Journal of Materials Processing Technology 139 (2003) 422–427

Journal of Materials Processing Technology

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New processes to prevent a flow defect in the combined forward–backward cold extrusion of a piston-pin

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Abstract

A flow defect of a piston-pin for automobile parts are investigated in this study. In the combined cold extrusion of a piston-pin, a lapping defect, which is a kind of flow defect, appears by the dead metal zone. This defect is evident in products with a small thickness to be pierced and is detrimental to dimensional accuracy and decrease of material loss. The flow defect that occurs in the piston-pin has bad effects on the strength and the fatigue life of the piston-pin. Therefore, it is important to predict and prevent the defect in the early stage of process design. The best method that can prevent the flow defect is removing or reducing dead metal zone through the control of material flow. Finite element simulations are applied to analyze the flow defect. This study proposes new processes which can prevent the flow defect by removing the dead metal zone. Then the results are compared with the results of experiments for verification. These FE simulation results are in good agreement with the experimental results.

Keywords: Flow defect; Piston-pin; Material flow control; Forward–backward extrusion; Dead metal zone; FE simulation

1. Introduction

Cold forming is extremely important and economical processes, especially for producing parts in large quantities. Because of advantages of cold forming such as high production rates, excellent dimensional tolerances and surface finish, mechanical and metallurgical properties, cold forming is by far the largest application of industry for producing parts.

However, cold forged parts are also used in manufacturing aircraft, motorcycles, nuts and bolts [1], but it is possible for defects to occur in forged parts, depending on the deformation history, forming conditions and material flow pattern, etc. The kind of defects are ductile fracture caused by the state of stress and the deformation history, flow defects caused by unstable material flow, and poor dimensional tolerances caused by inferiority of the die and friction condition. Further, defects in forged parts are classified as internal defects and external defects [2–4].

These defects have harmful effects on the quality of the product and an increase in the cost of production. Therefore, it is important to predict and prevent defects in the early stage of process design.

Wifi et al. [5] studied ductile fracture in bulk formed parts, using different workability criteria by the finite element method. Kim and Kim [6] studied internal and external defects of cold extruded products with double ribs and performed process design to prevent these defects.

In this study is examined a defect which occurs in producing a forward–backward extrusion product, a piston-pin for an automobile part, and new processes are designed to prevent the defect by finite element method in the early stage of process design. Then the results are compared with the results of experiments for verification.

2. Forming and defect-occurrence analysis

2.1. Forming process

The piston-pin is an automobile components used in the transmission of power between the connecting rod and the crankshaft. In the cold extrusion of a piston-pin, the design requirements are to keep the same height of the forward extruded part and the backward part (Fig. 1) without any defect in the forged product, for use under high and repeated

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doi:10.1016/S0924-0136(03)00515-6

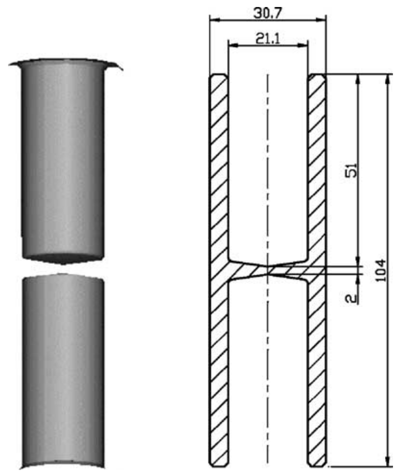

Fig. 1. Shape and dimension of the piston-pin.

