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Three-Dimensional Rigid Plastic Finite Element Analysis of Extruding-bulging Process of Tee Tubes

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Abstract

Three-dimensional rigid plastic FEM is adopted to analyze the extruding-bulging process of tee tubes. Equivalent strain-rate, stress distributions and the deformation characteristic in extruding-bulging process of tee tubes are revealed, which provide scientific and reliable basis for correctly designing technological scheme and rationally selecting parameters. Meanwhile, some approaches for three-dimensional rigid plastic FEM are also discussed in this paper.

Key Words : Rigid plastic FEM, Extruding-bulging process, Tee tubes

1. Introduction

Tee tubes are widely applied as important pipe junctions in pipage in all kinds of industry departments. With the development of industry, the need for tee tubes is increasing and the demand to their quality is becoming more and more strict, thus the conventional manufacturing methods could not meet with this demand. Extruding-bulging of tee tubes is a forming method that fills plastic medium in the tube as a force-building medium. The advantages of this technology are high utilization ratio of material, high ratio of finished products, short period of manufacture and low comprehensive cost, compared with formerly technology such as casting, forging and welding[1-4]. The deformation characteristic of tubular blank in extruding-bulging is not understood well for its appearance before long. FEM (finite element method) is the most effective numerical method to solute the problems of continuous areas approximately, which can provide the approximately continuous mathematics description about the process of plastic deformation[5,6]. In this paper, three-dimensional rigid-plastic finite element method is adopted to simulate the process of extruding-bulging of tee tubes, and the characteristic of metal deformation is revealed. They provide scientific basis for designing technological scheme correctly and selecting process parameters reasonably.

2. FEM Simulation Approach

2.1 Rigid-plastic FEM formulation

The method used in the present paper is based on

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the variational principle for the functional of a rigid-plastic material. The constitutive equation for the rigid-plastic deformation is represented by

$$\sigma_{ij}' = \frac{2}{3}\frac{\bar{\sigma}}{\dot{\bar{\varepsilon}}}\dot{\varepsilon}_{ij} \quad (1)$$

where $\bar{\sigma}$ is the equivalent stress, $\dot{\bar{\varepsilon}}$ is the equivalent strain rate, and $\dot{\varepsilon}_{ij}$ is the strain rate component. The variational principle for the functional Φ can be written as

$$\Phi = \int_V \bar{\sigma}\dot{\bar{\varepsilon}} dV - \int_{S_F} F_i \nu_i dS + K\int_V \frac{1}{2}\dot{\varepsilon}_V^{\,2} dV \quad (2)$$

where F_i is the force of given surface on force surface S_F, ν_i is velocity vector, K is a penalty constant to neglect the incompressibility condition, and $\dot{\varepsilon}_V$ is volume strain velocity, $\dot{\varepsilon}_V = \dot{\varepsilon}_{ii}$.

The variational functional (2) can be converted to a set of non-linear algebraic equations which can be solved by the Newton-Raphson method.

2.2 Description of the die

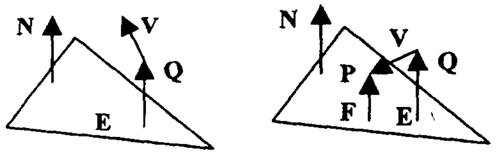
The surface of the die cavity near the junction of the main and branch tube is complex and difficult to describe with regular curve surface. Considering the flexibility and universal suitability of B-spline, in this paper, double cubic even B-spline is adopted to describe the surface of the die cavity of extruding-bulging of tee tubes. In this kind of description, the subdivision of surface patches can be performed by changing the subdivision density coefficient of the surface patches along the two parameter directions, the surface patches can be divided into triangles and normal vector of each surface patches is provided at the same time. This description provides convenient and flexible numerical geometrical information to deal with the contact between the nodal points and the die surface.

