Metal Flow in the Precision Forging of Aluminum Alloys

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To research impeller parts flow behaviors in the die forging process, the finite element method is used to study the deformation flow behavior of different shapes in the blank forming process. The results show that the blade parts of the forgings were hard to fill, but with the section of the blade shifting down, the metal has a marked trend to flow toward this area of the die cavity. Compared with a cylindrical shape, the die cavity of the blade part can be filled more easily and the uniformity of metal flow will increase. Using a ladder shape to manufacture forgings of impellers can meet requirements for design and properties.

INTRODUCTION

Precision forging is complicated, dependent on man-made objective factors which cannot meet the demands of modern design. With developing computer technology, we can find out the flow conditions of a material in the die cavity by the finite element method (FEM)[1] and optimize the parameters of the forging process.[2–4] The result is an increase in product quality and a reduction of cost.[5–7] For example, we can make a precognition of the shape of an impeller without parting-line flash by using reversion technology and FEM.[8] Using the finite element of rigid-stickiness method to research the die forming of a rotor, we can learn that the metal in the deformed body flows inhomogeneously and will be mainly grouped near the hole of the die.[9] According to research on fairing variety distribution, fairing disorder and pierce-flow fault mechanization occur in complex shapes and provide a theory basis for a correct process.[10]

Although FEM has been used to define the technology parameters of forgings,[11,12] the conditions of impeller application are difficult, and thus a high quality structure is required. This article reports on a three-dimensional (3-D) finite element analysis of the forming flow of the die forging process.

How would you…

…describe the overall significance of this paper?

In order to research the effects and mechanism of impeller parts flow behaviors in the die forging process, the finite element method is used. This method makes possible the research of deformation flow behaviors of different shapes during the blank forming process.

…describe this work to a materials science and engineering professional with no experience in your technical specialty?

The results show that the blade parts of the forgings were hard to fill, but with the section of the blade shifting down, the metal has a marked trend to flow toward this area of the die cavity. Compared with the cylindrical shape, the die cavity of the blade parts can be filled more easily, and the uniformity of metal flow will also have a marked increase. According to the experiment process, using a ladder shape to manufacture high quality forgings of impellers can both meet the design requirements of the size accuracy and the properties.

…describe this work to a layperson?

Precision forging has been complicated and uncontrolled for a long time; the rules of the forging depend on experience and trial. These were all influenced by the man-made objective factors, and these cannot meet the demands of modern design. This article uses three-dimensional finite element analysis to research the forming flow regularities of the die forging process.

FINITE ELEMENT MODEL

The software DEFORM™-3D imitates the forming process in cylindrical and stepped shapes. To reduce unit partitioning and increase velocity and time, only 1/4 of the billet was used for a research target. In the calculation process, we can re-adjust at any time by net-division aberration to make sure the calculations are precise. The finite element model is shown in Figure 1. In the modeling process, the deformation of the die should not be considered as the material is rigid; the billet uses 7050 aluminum alloy, forming velocity is 2 mm/s, and forming temperature is 435°C. The friction factor, which is measured by the ring heated-compression experiment, is 0.3.

DISCUSSION AND ANALYSIS

Plastic Deformation

The effective strain distribution of a cylindrical billet under the compressed quantities of 10.25 mm, 25 mm, and 37.25 mm is shown in Figure 2. The figure shows that the prime plastic deformation of the cylinder billet is mainly concentrated in the bottom, which contacts with the die; material in the other areas almost appears rigid. As the die fills, the metal near the axis displays little deformation, while metal in most other areas shows marked plastic deformation. At this time, with the force from the die, the compressed metal shifts its flow toward the impeller area, and filling the die. With the upper die's continue compression, the plastic area expands, and following the increasing radial distance near the axial center, the degree of the plastic deformation increases. The parting-line flash has the greatest deformation of all.

