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A STUDY ON SIMULATION OF DEFORMATION DURING ROLL-FORGING PROCESS USING SYSTEM OF SPECIAL SHAPED AND HAT GROOVE

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Abstract. The parameters of groove are important in designing roll-forging mould. In this paper, a kind of special shaped groove is presented to replace the usual rectangular groove, it can improve the uniformity of material distribution, and decrease loading. Three-dimensional rigid-plastic FEM has been used to simulate the deformation process of pass rolling, and the effect of the system of special shaped and hat groove during deformation of billet is researched. This paper analyzes the velocity field of material flow, stress-strain field, the characteristics of the temperature field, the dynamic evolvement process as well as the force-time curve of mould and mould damage. Application shows that the system of special shaped and hat groove can improve the uniformity of materials distribution and increase broadening quantity of spring plates in the process of automobile front-axle roll-forging.

1. INTRODUCTION

Roll forging is a process for reducing the cross-sectional area of heated bars or billets by passing them between two driven rolls that rotate in opposite directions and have one or more matching grooves each roll [1]. During roll-forging process, a part of material flows along the axial direction to increase length of billet; the other part of material flows along the radial direction to increase width of billet. roll forging has remarkable advantages such as high productivity, high utilization rate of material, good labor condition, simple equipment structure, long life of the rolling dies and so on [2]. There are two factors affecting the quality of products, one is the material distribution of billet in axial direction; the other is the spread of billet in the forming process.

To improve the uniformity of material distribution in the performing procedure, a kind of special shaped groove is presented, and a numerical value matrix of the special shaped and hat groove roll-forging process is set up. Besides, the author analyzed the dynamic evolvement process of the mold damage as well as the affect of hat groove and special shaped groove.

2. FEM MODEL

2.1. Special shaped groove design

In traditional design, rectangular groove was used to distribute material in roll forging process, and put pressure on the top of the billet. This groove will reduce uniformity of distribute material, cause uneven wear in mould, thus affects the subsequent process [3]. The cross-section shape of rectangular groove is shown in Fig. 1a.

A kind of special shaped groove is presented to resolve the problems above in this paper. As a combination of oval groove and diamond groove, it puts pressure on the side of billet, and keeps clear of the top of billet. This structure of groove increases

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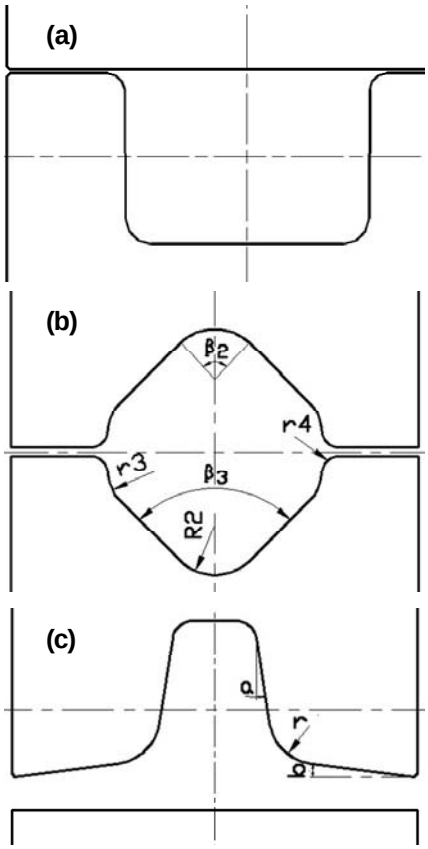

Fig. 1. Cross-section shape of grooves for simulate: (a) Rectangular groove; (b) Special shaped groove; (c) Hat groove.

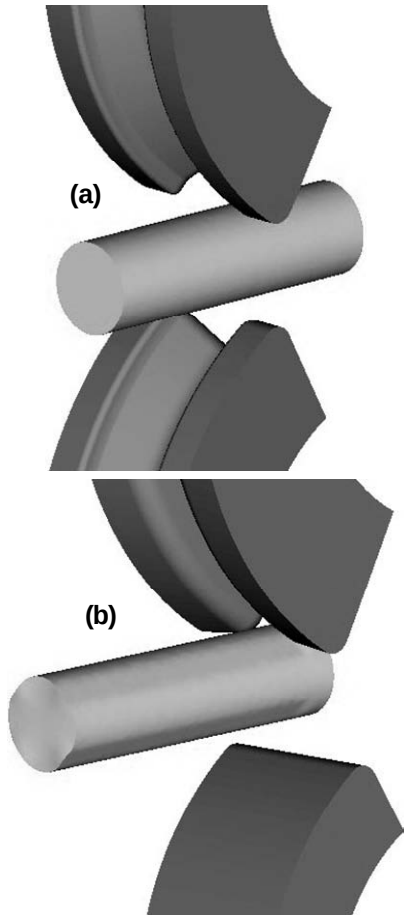

Fig. 2. Finite element model of roll forging: (a) First rolling pass; (b) Second rolling pass.

