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THEORETICAL AND EXPERIMENTAL RESEARCH OF HAMMER FORGING PROCESS OF RIM FROM AZ31 MAGNESIUM ALLOY

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The results of theoretical analysis and experimental tests of hammer forging process of rim part from AZ31 magnesium alloy are presented in this paper. On the basis of numerical simulation results, the analysis of limiting phenomena was made. These phenomena include: possibility of overlapping presence, not filling of die impression, overheating of material and cracks. The results of theoretical analysis provided the support for planning of experimental tests in industrial conditions. Forging tests were conducted in one of Polish forming plants, applying steam-air hammer of blow energy 63 kJ. On the basis of experimental verification, it was stated that it is possible to obtain rim forging from AZ31 alloy of assumed quality in the hammer forging process.

Key words: hammer forging process, AZ31 magnesium alloy, finite element method, industrial test

INTRODUCTION

Magnesium alloys, due to low weight are very attractive to automotive and aviation industries. They are applied on low or medium service loaded parts including rims. Two technologies are applied for rims manufacturing: casting and metal forming. Semi finished parts obtained by these methods are machined to obtain final parts.

Manufacturing of rim by casting is realized by means of gravity casting, low pressure casting or squeeze casting [1]. Parts made by these technologies posses typical casting defects as different inclusions or porosities, which causes that their mechanical properties do not meet stated requirements.

Much better effects are obtained applying metal forming methods. For rims metal forming are used: press forging [1], hollowed billet extrusion [2], flow-forming process [3], and spin forging process [4]. Limitations in metal forming of magnesium alloys are the effect of small plasticity in too low temperatures. Favorable forming conditions are obtained at low strain rates and at preserving isothermal conditions. Due to that forging processes of these alloys are realized on presses equipped with special tools heating systems. Guaranteeing of these process conditions increases costs of forming in comparison with typical forging methods.

In the presented paper, the results of conventional forming process of a rim forging from AZ31 magnesium alloy on a die hammer are presented. In this process unfavorable conditions are noticed: large strain rates and relatively low tools temperature, which acts on lowering of the formed material temperature [5]. It was assumed that positive results of such a forming process would allow for its application in factories equipped in die hammers. In consequences, the number of potential manufacturers of rims from magnesium alloys would increase and manufacturing costs would lower due to cheaper tools (lack of heating elements), which justifies the rightness of the conducted research works.

DESCRIPTION OF THE SCOPE OF RESEARCH WORKS

The rim, which model is shown in Figure 1a, is destined for application in light planes. It was designed at Aviation Institute in Warsaw (Poland). In order to obtain better mechanical and functional properties it was assumed that the rim would be made from a semi-finished product in the form of forging. Considering allowance, a forging, which model is shown in Figure 1b, was designed. One of the analyzed technologies was die forging on hammer. The research works were divided

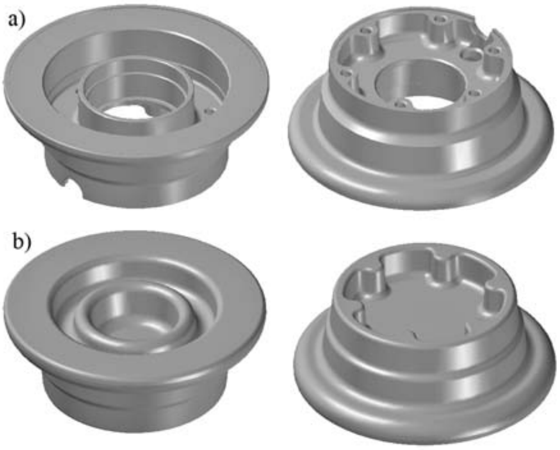

Figure 1 Rim model (a) and drop forging model (b)