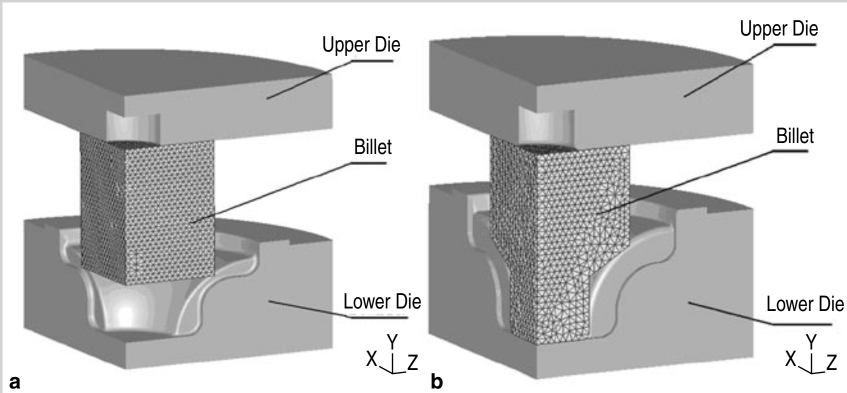

Figure 1. The finite element model: (a) cylinder billet and (b) ladder billet.

The effective strain distribution of a ladder billet under the compressed quantity of 6 mm, 12.2 mm, and 18.2 mm is shown in Figure 3. The figure shows that the billet has a deformation like an upset deformation with a constraint force on its bottom. Therefore, the metal near the bottom has a smaller deformation, and the metal on the top of the billet near the outside has a large deformation. With the forging being in progress, the telos of the billet flow slowly into the main body of the die.

The metal displaying plastic deformation is mainly concentrated on the outside of the billet telo. The metal near the inlet of the upper die has the greatest deformation, while the metal that flows in by inertia shows almost no plastic deformation. While the upper die keeps moving down, after the body is formed, the metal flows to fill the impeller area. The outline in the area appears to show a curve distribution from up to down, but the metal of the impeller area has equal deformation, and some flows out forming a parting-line flash. For this reason, the stepped shape billet is better for its filling ability and for increased flow homogeneity.

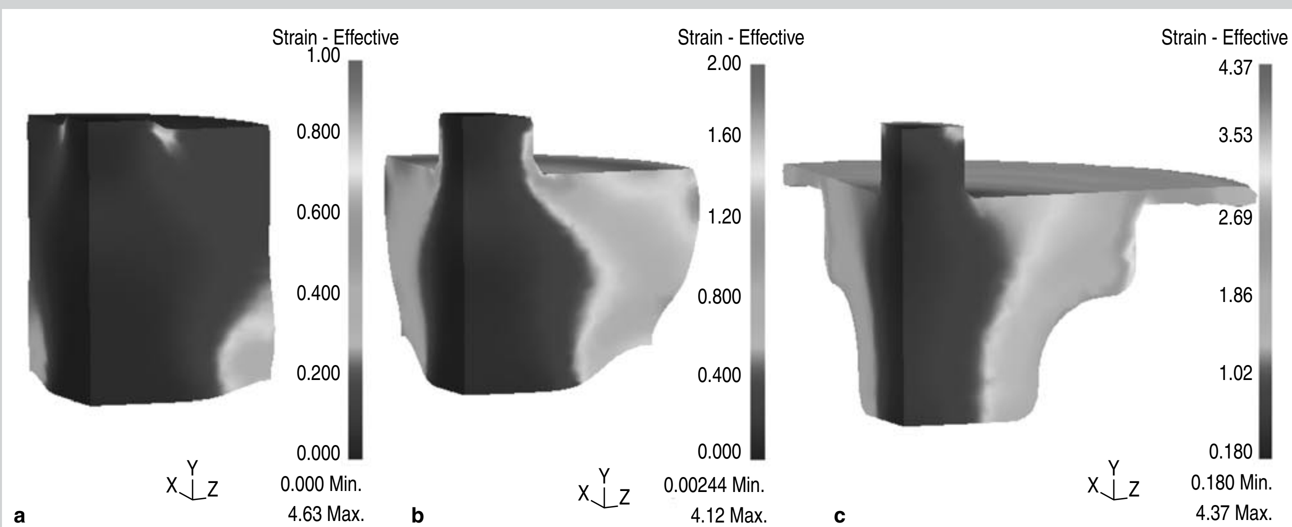

Figure 2. The effective strain distribution of a cylinder billet: (a) 10.25 mm, (b) 25 mm, (c) 37.25 mm.

