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Finite element analysis of effect of interface lubrication on tube-compression of thin-walled part in viscous pressure forming

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Abstract: The forming process was simulated numerically by ANSYS/LS-DYNA. The material flowing of tube-blank in the tube-compression process and the effect of the friction coefficient between die and tube-blank on the forming process were analyzed. The research results show that the flowing direction of tube-blank and the flowing direction of viscous mediums are coincident. When the friction coefficient between die and tube-blank is less than 0.12, there is no significant effect on the forming process. When the friction coefficient between die and tube-blank is greater than 0.12, the effect on the forming process is becoming more and more severe constantly with the increase in the friction coefficient between die and tube-blank. Therefore, improving the interface lubrication conditions is beneficial to increasing the forming limit.

Key words: tube-compression; interface lubrication; thin-walled part; viscous medium forming

1 Introduction

Tube-compression is one of the most typical forming methods for variable diameter parts [1−2]. Due to the influence of compression instability, buckling and wrinkling are prone to occur in tube-compression process viscous pressure forming (VPF), especially for the thin-walled parts, which restricts the application of tube-compression [3−5].

Viscous pressure forming (VPF) uses a semi-solid, flowable, highly viscous and strain rate sensitive macromolecule polymer (called viscous medium) as the flexible-punch [6]. WANG et al [7] reviewed the effect of viscous medium on the deformation of sheet metals. Sheet metals are subject to not only normal pressure but also tangential adhesive stress of viscous medium, both of which are non-uniform and changeable. The viscous medium can promote the flow of the material and delay the strain localization. VPF is especially suitable for the deformation of difficult-to-form materials with low plasticity or high strength [7−9]. The VPF process is a combination of the bulk (viscous media) and sheet metal forming processes. Finite element analysis software DEFORM has been chosen to simulate the axisymmetrical viscous pressure forming of sheet metals, i.e., stretching and drawing [10−12].

The principle of tube-compression by viscous pressure forming is shown in Fig. 1. Firstly, the tube-blank is placed on die. The medium chamber has been filled with the viscous medium before forming parts. The pressure of tube-compression is offered by viscous medium pushed with punch. The effect of interface lubrication on tube-compression of thin-walled part in viscous pressure forming is remarkable. Reasonable interface lubrication conditions can make the tube-blank have a better flow, and the reduction of wall thickness is less, which is very important to the forming of the thin-walled parts.

In this work, the forming process of tube-compression of nickel based super-alloy thin-walled parts is simulated numerically by FEA software ANSYS/ LS-DYNA. The material flowing of tube-blank in the tube-compression process and the effect of friction coefficient between die and tube-blank on the forming process are analyzed.

2 Finite element analysis model

2.1 Finite element modeling

Figure 2 shows shape and dimensions of nicked based super-alloy thin-walled part with the thickness of 0.2 mm. In order to analyze the deformation characteristics of the nickel based super-alloy thin-

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walled part during the forming in visco-elasto-plastic medium, the FEA software package LS-DYNA3D was employed to simulate the forming process. FEA model with 1/4 in the circumferential direction and 1/2 axial direction (Fig. 3) was established according to symmetry of the die and tube-blank. The pressure of tube-compression was offered by viscous medium pushed with punch. In the FEA model the cylinder blank was meshed as B-T shell element, and the visco-elasto-plastic medium was meshed as bulk element. Coulomb friction model was applied to interface between tube-blank and die. The six different friction coefficients between die and tube-blank were chosen as 0.00, 0.04, 0.08, 0.12, 0.16 and 0.20 in the FEA model.

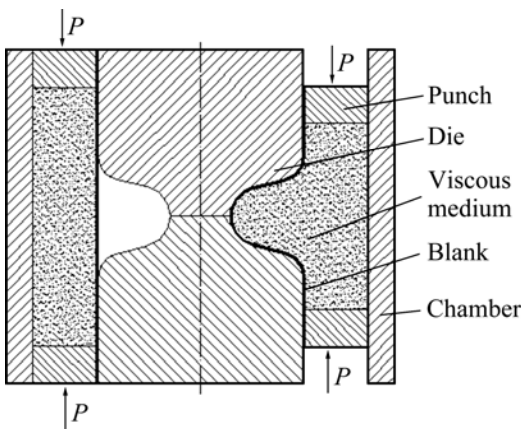

Fig. 1 Principal diagram of tube-compression by viscous pressure forming

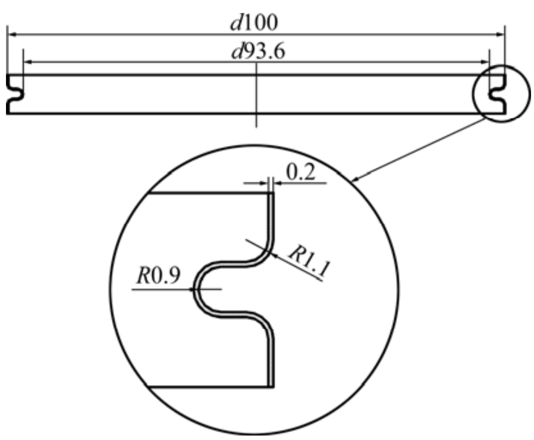

Fig. 2 Shape and dimension of part (unit: mm)