2.3 Contact algorithm

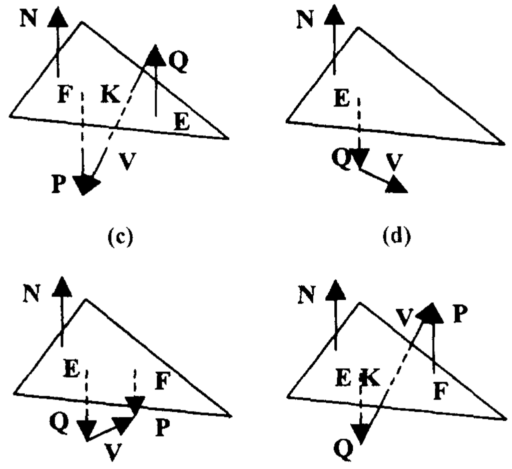
In three-dimensional metal deformation problems, the contact between the nodes and the die surface must be checked carefully to obtain accurate solutions. A method is presented to judge the contact between an arbitrary node and an arbitrary die triangular element. Firstly, four vectors should be defined, **N** is normal vector of the dies triangular element whose node code is anticlockwise, **V** is velocity vector of deforming node Q, **QE** is vector pointing from dies triangular element plane to node Q, **PF** is vector pointing from dies triangular element plane to node P which is the new position of node Q after the iteration step. The relative orientation between node and dies triangular element can be determined by vector **N**, **QE** and **PF**, then the relative velocity direction between node and dies triangular element can be determined by vector **V**. As shown in Fig. 1, there occur six instances among the four vectors.

1) **N** · **QE** > 0 and **N** · **V** > 0, node deviates from the element.
2) **N** · **QE** > 0 and **N** · **V** < 0, node moves toward the element. There occur two instances, if **N** · **PF** > 0, the node could not contact the element, if **N** · **PF** < 0, the node might contact the element.
3) **N** · **QE** < 0 and **N** · **V** < 0, node deviates from the element.
4) **N** · **QE** < 0 and **N** · **V** > 0, node moves toward the element. There occur two instances, if **N** · **PF** < 0, the node could not contact the element, if **N** · **PF** > 0, the node might contact the element.

In fact, only when **N** · **QE** > 0, **N** · **V** < 0, **N** · **PF** < 0 or **N** · **QE** < 0, **N** · **V** > 0, **N** · **PF** > 0, could the node Q contact the dies element. After this search, all dies elements who might contact the node Q can be selected, then a local search is performed to select the element who contact the node Q.



(a) (b)



(c) (d) (e) (f)

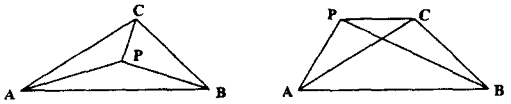
Fig. 1 Relation between node and dies triangular element : (a) N · QE > 0, N · V > 0, (b) N · QE > 0, N · V < 0, N · PF > 0, (c) N · QE > 0, N · V < 0, N · PF < 0, (d) N · QE < 0, N · V < 0, (e) N · QE < 0, N · V > 0, N · PF < 0, (f) N · QE < 0, N · V > 0, N · PF > 0

The node Q and P are projected on the selected dies triangular elements and the cross-point K of line QP and dies triangular element plane is calculated. The area difference of triangles is used to accurately judge the correlation of point E, F, K and dies triangular element. As shown in Fig.2, supposing the point A, B and C are three vertexes of a triangular element and $S_{\Delta ABC}$ is its area, point P is a point on the triangle ABC plane and $S_{\Delta ABP}$, $S_{\Delta BCP}$ and $S_{\Delta ACP}$ are areas of triangle ABP, BCP and ACP, ΔS is area difference of triangle ABC and triangle ABP, BCP and ACP.

$$\Delta S = S_{\Delta ABP} + S_{\Delta BCP} + S_{\Delta ACP} - S_{\Delta ABC} \qquad (3)$$

When the area difference $\Delta S=0$, point P is inside the triangle element ABC. When the area difference $\Delta S>0$, point P is outside the triangle element ABC.

If point E, F and K are inside the triangle element or F and K are inside the triangle element, node P will contact with the dies triangular element after this iteration step and the point F is a new position of node P. Otherwise, if point K is inside the triangle element, node P will contact with the dies triangular element and the point K is a new position of node P.