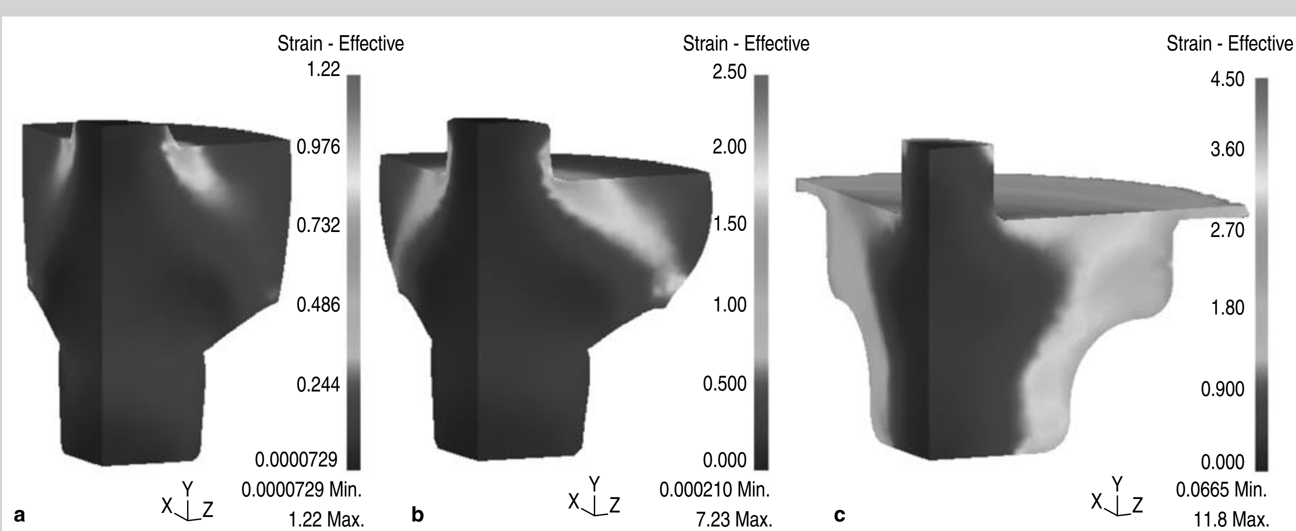

Figure 3. The effective strain distribution of a ladder billet: (a) 6 mm, (b) 12.2 mm, (c) 18.2 mm.

Deformed Flow Behavior

The velocity field distribution of a cylinder billet under the compressed quantity of 10.25 mm, 25 mm, and 37.25 mm is shown in Figure 4. In the figure, we can see that the prime deformation can be abstract, seen as a ring compression which has an interior constraint. The material of the constraint position on the inside flows down equally, and the material on the outside has a decreasing trend of flow velocity from up to down because of the contraction with the end face of the die. The inside has a constraint so that the deformation behavior of the ring compression in the outside has a marked change; the flow velocity of the material in the bottom has a decrease in distribution from inside to outside.

As the process of the deformation develops, the material in the middle area shifts slowly toward the neck of the axis, and the deformed characteristic of the billet at this time can be seen as a coupling by a ring compression and an extrusion deformation. Because of the inertia which comes from the upper die moving down, the material in the middle has an up-flow trend to fill the neck of the axis die cavity. The flow behavior of the material in this area can be seen as an extrusion compression mode, as the coupling of the outside ring compression mode and the difference among the deformation conditions. The instant flow velocity of the metal in this area has a reverse direction with the deformed direction. While the upper die moves down, the billet deforms gradually and fills the die cavity. The unnecessary metal flows out and forms a parting-line flash.

The velocity field distribution of a ladder billet under the compressed quantity of 6 mm, 12.2 mm, and 18.2 mm is shown in Figure 5. The figure shows that, because of the limit of the lower die, in the prime, the ladder billet's deformation is similar to a circular compression deformation that has a restrain on its bottom. Therefore, material in the bottom almost never displays deformation, and the material in the top has a flow-down deformation by the axial and a flow-out one by the radial. While the upper die move down, the metal that flows out by the radial increases markedly, and the material in the middle area flows toward the neck of the axis. We can abstract this area as a coupling mode of a ring compression and an extrusion form, and it has a similar form characteristic with the deformed process of the circular billet. At the last stage of the deformation, there is a flow trend toward the blades and the neck of the axis, until the corner of the die is filled. The unnecessary metal flows out by the connect mouth.

