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STUDIES ON THE CONDITIONS OF HOMOGENIZATION AND PROPERTIES IN HOT FORMING OF ZK60 CAST MAGNESIUM ALLOY

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This paper presents a study of temperature conditions for the homogenization of a cast high-strength ZK60 alloy belonging to the Mg-Zn-Zr group of magnesium alloys. On the basis of a literature review, two-stage homogenization conditions were selected to improve the forgeability of the ZK60 casting. The effectiveness of this treatment was evaluated experimentally on the basis of structure and hardness tests and was found to be satisfactory. Plastometric tests were carried out for the samples made from the ingots after homogenization. These tests were performed in a compression test in hot forming conditions at three temperatures (350 °C, 400 °C and 450 °C) and four strain rates (0,01; 0,1; 1,0 and 10 s-1). The determined flow curves will be used to develop a material model of the cast magnesium alloy ZK60 for numerical simulations.

Keywords: ZK60 cast, homogenization, hot forming, plastometric tests, properties

INTRODUCTION

This article describes a study of material properties that was conducted to obtain data for designing a new process for manufacturing connectors by die forging from a cast preform. The cast ZK60 alloy is prone to cracking during forging. Its forgeability can be improved by applying homogenization heat treatment [1]. The parameters of this treatment (temperature and duration) were selected based on a literature review and the authors' own research on the basis of analysis of the structure and hardness after heat treatment of castings. The design of the preform shape will be assisted by the finite element method (FE) analysis, which requires knowledge of the material's flow properties. Therefore, the flow stress curves of the homogenized ZK60 casting were obtained from compression tests for implementation into the FE model [2].

RESEARCH METHODOLOGY

The high strength ZK60 alloy (having a wide range of applications in the automotive and aerospace industry), belonging to the Mg-Zn-Zr group of Mg alloys, has been selected for the study [3, 4]. The chemical composition of the ZK60 is shown in Table 1 [5].

Based on the analysis of available standards and specialized literature [6-18], the technological parameters of homogenization heat treatment for ZK60 alloy for testing were determined. The following conditions were selected for testing: use a two-stage homogenization treatment:

- first stage at temperature of 350 °C for 10 h,
- second stage at temperature of 450 °C for 6 h. Cooling in water recommended, but not necessary (air) depending on the shape of the casting.

Table 1 **Chemical composition of ZK60 magnesium alloy cast / wt. % [5]**

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	

Subsequently, heat treatment was performed on sand casting ingots (Figure 1) made of magnesium alloy ZK60 in LAC's electric furnaces to check the effectiveness of the defined homogenisation heat treatment conditions.

Structure and hardness tests were performed for the ingots after casting and after homogenization. Firstly, samples were prepared for structure testing, which were subjected to the process of grinding and polishing. Initially, grinding was applied on a SiC-coated abrasive disc with grain size of 400 µm for 60/120 s. Then, polishing with a diamond suspension of 9 µm was applied for 3 minutes. The next step was polishing with the use of a diamond suspension with a grain size of up to 3 µm for 180/360 s. After polishing was carried out with colloidal silica with a grain size of 0,05 µm for 240 s. Between each step, the samples were rinsed substantially with alcohol to counteract surface oxidation. Then, the polished samples' surfaces were made, and the samples were etched by immersion and gentle stir-

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Figure 1 Ingots cast from ZK60 magnesium alloy

Table 2 **Findings of the literature review on homogenization conditions of ZK60 cast magnesium alloy**

Literature source	Conditions for homogenization
[6]	The optimal treatment was found to be homogenisation at the temperature of 420 °C for 10 h. This founding was consistent with the result obtained by homogenising kinetics.
[7]	Specimens machined from a cast ingot were heated at a temperature of 450 °C for 3,5 h.
[8]	Homogenized at about 430 °C for 16 h to eliminate the possible structural inhomogeneities.
[9]	The as-cast material was homogenized for 4 h at 400 °C in a fluidized sand bath furnace followed by water quenching.
[10]	The suggested homogenizing treatment for ZK60 alloy is 470 °C for 14 h. Homogenization at 400 °C leads to the effective dissolution of second-phase particles whereas homogenization at 300 °C has little effect on them.
[11]	ZK60 magnesium alloy after the annealing treatment was heated at 500 °C for 2 h and then cooled to room temperature in the air.
[12]	First, the ingots were subjected to a homogenizing annealing treatment at 330 °C for 24 h followed by 4 h at 420 °C h.
[13]	Before extrusion, samples were homogenized at 450 °C for 8 h, followed by quenching in water.
[14]	ZK60 alloy was subjected to the homogenization heat treatment at 400 °C for 4 h.
[15]	Homogenisation heat treatment at 400 °C for 24 h.
[16]	Cast billets were homogenized at 440 °C for 8 h and then water quenched.
[17]	The homogenization treatment was carried out at a temperature of 350 °C for 10 hours followed by another homogenization at 450 °C for 5 hours to dissolve Zn and Zr intermetallic compounds which could cause cracking during rolling.
[18]	The ingots were homogenized at 350 °C for 10 hours with subsequent heating to 450 °C and soaking at this temperature for 5 hours.

ring for 10/15 s in a solution of the following composition: 100 ml ethanol, 10 ml distilled water, 10 ml acetic acid, and 5 g picric acid etchant. Microstructural examinations were carried out using the Nikon MA200 optical microscope. Hardness measurements were made using the Vickers method with the Future-tech FM800 hardness tester. Measurements were made on the HV0,5 scale in accordance with PN-EN ISO 6507-1: 2006.

