A. GONTARZ, Z. PATER, K. DROZDOWSKI

ISSN 0543-5846
METABK 52(3) 359-362 (2013)
UDC – UDK 669.721:621.73:621.974=111

HAMMER FORGING PROCESS OF LEVER DROP FORGING FROM AZ31 MAGNESIUM ALLOY

Received – Prispjelo: 2012-09-22
Accepted – Prihvaćeno: 2012-12-28
Preliminary Note – Prethodno priopćenje

The results of theoretical and experimental analysis of hammer forging process of lever drop forging from AZ31 magnesium alloy are presented in this paper. In order to design a process guaranteeing obtaining a proper product, numerous simulations were made, in which material flow kinematics, strain and damage criterion distributions and forging energy were analyzed. On the basis of the obtained results, the analysis of limiting phenomena, which could appear during the process, was made. Experimental tests in industrial conditions according to designed technology were carried out. Good quality of drop forgings were obtained. On the basis of conducted research, it was stated that hammer forging of lever drop forging from AZ31 magnesium alloy is possible.

Keywords: AZ31 magnesium alloy, lever drop forging, hammer forging process

INTRODUCTION

The basic advantage of magnesium alloys is small mass density and good mechanical properties at the same time. This causes that they are very attractive e.g for aviation industry. Works, which results are presented in the following paper and aiming at implementing a lever from magnesium alloy AZ31 in light planes design, seem to be within this tendency. It was assumed that due to resistance reasons the lever will be made from a semi-finished product in the form of a drop forging. Technologies of drop forgings manufacturing from magnesium alloys described in specialist literature are based on forging with small velocities in conditions close to isothermal [1 - 7]. Special devices are usually used for tools heating.

The authors of the paper tried to make a lever forging by means of forging on die hammer without special devices for tools heating. The hammers advantages result from their universality, which is especially crucial in the case of elongated forgings manufacturing.

Mastering this technology in relation to magnesium alloys will widen number of plants, potential manufacturers of forgings form magnesium alloy.

DESCRIPTION OF RESEARCH WORKS

The scope of research works included designing of a forging on the basis of finished part, designing of forging technology, theoretical and experimental verification of assumed solutions. Figure 1a shows a model of a finished lever. On the basis of this model a forging was designed, assuming all necessary allowance (Figure 1b).

The next stage was designing of hammer forging technology, in which the most important operations are:

- cutting of billet in the form of bar into dimension ∅ 40 mm × 210 mm,
- billet material heating to the temperature of forging beginning equal 410 °C,
- bending and initial forging (it was assumed that bending operation will be made with application of one stroke, yet, initial forging operation with application of 2 - 4 strokes),
- manufacturing allowance trimming,
- preform heating to the temperature of forging beginning equal 410 °C,
- final forging (2 strokes assumed),
- trimming.

Next stage of research works was theoretical verification of the worked out forging technology. In order to do that numerical simulations were made with the application of software Deform 3D basing on finite ele-

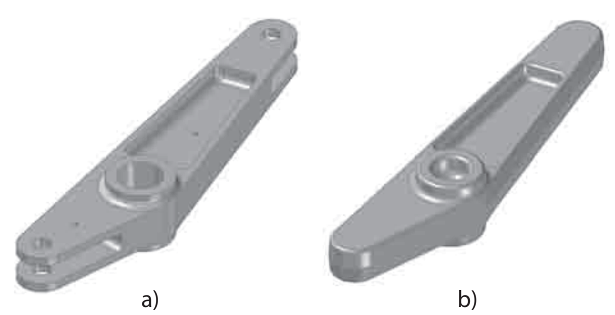
a) b)

Figure 1 Models of part (a) and forging (b) of lever from magnesium alloy AZ31

A. Gontarz, Z. Pater, K. Drozdowski, Lublin University of Technology, Lublin, Poland

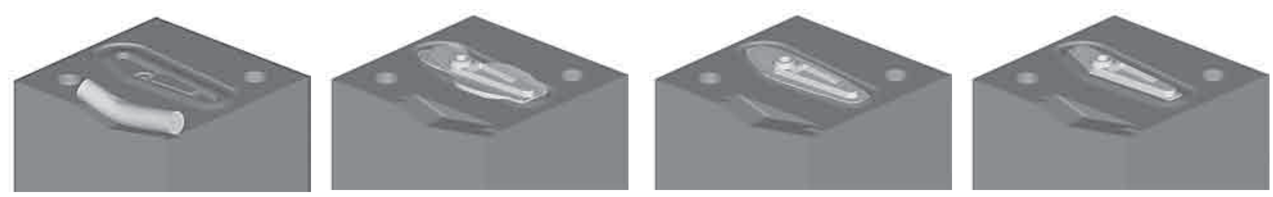

Figure 2 Results of numerical simulation presenting particular forging operations: a) bending, b) initial forging, c) preform after allowance trimming, d) finished forging

