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Finite element analysis model of rotary forging for assembling wheel hub bearing assembly

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Abstract

In this paper, a computationally efficient finite element analysis model of the rotary forging process for assembling a wheel hub bearing assembly is presented. The analysis model is composed of a part of material defined by two artificial planes of symmetry, which is to reduce computational time taken in simulating the holistic process. Three cases of 30°, 60° and 90° analysis models for simulating rotary forging processes are studied to validate the present finite element analysis model. The predictions at their planes of symmetry and mid-planes are investigated and compared with the experiments, revealing that the predictions at the mid-planes are in good agreement with the experiments for all the cases while those at the planes of symmetry are to the contrary. Thus, the 60° analysis model is recommended for both computational efficiency and solution reliability. With the present finite element analysis model, one hour of computational time with PC can be sufficient enough to obtain valuable information about such rotary forging processes as the wheel hub bearing assembly making process.

Keywords: Hub bearing; Rotary forging; Finite element method; Partial analysis domain; Plane of symmetry

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1. Introduction

In the past the wheel hub bearing assembly was assembled by incredible method which was much dependent on the manual experience. Thus the tolerance changed from situation to situation. It has passed quite long time since rotary forging approach was used to fabricate the wheel hub bearing assembly. The shaft clinching technology was developed to meet the requirement of customers on light weight and improved wheel bearing performance (Toda et al., 2001). The rotary forging approach needs quite much assembly time compared to a kind of simple forging approach. However, rotary forging requires relatively small forming load with the result that precision assembly can be achieved. Of course, due to quite large assembly time of the rotary forging approach, a direct forging method has been studied but failed because of difficulty in controlling the preload within the required accuracy and frequent fracture of the hub bearing unit (Shim et al., 2012)

An assembly process of the wheel hub bearing assembly is affected by many factors, especially including die geometry, feed rate, initial shape of material and metallurgical state of material, which are much correlated with each other. Thus a systematic approach to determine the factors and to reveal their relationship is needed. The important factors from standpoint of process design engineers include plastic deformation history of the hub, some information about the possibility of ductile fracture occurrence at the end of the hub, and the pushing force on the hub bearing unit, which are complicatedly coupled with each other. Of course, metal forming simulation technology may be appropriate to satisfy the need of the process design engineers.

Several researchers studied rotary forming processes by experiments and/or predictions (Hawkyard et al., 1977; Zhou et al., 1992; Choi et al., 1997; Yuan et al., 1998; Toda, 2001; Guangchun and Guoqun, 2002; Liu et al., 2004; Wang et al., 2005; Munshi, 2005; Moon et al, 2007; Nowak et al., 2008; Han et al., 2013). However, few researchers (Toda et al., 2001; Munshi et al., 2005; Moon et al., 2007) applied the technologies to predicting plastic deformation occurring during rotary forging of wheel hub bearing assembly. Toda et al. (2001) predicted the clamping force by applying the given force on the wheel hub bearing assembly using a dynamic analysis software but they did not mentioned the plastic deformation during rotary forging process itself. Munshi et al. (2005) employed a so-called rigid-super-element scheme for reducing computational time drastically in simulating the similar orbital forming process but the predictions did not look as good as the number of elements.

In spite of remarkable contributions by many researchers, there still stand some strong obstacles against metal forming process design engineers in simulating such difficult forming processes as the rotary forging process for assembling the hub bearing assembly. It should be emphasized that it takes inherently quite long computational time to conduct the process simulation with its entire solution domain considered in such incremental forming processes as rotary forging (Munshi et al., 2005). In recent, Cho et al. (2011) developed a method of artificial planes of symmetry for simulating a sort of incremental forming processes and showed that it predicts quite reliable solutions at the mid-plane of the solution domain defined by two planes of symmetry when the plastic deformation occurs only around the local contact area.

In this paper, an analysis model of the rotary forging for fabricating wheel hub bearing assembly is presented, based on the method of artificial planes of symmetry and the predictions are compared with experiments.

2. FE analysis model for assembling wheel hub bearing assembly

Fig. 1 shows the schematic drawing of a wheel hub bearing assembly of which manufacturing approach is studied in this paper. This assembly is fabricated by assembly of a hub machined after forged and a hub bearing unit by a cold rotary forging process. Fig. 2 shows the mechanism of the rotary forging process for assembling the hub and the hub bearing unit. During being assembled, the bearing unit can be fractured if the excessive forming load is exerted. Also, the preload endowed in the hub bearing during assembly process has a strong influence on the performance of the assembly in its service because it can affect the wear characteristics of the assembly. Thus the forming load should be properly controlled.

