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Influence of nominal reduction of the blank radius per path on the neck spinning of oblique tubes

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Abstract: The process of the neck spinning of oblique tubes is simulated by means of the 3D elastic－plastic finite element software, MSC. MARC. The dynamic boundary and contact problems in simulation are solved. The characteristics of the metal flowing, the distributions of the stress and strain, the possible defects and areas during spinning are obtained. The influence of the nominal reduction of the blank radius per path on the metal flowing and deformation is also researched theoretically and experimentally. It shows that the nominal reduction of the blank radius per path has great influence on the neck spinning process of oblique tubes. A reasonable nominal reduction of the blank radius per path is very important to guarantee the proceeding of the spinning process and to obtain a sound products.

Key words: oblique tube; neck spinning; nominal reduction; numerical simulation

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1 Introduction

Spinning is a widely used metal forming process. It is characterized by board wide producing range, high forming precision, low production cost and high utilization of the forming equipment and material[1]. In the traditional opinion, spinning is considered as only can be used to produce the axisymmetric rotational part. However, the innovation of the spinning technology in recent years has made it break through the limit of producing the axisymmetrical rotational part, and some of the oblique and offset non-axisymmetric parts can also be produced by spinning[2].

Comparing with the traditional spinning technology, besides the same forming characteristics of the point-by-point deformation and local loading and unloading, the deformed metal of the oblique part spinning has the features of the bending, undergoes the tensile stress on one side and the compressive stress on the other side along the axial direction. Therefore, the distributions of the stress and strain of the oblique part spinning are also non-axisymmetric. Its deformation characteristics and the factors of affecting the product quality are more complex than that of the traditional axisymmetric part spinning, and the deformation mechanism, the states of the stress and strain, the characteristics of the metal flowing are also different from that of the traditional spinning process.

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The objective of this paper is to obtain the deformation rule of the each mass point of the deformed metal by means of the numerical simulation and the experiment research, therefore to establish the comprehensive understanding on the spinning process of the oblique parts.

2 Forming process and FEA model

2.1 The spinning forming process of the oblique tubes

Prior to spinning per path, the tube is inclined the required angle α on the horizontal surface of the workbench (see Fig. 1). During forming, the roller set, installed on the main spindle of the machine, is rotated together with the main spindle besides the rotation caused by contacting with the tubal blank. At the same time, the rollers move along the direction of the revolution radius and the tubal blank moves along the direction of the revolution axis of the rollers. After multi-path spinning, the oblique part with a total oblique angle $\alpha 0$ can then be produced[3].

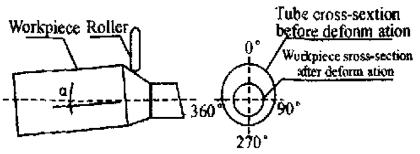

Fig. 1 Diagram of the spinning process of the oblique tube

The processing parameters of the oblique tube spinning adopted in the simulation and experiment are shown in Table 1, where the nominal reduction of the blank radius per path $\lambda = (D_0 - D_1)/2$ (D_0 is the tubal blank diameter and D_1 is the workpiece diameter).

Table 1 Processing parameters adopted in the simulation and experiment

Oblique angle per path/(°)	Nominal reduction of the blank radius per path/mm		Feed rate/(r · min^{-1})
3	3, 4, 5		0.5
Roller roundness radius/mm	Roller diameter/mm	Tubal blank diameter/mm	Tubal blank thickness/mm
10	170	80	3

2.2 FEA model

Based on the forming characteristics of the oblique part spinning, a 3D elastic-plastic finite element model is established by means of MSC. MARC software. The deformable-rigid contact pairs are set between the tubal blank and clamp, the tubal blank and rollers. Take the three rollers and clamp as rigid, the tubal blank as deformable. The tubal blank is meshed by the solid element of the hexahedron (eight nodes). The total element number is 1870, the loading time is 5 s and the total loading step is 4000. The three rollers are spaced circumferentially at 1200 apart along the revolution cross-section (see Fig. 2).