the contact area between die and billet, avoids the heterogeneous deformation, and increases the stability of billet. The range of the slope ($\beta 2$) and slope ($\beta 3$) is 85°~115° [4].The cross-section shape of the special shaped groove is shown in Fig. 1b.

2.2. FEM model

The system of special shaped and hat groove used for simulation is shown in Figs. 1b and 1c. The parameters in simulation are shown in Table 1. The billet is pre-formed in this kind of special shaped groove pass and then enters the hat groove pass after rotating 90° around its axis, Fig. 2 shows the FEM model of the process.

3. THE EFFECT OF SPECIAL SHAPED AND HAT GROOVE SYSTEM ON THE FORMING

The rolling forging process of system of special shaped and hat groove is researched, the variation process of the stress-strain field, velocity field and temperature field is discussed, and the mechanical parameters and injury in the forming is analyzed when the slope (a) of hat groove is 9°, slope (b) is 6°, and transition round corner radius (*r*) is 30 mm.

3.1. Stress and strain field

Fig. 3 shows the stress and strain distribution in deforming zone of billet of special shaped groove. It is uniform distribution in the cross-section. The maximal stress and strain distribute in the contact area of billet and mold. Besides, the stress and strain are brought down with the reduction of distance from the contact area. The effective strain is 0.034 in the center of blank and non-contact area, which

Table1. Parameters in simulation.

Parameters	Value
Diameter of billet	140 mm
Length of billet	500 mm
Friction coefficient	0.5
Angel velocity	1.8 rad/s
Material	AISI 1045
Initial temperature	1100 °C

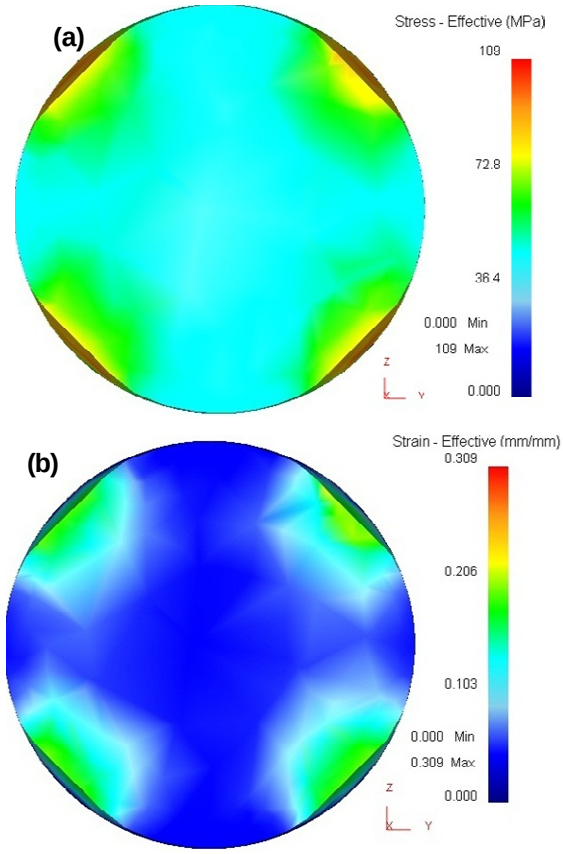

Fig. 3. Stress and strain field in special shaped groove pass rolling during roll-forging: (a) Stress; (b) Strain.