(a) (b)

Fig. 2 Relation between point and triangle
(a) point in triangle (b) point out of triangle

3. Simulation of Extruding-bulging Process of Tee Tubes

Consider the symmetry, only one forth of the whole blank has been simulated. Fig. 3 shows the die and initial tubular blank mesh. The mesh consists of 1024 eight-nodes hexahedron elements and 1701 nodes. The surface of the die is divided into five patches and described with B-spline respectively, eventually, is subdivided into 480 triangles elements altogether. The pressure of inner media is obtained by Ref. [1]. The initial pressure on inner medium is 45 MPa, and the pressure changes with the deformation and acts on inner surface of tube evenly. The extruding speed of punch is 1.0mm/s. The friction factor between the die and blank is 0.05. The material flow stress equation is: $\bar{\sigma} = 738\bar{\varepsilon}^{0.21}$

Experiments have been carried out using low carbon steel. Fig.4 shows the load-displacement curves of FEM calculation and experiment[1]. The results of the simulation are in good agreement with that of the experiments.

Fig.5 and Fig. 6 show the equivalent strain-rate and stress distributions on the inner surface with extrusion amount of 13% and 23.5%. The plastic deformation concentrates on the branch tube and the junction of the main and branch tube. At the beginning, the inner pressure built by the medium is small. The tubular blank is deformed by the extrusion of the punch and the plastic deformation is compressive. With the movement of the punch, the inner pressure becomes larger and larger. Metal on the branch tube is bulged by the inner pressure, the plastic deformation is tensile and the thickness becomes thinner and thinner. But, metal on the main tube is forced to flow into the branch cavity of die under bulging of inner medium and extruding of punches. Therefore, the extrusion of punches, which forces metal to replenish branch tube continuously, prevents the decrease of branchs thickness effectively. The deformation degree of tubular blank depends on maximal reduction of the metal on end of branch tube.

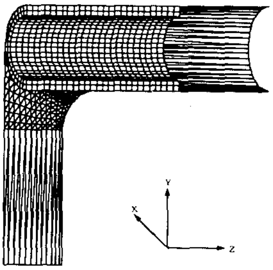


Fig. 3 The die and initial tubular blank mesh

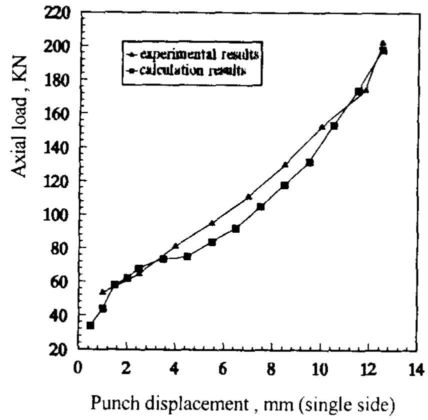
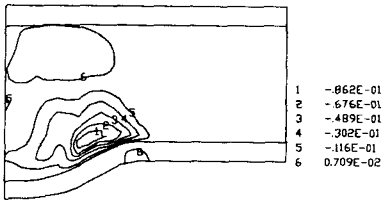
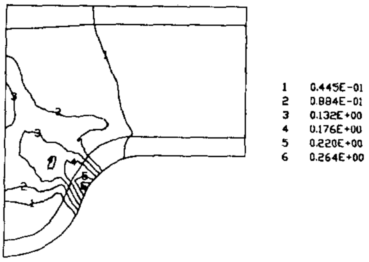


Fig. 4 The load-displacement curves of FEM calculation and experiment

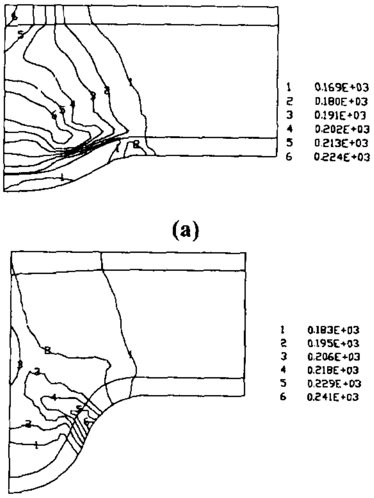


(a)



(b)

Fig. 5 The equivalent strain-rate distributions on the inner surface : (a) Extrusion amount 13%, (b) Extrusion amount 23.5%



(a)

(b)

Fig. 6 The equivalent stress distributions on the inner surface : (a) Extrusion amount 13%, (b) Extrusion amount 23.5%

4. Conclusions

In this paper, the procedure of extruding-bulging is simulated successfully by three-dimensional rigid-plastic FEM, and the simulation results are in good agreement with the practical forming process. Equivalent strain-rate, stress distributions and the deformation characteristic in extruding-bulging process of tee tubes are obtained, which reveal the characteristics of metal deformation.

Acknowledgement

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