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FE TECHNIQUES TO IMPROVE PREDICTION ACCURACY OF DIMENSION FOR COLD FORGED PART

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ABSTRACT

Since the dimension of cold forged part is larger than the cavity size of forging die, the difference results from the various features, such as, the elastic characteristics of die and workpiece, thermal influences, and machine-elasticity. All of these factors should be considered to get more accurate prediction of the dimension of forged part.

In this paper, severe FE techniques are proposed to improve the prediction accuracy of dimension for cold forged part. To validate the importance of the above mentioned factors, and the estimated results are compared with the experimental results. The used model is a closed die upsetting of cylindrical billet. The calculated dimensions are well coincided with the measured values based on the proposed techniques. The proposed techniques have put two simple but important points into Fe simulation. One is the separation of forging stages into 3 steps, from a loading through punch retraction to ejecting stage. The other is the dimensional change, according to the temperature changes due to the deformation. The FE analysis could predict the dimension of cold forged part within the 10μm, based on the more realistic consideration.

KEYWORDS: closed-die-upsetting, loading, unloading, ejecting, applied load

1. Introdution

The improvement of dimensional accuracy for forged part is one of the major topics in cold forging industry. The dimensional accuracy could raise the value of forged part, such as, precision gear with a huge amount. Since the dimensional tolerance of precision gear for automotive would require only severe micrometers, some more accurate analysis has to be performed with a dimensional control along the whole configuration of the forged part. Therefore, the appropriate FEM analysis techniques need to be developed to analyze the dimensional changes during forging process.

Up to now, many studies for elastic characteristics of die and workpiece have been performed experimentally or numerically.[1-8] Also, a lot of works have been studied about the dimensional changes by the temperature influences. [9-12] In this paper, some FE techniques are proposed to improve the prediction accuracy of dimension for cold forged part. The calculated results are compared with the experimental results. The used model is a closed die upsetting of cylindrical billet. The estimated dimensions are well coincided with the measured values implemented with the proposed techniques. The proposed techniques have put two simple but important points into Fe simulation. One is the separation of forging stages into 3 steps, from a loading through punch retraction to ejecting stage. The other is the dimensional change, according to the temperature changes due to the deformation.

2. Experimental and FE analysis

The closed-die upsetting of a cylindrical billet was used in experimental and FEM analysis, as shown in Fig.1. Tool steel, AISI H-13, was used as die material. The workpiece material was KS-SCM420 (BS-708M20, 0.2C-0.25Si-0.72Mn-1.05Cr), which was heat-treated for spheroidization and Zn-phosphating.

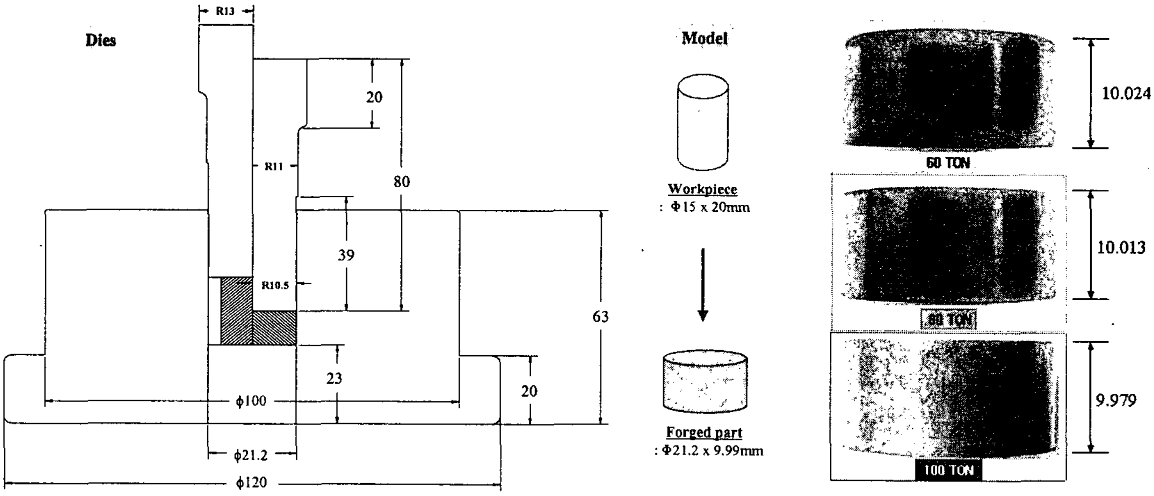


Fig. 1. Model and die used in experiment and FEM analysis

Several strain gages were attached on die surface to detect the elastic strain of die during forging (loading), tool retraction (unloading). The low-speed-hydraulic compressive-testing-machine (Tinius Olsen 200ton) was used to minimize the effects by the temperature increase and machine-elasticity. Since the in-situ measurement of dimensional change of die for the each forging steps is quite difficult or sometimes impossible job, the FE analysis has been thoroughly utilized in the present study. The commercial FEM package, DEFORM-2D^{TM} V7.2, was used to estimate the elastic strains and stresses of die and the dimensional changes of workpiece for each stage. For validation of FEM results, the estimated strains for the die were compared with the measured strains by the strain gages attached on the available locations as many as possible. The comparisons between experimental results and FEA results were illustrated in ref.[13]. To investigate the dimensional changes at each stage, in the present study the material of die and workpiece were treated as elastic and elasto-plastic behaviours, respectively. The material properties used in analysis are shown in Table 1.