ment method. The analysis was conducted assuming three dimensional state of strain. Material model was worked out on the basis of literature data [8,9]. Friction conditions were described by means of constant friction model. On the basis of own research works it was assumed that friction factor corresponding to conditions of grease lubrication in form of tallow-graphite was *m*=0,24 [10]. Moreover, it was assumed that heat transfer coefficient between the deformed material and tool was assumed equal 11 000 $W \cdot m^{-2} \cdot K^{-1}$, and between the material and the environment 20 $W \cdot m^{-2} \cdot K^{-1}$ [6]. Tools rigid material was assumed.

Experimental research works were planned after theoretical verification. It was assumed that they would be made in one of Polish forging plants. Drop forging dies were designed and constructed. In order to lower costs flash was cut by means of band-saws, due to which there was no necessity of blanking die manufacturing. Electric box-type furnace was used for billet and preform heating. Forging tests were made on die steam-air hammer of stroke energy equal 63 kJ and mass of the falling part 2 100 kg.

THEORETICAL ANALYSIS RESULTS

Figure 2 presents results of simulations of particular forming operations. Bending of billet heated to the temperature 410 °C was made applying one stroke of hammer ram (Figure 2a). Next, it was placed in die impression rotating at 90 ° and forged with unfilling equal 3 mm (Figure 2b). After preform cooling allowance was cut (Figure 2c) and after reheating to the temperature 410 °C it was forged in die impression until finished forging was obtained (Figure 2d).

The analysis of finished forming shape showed that it does not contain faults connected with improper filling of the impression. However, detailed analysis of flow kinematics indicates the possibility of overlapping in the initial forging operation. The stage of the process in which overlapping appears is shown in Figure 3. Faults are located in the area of rounding of internal rib part. The cause of these faults appearance is material flow in two opposite directions. It should be considered that in initial forging operation overlapping will appear, and its depth is relatively large. It was assumed that if this fault appears in experimental tests it will be necessary to introduce additional initial impression. In present technology this impression is omitted due to the necessity of additional die usage, which will considerably increase the product cost by piece.

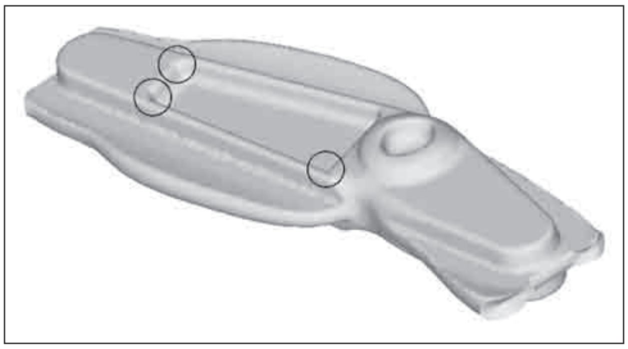

Figure 3 Overlapping appearance (marked by circle) in initial forming operation

Unfavorable phenomenon in forging process on hammer, concerning especially magnesium alloys, can be material cracking. In software for forming processes simulations are available numerous criteria for cracks analysis. The normalized Cockroft-Latham criterion is often applied, described by dependency [11,12]:

$$C = \int_0^{\varepsilon} \frac{\sigma_1}{\sigma_i} \, d\varepsilon, \qquad (1)$$

where:
σ_1 – the largest main stress,
σ_i – equivalent stress,
ε – strain.
C – integral value.

It results from own experience that precise forecasting of cracking beginning is very difficult, yet this criterion can be applied for qualitative evaluation, that means pointing at areas where the danger of material cracking is the biggest. Because of that damage criterion according to Cockroft-Latham was analyzed. Figure 4 presents distribution of integral *C* characterizing this criterion at final stage of initial forging operation, in which it reaches the largest values. As it can be observed they are upper ribs parts and lever hub (without flash considering). Hence, they are areas in which the danger of cracks is the largest.

