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ISSN 0543-5846
METABK 62(3-4) 467-470 (2023)
UDC – UDK 669.721.5.296:621.73: 621:825:620.16:518.1=111

NUMERICAL ANALYSIS OF FORGING A CONNECTOR FOR LIGHT VEHICLES FROM CAST MAGNESIUM ALLOY PREFORMS

Received – Primljeno: 2023-03-01
Accepted – Prihvaćeno: 2023-04-30
Preliminary Note – Prethodno priopćenje

The article presents the results of numerical analysis of the new forging process of the connector forging from cast preform on hydraulic press. The high strength ZK60 alloy (belonging to the Mg-Zn-Zr group of Mg alloys) was selected to numerical tests. Currently, this part in the industry is produced by multi-stage forging consisting of operations: bending, preforming, and finishing. The use of the cast preform would enable forging this component in one operation. However, obtaining specific mechanical properties requires inducing a certain level of strain within the forged part. Therefore, the design of the preform, its shape and volume, is of paramount importance. In the work presented in this article, preforms of different shapes were designed and assessed using Finite Element Method (FEM) analysis.

Keywords: ZK60 magnesium alloy, forging, connector, strain, numerical simulation.

INTRODUCTION

The purpose of this paper was to design a new forging technology for connector forgings from ZK60 magnesium alloy cast preforms. Figure 1 shows the connector selected for the study and the forming designed for it.

The current forging technology for this connector uses cylindrical billet and consists of three operations: bending, preforming and finishing. Shapes formed in the mentioned operations are shown in Figure 2. The process used already is lengthy and material-consuming. Sometimes it is not possible to obtain the correct product using this method from hard-to-deform magnesium alloys. This is especially the case when they are deformed in several stages from a plastically processed billets.

The use of a cast preform would enable these connectors to be forged in a one operation. However, obtaining certain mechanical properties requires inducing a certain level of strain within the forged part. For this reason, the geometry of the preform is of great importance, particularly its shape and volume, which should also be considered in order to minimize material consumption. In the current forging process, the volume of the forging accounts for 62,1 % and the waste 37,9 % of the billet material. Table 1 presents a summary of the volume of material consumption for the current technology.

This article describes the work conducted to determine the shape and size of the preform to be used in validation forging tests of the proposed new forging technology. The considered preform designs were veri-

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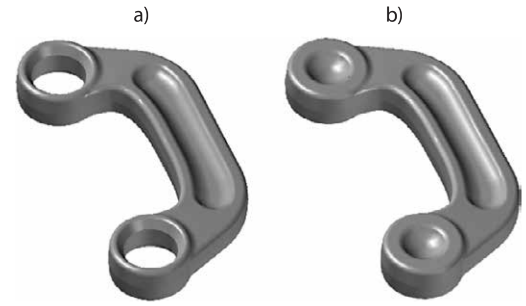

Figure 1 Models 3D of the analyzed connector: a) finished part, b) forging

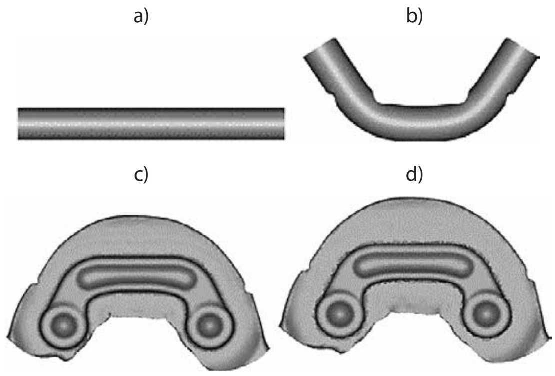

Figure 2 Current forging technology for connector: a) cylindrical billet; b) shape obtained in the bending operation; c) shape obtained in the preliminary die forging; d) shape obtained in finishing die forging

Table 1 **Summary of the volume of material consumption for the current technology forging of automotive connector forging**

Component	Part	Billet	Forging	Flash
Volume / mm^3	65 863,25	123 094	76 479,25	46 614,75
Volume / %	53,5	100	62,1	37,9

fied on the basis of numerical simulations of the assumed process using the finite element method.

Research methodology

The new technology assumes the forming of a connector forging from a cast preform. The new process will be realized in one forging operation in a finishing impression on a hydraulic press.

It should be mentioned that the use of a finished cast preform for the forging process will reduce the number and time of operations needed to obtain the forging, which will increase productivity and reduce the labor intensity of the process. Based on the geometry of the forging (Figure 1b) three preform geometries were developed as shown in Figure 3 - 6, which are as close as possible to the outline of the forging in the plane of division of the dies, which is expected to have a positive effect on the flow kinematics of the metal especially when forming hard-to-deform magnesium alloys.

