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INVESTIGATION OF TECHNOLOGICAL PARAMETERS FOR MAGNESIUM ALLOYS PRODUCTION

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ABSTRACT

Magnesium alloys are an important structural material in aerospace and car industries, as well as in some other areas. Their main characteristics are small specific weight, good mechanical properties, good processing and resistance to corrosion. Based on great marketing interest of magnesium alloys, the investigation of technological parameters of workout of magnesium alloys on a laboratory and pilot-plant scale is carried out. In this paper, a part of results on design and definition of melting, alloying and casting conditions of magnesium alloys are presented. These investigations involved the alloys of Mg-Al, Mg-Al-Zn, Mg-Al-Zn-Mn, Mg-Zn-Zr, Mg-Zn-Zr-Cd, and Mg-Zn-Zr-Cd-Ag types. Influence of alloying temperature, alloying time, amount of alloying elements, sequence of their adding and casting temperature on the chemical composition, microstructure and mechanical properties are investigated. Both technically pure metals and master alloys were used for alloying. For protection and refining, the appropriate salts were used. Melting and alloying were carried out in electric induction furnaces with a constant temperature control, while the casting was done in sand moulds. The obtained results provided valuable information on technological conditions of work-out of magnesium alloys as well as on the influence of alloying elements on mechanical properties and structure of investigated alloys.

Key words: magnesium alloys, alloying conditions, melting Mg alloys, mechanical properties

INTRODUCTION

Magnesium alloys represent a contemporary construction material that has, due to its specific properties, an ever growing application in the various technical areas as space technology, rocket techniques, aviation, car and tractor industries, radio industry, optics, precise mechanics, corrosion protection, consumer goods industry etc. Such a wide application of magnesium alloys is a consequence of their small specific weight and hence a high strength and brittleness, beside a satisfactory refractoriness (up to 700 K), good vibration amortization and excellent machining [1-3]. Starting with the fact that a metal magnesium is produced in Yugoslavia, with a clear perspectives of use of its alloys in this country, the systematic investigations directed to mastering of production of magnesium alloys have been undertaken. The results presented in this paper are a part of these investigations.

EXPERIMENTAL

Work out of alloys belonging to the following systems was investigated Mg-Al, Mg-Al-Zn, Mg-Al-Zn-Mn, Mg-Zn-Zr, Mg-Zn-Zr-Cd and Mg-Zn-Zr-Cd-Ag. The following investigations were carried out: a) parameters and conditions of melting, alloying and casting such as temperature, time of alloying, the amount of alloying elements and the sequence of their adding; b) the characterization of obtained alloys, such as the chemical composition, microstructure and mechanical properties. The alloying was carried out with technically pure metals: Al, Zn, Cd, Ag and master alloys of Mg-Mn and Mg-Zr, while the master alloy with zirconium (15 - 20 % of Zr) was obtained before that by a metallothermal reduction of K_2ZrF_6 salt by liquid magnesium.

The experiments of melting and alloying were performed in a laboratory induction furnace of 15 kW, with a charge of 1 kg and in a laboratory industrial furnace of 50 kW, with a charge of 10 kg. A crucible produced of carbon steel was used, while melting and alloying was done under a layer of protective salt Engesal-fluks 18. The metals, protective salt and utilities were dried beforehand at 380 K. Furnaces allowed for additional stirring of charge and automatic temperature control. Melted alloy was poured into a steel mould, adjusted for cast out of test rods, later used for testing of mechanical properties. In order to prevent sticking of metal, an emulsion based on talcum and borax coated the moulds.

The effects of alloying temperature, alloying time, sequence of adding of alloying elements, repose time after alloying and alloying temperatures were investigated. The effects of alloying temperature were observed at 1020 K, 1090 K and 1120 K. At higher temperatures (1120 K), the prevention from magnesium ignition is difficult, and it is excessively oxidized. The time of alloying, i.e. the time of mechanical stirring after addition of alloying elements was investigated in the range of 2, 5, 10 and 15 min. prior of pouring out, the melt was left to repose for 0, 5, 15 and 30 min. On the basis of gained experience and the chemical analysis of test bars, it is found out that the best repose time is 5 min. The casting temperature was also investigated in a range of 1020 K, 1070 K and 1090 K.