Large strain rates, characteristic in hammer forging processes, can cause excessive increase of the material temperature and overheating, in consequences. The analysis of temperature distribution in forging volume showed that the largest temperature was noticed in flash, where the temperature increased above 500 °C (Figure 5). Flash is removed so this result will not have influ-

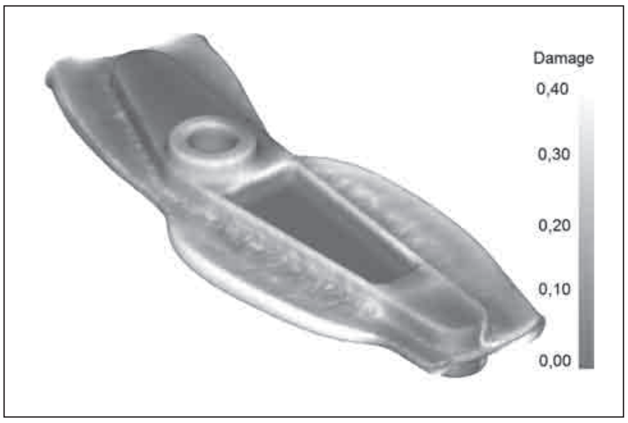

Figure 4 Distribution of damage criterion according to Cocroft-Latham at final stage of initial forging operation

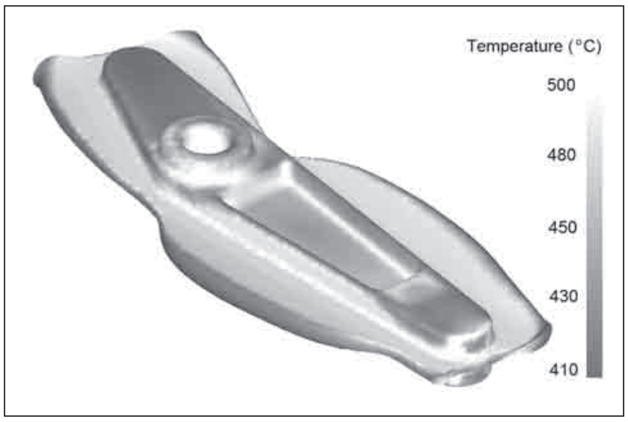

Figure 5 Temperature distribution in the drop forging at final stage of final forging operation

a) b) c) d)

Figure 6 The product shape after the following forging stages: a) bending, b) initial operation, c) trimming, d) final operation

ence on the forging quality. Large increase of the temperature was also present in flat bottom of the forging ribbed part in the final forging operation. Calculated distribution of this parameter shows that overheating is possible in some places.

On the basis of simulations results it was stated that bending operation can be made applying one stroke, initial forging operation can be made with four strokes, and however final forging operation can be made with two strokes. This confirms appropriate choice of the hammer size of stroke energy 63 kJ.

EXPERIMENTAL TESTS RESULTS

First forging tests were conducted according to the designed technology. The applied number of strokes in convergence with simulations was appropriate for forging manufacturing. The product shape at particular stages of forging is presented in Figure 6. Qualitative evaluation of the first series of preforms and forgings show that they contain overlapping (Figure 7). Its localization is consistent with theoretical model (compare Figure 3). Faults appear during initial forging operation in the area of rounding of cavity in the product head part, at its both sides. Because of that the initial forging operation was made by means of eight strokes (instead of four) of smaller energy. It occurred that material flow improved considerably. Products of good quality without faults were obtained (Figure 8). Application of larger number of strokes results, in consequences, in decrease of the deformed material temperature. Because of that, this parameter should be thoroughly controlled. In case of necessity, preforms were heated in order to finish initial forging operation, which is crucial in the aspect of overlapping presence.