Investigations of the die forging process of the connector forgings from the designed preforms were conducted based on FEM analysis in Deform 3D software [1-3].

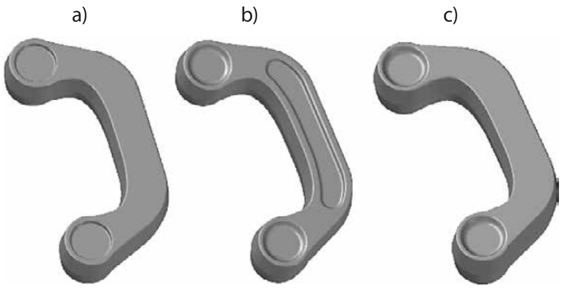

Figure 3 Summary of the designed geometries of the performs by variants: a) no. 1; b) no. 2; c) no. 3

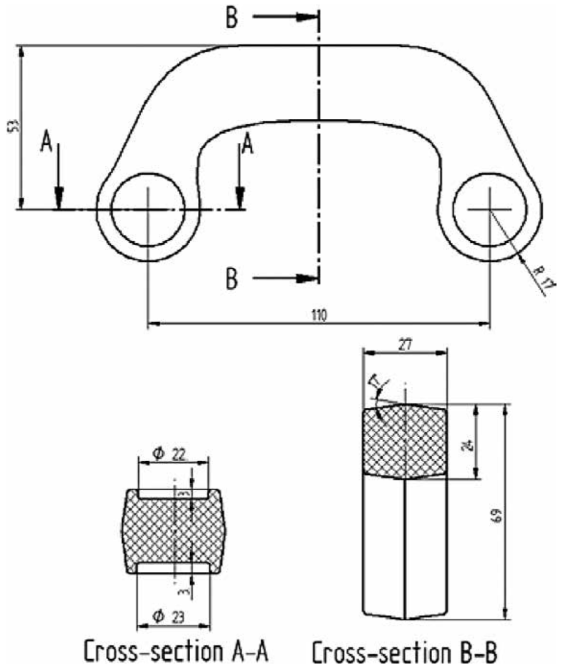

Figure 4 Characteristic dimensions of the preform by variant no. 1

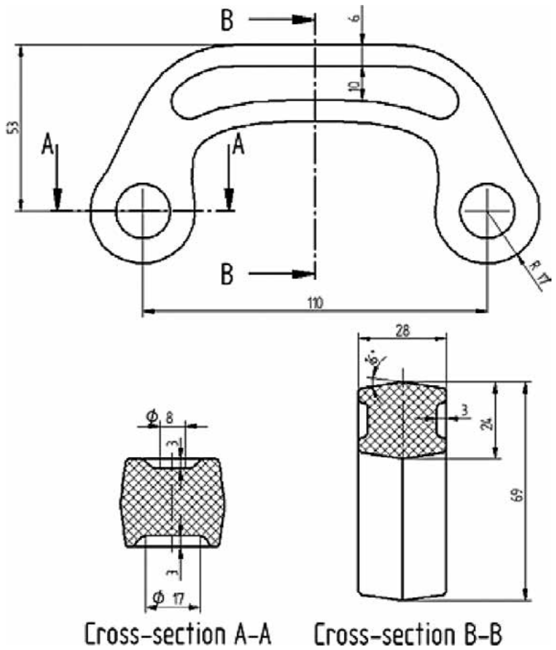

Figure 5 Characteristic dimensions of the preform by variant no. 2

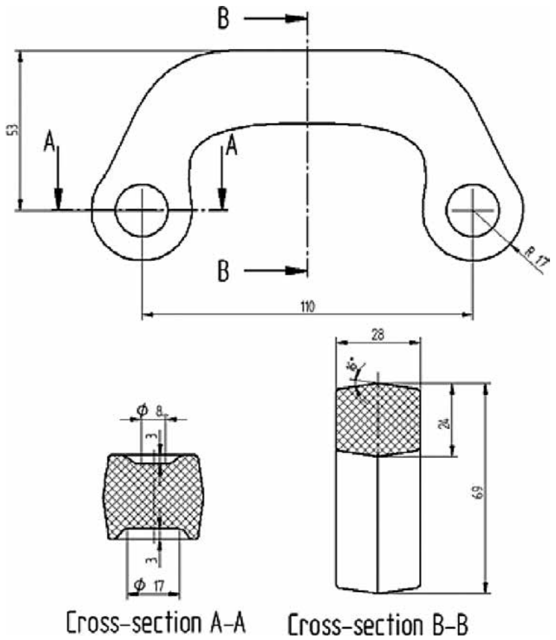

Figure 6 Characteristic dimensions of the preform by variant no. 3

The calculations performed assumed that the preform is made of ZK60 magnesium alloy, which will be forged at an initial temperature of 400 ˚C, using dies heated to 250 ˚C [4], and top die velocity of 10 mm/s. Material models of the ZK60 magnesium alloy (Table 2) as cast in sand moulds were developed on the basis of the authors' own plastometric tests carried out using a compression test at temperatures of 350 ºC, 400 ºC and 450 ºC and four strain rates of 0,01s^{-1}, 0,1 s^{-1}, 1,0 s^{-1} and 10,0 s^{-1}. The stresses were entered into the programme in tabular form and depended on temperature, strain rate and strain value.

The friction conditions between the billet and tools were described using a shear friction model assuming a

Table 2 **Chemical composition of ZK60 magnesium alloy cast / wt. % [1, 6]**

Mg	Zn	Zr	Mn	Fe
Balance	6,04	0,78	0,02	0,001
Si	Cu	Al	Ni	
0,005	0,001	0,001	0,001	

shear factor of m = 0,25 [5]. The heat conduction coefficient between the aforementioned objects was assumed to be equal to 4,5 kW/m^{2}K, while that between the billet and the environment was assumed to be equal to 0,02 kW/m^{2}K.

Analysis of the results

The computed shape of the connector forged using the preform by variant no. 1 is shown in Figure 7.

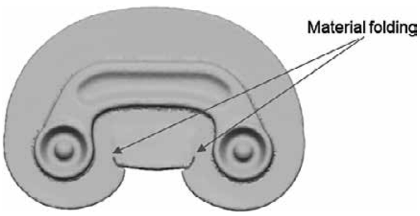