In addition, because the end of the hub is much elongated in the circumferential direction during the assembly process, it sometimes exposes to ductile fracture due to the cumulative damage. For this reason, the contact condition between the end region of hub and the inner race of hub bearing should be optimally controlled and thus

the optimal initial shape of hub material and optimal process parameters should be utilized for the successful assembly procedure.
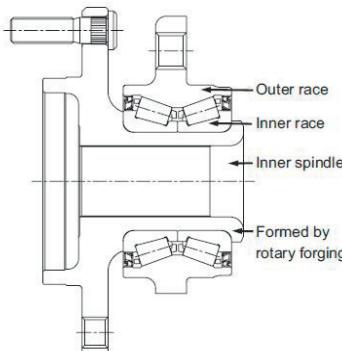

Fig. 1. Schematic drawing of wheel hub bearing assembly to be studied.
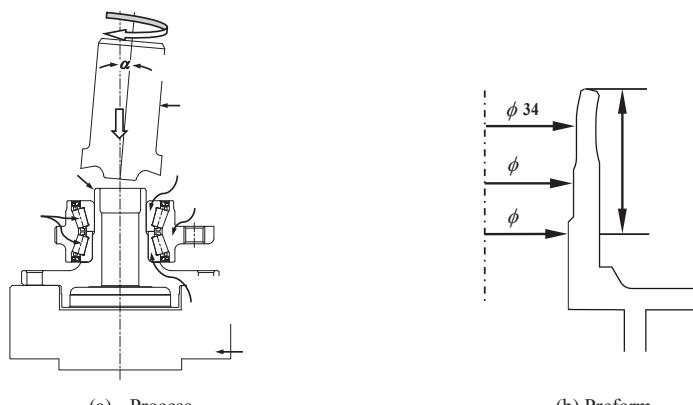

(a) Process   (b) Preform

Fig. 2. Schematic drawings of process and preform to fabricate wheel hub bearing assembly.

Unfortunately, this kind of rotary forging processes requires too much computational time to be simulated using a full domain analysis model because they have very long strokes compared to a conventional forging. It should be noted that the plastic deformation occurs due to quite small local contact of the forming die with material in the early stage, implying that the plastic deformation has a restricted effect on the neighborhood of the local contact region. This fact can be observed from Fig. 3, indicating that the contact region during rotary forging for assembling a wheel hub bearing assembly is quite small.

Therefore, as shown in Fig. 4, a partial analysis model defined by two artificial planes of symmetry is proposed for the engineering analysis model in this paper, which was successfully applied for simulating a flow forming process (Cho et al., 2011). Of course, it is noted that the analysis results of this model may be more or less different from the real phenomena, especially at the planes of symmetry. However, it can be expected that quite reliable predictions can be obtained for the present rotary forging process because the plastic deformation occurring at the local contact area has little influence on that at the opposite side as shown in Fig. 3, emphasizing that the effective strain rate distribution is concentrated around local contact area.

To check validity of the proposed approach, a rotary forging process of Fig. 4(a) was analyzed, which was previously studied using a hexahedral element (Moon et al., 2007). The shape of a preform and its dimensions are shown in Fig. 4(b). The lower part of the preform is far away from being plastically deformed and its displacement was constrained by a constraint box in which all nodal degrees of freedom of the nodes are constrained. Flow stress of the material used is $\overline{\sigma} = 520.0(1.0 + \overline{\varepsilon}/0.001)^{0.135}$ MPa. The upper die revolves without any power exerted and the frict

ion between the upper die and material was thus neglected. If the friction is considered, the revolving velocity shou
ld be an unknown, which may enhance a negligible solution accuracy at a great expanse of computational time.


