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Heat treatment impact on the structure of die-cast magnesium alloys

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ABSTRACT

Purpose: In the following paper there have been the structure and properties of the MCMgAl6Zn1 magnesium cast alloy as-cast state and after a heat treatment presented.
Design/methodology/approach: A casting cycle of alloys has been carried out in an induction crucible furnace using a protective salt bath Flux 12 equipped with two ceramic filters at the melting temperature of 750±10ºC, suitable for the manufactured material. The following results concern light and scanning microscopy, X-ray qualitative and quantitative microanalysis.
Findings: The results of the EDS chemical composition analysis confirm the presence of magnesium, aluminum, manganese, and zinc, constituting the structure of α solid solution with the $Mg_{17}Al_{12}$ placed mainly on the grain order in the form of plates, also the phase AlMnFe with irregular shape, occurred often in the shape of blocks or needles and the Laves phase Mg_2Si.
Research limitations/implications: According to the alloys characteristic, the applied cooling rate and alloy additions seems to be a good compromise for mechanical properties and microstructures, nevertheless further tests should be carried out in order to examine different cooling rates and parameters of solution treatment process and aging process.
Practical implications: A desire to create as light vehicle constructions as possible and connected with it low fuel consumption have made it possible to make use of magnesium alloys as a constructional material in automotive industry.
Originality/value: The undertaken examinations aim at defining the influence of a chemical composition and precipitation processes on the structure and casting magnesium alloy properties in its as-cast state and after heat treatment with a different content of alloy components.
Keywords: Heat treatment; Metallography; Magnesium alloys; Structure

1. Introduction

The material selection is preceded by the analysis of many factors like: mechanical, design, environmental, urbanization, recycling, cost, availability, and weight related issues, which may change the existing conditions and emerge the needs resulting from the supplier-customer relation. The strive to decrease the weight of products becomes an important challenge for designers and process engineers. The excessive weight verifies a significant extent the possibilities of employing particular material groups. Contemporary materials should possess high mechanical properties, physical and chemical, as well as technological ones, to ensure long and reliable use. The above requirements and expectations regarding the contemporary materials are met by the non-ferrous metals alloys used nowadays, including the magnesium alloys [1-10].

Magnesium alloys which are successfully used for a long time in different industry branches are a combination of low density and high strength (Table 1) [11-15].

The above features together with low inertia have significantly contributed to the wide use of magnesium alloys in fast moving elements, in locations where rapid velocity changes occur and in products in which lowering a final mass of a product is required. The greatest interest in magnesium alloys was shown and is still shown by an automotive industry [1-6].

The goal of this paper is to present of the investigation results of the casting magnesium alloy in its as-cast state and after heat treatment.

Table 1.
The examples of applications magnesium alloys [11-15]

Industry	Products	Required Properties									
		Lightness	Strength	Ductility	Vibration damping	Heat resistance	Heat dissipation	EMI shielding	Recyclable	Dimensional precision	Thin-wall molding
Auto-mobiles	Seat frames	•	•	•	•				•	•	•
	Steering wheels	•	•	•	•				•	•	
	Road wheel	•	•	•					•	•	
	Oil pumps	•	•						•		
	Key lock housing	•	•						•	•	
	Transmission parts	•	•		•				•	•	•
	Navigation system parts		•			•		•	•	•	•
Electronic equipment Office equipment Communi-cations	Cameras	•	•						•	•	•
	Video cameras	•	•				•	•	•	•	•
	Digital cameras	•	•					•	•	•	•
	Minidisk players	•	•					•	•	•	•
	(Personal Data Assistant parts	•	•				•	•	•	•	•
	Notebook type PC	•	•				•	•	•	•	•
	Cellular phone	•	•					•	•	•	
	Hard disk drives	•	•					•	•	•	
	CD-ROM drives	•	•			•	•		•	•	
	Optical pickups	•	•			•	•	•	•	•	•
	TV monitors	•	•				•	•	•	•	•
	Plasma displays	•	•			•	•	•	•	•	•
	LCD projectors	•				•	•		•		
Others	Power tools	•	•	•					•	•	
	Bicycle wheels	•	•						•		
	Fishing gears	•	•	•					•	•	