2.2 Materials

The nickel based super-alloy used in finite element analysis was GH4169 with a thickness of 0.2 mm. Its material properties are given in Table 1. The viscous medium was silicone rubber. The flow stress vs strain rate curve of the viscous medium is shown in Fig. 4.

Area variation of deformation region of cylinder blank during the tube-compression is shown in Fig. 5.

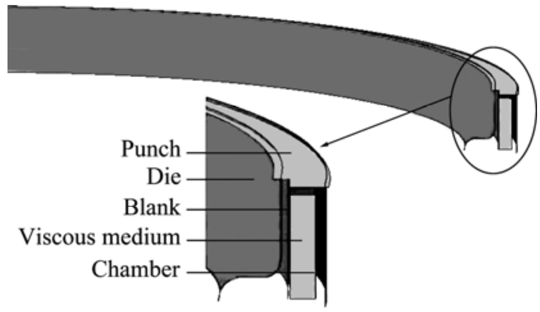

Fig. 3 FEA model

Table 1 Material properties of GH4169 [14]

Yield strength/ MPa	Tensile strength/ MPa	Elastic modulus/ GPa	Elongation/ %	K/ MPa	n
550	965	210	30	1 180	0.30

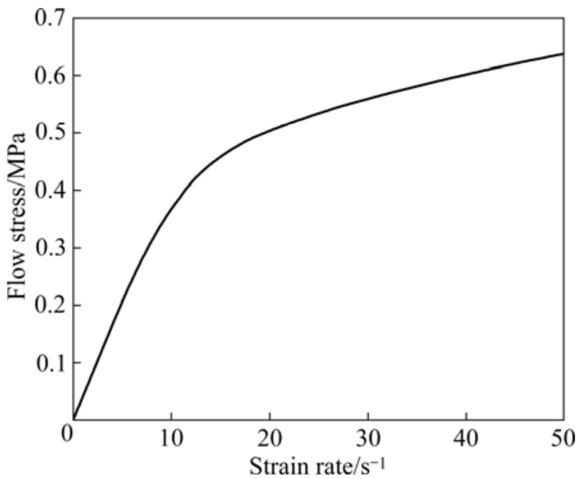

Fig. 4 Flow stress vs strain rate curve of viscous medium [13]

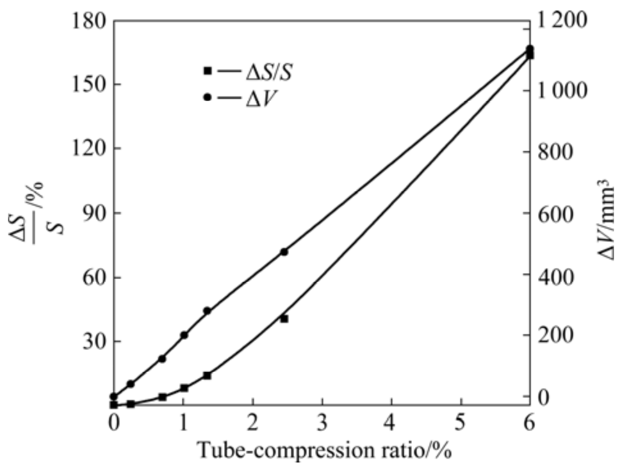

Fig. 5 Area variation of deformation region of cylinder blank during tube-compression

The area of the deformation region increases gradually, and the area of the final shape increases by 1.63 times. Therefore, in order to restrict the reduction of wall thickness of deformation region, the end material needs to supply the deformation region of tube-blank. The viscous medium is a semi-solid, flowable, highly viscous and strain rate sensitive macromolecule polymer in viscous pressure forming (VPF) [15−16]. The tube-blank forms gradually under the pressure of the viscous medium on the surface of tube-blank all the time. Figure 6 shows the flowing directions of tube-blank and viscous medium during the tube-compression. The flowing directions of tube-blank and the flowing direction of viscous mediums which act as the surface of tube-blank are coincident, which can make the end material supply the deformation region of tube-blank and restrict the reduction of wall thickness of deformation region.