Tensile properties and hardness of investigated alloys were tested. The specimen microstructure was examined on the optical microscope.

Table 1 - The chemical composition and mechanical properties of investigated magnesium alloys

Alloy	Required camposit.	Alloying temperat.	Casting temperat.	Obtained composit.	Hardn. HV	Tensile strength Rm	Elong. A_5
	mass. %	K	K	mass. %		MPa	%
MgAl 8-9.5	Al-9.0 Mg-rest	1030	1020	Al-9.23 Mg-rest	61	/	/
MgAl 8-9.5 Zn 0.3-1.0	Al-9.0 Zn-0.7 Mg-rest	1030	1020	Al-9,25 Zn-0.71 Mg-rest	64	116	1
MgAl 8.5-9.5 Zn 0.3-1.0 Mn 0.1-0.3	Al-9.0 Zn-0.7 Mn-0.2 Mg-rest	1030	1020	Al-9,13 Zn-0.77 Mn-0.24 Mg-rest	63	147	1.8
MgZn 4.0-5.0 Zr 0.6-1.1	Zn-4.0 Zr-1.2 Mg-rest	1100	1030	Zn-4.30 Zr-0.75 Mg-rest	49	208	12.8
MgZn 7.0-8.0 Zr 0.7-1.1 Cd 0.4-1.0	Zn-7.0 Zr-1.2 Cd-0.8 Mg-rest	1070	1030	Zn-7.11 Zr-0.85 Cd-0.76 Mg-rest	65	215	6.0
MgZn 7.0-8.0 Zr 0.7-1.1 Cd 0.4-1.0 Ag 1.0-1.6	Zn-7.0 Zr-1.2 Cd-0.8 Ag-1.3 Mg-rest	1070	1030	Zn-7.38 Zr-1.16 Cd-0.81 Ag-1.10 Mg-rest	66	227	6.3

Refining of magnesium from silicon

Because of silicon content in the master alloy that exceeded the tolerable limit, an investigation of its removal was carried out. Among the known and possible method, the refining by hard meltable metals, zirconium and titanium, was selected. It is based on adsorption of Si at the surface of spongy Ti or comminuted Zr, with a subsequent diffusion of silicon deeper into Ti or Zr particles and formation of solid solutions of intermediaries being deposited at the bottom of refining tank. The method is simple, efficient and cheap, while consumption of Ti or Zr is low, due to a low solubility. Refining was carried out at 990 K (for Ti), or 1090 K (for Zr) in duration of 10 min. of stirring while the amount of Ti or Zr was 1% of magnesium weight.

RESULTS AND DISCUSSION

The performed investigations showed that melting and alloying should be carried out in the following way: the bottom of a steel crucible is first covered by a small amount of protective salt, then the pieces of solid magnesium are placed and again covered by thin layer of protective salt. After merging and reaching of alloying temperature, the comminuted alloying element is introduced through the layer of protective salt, while continuously stirring the melt. The alloying elements may be introduced together, while to the alloys with Zr, the sequence should be master alloy Mg-Zr first, and then other elements. The alloys of the required composition and properties may successfully be obtained, depending on the type, at the following working parameters: alloying temperature from 1030 K to 1100 K, alloying time 10 - 15 min., casting temperature from 1020 K - 1030 K and mould temperature of 390 K (Table 1).