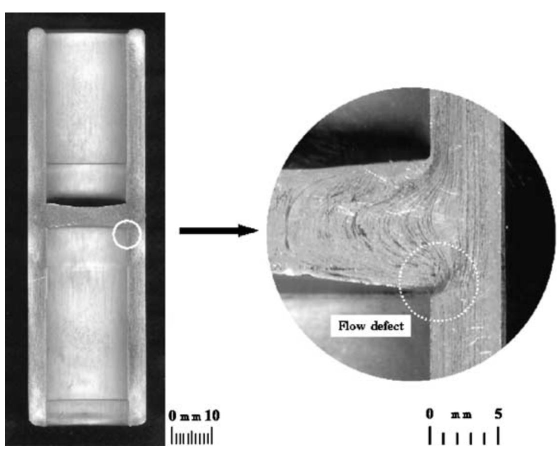

Fig. 2. Photograph of a flow defect of a piston-pin.

load. The material used for the piston-pin is AISI-4135H (Fig. 2) alloy steel, with the following flow stress behavior:

$$\bar{\sigma} = 768.06\bar{\varepsilon}^{0.139}\ \text{(MPa)}$$

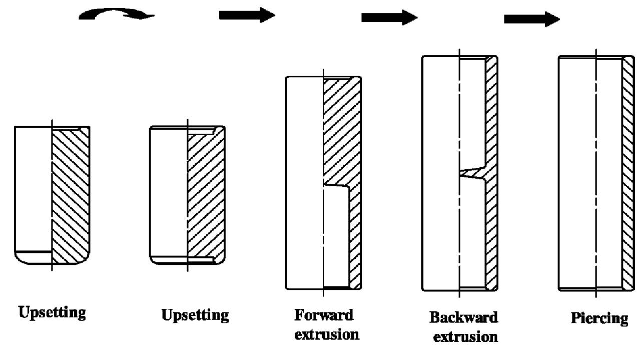

Fig. 3. Conventional forming process for a piston-pin.

The lubricant used is phosphate coating and bond lube. The friction factor, *m*, is assumed to be 0.1, which is confirmed by the ring compression test.

The sequence of the conventional process for the piston-pin is performed using a multi-stage former (Fig. 3). The first and second stages are pre-upsetting to eliminate defects by the cropping process such as ovality and eccentricity of the billet for improvement of dimensional tolerances and die life whilst the third and forth stages are forward or backward extrusion for the forming of one direction from the web, and final stage is the piercing process for the pin shape.

However, the results of experiment for the conventional process displayed a defect in the web part formed early in the third process (Fig. 3). Especially, a nonuniform flow pattern is observed in part of the defect occurrence, which looks like a flow defect similar to lapping with an undesirable flow pattern.

2.2. Prediction of defects by FE analysis

DEFORM is used, which is commercial code of a rigid-plastic FE program for forming and defect analysis. The diameter of the initial billet is ϕ30 mm and the height is 61 mm, the whole volume of final product being

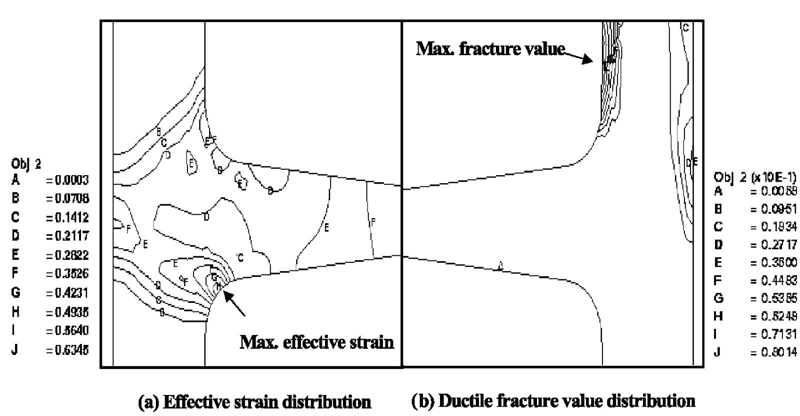

Fig. 4. Distribution of effective strain and fracture value.