It should be added that some finished forgings had cracks at ribs base. Conditions favorable in this fault presence are: lowering of the temperature and large stroke energy in the final forging operation. Larger number of strokes with smaller energy should be used. Improvement of forming conditions can be also reached by increasing rounding radius from 3 mm to 5 mm, which will be applied in the case of series production. Apart from limiting phenomena, retaining appropriate

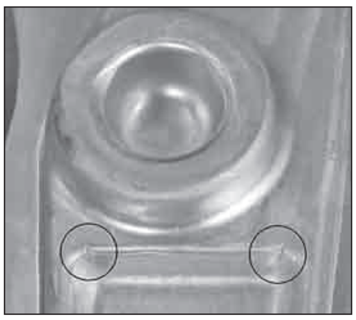

Figure 7 Overlapping present in the product after initial operation

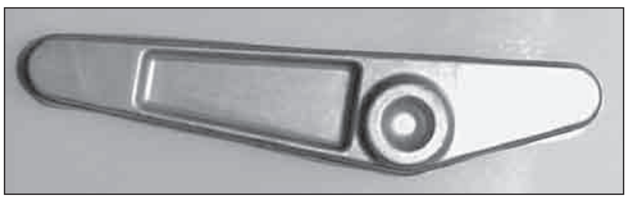

Figure 8 Lever drop forging

process course and application of given corrections will allow for obtaining proper products.

CONCLUSIONS

On the basis of conducted theoretical- experimental research, it was stated that forging of the analyzed lever forging from alloy AZ31 with application of die hammer and without tools heating is possible. Although the temperature and velocity conditions are not favorable, products of good quality can be obtained by means of this technology.

It should be highlighted that application of numerical simulations at the stage of forging technology working out allowed for verification of correctness of the process parameters and tools design, as well as for choice of forging machine. Because of that it is possible to lower experimental research costs.

One of the limitations of the lever forging process is overlapping. The application of larger number of strokes of smaller energy acted on the improvement of material flow and allowed for elimination of this fault. It can be supposed that the application of initial die impression will also limit overlapping presence.

The next limitation noticed in some products are cracks localized at ribs base. In this case, the application of initial die impression will improve forming conditions and limit this fault presence as well. However, the key parameters seem to be the temperature and strain rate. Hence, the process should be realized applying larger number of strokes with smaller energy and, moreover, the temperature requirements should be fulfilled.

Acknowledgments

Financial support of Structural Funds in the Operational Programme - Innovative Economy (IE OP) financed from the European Regional Development Fund - Project "Modern material technologies in aerospace industry", No POIG.01.01.02-00-015/08-00 is gratefully acknowledged.

REFERENCES

[1] Q. Wang, Z. Zhang, X. Zhang, J. Yu, Transaction of Nonferrous Metals Society of China, 18 (2008), 205-208.

[2] Q. Wang, Z. Zhang, X. Zhang, G. Li, Transaction of Nonferrous Metals Society of China, 20 (2010), 599-603.

[3] K. Schemme, H. Lowak, Manufacturing of light-weight wheels by forging and flow-forming - Competitive Advantages by Near-Net-Shape Manufacturing, H. D. Kunze (ed.), DGM Informations-gesellschaft mbH, Frankfurt/Main, 1997, 115-120.

[4] M. Fujita,Y. Yamamoto, N. Sakate, S. Hirabara, Method of making an article of manufacture made of a magnesium alloy, U.S. Patent No. 5902424, (11.05.1999).

[5] P. Skubisz, J. Sinczak, S. Bednarek, Journal of Materials Processing Technology, 177 (2006) 1-3, 210-213.

[6] L. Juan, C. Zhenshan, Journal of Materials Processing Technology, 209 (2009) 18-19, 5871-5880.

[7] D. B. Shan, W. C. Xu, Y. Lu, Journal of Materials Processing Technology, 151 (2004) 1-3, 289-293.

[8] M. Legerski, E. Hadasik, D. Kuc, Hutnik - Wiadomości Hutnicze, 8 (2008), 494-497 (in Polish).

[9] S. R. Agnew, O. Duygulu, International Journal of Plasticity, 21 (2005) 6, 1161-1193.

[10] A. Gontarz, A. Dziubinska, L. Okon, Archives of Metallurgy and Materials, 56 (2011) 2, 379-384.

[11] M. G. Cockcroft, D. J. Latham, Journal of the Institute of Metals, 96 (1968), 33-39.

[12] K. H. Shim, S. K. Lee, B. S. Kang, S. M. Hwang, Journal of Materials Processing Technology, 155-156(2004), 1935-1942.

Note: The professional translator for English language is A. Bartnicka, SIMPTEST Lublin, Poland