It is evident from the obtained results of the chemical composition of alloys (Table 1), that the contents of alloying elements are within tolerable limits. At the same time, this composition show that the content of alloying elements in the alloy, with the exception of zirconium, are somewhat higher then it was required, i.e. entered. This is probably due to a certain loss in Mg because of combustion, which was difficult to avoid under the applied conditions, particularly those for casting. It is an indication that the alloying elements should be taken in the amount that corresponds approximately to the lower boundary limit, as set by relevant standard. Probably due to low solubility, the content of zirconium in the obtained alloy is significantly lower from the entered amount. This means that Zr should be taken in the amount that corresponds to the upper boundary limit of the tolerable content.

The microstructure of alloys belonging to Mg-Al, Mg-Al-Zn and Mg-Al-Zn-Mn systems was composed, without exception, of δ - solid solution and intermediary $Mg_{17}Al_{12}$ phase. This phase is located over the boundaries of δ - solid solution grains, as a eutectic (δ + $Mg_{17}Al_{12}$), or as a self-contained phase, in a form of separated eutectic [2,3].

In Mg-Al-Zn-Mn alloy with increased concentration of Zn, it may be assumed that $Mg_{32}(Al,Zn)_{49}$ phase makes part of eutectic. In the structure of 4 - component alloys, the presence of MnAl phase, in a form of individual inclusions of light gray color, was also detected. The microstructure of 3 - component alloy Mg-Zn-Zr is composed of α - solid solution of Zn and Zr in magnesium and small amount of intermediary Mg_2Zn_3 phase, located along grain boundary. The microstructure of 4-component alloy Mg-Zn-Zr-Cd is characterized by practically the same phase composition as it was the case with 3-component alloy Mg-Zn-Zr, since cadmium is completely dissolved in a solid solution based on magnesium. Alloy Mg-Zn-Zr-Cd-Ag consisted of solid solution of Zn, Zr, Cd and Ag in magnesium and intermediary metastable MgZn phase. It is probable that the presence of Ag in the alloy contributes to a stability of MgZn phase [3-5]. The alloys that belong to Mg-Al, Mg-Al-Zn and Mg-Al-Zn-Mn systems of approximately the same content of Al have in as cast state, practically the same hardness values (Table 1). The obtained values of hardness are in a good agreement with the required ones, by standards (DIN, GOST). Mg-Zn-Zr alloy was of a lower hardness, in comparison to multi-component alloys with Cd and Ag.

The microstructure of investigated Mg-Zn-Zr alloy, is composed of α-solid solution of Zn and Zr in a solid solution of magnesium and intermediary Mg_2Zn_3 phases located along the grain boundaries. According to literature, the presence of small amounts of Zn, zirconide and metastable phases, based on magnesium and zinc have to be expected [2,3]. However etching of investigated alloy in 1% HNO_3 do not enable the separation of the present phases. In all these cases, it has been found that hardness of investigated alloys was dependent neither on the testing location on investigated sample, nor on the cooling rate during crystallization.

Metallographic examination of investigated alloys was performed preliminary, and details will be presented elsewhere.

It is found that there are no variations in the chemical composition along the vertical section of the sample. This also means that there is no significant problem with segregation of alloying elements [6].

The obtained results on tensile strength and elongation (Table 1) were in accordance with the values from the relevant standards. The comparison of results showed that one of the alloys containing Cd and Ag, at approximately the same level of hardness has higher values of tensile strength. This is in agreement with differences detected in the microstructures i.e. with a smaller amount of intermediary phases.

CONCLUSIONS

The results obtained from these investigations lead to the following conclusions:

- The optimum operational technological parameters of preparation and casting of magnesium alloys, alloyed with Al, Zn, Mn, Zr, Cd and Ag are: alloying temperature of 1030 K to 1100 K, alloying time 10-15 min. casting temperature 1020 K - 1030 K and mould temperature of 390 K.

- When obeying the optimum technological parameters as listed above, the differences in the chemical composition along vertical section of investigated sample could not be detected, which means that there is no significant segregation of alloying elements in investigated Mg-alloys.

- All investigated magnesium alloys, produced at the optimum technological parameters, possessed the technological properties that conform the requirements, set by the relevant international standards.

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