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Numerical and Experimental Investigation of Preform Design for High Rib Complex AA7075 Component

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Abstract: The numerical and experimental investigation was proceeded in order to avoid the forming defect such as folding and underfilling for high rib complex component. The component was widely used in the equipment field as main structures with complex shape and high rib. Different billet shapes were used to simulate the forming process and study the metal flow laws. The forming processes of preform and finisher were analyzed using the finite element method models to predict the detail characteristics of material flow. The occurrences of defects were studied and a suitable preform designs were obtained. The experimental results also showed that the suitable scheme can obtain the qualified component.

Key words: Preform design, AA7075, Numerical simulation

INTRODUCTION

The high rib complex component was shown in Fig. 1 which is an important structure with complex section used in load of instant impact. The component is more than 600 mm in width, 175 mm in height. Maximum rib height to width ratio is 3:1. The cross-section of component has complexity shape which leads to great difficulties in deformation. Some defects may be produced during the forming process such as underfilling or folding.

One of the conventional process of component was machining to meet the final dimensions. However, flow lines become discontinuous by machining which degraded the mechanical properties such as tensile strength and impact toughness. Another way is to assemble the simple part from stamping by welding, but the concentration of stress along the welding line will cause the flaws from instant impact.

In general, these complex components are produced through various processes where one approach is to preform the billet by forging and then through machining to obtain the final dimensions.

Another way is to assemble the simple forgings by welding. These methods not only lead to material waste, high cost, but also cause the metal flow lines to be cut off which cannot achieve the demands in some important domain because the structure strength was reduced greatly (Siegert *et al*., 1997; Zhao *et al*., 2004).

Due to complex geometric shape and features of the forged product, two or more preforming stages are often required to ensure proper material flow and distribution as well as minimum raw material consumption before the final forging for the finished part (Altan *et al*., 1983).

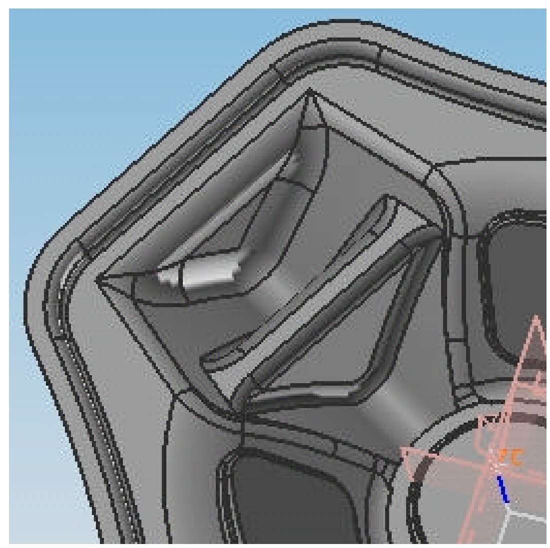

Fig. 1: The 3D model of NAHR component

Park and Hwang (2007) studied the billet design for precision forming of a typical non-symmetrical rib-web component used in aviation field. Joun and Hwang (1998) conducted the optimization of the die shapes in terms of the forming load. Various shapes such as polygons, T-shapes and half round-half ellipse shapes of extrusion were considered. Through optimization, the forming load was decreased remarkably. At the same time, more homogeneity of the effective strain distribution in the part was obtained.

The study in this paper aims to carry out a numerical and experimental investigation of preform design in

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non-axisymmetric high-rib complex component isothermal forming. The optimization goal is to avoid forming defects within the final forming so that a more uniform deformation can be obtained. The finite element method was used to determine the deformation behavior with different schemes of trial preforms. The optimized performs were examined during the course of the study. Then, the optimized preform of non-axisymmetric high-ribs complex component forming process was designed and verified by experiment. Based on the research, reasonable forming process for NAHR complex component has been formed successfully.

FE MODELING

In order to select suitable preform of component, FEM simulations of the basis shapes are performed to find the folding and underfilling defect for preliminary analysis as shown in Fig. 2. The component not only has a complex structure with high ribs, but also has an extreme size characteristic. So the boundary condition of the backward simulation is difficult to be determined; and the design variable is difficult to be chosen; and the objective function is difficult to be established. In order to improve the computational efficiency, just one in six of the model is used.

The material of the billet is AA7075. In the forming process, the upper die descending speed was 5 mm sec^{-1} and the initial forming temperature of the billet was 460?. Contact between the billet and the dies (upper die and lower die) were modeled with the shear friction factor and a friction coefficient of 0.25 was used in the analysis. The simulation was solved using the Newton-Raphson iteration method. The billet was meshed using four-node tetrahedron isoparametric elements. Based on the extent of mesh distortion, the mesh was automatically re-subdivided to ensure accuracy and convergence.