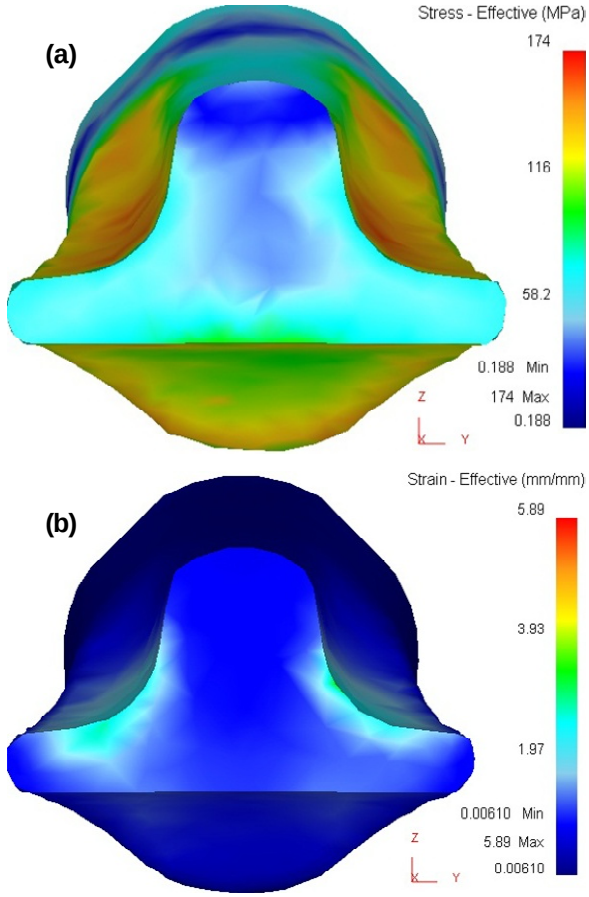

Fig. 4. Stress and strain field in hat groove pass rolling during roll-forging: (a) Stress; (b) Strain.

indicates that the deformation is small in the major area of the special shaped groove.

Fig. 4 shows the stress and strain distribution in deforming zone of billet of hat groove. The stress and strain distributes symmetrically on the cross section of hat groove rolled piece. The value of strain is the largest on the circular arc transition, and reduces towards the center of billet. The stress reduces from bottom to top in the deformed area, and the maximal stress is on the center of bottom. The equivalent stress in the outer layer of billet is higher than that of the center. And it is the lowest on the top.

3.2. The velocity field in the roll forging process

Fig. 5a shows the velocity field distribution of billet in the deforming area of hat groove. Fig. 5b shows the velocity field distribution in the *Y*-direction. The billet extends in the axial direction and spreads in radial direction. In different nodes, the flow velocity is different. From Fig. 5a, it can be seen that the flow velocity reaches its maximum in the forward slip zone, and gradually reduces toward the backward slip zone. In the *y-o-z* cross section, the flow velocity is the largest in the circular arc transition, and gradually reduces toward the center of blank and the edge. From Fig. 5b, it can be seen that *Y*-direction flow velocity is the highest on the edge of blank, and gradually reduces toward the center of blank [5].

3.3. The influence of mold in roll-forging process

Fig. 6 shows the wear depth distribution of special shaped and hat groove roll-forging mold. The tool wear focuses on the groove lateral in special-shaped groove roll-forging mold, because the pressure exerted by groove side forces the billet to deform, and other parts don't exert pressure to the billet. The maximum wear depth is 0.00519. The wear depth of hat groove roll forging mold focuses on the transitional rounding, and the farther to the center, the wear depth is lower.