3 Results and discussion

Figure 7 shows that the material flowing of the tube-blank with different friction coefficients. With an larger friction coefficient between tube-blank and die, the end materials supply more difficult deformation zone of tube-blank. When the friction coefficients between die and tube-blank are 0 and 0.12, the displacements of end are 2.05 mm and 1.90 mm, respectively, and difference between the two is only 0.15 mm. Therefore, when the friction coefficient between die and tube-blank is less than 0.12, there is no significant effect on the forming process. When the friction coefficient between die and tube-blank is greater than 0.12, the displacement of end decreases remarkably. The effect on the forming process is becoming more and more severe constantly with the increase in the friction coefficient. When the friction coefficient between die and tube-blank is 0.2, the displacement of end is only 0.39 mm.

Figure 8 shows curves of the max tensile stress and the maximum reduction thickness of tube-blank vs

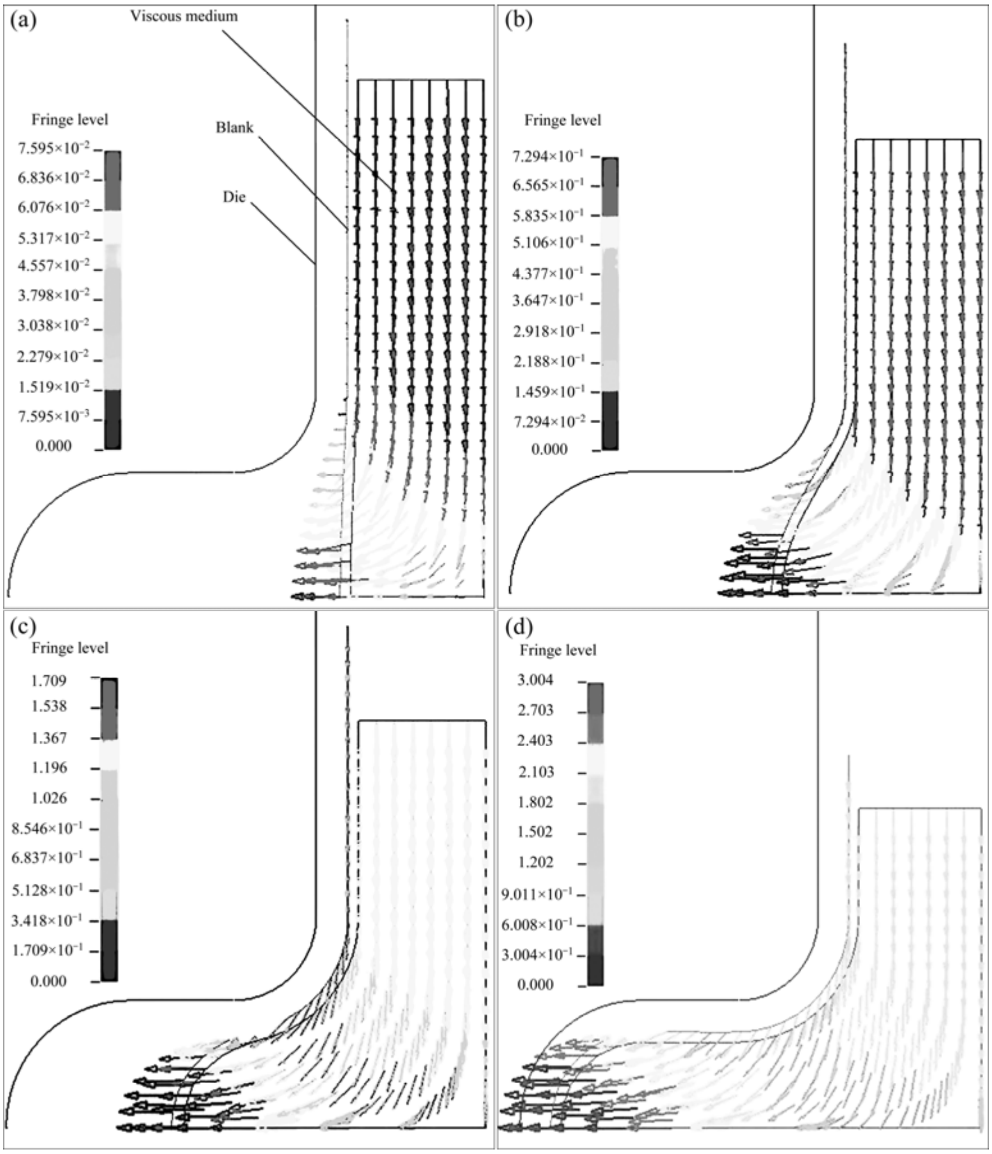

Fig. 6 Flowing directions of tube-blank and viscous medium during tube-compression: (a) Stroke of punch of 0.1 mm; (b) Stroke of punch of 0.6 mm; (c) Stroke of punch of 1.2 mm; (d) Stroke of punch of 2.1 mm