Preform shapes have an important influence on both the forming process and the resulting component. Different designs of preform will strongly affect the material flows. Aiming to evaluate the individual effects as well as the changes in H, R and L on the research outcomes, four forming schemes with different parameters were designed to analyze the forming process. Figure 3 shows the different loading schemes, scheme 1has the same dimensions with the component outline. Scheme 2, 3, 4 was optimized with different dimensions by the principle of volume invariable. Both four schemes can be seen as integral loading forming process. Four simulations were carried out which were built by the various H, R and L values showed in Table 1.

Table 1: The trail prefroms with different dimensions

Trail prefrom	H (mm)	R (mm)	L (mm)
Scheme1	46	847	290
Scheme2	49	364	240
Scheme3	86	404	160
Scheme4	114	444	79

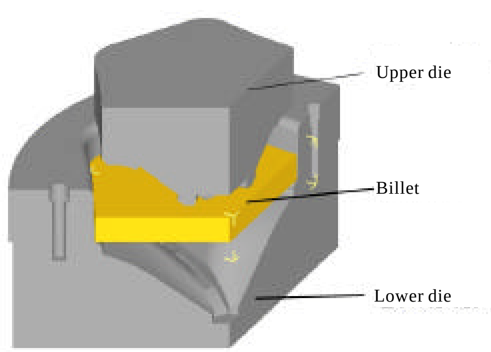

Fig. 2: The FE model for NAHR component

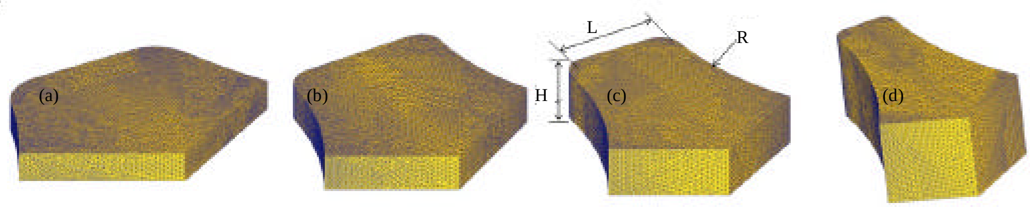

Fig. 3(a-d): The different schemes (a) Scheme 1 (b) Scheme 2 (c) Scheme 3 and (d) Scheme 4