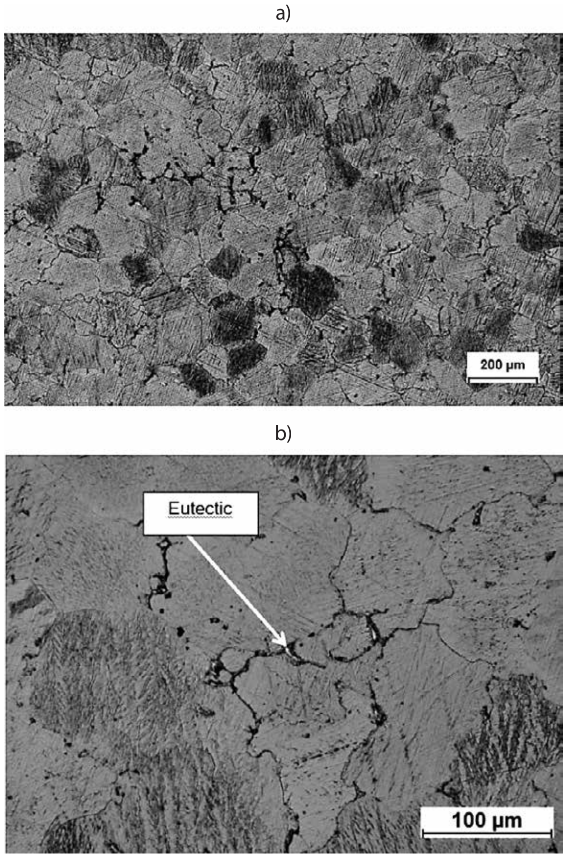

Figure 2 Microstructures of as-cast ZK60 magnesium alloy with magnification 50 x (a) and 200 x (b)

Plastometric tests were carried out to determine the properties of ZK60 cast magnesium alloy in hot forming conditions.

Compression specimens were machined from the homogenised cast ingots (Figure 1). Tests were carried out at temperatures 350 ºC, 400 ºC, 450 ºC, and strain rates 0,01; 0,1; 1,0 and 10 s^{-1}. The tests were performed on a Zwick 250 testing machine using specimens with dimensions Æ12 mm x 18 mm. All samples were compressed to a height reduction of 50 %. For each parameter, three measurements were used, and the results were averaged.

ANALYSIS OF THE RESULTS

Homogenisation heat treatments applied to the cast ZK60 magnesium alloy before forging by different researchers is summarised in Table 2 [6-18]. Homogenisation conditions varied considerably in the reviewed articles. Some authors were applying two-stage treatment, others one-stage treatment. In a two-stage treatment, the first stage was carried out at temperatures ranging from 300 ºC to 350 ºC while the second stage at temperatures above 400 ºC but not exceeding 450 ºC. The duration of the first stage was longer than the duration of the second stage. The one-stage homogenisation treatments were carried out at temperatures ranging from 400 ºC to 500 ºC. Again, the duration of the treatment varied and wasn't always shorter at higher tem-

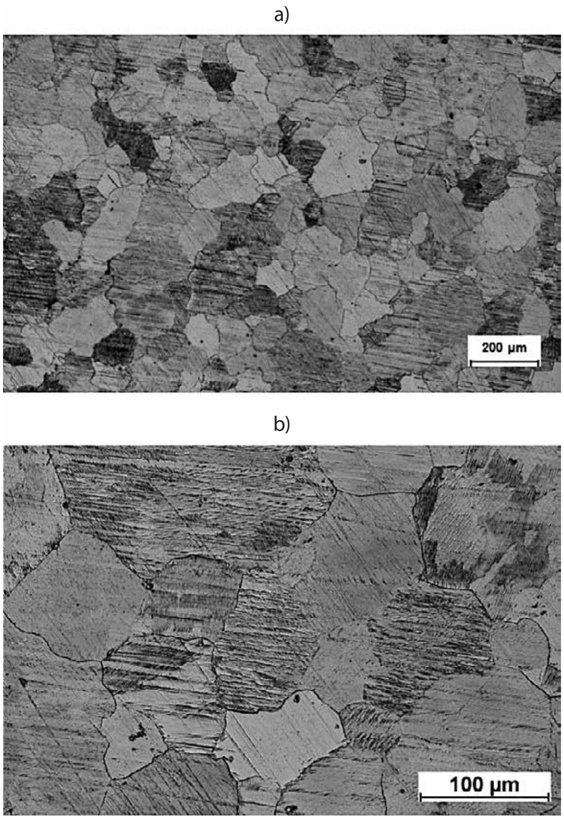

Figure 3 Microstructures of homogenised ZK60 cast magnesium alloy with magnification 50 x (a) and 200 x (b)