We separated a forging cycle into three characteristics steps, that is, loading, unloading, and ejecting. In order to investigate the effect of each steps on FE results, we have set up three different FE models as shown in Table2. Especially, FEM-A scheme considers the 3 steps, which is a host realistic model much like an experiment itself.

Table 1. Material properties of die and workpiece

	Material	Elastic modulus (Gpa)	Poission's Ratio	Flow Stress (Mpa)	Thermal Expansion (/°C)	Thermal Conductivity (N/sec./°C)	Heat Capacity (N/mm^2/°C)	Yield Stress (Mpa)
Die	AISI H-13	218	0.29	-	13.1E-6	23.7	1.08	415
Work-piece	SCM420H	211	0.29	$759\varepsilon^{0.12}$	10.4E-6	46.6	4.51	-

Table 2. FEM variables to investigate the effects of unloading and ejecting stage

	Loading (forging)	Unloading (punch retraction)	Ejecting	Remarks
FEM-A	Considering	Considering	Considering	Whole cycle
FEM-B	Considering	Considering	Not considering	Unloading → Stress Relief
FEM-C	Considering	Not considering	Not considering	Loading → Stress Relief

3. Results and discussion

3.1 Characteristics of unloading and ejecting stage

From the analysis point of view, FEM-A approach considers more practically the unloading and ejecting stage than other models. For the case of FEM-B approach, which has been tried by many researchers previously, the additional deformation during the ejecting stage could not be predicted even though the secondary yielding of workpiece from die contraction would appear in FE analysis. We have tried the FEM-C model to check the stress distribution on the final ejected forged part even after it was expected impossible to predict the secondary yielding properly. The secondary yielding effect on unloading is also represented in dimension of forged part after ejecting. The estimated radius of forged part is best fitted with experimental in FEM-A within the range of 15μm, as shown in Fig.2. On the other hand, the radius differences between experimental and estimated results are up to 100μm in FEM-C because the secondary yielding is not taken account and elastic recovery occurs after loading. The estimated radius of FEM-B is somewhat larger than that of FEM-A because the additional deformation of workpiece is not considered during ejecting stage.

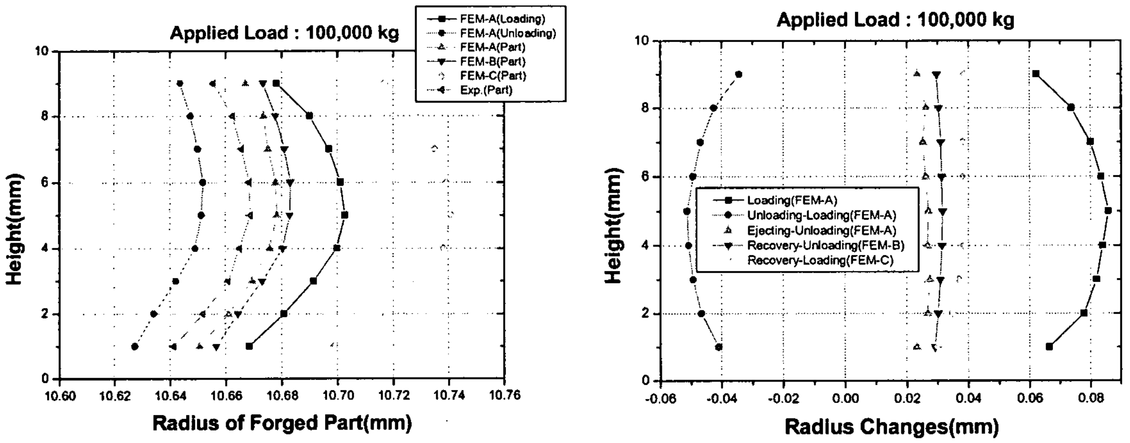
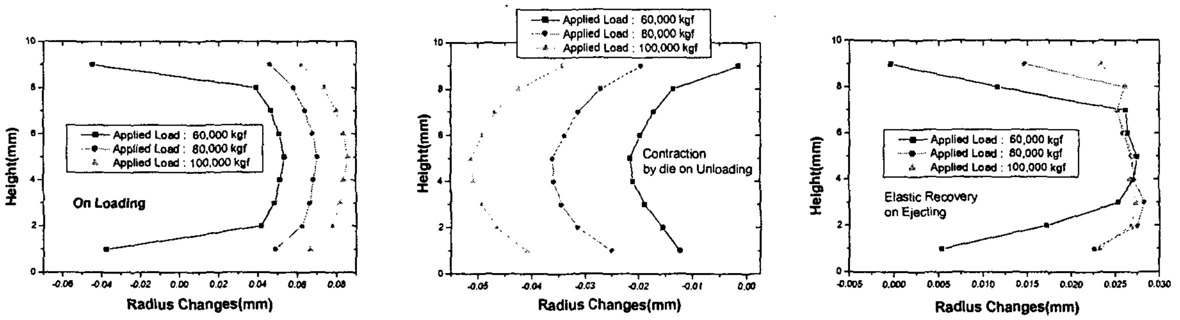