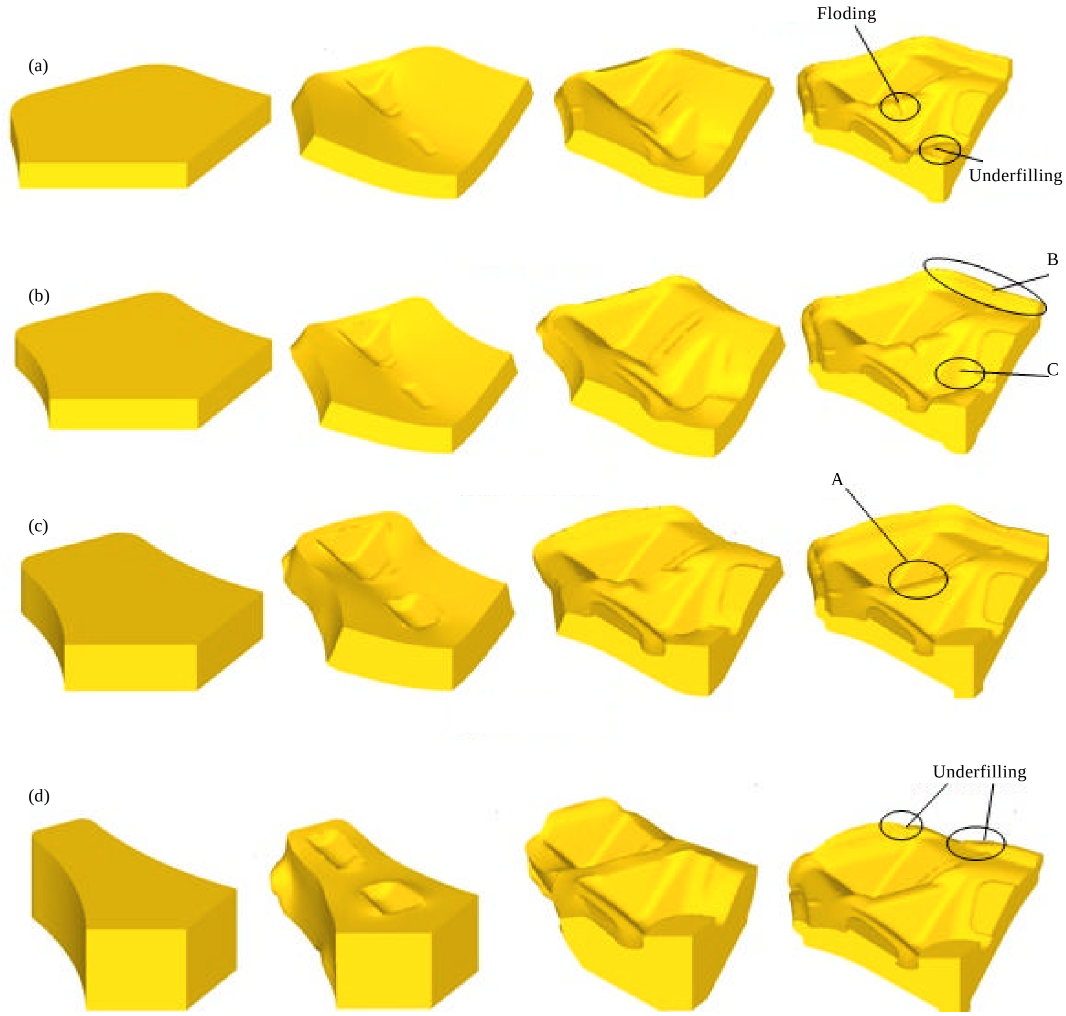

Fig. 4(a-d): Metal flow law in different schemes (a) Scheme 1 (b) Scheme 2 (c) Scheme 3 and (d) Scheme 4

ANALYSIS OF SIMULATION RESULT

Figure 4 shows the forming process of component using the single-step integral loading method with different schemes.

In initial stage deformation primarily occurs on the contact area of billet and upper dies. As the upper die moved down, the material of flanking regions was forced to flow mostly toward the center of high ribs until the high ribs are quite filled. However, as shown in final stage of scheme 1 and scheme 2, a folding defect occurred at the center of ribs with the primary flow direction was perpendicular to the height of rib (region A) which was attributed to the metal flow pattern with differences in height and volume between flank and center regions of ribs were too large for the material to flow smoothly. The Fig. 5 shows the folding defect with scheme 1in experiment.

Fig. 5: Folding defect by scheme 1 with experiment

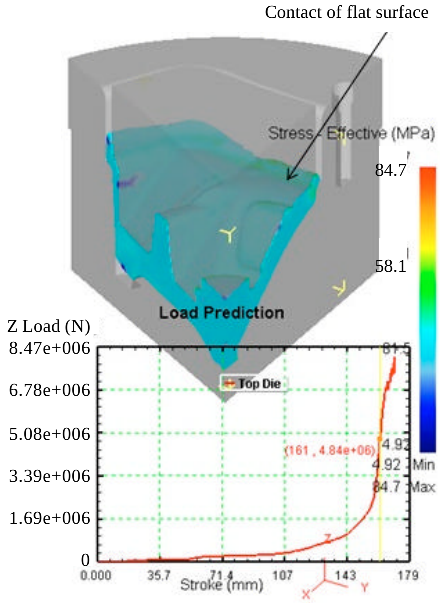

Fig. 6: Load-Stroke curve of schemes 3

When the flat surface of upper dies meets the billet in final stage, the contact of flat surface area (region B) becomes larger, then the metal is difficult to flow into the die cavity to form the side of the flange (region C).

At the final stage, the forging part almost becomes a rigid body, the center of the die cavity difficult to be filled up. The final product as showed in the final stage with a good shape cannot be guaranteed and some defects such as folding and underfilling may be generated.

Figure 4c shows the different characteristics for scheme 3. There are significant differences between scheme 3 and scheme 1. The folding defect has disappeared with the different dimensions of billet and flow model for two schemes. With the upper die moved downwards, the metal of high rib regions (A) begins plastic deformation to fill the die cavities in the regions first, it can significantly reduce the tendency of folding defect. As the upper die continues to descend, the die cavities in center regions have been filled completely. The final forming stage shows a good shape without defects such as folding and underfilling. The scheme 4 also has no folding defect in high-rib, but the underfilling defect was appeared at the fringe shown in Fig. 4d.

In the final stage, with the upper die continues to descend, the load increases rapidly with the flat surface of upper die contact the billet showed in Fig. 6.

Fig. 7: The final forming complex component

EXPERIMENT OF OPTIMIZED LOADING PROCESS

The final forming product was shown in Fig. 7. The component for a good shape is forged under the pressure of 12,500 KN which has no visible defects with using the optimized loading scheme. The surface quality and physical dimension meets the requirement for the subsequent process.

All the results showed that the various parts of the component were in good condition and the dimensional accuracy of the components was acceptable. The experimental results were in good agreement with the results calculated by FEM.

CONCLUSIONS

The most rational precision forming scheme was designed to prevent forming defects based on FEM simulation and experimental test. Different billet shapes were used to simulate the precision forming process. Scheme 3 was shown superiority to prevent the folding and underfilling defect. These results can be applied to form other components with similar shapes.

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