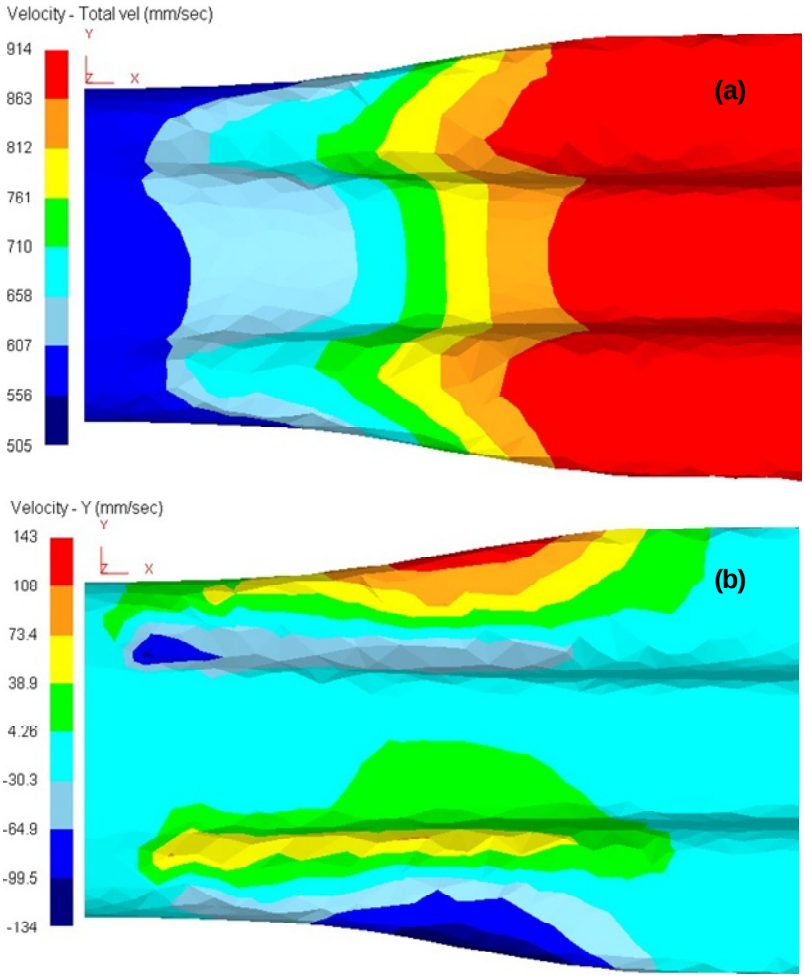

Fig. 5. Velocity field in hat groove pass rolling during roll-forging; (a) Total velocity (b) *Y* direction velocity.

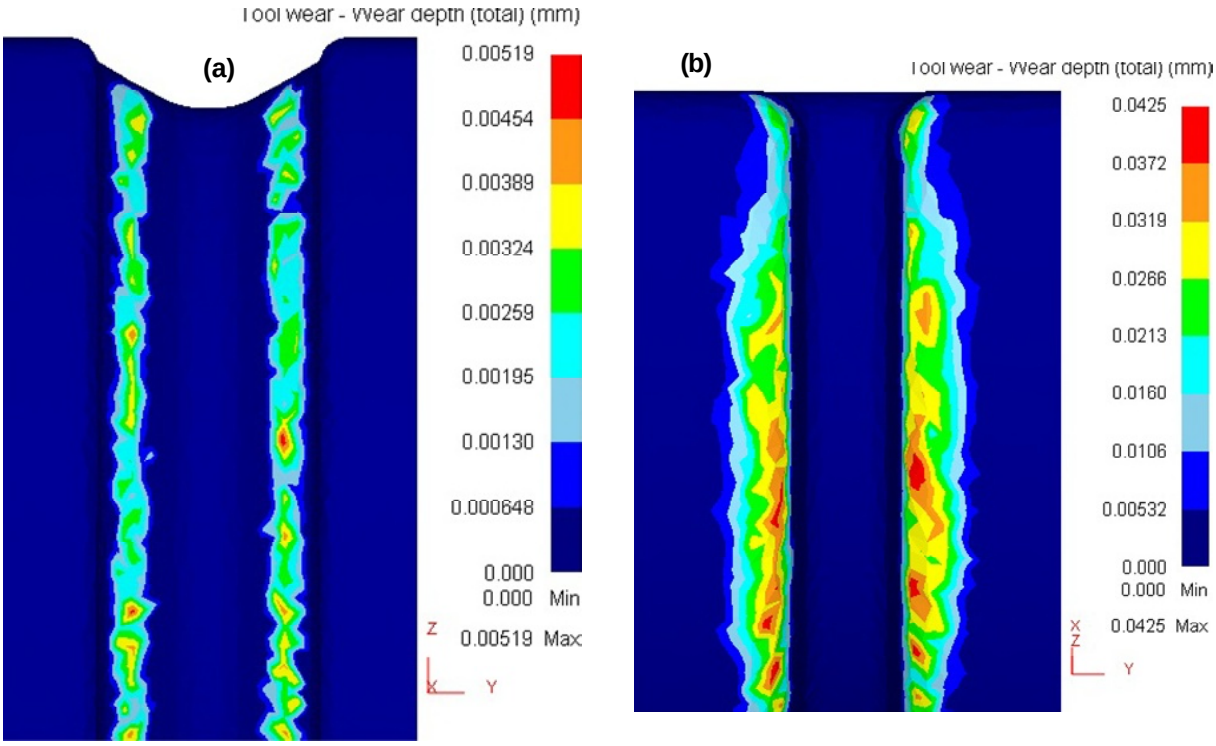

Fig. 6. The wear depth distribution of special shaped and hat groove roll-forging mold; (a) Special shaped groove mold (b) Hat groove mold.