(a) Contact area (b) Effective strain rate(/s)
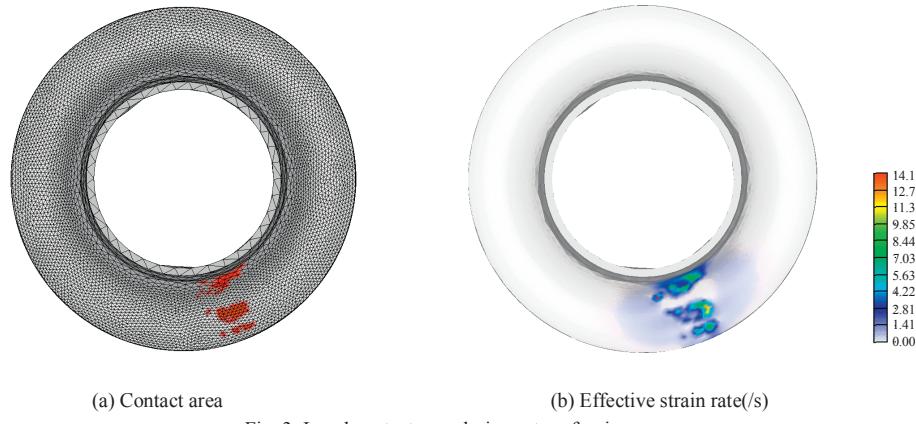
Fig. 3. Local contact area during rotary forging.

(a) Top view (b)Side view
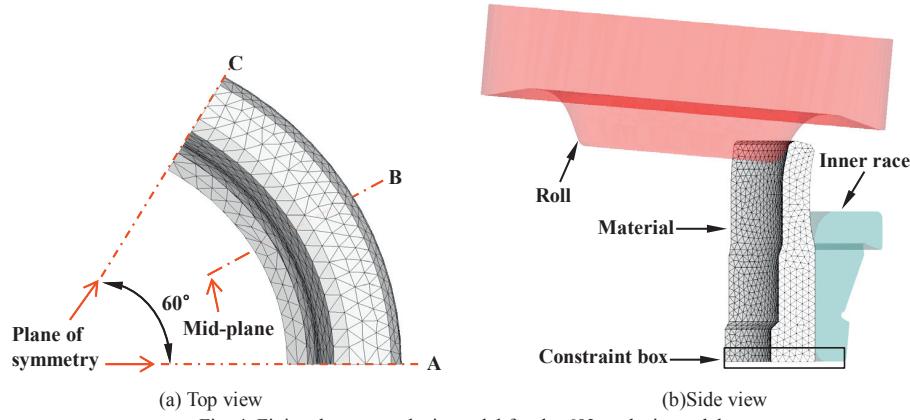
Fig. 4. Finite element analysis model for the 60° analysis model.

(a) 0° (b) 10° (c) 20° (d) 30° (e) 40° (f) 50° (g) 60°
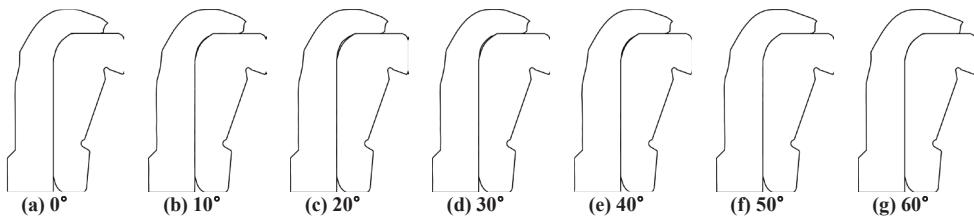
Fig. 5. Predictions for the 60° analysis model.

| t = 1.79 s | t = 3.60 s | t = 4.77s | t = 6.00 s | t = 1.79 s | t = 3.60 s | t = 4.77s | t = 6.00 s |

(a) At A section   (b) At B section
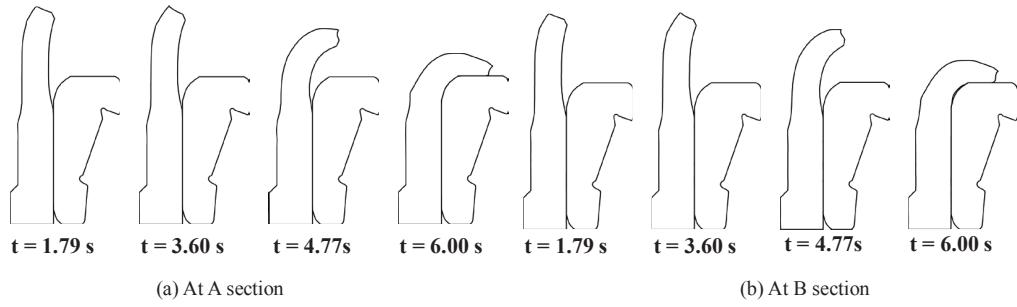
Fig. 6. Deformation history for the 60° analysis model.