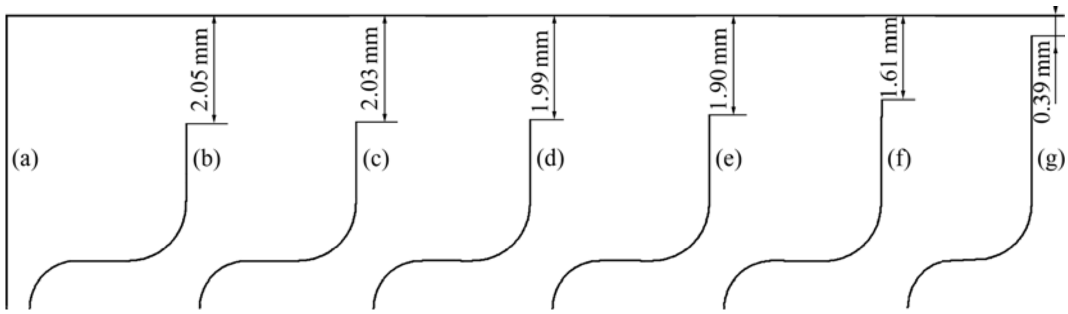

Fig. 7 Material flowing of tube-blank with different friction coefficients between die and tube-blank: (a) Tube-blank; (b) μ=0; (c) μ=0.04; (d) μ=0.08; (e) μ=0.12; (f) μ=0.16; (g) μ=0.20

friction coefficient. With a larger friction coefficient between tube-blank and die, the maximum tensile stress and the maximum thickness reduction of tube-blank increase more evidently. When the friction coefficients between die and tube-blank are 0 and 0.12, the maximum tensile stresses of tube-blank are 271 MPa and 501.5 MPa and the maximum reduction thickness values of tube-blank are 0.4% and 5.12%, respectively. When the friction coefficient between die and tube-blank is 0.16, the maximum reduction thickness of tube-blank quickly increases to 18.54%. When the friction coefficient between die and tube-blank is 0.20, the crack comes into being. Therefore, when the friction coefficient between die and tube-blank is less than 0.12, there is no significant effect on the maximum tensile stress and the maximum reduction thickness. When the friction coefficient between die and tube-blank is greater than 0.12, the effects on the maximum tensile stress and the maximum reduction thickness are becoming more and more severe constantly with the increase in the friction coefficient.

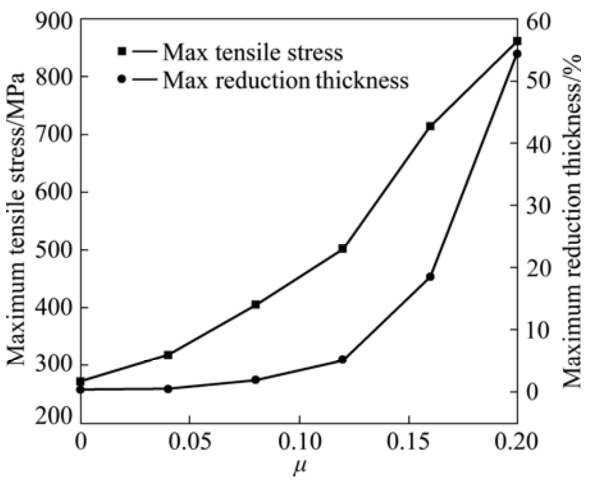

Fig. 8 Maximum tensile stress and maximum reduction thickness vs friction coefficient between die and tube-blank

4 Conclusions

1) The flowing directions of tube-blank and viscous mediums on the surface of tube-blank are coincident to make the end material supply the deformation zone of tube-blank and restrict the reduction of wall thickness of deformation zone.

2) When the friction coefficient between die and tube-blank is less than 0.12, there is no significant effect on the tube-compression forming process. When the friction coefficient between die and tube-blank is greater than 0.12, the effect on the tube-compression forming process is becoming more and more severe constantly with the increase in the friction coefficient.

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界面润滑条件对薄壁零件黏性介质压力缩径影响的有限元分析

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摘 要：利用有限元软件 ANSYS/LS-DYNA 对薄壁零件黏性介质外压缩径过程中模具与筒坯之间摩擦因数对变形的影响进行有限元分析模拟。结果表明：在缩径过程中筒坯料的变形速度方向与作用在表面的黏性介质的运动方向始终保持一致。模具与筒坯的摩擦因数的临界值是 0.12，当小于 0.12 时，摩擦因数对缩径成形过程的影响较小；当大于 0.12 时，随着摩擦因数的增大，其对缩径成形过程的影响不断加剧。改善模具与筒坯之间的界面润滑条件有助于缩径成形极限的提高。

关键词：缩径；界面润滑；薄壁零件；黏性介质成形

(Edited by YANG Hua)