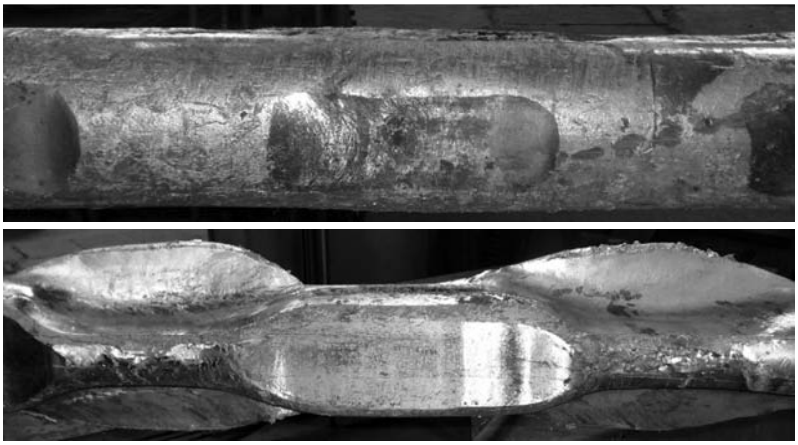

Fig. 7. Shapes of the workpiece in rectangular-hat groove pass rolling during roll-forging: (a) in rectangular groove: (b) in hat groove.

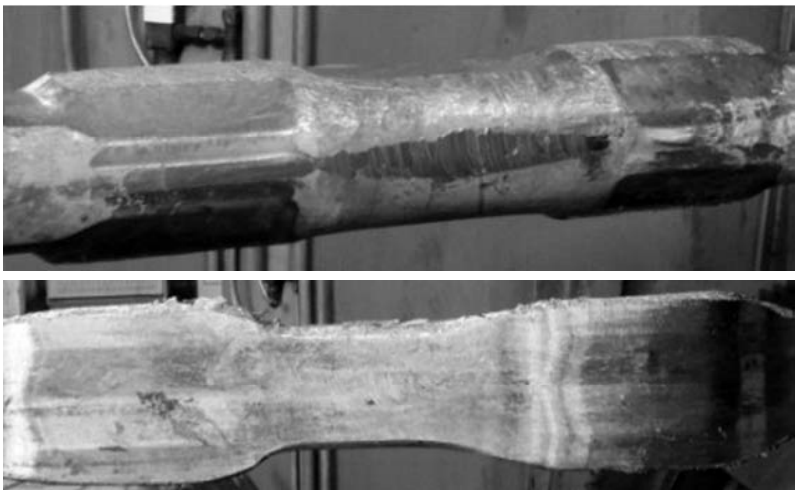

Fig. 8. Shapes of the workpiece in special shaped and hat groove pass rolling during roll-forging: (a) in special shaped groove: (b) in hat groove.

4. EXPERIMENT

Front axle is an important component of automobile that bears heavy loads [6]. Process of automobile front-axle roll-forging is carried out to validate the simulation results, and the comparison of forming effect between the system of rectangular-hat groove and the system of special-shaped and hat groove. All experiments use lead rods. Fig. 7 shows the shapes of workpiece under system of rectangular-hat groove at the end of two procedures respectively. Fig. 8 shows the shapes of workpiece under system of special-shaped and hat groove. From the comparison, it can be found that the simulation is in good agreement with the experiment. When the system of rectangular-hat groove is used for roll forging mould, the front-axle billet has a fan-shaped spring plates. When the system of special-shaped and hat groove is used for roll forging mould, the fan shaped structure at spring plates is replaced by rectangular structure, and the shape of spring plates becomes consistent with a larger spread amount.

5. CONCLUSIONS

The deformation behavior in roll-forging process under different shaped grooves has been studied. Some conclusions can be drawn out as follows:

(1) In this paper, a special shaped and hat groove is proposed, which could improve uniformity of material distribution effectively due to the constraint offered by lateral pressure.

(2) In the roll-forging process of automobile front-axle, the system of special-shaped and hat groove can improve uniformity of materials distribution effectively, and increase the spread quantity of spring plates, and reduce loading.

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