Table 2.
Chemical composition of investigation alloy

The mass concentration of main elements, %								
Al	Zn	Mn	Si	Fe	Pb	Ce	Mg	Rest
5,624	0,46	0,16	0,034	0,07	0,034	0,01	93,6	0,008

2. Experimental procedure

The investigations have been carried out on test pieces of MCMgAl6Zn1 magnesium alloys in as-cast and after heat treatment states (Table 3). The chemical composition of the investigated materials is given in Table 2. A casting cycle of alloys has been carried out in an induction crucible furnace using a protective salt bath *Flux 12* equipped with two ceramic filters at the melting temperature of 750±10ºC, suitable for the manufactured material. In order to maintain a metallurgical purity of the melting metal, a refining with a neutral gas with the industrial name of *Emgesalem Flux 12* has been carried out. The material has been cast in dies with betonite binder because of its excellent sorption properties.

The cast alloys have been heated in an electrical vacuum furnace *Classic 0816 Vak* in a protective argon atmosphere.

Metallographic examinations have been made on magnesium cast alloy specimens mounted in thermohardening resins. In order to disclose grain boundaries and the structure and to distinguish precisely the particular precipitations in magnesium alloys as an etching reagent a 5% molybdenic acid has been used. The time of the etching for each specimen was between 5-10 s. The observations of the investigated cast materials have been made on the light microscope LEICA MEF4A at magnification 500x as well as on the electron scanning microscope Opton DSM-940.

The X-ray qualitative and quantitative microanalysis and the analysis of a surface distribution of cast elements in the examined magnesium cast alloy specimens in as-cast and after heat treatment have been made on transverse microsections on the Opton DSM-940 scanning microscope with the Oxford EDS LINK ISIS dispersive radiation spectrometer at the accelerating voltage of 15 kV and on the JEOL JCXA 733 x-ray microanalizer.

3. Discussion of experimental results

As a result of metallographic investigations made on the light and scanning microscopes it has been confirmed that the magnesium cast alloys MCMgAl6Zn1 in the cast state are characterized by a microstructure of the solid solution α constituting the alloy matrix as well as the β – $Mg_{17}Al_{12}$ discontinuous intermetallic phase in the forms of plates located mostly at grain boundaries. Moreover, in the vicinity of the β intermetallic phase precipitations the presence of the needle eutectics (α+β) has been revealed (Fig. 1a).

There have appeared, after the process of solutioning with cooling in water and in the air, trace quantities of the β ($Mg_{17}Al_{12}$) phase and single precipitations of a Mg_2Si phase in the structure of the alloy. There have not been noticed any locations of eutectic occurrences in the structure (Fig. 1b). After the cooling bell annealing the structure of the solid solution α with many precipitations of the secondary phase β has been revealed (locations resembling eutectics). The precipitations of the β ($Mg_{17}Al_{12}$) phase, located at grain boundaries and the Mg_2Si phase located mostly at the phase β boundary have also been observed. The structure of this alloy is similar to the structure of the as-cast alloy (Fig. 1c). The applied ageing process after the solution heat treatment with cooling in the air has caused the release of the β phase at grain boundaries as well as in the form of pseudo eutectic locations. There have been revealed, in the structure of the material, the parallel twinned crystals (Fig. 1d).

a) b) c) d)