Figure 7 The shape of the connector forged using the perform by variant 1 and folds detected

The strain distribution in the cross section along and perpendicular to the shaft groove, and in the cross section going through the centre of heads are shown in Figure 8. The average strain in the groove areas of the shaft is 1,40 (Fig. 8a), while in the head areas it is less than 1 (Fig. 8c).

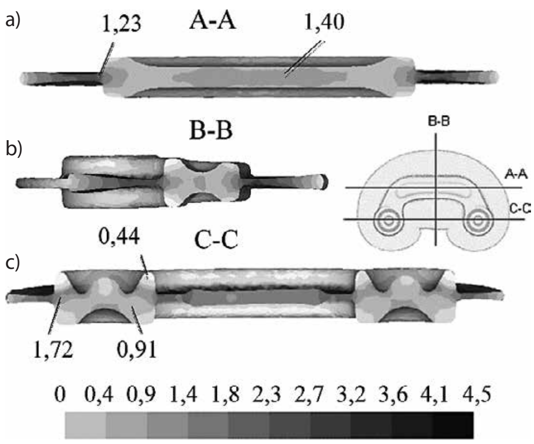

Figure 8 Distribution of strain in the cross section: a) along the shaft groove, perpendicular to the shaft groove, c) through the middle of the heads

Folding of material was detected by the software only in the flash as shown also in Figure 7. However, examining the flow of material in all saved simulation increments revealed folds in both heads; these appeared at the earlier stage of the deformation but were concealed in the following remeshing steps. This is illustrated in Figure 9. The presence of folds in the forging disqualifies the preform by variant no. 1.

Figure 9 Cross section of the connector head showing a) folds created in the earlier deformation stage, and b) their disappearance due to remeshing later

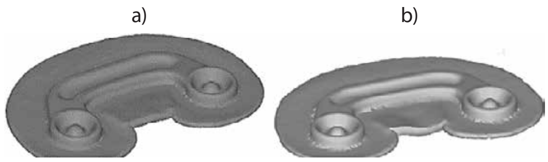

Figure 10 The shape of the connector forged using the perform by variant: a) no. 2, b) no. 3

The computed shape of the connector forged using the preform by variant no. 2 is shown in Fig. 10a.

The strain distribution in the cross section along and perpendicular to the shaft groove, and in the cross section of heads is shown in Fig. 11. Adding 3 mm deep grooves on both sides of the preform with simultaneous increase of the preform height by 1 mm decreased the average strain induced in this section of the connector to 1,28 (Fig. 11a) compared to 1,40 obtained using the preform no. 1. However, strain in the heads slightly increased and was about 1,0. As a result, strain distribution in the forging was more uniform. Folding of material was not detected by the software even in the flash.