The Coulomb frictional model is adopted between the three rollers and the tubal blank. The friction coefficient is 0.1. The tubal blank material is LF21. Its mechanical properties are listed in Table 2[4,5]. The real stress-strain relation is $Y = 174.24\in^{0.2}$

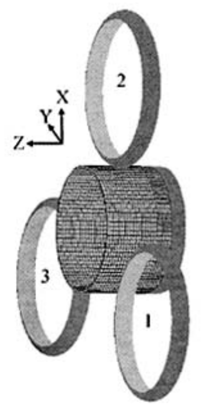

Fig. 2 The FEA model of the oblique tube spinning

Table 2 Material properties

Elastic modulus E/MPa	Poisson ratio γ	Yield strength σ_s/MPa	Hardening coefficient n	Thickness anisotropic exponent r
71000	0.3	114	0.20	0.87

The loading of the oblique tube spinning can be realized by the movement of the three rollers. In the established FEA model, the right end of the tubal blank is fixed in the clamp and its deformation is restrained by the clamp. The left end of the tubal blank is free, plastic deformation occurs under the action of the three rollers. The relative movement traces between the three rollers and the tubal blank are the spatially spiral curves. During simulation, the incline of the blank prior per path spinning is realized by the incline of the clamp. The other movements, including the revolution and rotation of the rollers, the feeding movement of the rollers along the direction of the revolution radius, and the axial movement of the blank, are realized by controlling the movement traces of the three rollers. The forward spinning is adopted in this simulation and experiment, the oblique angle of the workpiece is 3°.

3 Simulation result and analysis

3.1 The metal flowing and deformation

Fig. 3 shows the mesh deformation for different nominal reduction of the blank radius per path. It shows that comparing with the original tubal blank, the deformed workpiece is obviously stretched along the axial direction. When the nominal reduction of the blank radius per path is less than 3 mm, the mesh deformation is uniform. There is no obviously difference between the oblique part spinning and the traditional axisymmetric part spinning (Fig. 3(a)). When the path nominal reduction is greater than 4 mm, the obvious waves appear in the circumferential meshes along the axial direction (Fig. 3(b)). It shows that the

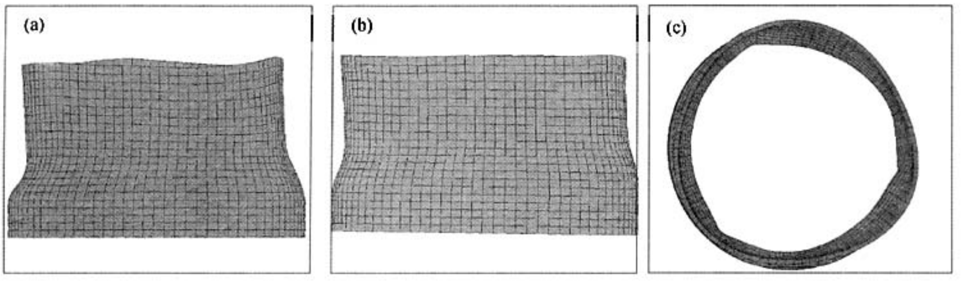

Fig. 3 Influence of the nominal reduction of the blank radius per path on the metal flowing and deformation
(a)—mesh deformation at the 4000 steps for 3 mm nominal reduction; (b)—mesh deformation at the 4000 steps for 4 mm nominal reduction; (c)—mesh deformation at the 2 steps for 5 mm nominal reduction

deformation force of the workpiece endured along the axial direction is non—uniform. The macro behave of the wave—shaped mesh is that earring occurs at the free end of the workpiece. This phenomenon is the same as the deep drawing of the cylindrical parts. It is mainly caused because of the anisotropic of the material. When the path nominal reduction is greater than 5 mm, the local buckling and wrinkling occur in the initial stage of the spinning, it results in the damage caused by the fracture and the spinning process can't proceed continually (Fig. 3(c)).

Fig. 4 shows the comparison of the deformed mesh around the circumferential direction. It shows that both the deformation and the twist of the deformed mesh near 0° are more serious than other area. It is because that the tubal blank inclined towards the 0° arêa during spinning, and the actual reduction of the blank radius is greater than that of the nominal one.

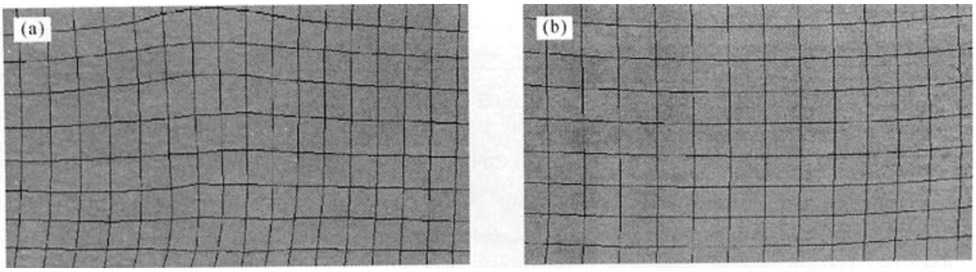

Fig. 4 Influence of oblique angle on metal flowing and deformation

(a) mesh deformation near 0°area for 4 mm path nominal reduction; (b) mesh deformation near 180°area for 4 mm path nominal reduction

3.2 Distributions of the stress and strain

Fig. 5 shows the strain distribution of the outer surface of the workpiece after one path neck spinning when the nominal reduction of the blank radius per path is 3 mm.