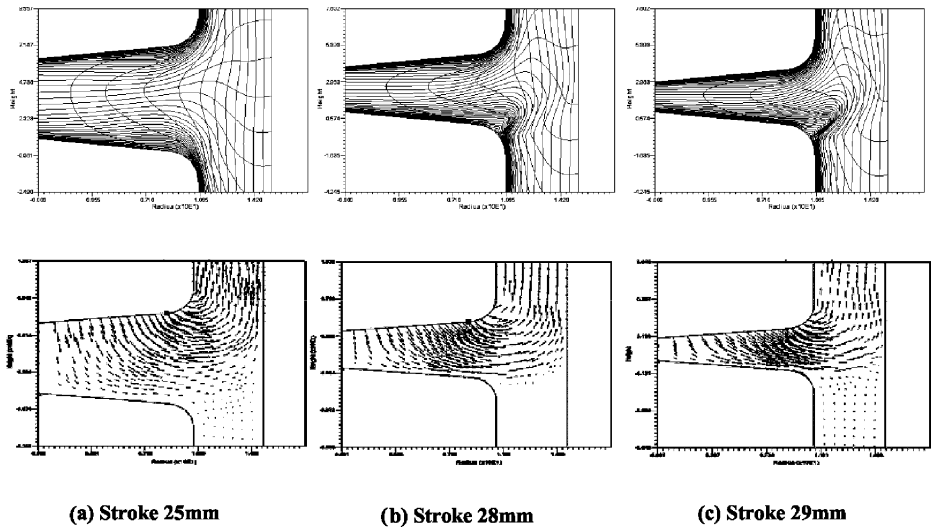

Fig. 5. Metal flow and velocity distribution, where a defect occurs according to stroke.

43,118 mm^3. The forming is simulated with a conventional process sequence.

The maximum fracture value that can estimate the occurrence of a crack [7] is small at 0.08 and is distributed in a position within the head part of the punch, so that a defect does not occur. Thus this defect is not one due to ductile fracture (Fig. 4). Then flow line-tracking scheme that was proposed by Altan and Knoerr [8] is performed for defect analysis. According to the progress of the punch stroke, severe variation of flow lines appears and discontinuity of velocity occurs in the part that a defect occurred in the experiment (Fig. 5).

Consequently, the metal flows only in the backward direction without flow to the forward direction in the fourth process and metal near the web part is pulled up in the rib part like a lapping defect. Therefore, the cause of the initiation and development of the flow defect that occurred in piston-pin is the velocity discontinuity between backward and forward direction by the formation of a dead metal zone. This appearance evidently occurs in products like a piston-pin with a low thickness to be pierced for the dimensional accuracy and the decrease of material loss. A flow defect occurring in a piston-pin has harmful effects on the strength and the fatigue life of a piston-pin that has high and repeated load at high temperature. Therefore, it is necessary for a new process to prevent the flow defect.

3. Process redesign and analysis for the prevention of defect

The cause of the initiation and development of the flow defect is the restriction of metal flow by the dead metal zone. For the elimination of the dead metal zone in the early extruded part (3rd process) in the conventional process, the forward or backward extrusion process is modified to combined forward–backward extrusion, which is performed simultaneously in the two directions. Because of the variety of extrusion ratios and lengths in the forward and backward directions, the simultaneous completion of the material flow in the both directions is very difficult. Consequently, one of the directions is completed early, then material flow stopped and dead metal zone appears in this part just like that in the conventional process.

Therefore, in the case of piston-pin forming, the extrusion ratio and the length of both directions are the same at 1.89 and 51 mm. First, analysis of open die forward–backward extrusion is performed for an investigation of extrusion lengths of the piston-pin. The difference of two extruded ribs is 24.9 mm and the backward extruded rib is shorter than the forward extruded rib as shown in Fig. 6.