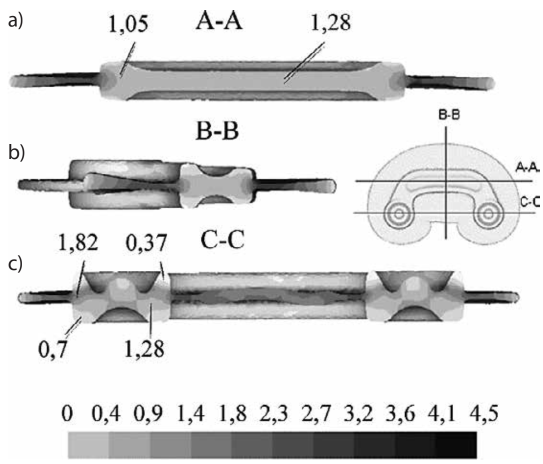

Figure 11 Distribution of strain in the cross sections of the connector forged using preform no. 2: a) along the shaft groove, b) perpendicular to the shaft groove, c) through the middle of the heads

The computed shape of the connector forged using the preform by variant no. 3 is shown in Fig. 10b. The strain distribution in the cross section along and perpendicular to the shaft groove in the section connecting heads, and in the cross section going through the centre of heads is shown in Fig. 12. Removing the grooves from both sides of the preform resulted in the increase of strain to 1,5 and its more uniform distribution in this section of the connector (Figure 12a) compared to that obtained for the preform no. 2.

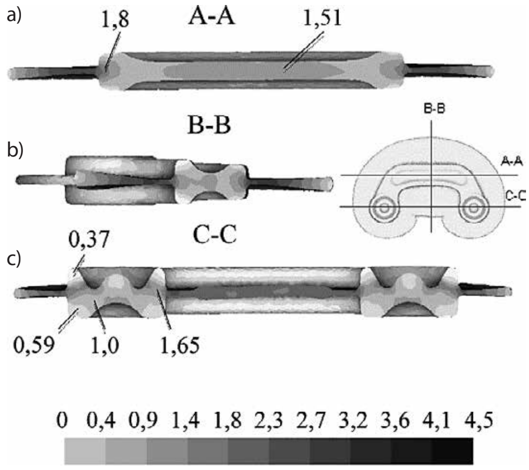

Figure 12 Distribution of strain in the cross sections of the connector forged using preform no. 3: a) along the shaft groove, b) perpendicular to the shaft groove, c) through the middle of the heads

Strain in the heads was similar as in the forging produced using the preform no. 2 as this section of the preform was not changed. The forging obtained using the preform by variant no. 3 also did not show any faults.

Table 3 shows a comparative analysis of billet volume, assuming different process variants, which is forging from preform by variants no. 1, no. 2 and no. 3.

Table 3 **Summary of the volume of material consumption for the new technology forging of automotive connector forging from cast preform**

Component	Volume / mm³	Flash Volume / mm³	Flash / %
Preform no. 1	117 765	41 285,75	35
Preform no. 2	117 242	40 762,75	34
Preform no. 3	123 684	47 204,75	38
Forging	76 479,25	0	0

The use of preforms by variant no. 1 and no. 2 reduces the material intensity of the process by 4,3 % (preform 1) and 4,8 % (preform 2) compared to forging from rod (Table 1). Forging from preform by variant no. 3 increases the material intensity of the process by 0,5 %.

CONCLUSION

On the basis of the analysis of the forging processes of the connector forgings made of three designs of the cast performs, the following conclusions were formulated:

- Designed preforms according to variants 2 and 3 ensure the correct forgings with the assumed shape and dimensions;
- The occurrence of folding during forging of the connector from the preform according to variant 1 disqualifies this geometry for further verification in experimental studies;
- Forging the connector forgings from the cast performs by variant no. 2 is characterised by a lower material consumption by approximately 4,8 % than forging directly from a rod;
- Forging from preform by variant no. 3 increases the material intensity of the process by 0,5 %. This means that the use of this preform would not benefit in terms of material savings.
- Specific mechanical properties must be achieved in the forgings which can only be verified by testing forgings produced in the experimental trials. The correctness of the modelled geometry of cast preforms should be verified in experimental tests. It is proposed to cast preforms for the validation forging trials using designs by variants no. 2 and no. 3.

Acknowledgement

The research leading to these results has received funding from the Norway Grants 2014-2021 via the National Centre for Research and Development

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Note: The responsible for English language is Pawel Szydlowski, Lublin, Poland.