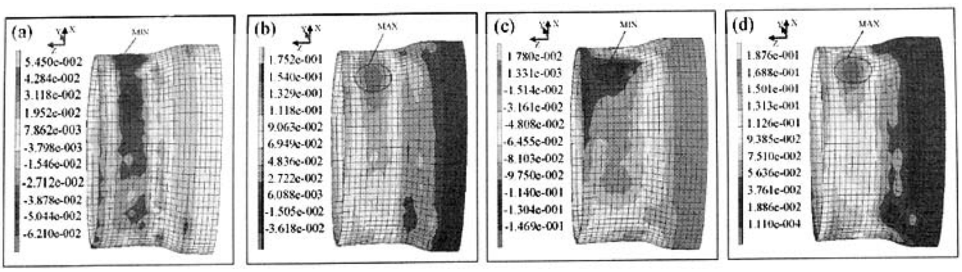

Fig. 5 Distribution of the strain for 3 mm path nominal reduction

(a) radial strain; (b)axial strain; (c) tangential strain; (d)total equivalent plastic strain

Fig. 5(a) shows the radial strain distribution during oblique tube spinning. It shows that most of the radial strain is compressive for oblique tube spinning, but local tensile strain appears near the 180° area of the workpiece. Meanwhile, the maximum compressive strain occurs near the 0° area along the circumferential direction, the radial compressive strain decreases from 0°to 180° area. The distribution of radial strain along the circumferential direction is non—uniform, local thickening exists while thinning for oblique tube spinning. The thinning is mainly caused by the axial tensile and radial compressive stresses during forward spinning. The thinning near the 0° area is the most serious.

Fig. 5(b) shows the axial strain distribution. It shows the axial stretching of the workpiece after spinning. All of the axial strain is positive; the maximum axial strain is near the 0° area and the minimum strain is near the 180° area. The deformed metal pileup in front of the roller near 0° area is more than that of 180° area because the tubal blank inclines towards the 0° area, hence to a large tensile stress during spinning near this area. The accumulative result caused by the unequal axial strain makes the difference of the axial length of the workpiece.

Fig. 5(c) shows the tangential strain distribution. When the rollers acting on the workpiece along radial direction, the deformed metal along the tangential direction is firstly pressed into a concaved shape; with the revolution of the three rollers, the metal around the contacting area is squeezed, too. Therefore, all the metal around the tangential direction is squeezed, compressive deformation occurs, all the strain are compressive. It is the same as the actual production. The tangential compressive strain shows that the circumferential dimension decreases, neck spinning produces finally.

The same as the radial strain, the maximum tangential compressive strain also occurs near the 0° area. This is because that the actual reduction near the 0° area is larger than other areas and has a bit large percentage deformation.

Fig. 5(d) shows the total equivalent plastic strain. It shows the total strain distribution of the workpiece after spinning. The distribution of the total equivalent plastic strain is similar with that of the axial strain, i. e., the total equivalent plastic strain near the 0° area is larger than that of 180° area.

Fig. 6 shows the equivalent Von Mises stress of the workpiece outer surface. It shows that the distribution of the equivalent Von Mises stress along the circumferential direction is basically uniform. But along the axial direction, form the fixed to the free end, the equivalent Von Mises stress increases gradually and reaches the maximum at the opening. Therefore, a suitable measure should be adopted to avoid the aged cracking caused by the residual tensile stress.

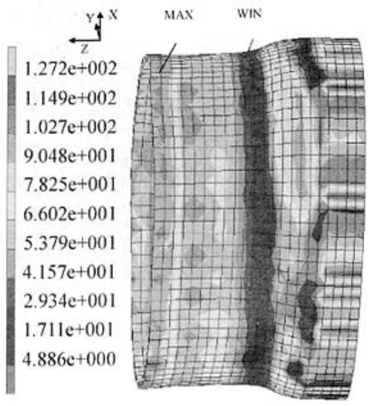

Fig. 6 Distribution of the equivalent Von Mises stress for 3 mm path nominal reduction

The simulation results also show that near the opening of the free end of the workpiece during oblique tube spinning, a bell mouth occurs more easily than that of the axisymmetric part. The simulation would stop if a serious bell mouth occurs. Therefore, it should pay more attention to the opening forming during actual production.

4 Comparison of the simulation and experimental results

4.1 Experiment conditions

The material used in this experiment was LF21. The processing parameters are listed in Table 1. The experiment was done in the HGPX-WSM CNC spinning machine (Fig. 7).