Table 3 **Hardness measurements of ZK60 cast magnesium alloy**

State of the sample	Mean of 6 measurements /HV05	Standard deviation
Cast	50,2	4,9
Cast after homogenisation	43,9	2,9

peratures than one could expect. There was no justification for using the specific conditions.

The microstructure of as-cast and homogenised ZK60 is shown in Figure 2 and Figure 3, respectively. The microstructure of the as-cast ZK60 alloy comprises a-Mg grains of dendritic structure and secondary phases (intermetallic compounds formed by Mg and Zn e.g., MgZn2, MgZn or others) which are distributed along grains boundaries. Because zirconium is added to control grain growth in ZK60, the point-size particles, seen as black points, are most likely to be Zr particles. Application of the homogenisation heat treatment resulted in the dissolution of secondary phases in the a-Mg matrix. There was no noticeable grain growth due to the addition of Zr. The microstructure developed during the applied homogenisation heat treatment was satisfactory, therefore, it was applied to the remaining ZK60 ingots.

Table 3 shows the results of measuring the hardness of samples made of ZK60 cast magnesium alloy for each of the tested variants. The hardness of the alloy in the state after casting averages 50,2 HV. After homogenization of the casting, the hardness of the alloy decreases to 43 HV.

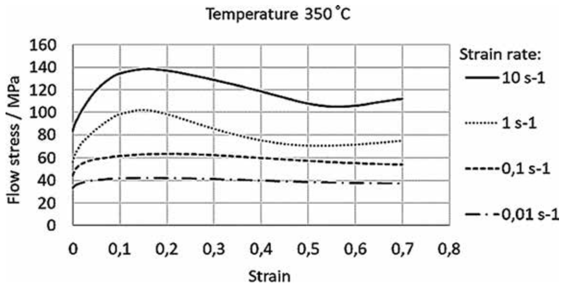

Figure 4 Flow stress curves of ZK60 cast alloy at a temperature of 350 ºC

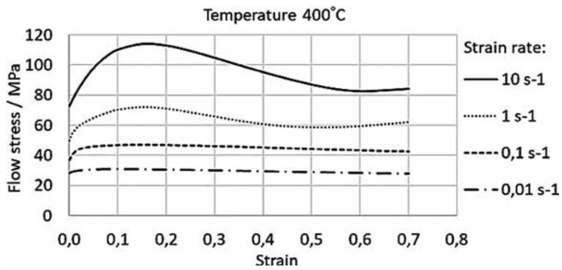

Figure 5 Flow stress curves of ZK60 cast alloy at a temperature of 400 ºC

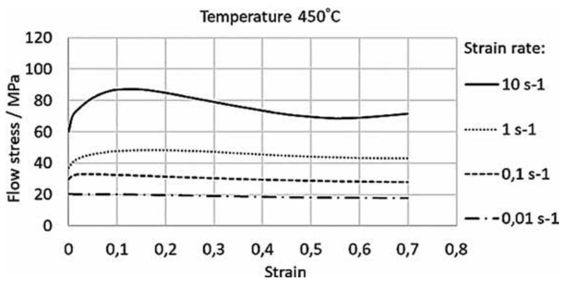

Figure 6 Flow stress curves of ZK60 cast alloy at a temperature of 450 ºC

Data recorded during plastometric tests (force and ram displacement) were used to calculate flow stress curves. Results in a form of charts are shown in Figures 4 - 6 for temperatures of 350 ºC, 400 ºC and 450 ºC, respectively.

CONCLUSION

Based on the obtained results the following conclusions are drawn:

- Application of the proposed two-stage homogenisation heat treatment to the cast ZK60 alloy resulted in a complete dissolution of the second phases in a-Mg matrix without noticeable growth of grains. Therefore, the treatment was satisfactory and will be applied to cast preforms prior to forging. The remaining ZK60 ingots were homogenised using this treatment before machining specimens for compression tests.
- Based on the results obtained from plastometric tests, the flow curves of the ZK60 cast magnesium alloy were determined. The obtained relations of flow stresses to strains will be implemented into the

material model in programs for the simulation of metal forming processes. In addition, based on the results from compression tests in plastometric tests conducted, the susceptibility of this alloy to hot forming at temperatures in the range from 350 ºC to 450 ºC, and strain rates 0,01; 0,1; 1,0 and 10 s^{-1} were confirmed.

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