The metal flow of backward direction must be restricted compulsorily for the satisfaction of the design conditions and this means the occurrence of a dead metal zone. Therefore, for the same extrusion length in both directions, three

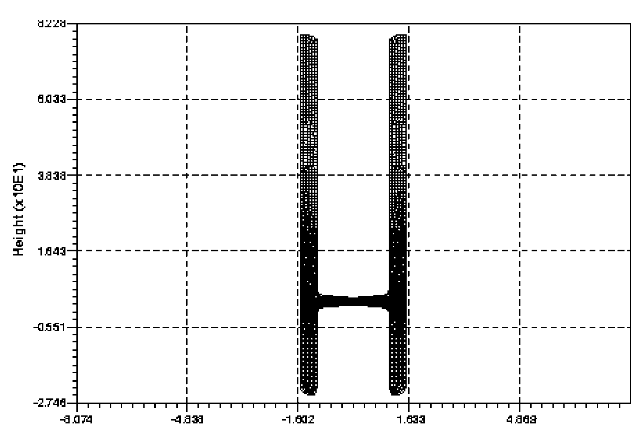

Fig. 6. Extrusion length in forward–backward extrusion.

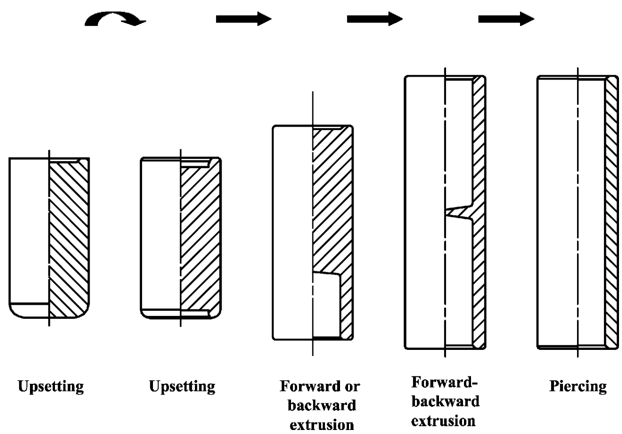

Fig. 7. Modified process sequence for a multi-stage former.

methods are proposed to control the metal flow without the compulsory restriction of metal flow

3.1. Change of preform shape

To secure the same length of both directions from the center of web, it is required that the backward extruded rib is performed by preform design as the difference of both-direction lengths at 24.9 mm from the above results, before forward–backward extrusion. Fig. 7 shows the modified process sequence, and Fig. 8 shows the metal flow of the final stage of forward–backward extrusion in this case. From the results of simulation, the lengths of two extruded ribs are 51 mm, which is the dimension of the piston-pin and satisfied the design condition. In addition, the metal flow is uniform in the defect zone where the flow defect occurred in the conventional process, and there is not a discontinuity of velocity in both extrusion directions. This means that metal flows uniformly in the whole process without a dead metal zone by restriction of metal flow.

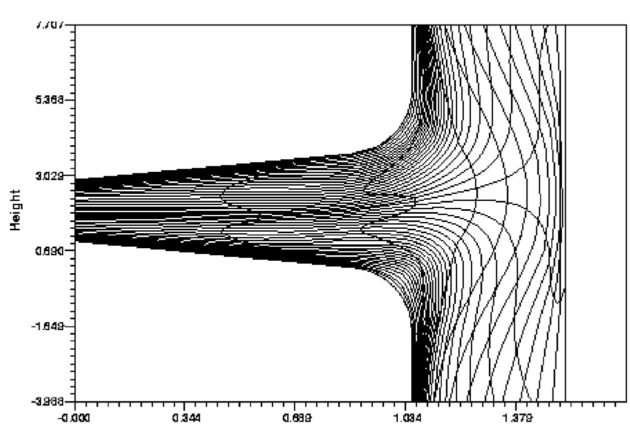

Fig. 8. Metal flow of web in case of using preform.