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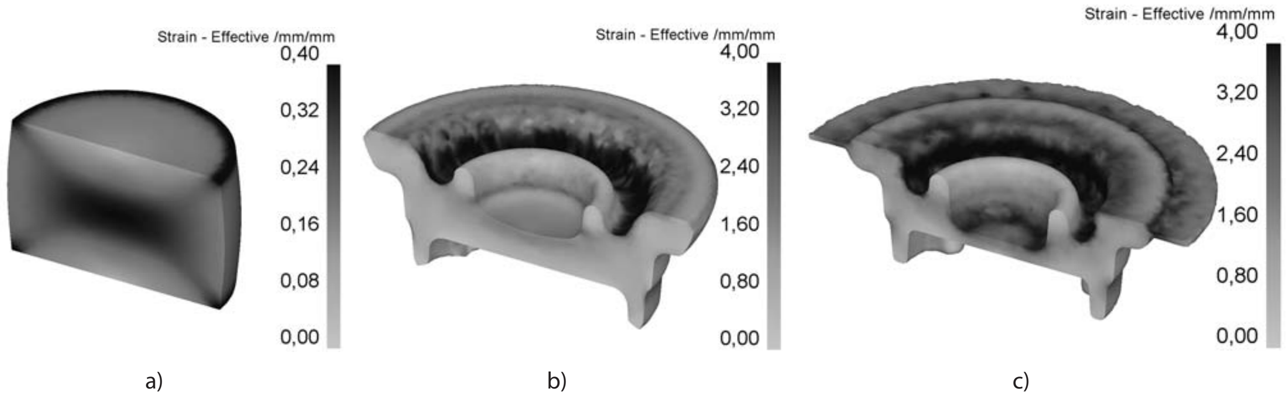


a) b) c)

Figure 2 Distribution of strain in the formed material after operation: a) upsetting, b) preliminary operation, c) final operation

into two stages. The first one considered numerical analysis based on numerous simulations by means of finite element method. The second stage concerned forging tests in industrial conditions.

THEORETICAL ANALYSIS RESULTS

Commercial software Deform 3D based only one on Finite element method was used for theoretical analysis. Thermo-mechanical model of the process was considered. Calculations were made assuming three-dimensional state of strain. Material model was worked out on the basis of literature data dealing with plastometric research on alloy AZ31 [6-8]. It was assumed in calculations that the material heating temperature was 410 °C, tools temperature equaled 250 °C. Heat transfer coefficient between the deformed material and tool was assumed equal 11 000 W·m^{-2}·K^{-1}, and between the material and the environment 20 W·m^{-2}·K^{-1} [9]. A model of constant friction was assumed in which the friction factor corresponding to conditions of magnesium-steel alloy contact with lubrication of graphite grease equaled m = 0,24 [10]. The model of a die hammer with the mass of falling part M = 2 100 kg and blow energy 63 kJ was used. It was assumed that the stroke efficiency was 60 %.

On the basis of the volume of a finished forming and considering the flash volume, the billet in the form a cylinder of dimensions ∅100 mm × 93 mm was chosen. It was assumed that the forging process would be conducted in two main operations: preliminary operation (forging in the initial impression) and final operation (forging in the final impression). After preliminary operation additional heating was predicted. The results of initial simulations showed that during forging in the initial impression overlapping appeared in the forging. Hence, upsetting operation of the billet at height h = 80 mm and proceeding the preliminary operation was introduced. Additional operation did not bring expected results. Overlapping was still present in the forging. Only the billet upsetting at the height h = 70 mm gave positive results. Results of simulations of such a forging variant showed that overlapping did not appear. Hence, it was assumed that the billet would be upset to this height. Numerical simulation of the whole forging process with the application of upsetting initial operation at the height h = 70 mm was conducted. The shape of the forging with presented distribution of strain after each forging operation is shown in Figure 2. Strains distribution character is typical for forming processes on hammer. Larger values are present in the forging upper part, from the striking tool side. Evaluation of the forging shape showed that the impression is properly filled and overlapping was not observed. The flash volume was small, which means that the billet volume was correctly chosen. On the basis of the obtained results it was stated that the analyzed process guaranteed achieving a product of good geometrical quality.