(a) 30°   (b) 60°   (c) 90°   (d) Experiments
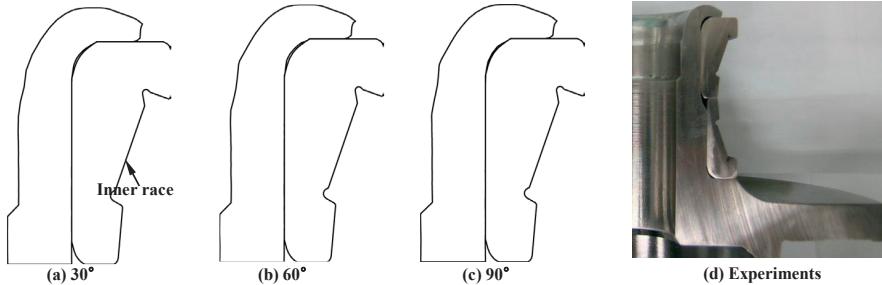
Fig. 7. Comparison of mid-planes of the 30°, 60° and 90° analysis models and experiments.
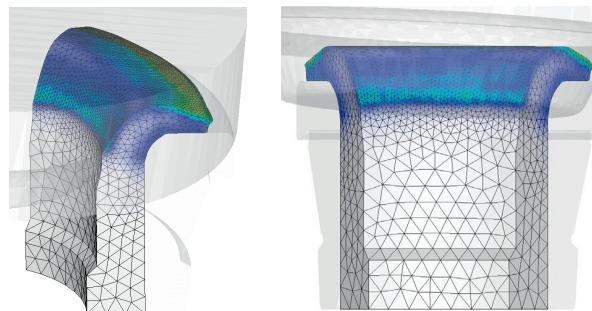

Fig. 8. Predictions by the 60 ° final shape analysis model.

Fig. 4 is a 60° analysis model, which is composed of two artificial planes of symmetry, a part of material defined by them, a constraint box and tools or dies. First, to reveal the size effect of the analysis domain defined by two planes of symmetry, 30°, 60° and 90° analysis models were investigated.

Fig. 5 shows the predicted configurations of the deformed material together with the inner race of hub bearing unit at the selected planes for the 60° analysis model. As shown in the figure, there exists a non-negligible difference in deformed shape of material around the bent region between the mid-plane and symmetric plane. It can be seen that change of the shape is stationary round the mid-plane between 20° and 40° planes, implying that the mid-plane is quite far away from the effect of the assumed artificial plane, i.e., end-effect.

Fig. 6 shows the history of deformation of sections A and B for the 60° analysis model. It can be seen at a glance that the deformation history of section A is nearly the same with that of section B as a whole. However, around the final stroke a distinct difference in contact region between the two planes can be observed. It is noteworthy that the size of cavity formed between the hub and inner race of hub bearing has a strong influence on the forming load when the process is controlled in terms of displacement (Shim et al., 2012) because the free surface around the major deforming region becomes very small at the final stroke.

Fig. 7(a)-(c) compares the deformed shapes at the mid-plane for the 30°, 60° and 90° analysis models, indicating

that all the predictions are nearly the same. Comparison of the predictions in Fig. 7(a), (b) and (c) with the experiments in Fig. 7(d) shows that they are acceptable. Less than one hour of computational time was taken for the 60° analysis model. Fig. 8 shows the predictions obtained by the 60° analysis model at the final stroke with emphasis on finite element mesh system used.

3. Conclusions

A computationally efficient finite element analysis model was proposed for analyzing a rotary forging process. The model is composed of one or two artificial planes of symmetry and a part of material defined by them. The model is based on the assumption that plastic deformation is concentrated on relatively small contact area. The model was employed for simulating a cold rotary forging process of a wheel hub bearing assembly, after local contact area was checked quite small, which is a typical application example of the proposed analysis model. The simulation was conducted using a rigid-plastic finite element method assisted by an intelligent remeshing technique.

Three cases of 30°, 60° and 90° analysis models were studied to validate the present finite element analysis model. The predictions at their planes of symmetry and mid-planes were investigated and compared with the experiments, revealing that the predictions at the mid-planes are in good agreement with the experiments for all the cases while those at the planes of symmetry are more or less different from the actual phenomena. Based on the discussion about the predictions, the 60° analysis model is recommended for both computational efficiency and solution reliability. With the present finite element analysis model, computational time could be reduced drastically.

Acknowledgement

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