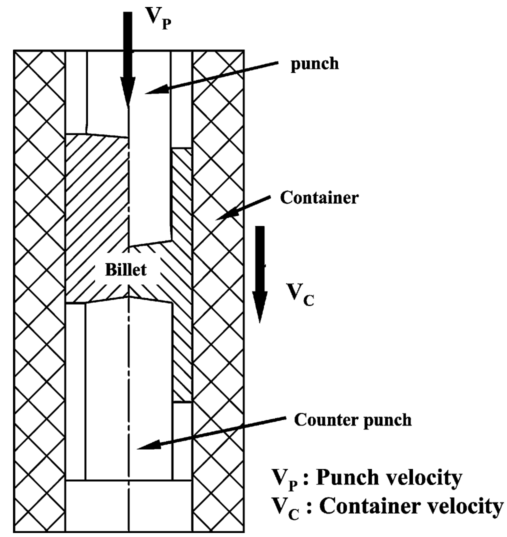

Fig. 9. Schematic diagram of the axially moving container die structure.

3.2. Driving of extrusion container

The driving extrusion container method [9] is used for metal flow control for the satisfying of the design condition. This structure is that the extrusion container is moved in the counter direction to the early extruded one (Fig. 9). This has the effect of increasing the metal flow in the late extruded direction and restricting metal flow in the early extruded direction. In the case of the piston-pin, because of the early completion of backward extrusion, the extrusion container is moved in the forward direction for the increase of metal flow to this direction. In this process, the principal process variables are the relative velocity ratio of the punch and the moving extrusion container, and the friction condition between the material and the moving extrusion container.

In this study, because the friction factor, *m*, is 0.1 between the material and container, simulation is performed only according to the variation of the relative velocity ratio ($V_C/V_P = 0.1, 0.25, 0.5, 0.75, 1.0$). If the relative velocity ratio is smaller than the optimum which can complete forming simultaneously, extrusion in the backward direction is completed earlier than in the forward direction and a flow defect occur in the same part as in the conventional process. Otherwise, if the relative velocity ratio is larger than the optimum one, extrusion in the forward direction is complete earlier than backward direction and a flow defect occurs in the opposite part to where a defect occurs in the conventional process.

Therefore, for satisfaction of the design conditions, the optimum relative velocity ratio is searched for by an optimization technique, the bisection method. From the result, the optimum relative velocity ratio is 0.48. Figs. 10 and 11 show the deformation modality and metal flow according to the relative velocity ratio (0.1, 0.48, 1.0) for a punch stroke of 42.7 mm, respectively. Fig. 11(c) shows the metal flow

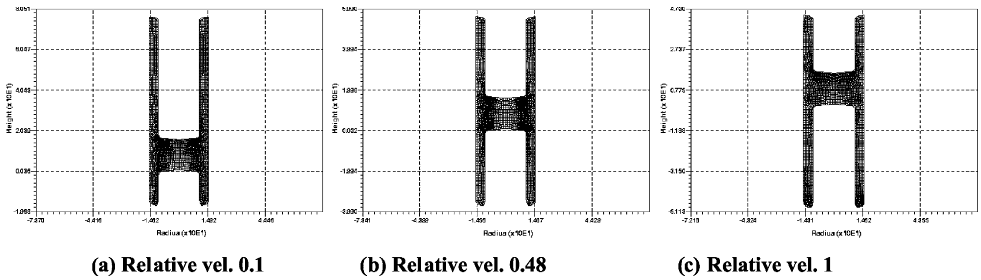

Fig. 10. Deformation modality of the piston-pin according to the relative velocity ratio.

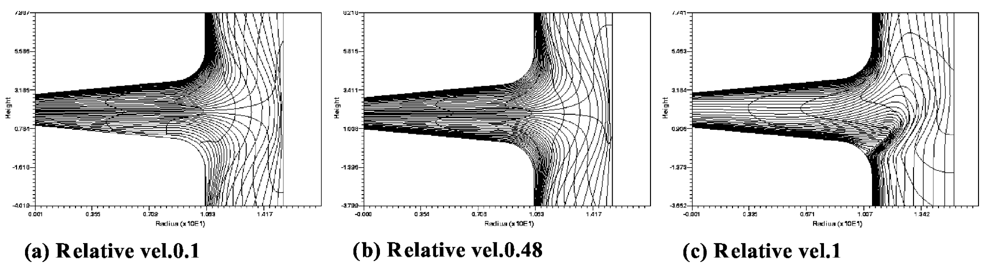

Fig. 11. Comparisons of metal flow according to the relative velocity ratio.

at the optimum relative velocity (0.48) where an improved flow pattern without a flow defect can be noted.