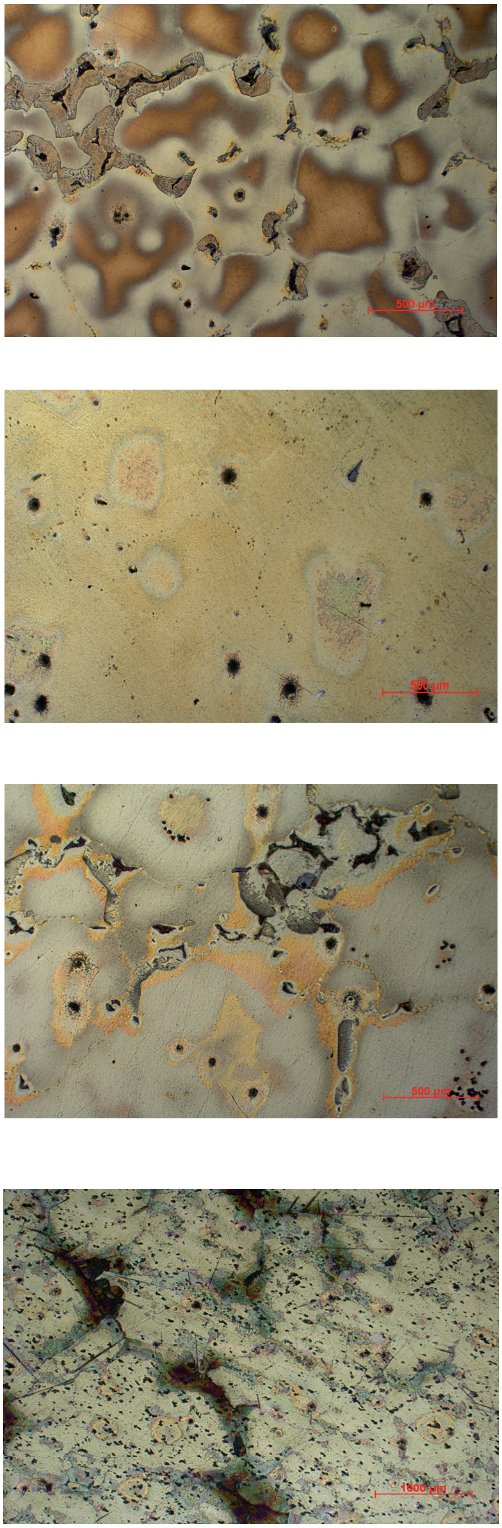

Fig 1. Microstructure alloy MCMgAl6Zn1: a) without heat treatment – 0, b) after heat treatment – 2, c) after heat treatment – 3, d) after heat treatment – 4

Table 3.
Parameters of heat treatment of investigated alloy

Sing the state of heat treatment	Solution treatment			Aging treatment		
	Temperature	Time	Cooling	Temperature	Time	Cooling
0	As-cast					
1	430	10	air	-	-	-
2	430	10	water	-	-	-
3	430	10	furnace	-	-	-
4	430	10	water	190	15	air

As a result of the surface decomposition of elements and the x-ray, quantitative micro analysis made using the EDS energy dispersive radiation spectrometer, the presence of the main alloy additions Mg, Al, Mn, Zn and also Fe and Si included in the magnesium cast alloys in as-cast and after the heat treatment has been confirmed. The chemical analysis of the surface element decomposition and the quantitative micro analysis made on the transverse microsections of the magnesium alloys using the EDS system have also confirmed the evident concentrations of magnesium, silicon, aluminium, manganese and iron what suggests the occurrence of precipitations containing Mg and Si with angular contours in the alloy structure as well as phases with high Mn and Al concentrations that are irregular with a non plain surface, often occurring in the forms of blocks or needles. A prevailing participation of magnesium and aluminium and a slight concentration of Zn has been ascertained in the alloy matrix as well as in the location of eutectics and big precipitations that arouse at phase boundaries identified as $Mg_{17}Al_{12}$.

4. Summary

The results of the metallographic examinations made on the light and scanning microscopes confirm the fact that the magnesium cast alloy MCMgAl6Zn1 is characterized by a microstructure of the solid solution α constituting the alloy matrix as well as the β – $Mg_{17}Al_{12}$ discontinuous intermetallic phase in the forms of plates located mostly at grain boundaries. Moreover, in the vicinity of the β intermetallic phase precipitations the presence of the needle eutectics (α + β) has been revealed. The applied ageing process after the solution heat treatment has caused the release of the β phase at grain boundaries as well as in the form of pseudo eutectic locations. In the structure of the material, the parallel twinned crystals extending along the whole grain have been revealed.

The results of the analysis of the EDS chemical composition confirm the presence of the main alloy additions Mg, Al, Mn, Zn and also Fe and Si included in the magnesium cast alloys in as-cast and after the heat treatment. The chemical analysis of the surface element decomposition and the quantitative micro analysis made on the transverse microsections have also confirmed the evident concentrations of magnesium, silicon, aluminium, manganese and iron what suggests the occurrence of precipitations containing Mg and Si with angular contours, as well as phases with high Mn and Al concentrations that are irregular, with a non plain surface, often occurring in the forms of blocks or needles.

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