Residual stress field evaluation of the blank of a casing part

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Abstract. Casing parts are the key components of many mechanical products. In this study, a FEM simulation model of the extrusion process of a cylindrical casing is built to assess the residual stress field after extrusion. Then, a residual stress evaluation FEM model of the turning process is established. The FEM model is validated by the stress measurement experiments. Results show that large tensile residual stress is generated near the surface of the cylindrical blank in the extrusion process. After turning process, the compressive stresses are distributed near the inner wall of the conical blank in the tangential direction, and the tensile stresses are near the outer wall. By contraries, the compressive stresses in the axial direction are near the outer wall in the axial direction, and the tensile stresses are near the inner wall.

1. Introduction

Due to the non-uniform temperature and stress fields in the forming process, the residual stress is generated in the blank [1]. The residual stress is released after the material is gradually removed from the blank in the machining process, which causes the machining deformation of the workpiece. The residual stress and the resulting machining deformation significantly affect the dimensional stability and machining accuracy [2]. Therefore, a comprehensive and systematic evaluation of the residual stress field in the blank is very necessary in the forming process. It is the basic conditions of the residual stress elimination and control.

Some experimental methods, such as hole-drilling [3], X-ray diffraction [4], neutron diffraction [5], and ultrasonic method [6], can be used for the residual stress assessment. The experiments usually combine with finite element method (FEM) numerical simulations because of the long-time consuming and high cost.

Singh and Agrawal [7] found that after cutting, bending and stretching, the surface residual stress of the part is the compressive stress. Zel and Zeren [8] established the numerical simulation model of residual stress in orthogonal thermal-structural cutting process by using arbitrary Lagrangian Eulerian coordinate method. Huang et al. [9] established the analytical model of residual stress induced by machining, and they studied the formation mechanism of machining induced residual stress. Gao et al. [10] proposed an evolutionary model of residual stress and deformation during the processing of plate and thin-walled frame parts by means of analytical and semi-analytical methods.
Casing parts are the key components of many mechanical products. The residual stress in the blank has significant influences on the dimensional stability of the casing. In this study, a FEM simulation model of the extrusion process of a cylindrical casing is built to assess the residual stress field after extrusion. Then, a residual stress evaluation model of the turning process is established. The residual stress is measured by hole-drilling and electronic speckle pattern interferometry technique. Eventually, the residual stress field of the casing blank is evaluation based on the simulation model and experiment results, which provides the basis for the stress control and elimination.

2. Modelling

2.1. Extrusion simulation model
The composition of 7075 aluminium alloy is shown in Tab. 1. The manufacture process of the casing part is shown in Fig. 1. The cylindrical blank is first obtained from the extruded bar, and the cylindrical blank is fabricated into the conical blank by turning process. Then, the conical blank is fabricated into casing part by turning-milling process. The obvious machining deformation appears in the turning-milling process due to the residual stress release under the large cutting volume. Therefore, in order to control the machining deformation, the residual stress field in the conical blank should be evaluated comprehensively and systematically.

The extrusion forming FEM numerical simulation model of the cylindrical blank is established in DEFORM-3D software. The FEM model includes the blank, upper die, and lower die. Tetrahedral elements are used, and the element size is set as 5mm. Johnson-Cook model is used as the constitutive model, and extrusion speed is set as 1.2m/min. The extrusion process of the FEM model is shown in Fig. 2. Thus, the residual stress in the cylindrical blank can be obtained based on the FEM model.

Table 1. Chemical composition of aluminium alloy 7075-T651 (%).

| Alloy | Si  | Fe  | Cu  | Mn  | Mg   | Cr   | Ni  | Zn  | Ti  | Al   |
|-------|-----|-----|-----|-----|------|------|-----|-----|-----|------|
| 7075  | 0.40| 0.50| 1.2–2.0 | 0.30| 2.1–2.9 | 0.18–0.28| 0.05| 5.1–6.1 | 0.20 | Bal |

Figure 1. Manufacture process of the casing part.
2.2. Residual stress evolution FEM model in turning process

The cylindrical blank is fabricated into the conical blank in turning process. The residual stress is released due to the removal of the material. Although the machining-induced residual stress is also generated in turning process, the influence layer of the residual stress is less than 0.2mm, which has little influence on the redistribution of the stress field. Therefore, the machining-induced residual stress is not considered in the evolution model.

The geometry model of cylindrical blank is divided into two parts: one is the conical blank part, and the other one is the material to be removed. The two parts are connected by boolean operation. The FEM model is built based on the geometry model in ANSYS 17.0 software. The residual stress results calculated by the extrusion simulation model is imported into the FEM model, which are taken as the initial residual stresses of the cylindrical blank. The element birth and death technology are used for simulating the material removal. Thus, the stresses in the blank can be calculated as the corresponding element is killed from the model.

2.3. Residual stress measurement experiments

The residual stress is measured by Prism system, which is produced by Stresstech Group (Vaajakoski, Finland). Electronic speckle pattern interferometry technique and hole-drilling method are integrated in Prism system. Four positions are selected along the circumferential direction of the blank, and there are two measuring points on each position. The measuring depth of each point is 1.6mm. Hence, the residual stress of each point can be evaluated by experiments.
3. Results and discussions

Residual Stress contours after extrusion process in different sections are shown in Fig. 4. The residual stress curve of the axis in each section is presented in Fig. 5. Fig. 4 and 5 show that, in the tangential direction, tensile stresses exist near the surface, and compressive stresses are in the subsurface layer. Small tensile stresses exist in the core area of the blank. In the radial direction, tensile stresses exist near the surface, and the compressive stresses are in the core of the blank. The maximum tensile stress in the tangential direction is 118MPa, and that in the radial direction is 178MPa. The results demonstrate that large tensile residual stress is generated in the extrusion process. These stresses will reduce the structural strength, fatigue life, and the dimensional stability of the blank.

Figure 3. Residual stress measurement experiments.

Figure 4. Residual Stress contour after extrusion process
Residual Stress contours after turning are shown in Fig. 6. The polynomial fitting method is used to obtain the residual stress curve function along the inclined direction of the conical blank in Fig. 7. As is shown in Fig. 6 and 7, in the tangential direction, the compressive stresses are near the inner wall of the blank, and the tensile stresses are distributed near the outer wall. By contraries, the compressive stresses in the axial direction are near the outer wall, and the tensile stresses are near the inner wall. The magnitude of the residual stress is much smaller than that before turning process because of the stress release. It indicates that the stress in axial direction is smaller than that in tangential direction, and the inner wall area has better fatigue life and strength than the outer wall area.
The experimental results of residual stress from 0~1.4mm depth are shown in Fig. 8. The comparison of the simulation and experiment results is presented in Fig. 9. Fig. 8 and 9 show that the simulation results agree well with the experimental results. The average absolute error in the tangential and axial are 5.2 MPa and 9.6MPa. It demonstrates that the FEM simulation can effectively present the evolution of the residual stress in extrusion and turning process. The residual stress field calculated by FEM simulation can provide the basis for the stress control and elimination in the subsequent process.

![Figure 8. Experimental results of residual Stress.](image)

4. Conclusion
Large tensile residual stress is generated near the surface of the cylindrical blank in the extrusion process. These stresses will reduce the structural strength, fatigue life, and the dimensional stability of the blank. After turning process, the compressive stresses are distributed near the inner wall of the conical blank in the tangential direction, and the tensile stresses are near the outer wall. By contraries, the compressive stresses in the axial direction are near the outer wall in the axial direction, and the tensile stresses are near the inner wall.

![Figure 9. Comparison of the simulation and experiment results.](image)

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