3.3. Modification of die structure

A modification of the die structure is proposed which can restrict the metal flow of backward direction, which is deformed early, for simultaneous completion of extrusion in both directions. In this case, for simultaneous completion and the same length in both directions, the stripper, which is equipment for punch extraction from products, is redesigned. If a fixed stripper of conventional type is used, a dead metal zone appears from the middle stage of backward–forward extrusion by the restriction of material flow.

Therefore, a structure is used that can delay the metal flow in the backward direction by spring force. Fig. 12 shows the die structure. For this method, it is very important to decide the proper spring force for simultaneous completion of forming. Therefore, the necessary spring force for this is calculated by FE simulation. From the simulation result, it was 5 t to be applied load to stripper. Fig. 13 shows metal flow in this case. The metal flow is similarly uniform at the defect zone without discontinuity of velocity in comparison with other modification methods.

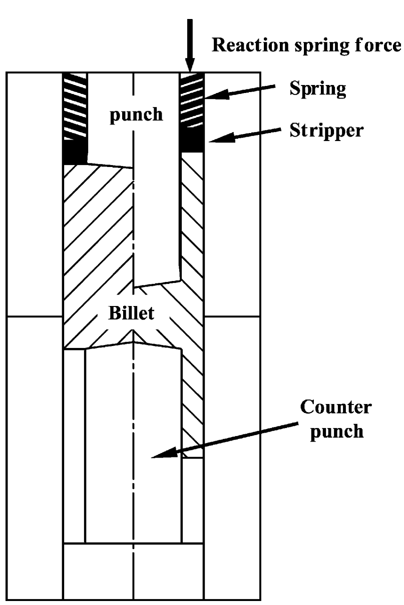

Fig. 12. Schematic diagram of die structure using stripper.

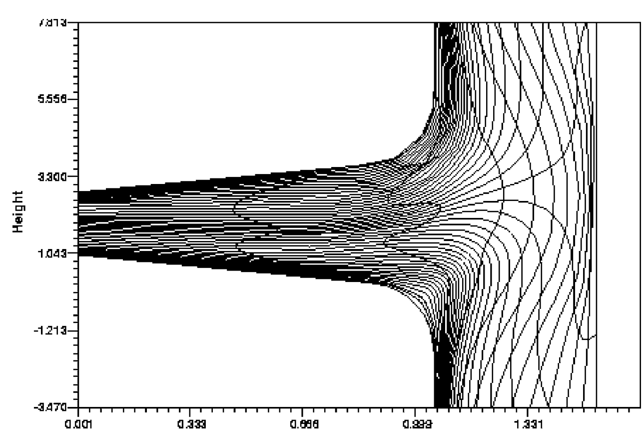

Fig. 13. Metal flow of web in case of using stripper.

Table 1
Comparison process for each of the proposed method

	Conventional method	Use of preform	Use of stripper	Use of moving container
Maximum load (t)	97.2	96.3	96.1	84.0
Process of extrusion	2 stage	2 stage	1 stage	1 stage
Defect	Exist	None	None	None

4. Results and experiment

From the FE simulation, the three proposed methods are proper to prevent a flow defect by metal flow control. The characteristics of each process are as follows. The first method that uses a preform needs three stage processes (preforming, forward–backward extrusion, piercing) and has a simple die structure; however, the second method that uses a stripper and the third method that uses an axially moving container need two-stage processes (forward–backward extrusion, piercing) and have a complex die structure. In respect of the forming load, the processes are similar to each other.