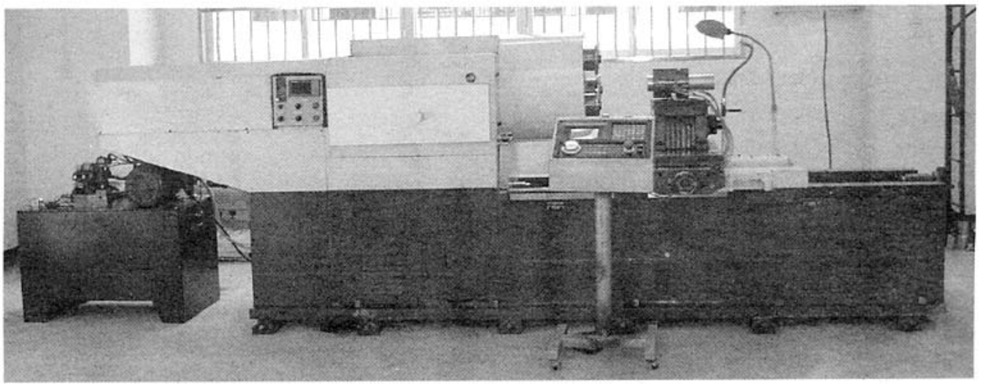

Fig. 7 . HGPX--WSM CNC spinning machine

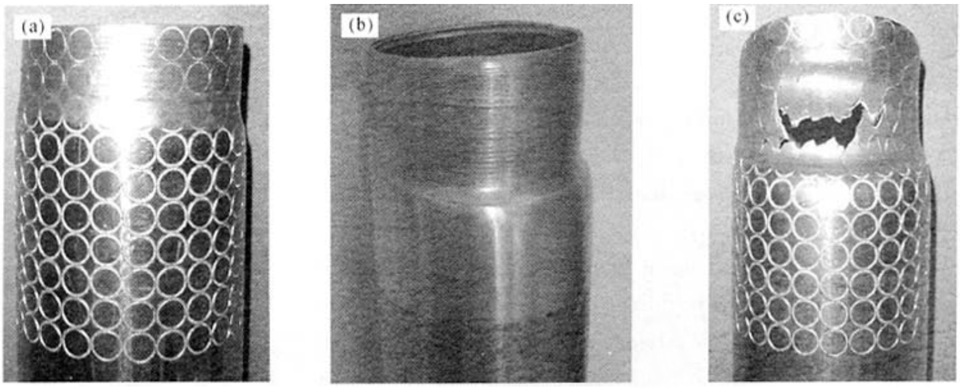

Fig. 8 Spun workpiece for different path nominal reduction

(a) spun workpiece for 3 mm path nominal reduction; (b) spun workpiece for 4 mm path nominal reduction; (c) spun workpiece for 5 mm path nominal reduction

4.2 Influence of the nominal reduction of the blank radius on the metal flowing and deformation

Fig. 8 shows the spun workpiece for different nominal reduction of the blank radius per path. It shows that when the path nominal reduction is less than 3 mm, a sound spun workpiece can be obtained (Fig. 8 (a)). When the path nominal reduction is greater than 4 mm, the wave—shaped appears at the opening of the free end; earring occurs (Fig. 8(b)). When the path nominal reduction is greater than 5 mm, the serious buckling and wrinkling occur at the initial stage of the oblique tube spinning, the percentage deformation is at its limit and fracture occurs (Fig. 8(c)).

The experimental results conform well to the simulation one. It proves that the FEA model established in this paper is correct and reasonable. The simulation and experiment results also show that for LF21, under the processing parameters provided by this paper, the maximum nominal reduction of the blank radius per path to guarantee the spinning process proceeds smoothly cannot be greater than 5 mm. The nominal reduction of the blank radius per path to guarantee a sound surface quality is 3 mm.

5 Conclusions

The spinning process of the oblique tube is simulated by means of the MSC. MARC FEA software and is validated by the experiment. The conclusions are as follows:

(1) The loading of the neck spinning of the oblique tubes during simulation can be realized by controlling the movement traces of the three rollers.

(2) Because the axis of the tubal blank and the spun workpiece has a certain included angle, the distributions of the deformation mesh, the stress and strain, the thickness and the axial elongation are obviously non—axisymmetrical, and earring occurs at the opening of the free end of workpiece.

(3) The tubal blank inclined towards the 0° area, a bit large tangential and axial tensile stresses and serious thickness thinning exist near this area. The 0° area of the free end of workpiece is the critical section during oblique tube spinning.

(4) Nominal reduction of the blank radius per path has great influence on the oblique tube spinning. A reasonable path nominal reduction is very important to guarantee the proceeding of the spinning and to obtain a sound product.

(5) The simulation results conform well to the experiment one. It shows that the 3D plastic-elastic FEA model established in this paper is correct and resonable.

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