Metal Flow in the Blades

The flow of metal in different sections on the blades was studied; the po-

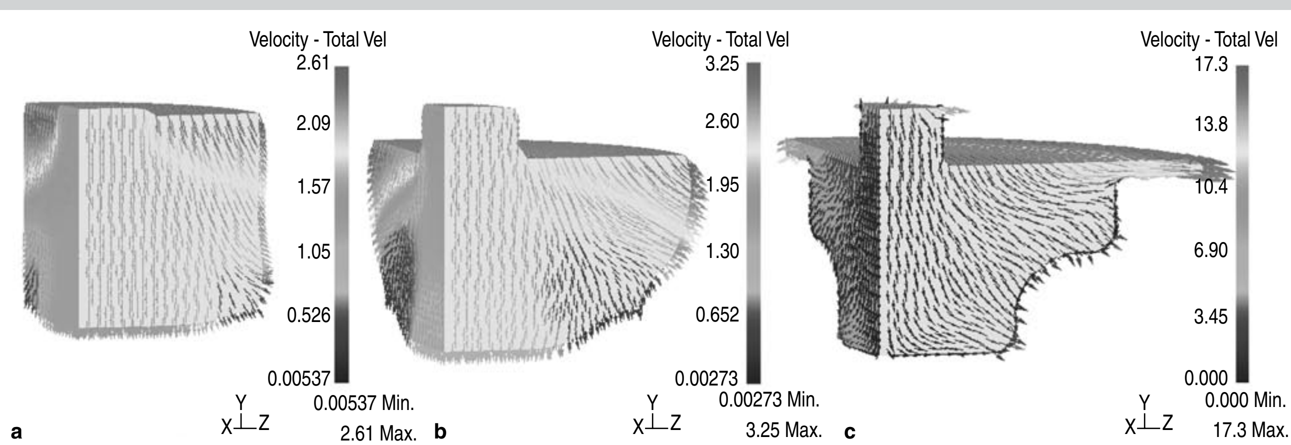

Figure 4. The velocity field distribution of a cylinder billet: (a) 10.25 mm, (b) 25 mm, (c) 37.25 mm.

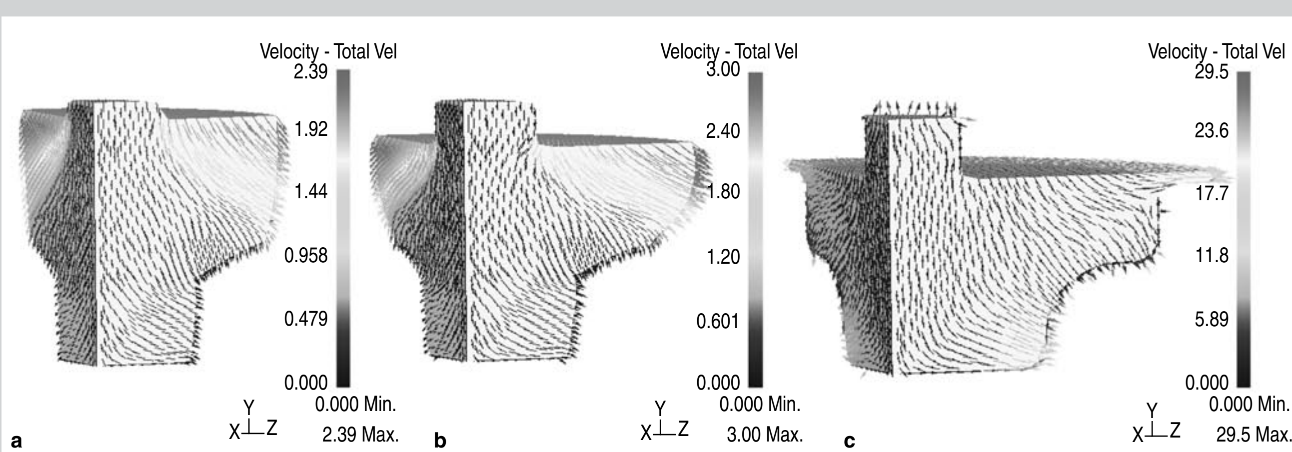

Figure 5. The velocity field distribution of a ladder billet: (a) 6 mm, (b) 12.2 mm, (c) 18.2 mm.

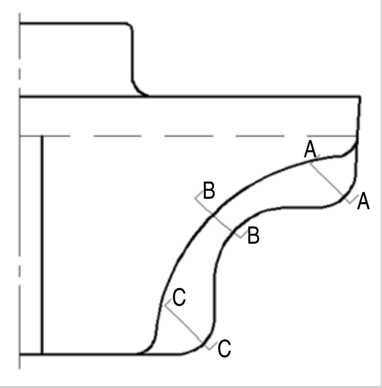

Figure 6. The position of different sections on the blades.