Especially, the maximum forming load is smaller than that of other processes by about 10 t in the case of the axially moving container, because the axially moving container increases material flow in the direction punch movement. It is compared with the proposed method for forming by a press in Table 1. In this study, an experiment using a preform is performed and uses a multi-stage former having 250 t capacity for the verification of simulation. Etching for observation of metal flow is performed to examine for a flow defect for the piston-pin before piercing. Fig. 14 shows the experiment result, based on the first proposed method, changing the preform. The experiment result shows that metal flow is uniform in the defect zone where the flow defect had occurred, and satisfied the simultaneous completion of forming and the same length in both extrusion directions. This tendency is in good agreement with the simulation result.

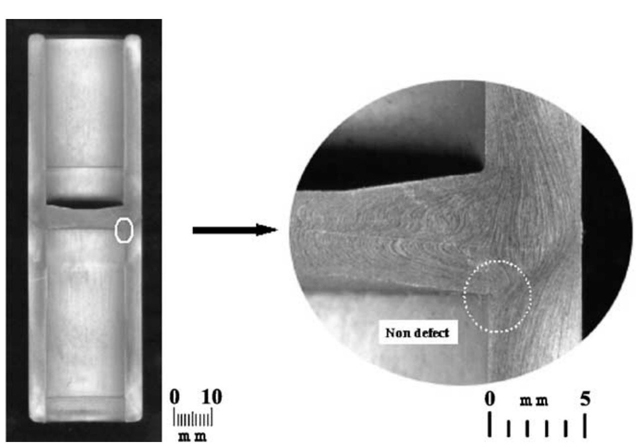

Fig. 14. The elimination of the flow defect by the first proposed method.

5. Conclusions

In this study, the flow defect that occurs in the manufacturing process of the piston-pin is examined and a new process to prevent the defect is redesigned by FE analysis. First, the cause of the defect is investigated, and the analytical approach is verified by comparison of experimental and simulation results. From these results, it is possible to design processes that can prevent the flow defect and satisfy the design condition to control the material flow.

Comparing the experiment and FE analysis for the proposed new processes, several conclusions can be drawn:

(1) The cause of the flow defect that occurs in the piston-pin forming is a dead metal zone by restriction of material flow, and it is very important to control the material flow for eliminating this zone.
(2) Design of the preform and change of the die structure and the use of an axially moving extrusion container are proposed to secure simultaneous filling for elimination of the flow defect in the combined forward–backward extrusion process.
(3) The proposed methods satisfy the requirements of process design, i.e. the same length of the forward extrusion part and the backward one, and these are verified by experiment.

Acknowledgements

The authors wish to thank the Engineering Research Center for Net Shape and Die Manufacturing, located in Pusan National University, Pusan, South Korea, for the support of this research.

References

[1] T. Altan, S.I. Oh, L. Gegel, Metal forming, ASM (1983).
[2] T. Okamoto, T. Fukuda, H. Hagita, Source Book on Cold Forming, ASTM, 1997, pp. 216–226.
[3] S.W. Oh, T.H. Kim, B.M. Kim, J.C. Choi, KSME 19 (12) (1995) 3121–3129.
[4] R.C. Batra, N.V. Nechitailo, Int. J. Plast. 13 (4) (1997) 291–306.
[5] A.S. Wifi, A. Abdel-Hamid, N. El-Abbasi, J. Mater. Process. Technol. 77 (1998) 285–293.
[6] D.J. Kim, B.M. Kim, J. KSTP 8 (6) (1999) 612–619.
[7] D.C. Ko, Pusan National University Dissertation, 1998.
[8] T. Altan, M. Knoerr, J. Mater. Process. Technol. 35 (1992) 275–302.
[9] K. Osakata, X. Wang, S. Hanami, J. Mater. Process. Technol. 71 (1997) 105–112.