Energy necessary for forming operations was also calculated in simulation. Figure 3 presents the energy of particular blows. As it results from calculations, for the upsetting operation one stroke is needed, for preliminary operation 2 strokes and for final operations likewise 2 strokes.

During designing of forging processes a rule is used, according to which the hammer size is appropriate if the forging operation is conducted by means of 2 - 4 strokes. Assuming this rule as evaluation criterion, it can be stated that the assumed die hammer is adequate for the analyzed process realization.

RESEARCH WORKS IN INDUSTRIAL CONDITION

On the basis of the obtained results of calculations, technology of wheel rim forging manufacturing was

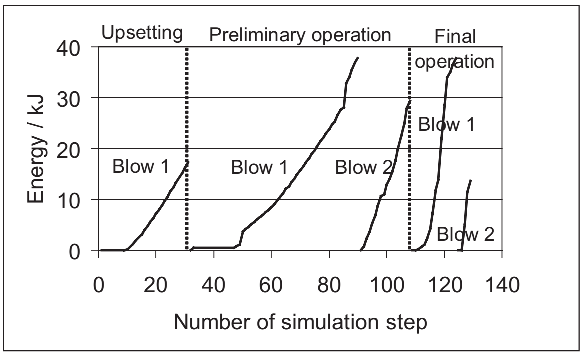
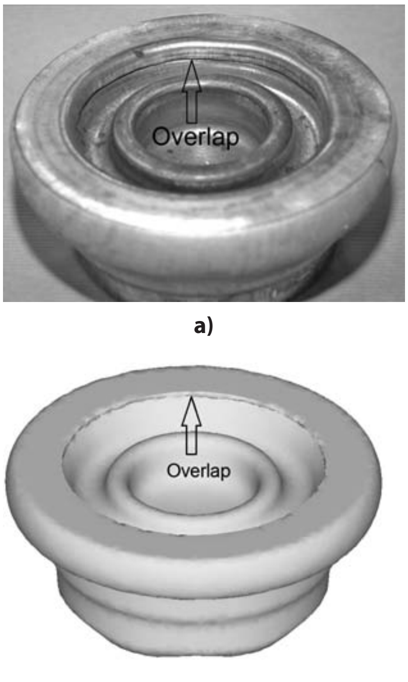


Figure 3 Forging energy at the particular operations of the process



a)

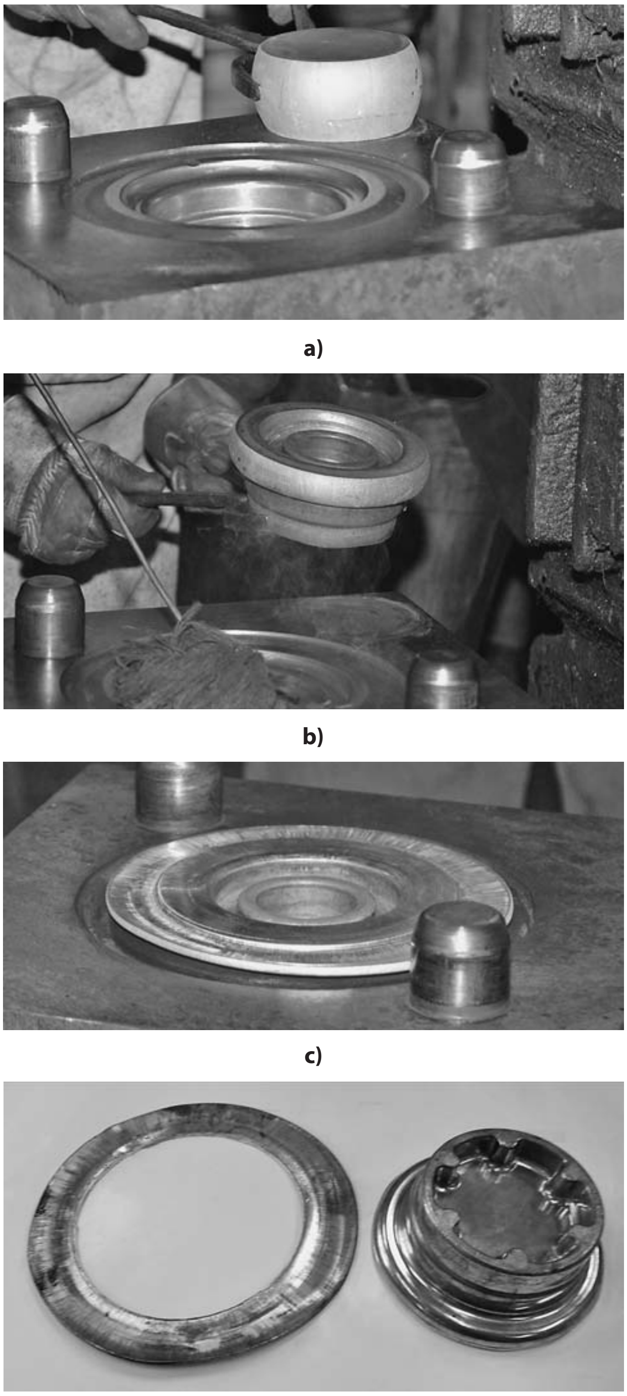
b)