Fig. 2. Radius comparisons of experimental and estimated results considering the unloading and ejecting stage or not (Applied load: 100,000 kgf)

The estimated values of radius changes during each stage resulting from each punch load are shown in Fig. 3. The amounts of die expansion on loading increases linearly with punch load, while the contraction of die on unloading decreases with increasing of punch load. However, the elastic recovery amounts (about 25 μm) of forged part on ejecting stage are almost same although the punch load increases. Irrespective of the applied punch load, the stress level of workpiece is found to be the flow stress of this material. The elastic recovery occurs from the same residual stress. Considering the elastic response characteristics, die deflections on loading and unloading may be more important than elastic recovery of workpiece on ejecting stage.



(a) Expansion by loading (b) Contraction by unloading (c) Elastic recovery

Fig. 3. The estimated values of radius changes during each stage resulting from each load

3.2 Temperature influences

The dimensional differences of forged part between estimated values and measured values are within 10μm, when the temperature by the deformation heat is not considered in FEA. Therefore, the estimated values are larger than that of the measured values. The temperature of forged part is up to 120°C on loading, 50°C after ejecting. The forged part was shrunk by the temperature decrease on unloading, and ejecting stages, as shown in Fig.4. The irregular distribution of dimension seems to be originated from that the temperature distribution of die and workpiece are non-steady state. It would be uniform when the temperature between die and workpiece become a steady state by the repeated operations.

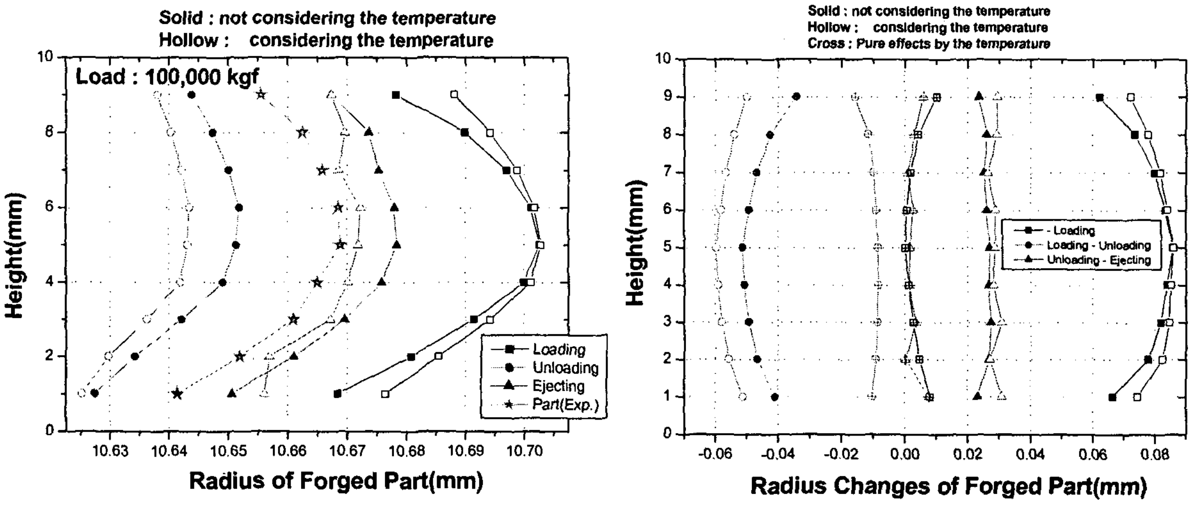


Fig. 4 Effects of temperature by deformation heat which affected in dimensional changes

5. Summary

A new realistic FE technique has been proposed to improve the prediction accuracy of dimension for cold forged part. In this study of FE analysis, two simple but important issues are taken into a consideration, which were neglected before. The first one is that a forging cycle is separated into 3 steps, loading, punch retraction and ejecting steps. Each step has a distinguished characteristic to be analysed independently. The second one is that we have taken temperature rise due to deformation heat into FE analysis, which was found to bring a serious dimensional change during forging stage. After considering these two factors into Fe analysis, the dimension of cold forged part could be predicted within 10μm.

Acknowledgement

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