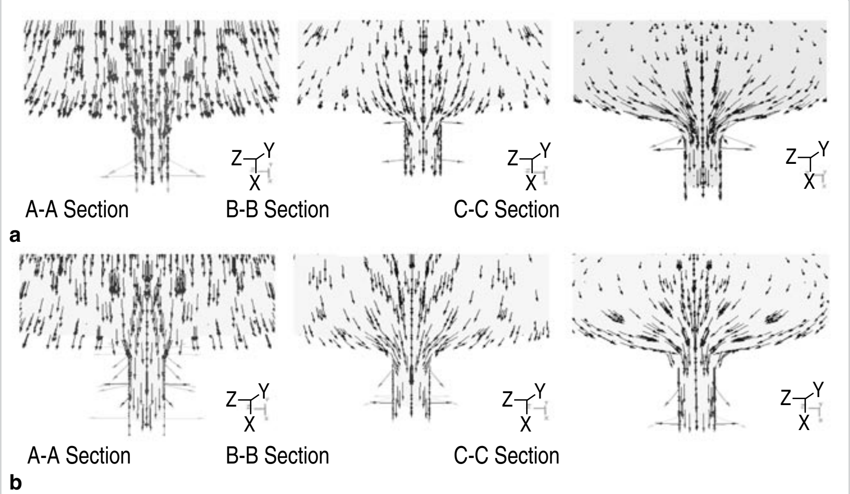

Figure 7. The velocity field distribution of different sections: (a) cylindrical billet and (b) ladder billet.

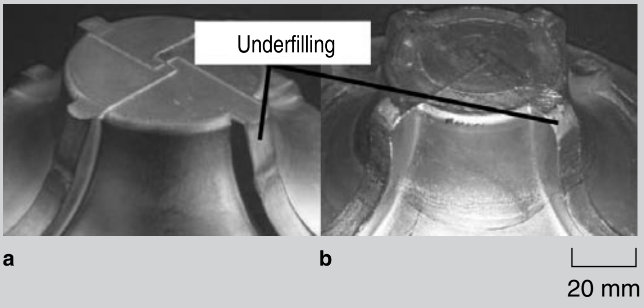

Figure 8. Photos of the impeller forgings: (a) cylindrical billet and (b) ladder billet.

sition of those sections is shown in Figure 6. Because the shape of the blades is thin, with a curve distribution, the forming process is challenging. Figure 7 shows the velocity field distribution of different sections when billets of different shapes were used to make a deformation. In the cylindrical billet deformation process, the metal in the A-A section almost has a vertical flow direction. Little metal in this area flows into the die of the blade position. In the B-B section, which is in the middle of the blade, the metal that flows into the die of the blade position increases and the metal near this area also has the same trend. With the section moving down, we can see that the metal in the C-C section almost all has a deformed flow toward the mouth of the blade die. Thus, metal in this area has the greatest flow trend toward the blade die.

In the ladder billet deformation process, the A-A and C-C sections have similar velocity field distributions. Compared with the cylindrical billet, metal in the B-B section has a greater deformed flow trend toward the mouth of the blade die. With the die pressure after the B-B section is full, some metal can continue moving down to fill the A-A section. The flow to fill the die of the cylindrical billet needs high pressure because the metal flows out radially, so the top of the blade die is difficult to supply with the overlying metal and gap defects are likely.

EXPERIMENTAL PROCEDURE

Photos of impeller forgings made by cylindrical and ladder billets are shown in Figure 8. When the measure of the compression is equal and the cylindrical billet is used, because the resistance to filled flow is larger, the telos of the blade die appears to exhibit gap defects. When using the ladder billet, the telos of the blade die exhibit fine filling. A physico-chemical examination shows that the filament line is completely distributed by the geometric form, there is no pierce-through or vortex defects. Also, its size accuracy and system functionality are up to the design demands.

CONCLUSIONS

The position of the blade is hard to deform, and with the section moving down, the metal flow in the die increases. As compared with the cylindrical billet, the ladder billet fills the blade die more easily. It also increases the homogeneity when the metal is deformed to flow into the die. Finally, according to the experiment, using a ladder billet can deform an impeller which conforms to the design demands of both deformed size accuracy and function of system.

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