Figure 4 Overlapping present in the forging made without upsetting: a) results of simulations, b) results of experiments

worked out, which consists of the following main operations:

- billet material cutting (extruded bar) to the dimensions ∅100 mm × 93 mm,
- billet heating to the temperature 410 °C,
- upsetting and initial forging,
- control of the preform quality,
- preform heating to the temperature 410 °C,
- forging in the final impression,
- flash trimming,
- solution heat treatment and aging,
- control of the forging quality,
- research on mechanical properties,
- manufacturing of a finished part by machining.

Forging tests were made after designing and manufacturing of tools. A die hammer with the mass of falling part equal 2 100 kg and blow energy equal 63 kJ was used. During forging lubrication was used by means of tallow and graphite type lubricant. The first forgings were made omitting the upsetting operation. The aim of these tests was verification of this operation necessity. A forging with overlapping in the same area as in the case of numerical simulations was obtained (Figure 4). During next tests, the billet was upset at the height 70 mm, yet, the following operations of the technological process were used. In the forging operations the following number of blows was applied: upsetting - 1 blow, preliminary operation - 3 blows, final operation - 3 blows. These results show that the hammer size was correctly chosen. Particular stages of the forging process are given in Figure 5. The manufactured forgings are without faults. Cracks, overlapping or infilling of the impression were not observed. Forgings underwent research on mechanical properties. During the tension test of specimens cut across fibres, the following results were obtained: tensile strength R_m = 268 MPa, yield strength R_e = 183 MPa, elongation A = 15 %. These properties fulfilled the requirements determined in technical conditions concerning the analyzed rim. Industrial tests results were assumed as positive; due to that a test series of forgings was made. Next, they underwent machining operations in order to obtain finished rims (Figure 6), which were destined for certification research works, allowing for these elements application in light planes.



a)

b)

c)

d)

Figure 5 The product shape after the following forging stages: a) upsetting, b) preliminary operations, c) final operation, d) trimming

Figure 6 Finished product made from the forging by means of machining

CONCLUSIONS

On the basis of obtained results of numerical analysis and industrial tests it was stated that the forming of magnesium alloy AZ31 wheel rim forging is possible by means of die forging hammer. In this process, despite of unfavorable temperature and strain rate conditions, a correct part without shape faults and characterized by good mechanical proper-ties was obtained.

Theoretical and experimental research works show that it is necessary to apply upsetting operations. Forging from the billet which has too small diameter causes overlapping during preliminary forging.

Confirmation of die forging hammer application in wheel rim part forming form magnesium alloy will permit to apply this technology in forging plants which are not equipped with presses with needed load, but which dispose die forging hammer. The advantage of the presented technology is lower cost and lower time of manufacturing preparation comparing with forging on presses in isothermal conditions.

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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, pp. 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] A. Gontarz, Z. Pater, K. Drozdowski, Metalurgija, 52 (2013) 3, 359-362.

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

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

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

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

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

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