameters was set as following: installation angle of roller was 30°, fillet radius of roller was 35mm, rotational speed of spindle was 200rpm, the amount of passes was 4, the gap between roller and mandrel was constant, the feed ratio of contact stage was 5mm/r, rotate out stage was 10mm/r. The simulation modeling is shown in Fig. 6, and Fig. 7 showed the mesh method of blank.

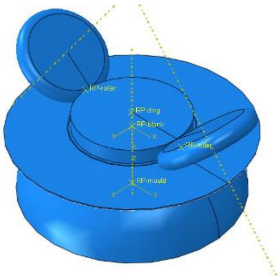


Fig. 6 FE model of multi-pass spinning

Fig. 7 Mesh of blank

Fig. 8 exacted and shown the thickness distribution of the three schemes. Since the thickness of variable thickness blanks is larger than the uniform thickness blank, which can enhance the ability in resisting the force from roller to become thinner.

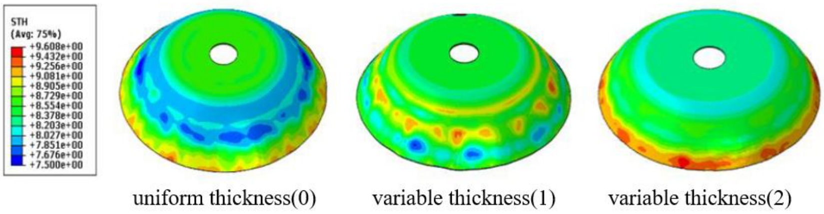


Fig. 8 Results of three different schemes

Then thicknesses of nodes along generatrix were extracted shown in Fig. 9. It can be seen that the maximum value of thinning ratio of scheme 1(uniform blank) is 15.6%, where the thickness is 7.6mm. While, the thinning ratios of scheme 2 and scheme 3 are lower (7.8% of scheme 2 and 1.1% of scheme 3), and the uniformity of thickness is improved (variance 0.226 of scheme 1, 0.057 of scheme 2 and 0.016 of scheme 3). Comparison of the two variable thickness blank indicates the thickness of scheme 3 is relatively higher, almost over 9mm, and the thickness is uniform, in other words, the thickness uniformity of variable thickness blank based on shear spinning is the best of the three schemes, the reason is that the original thickness of scheme 2 is bigger than scheme 3 in main forming stage, which results in severer vibration in scheme 2.

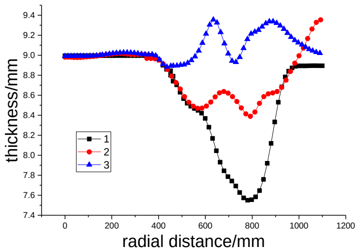


Fig. 9 Thickness uniformity of schemes

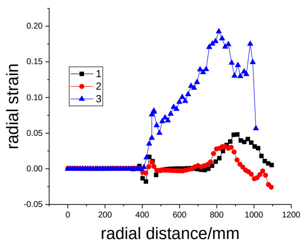


Fig. 10 Radial strain distribution

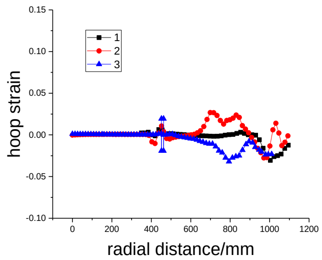


Fig. 11 Hoop strain distribution

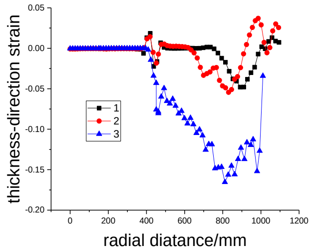


Fig. 12 Thickness-direction strain distribution

Fig. 10-12 are the radial, hoop and thickness-direction strains of the three schemes respectively. It can be seen that the variation trend of all strains of scheme 1 are similar with scheme 2, which indicates that the thinning ratio of the two schemes are close, and the thickness uniformity of scheme 2 is higher for its variable and larger initial thickness. When x < 850mm, the absolute values of radial and thickness-direction strains in scheme 2 and 3 increase to maximum, and then decrease, since the point is the end of shear spinning stage in blank thickness design (x_1 = 857.6mm theoretically from equation (5)). As for scheme 3, when x = 450mm, there is an obvious increase on radial and thickness-direction strain and a considerable vibration on hoop strain, which is caused by that the thickness of initial blank here has a relatively fast growth. The absolute values of radial strain and thickness-direction strain are approximately equal, and the hoop strain is nearly 0.

In earlier stage of spinning process of variable thickness blank, the forming state is similar to traditional spinning, and then the thickness begins decreasing, therefore, the forming force becomes lager, the material could better fit the mandrel. The mandrel fitting degree is shown in Fig. 13, and the largest fitting deviation is shown in Fig. 14, the values of which are 6.75%, 4.38%, 1.76% respectively. So, scheme 3 is the best method in mandrel fitting.

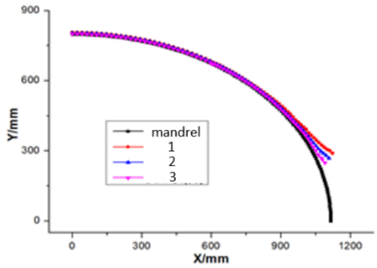


Fig. 13 Fitting degree

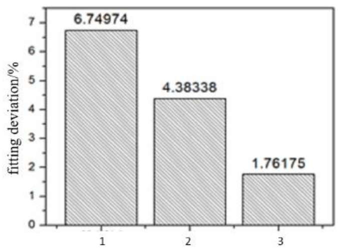


Fig. 14 Fitting deviation

4. Conclusion

In this paper, two different design methods of variable thickness blank were designed and applied to form an ellipsoid thin-walled part, then the triaxial strain and thickness variation were analyzed and compared. The simulation results could confirm that the two models are effective: the reverse deformation design method based on conventional spinning process could reduce the thinning ratio to a limited extent, and the variable thickness blank based on shear spinning process is fairly effective to reach the target of uniform thickness component.

Acknowledgment

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5. References

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