MATERIALS CHARACTERIZATION 86 (2013) 270–282

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/matchar

Structural characteristics and elevated temperature mechanical properties of AJ62 Mg alloy

*J. Kubásek**, *D. Vojtěch*, *M. Martínek*

Department of Metals and Corrosion Engineering, Institute of Chemical Technology, Prague, Technická 5, 166 28 Prague 6, Czech Republic

ARTICLE DATA

Article history:
Received 4 January 2013
Received in revised form 6 June 2013
Accepted 16 September 2013

Keywords:
Magnesium alloys
Thermal stability
Mechanical properties
AJ62

ABSTRACT

Structure and mechanical properties of the novel casting AJ62 (Mg–6Al–2Sr) alloy developed for elevated temperature applications were studied. The AJ62 alloy was compared to commercial casting AZ91 (Mg–9Al–1Zn) and WE43 (Mg–4Y–3RE) alloys. The structure was examined by scanning electron microscopy, x-ray diffraction and energy dispersive spectrometry. Mechanical properties were characterized by Viskers hardness measurements in the as-cast state and after a long-term heat treatment at 250 °C/150 hours. Compressive mechanical tests were also carried out both at room and elevated temperatures. Compressive creep tests were conducted at a temperature of 250 °C and compressive stresses of 60, 100 and 140 MPa. The structure of the AJ62 alloy consisted of primary α-Mg dendrites and interdendritic nework of the Al_4Sr and massive $Al_3Mg_{13}Sr$ phases. By increasing the cooling rate during solidification from 10 and 120 K/s the average dendrite arm thickness decreased from 18 to 5 μm and the total volume fraction of the interdendritic phases from 20% to 30%. Both factors slightly increased hardness and compressive strength. The room temperature compressive strength and hardness of the alloy solidified at 30 K/s were 298 MPa and 50 HV 5, i.e. similar to those of the as-cast WE43 alloy and lower than those of the AZ91 alloy. At 250 °C the compressive strength of the AJ62 alloy decreased by 50 MPa, whereas those of the AZ91 and WE43 alloys by 100 and 20 MPa, respectively. The creep rate of the AJ62 alloy was higher than that of the WE43 alloy, but significantly lower in comparison with the AZ91 alloy. Different thermal stabilities of the alloys were discussed and related to structural changes during elevated temperature expositions.

1. Introduction

Magnesium based alloys are characterized by a relatively high strength-to-weight ratio. It makes them of interest for various structural components in automotive and aerospace industry. Mg–Al–Zn (AZ designation, according to the ASTM) type die-casting alloys are the most widely used, because they combine a good strength, corrosion resistance and castability. Aluminum, as the main alloying element, improves the castability and provides strengthening effects by solid solution and by the formation of the $Mg_{17}Al_{12}$ phase. According to the Mg–Al phase diagram [1], the $Mg_{17}Al_{12}$ phase melts congruently at only slightly above 450 °C, suggesting a low thermodynamic and structural stability of this phase at elevated temperatures. For this reason, AZ type alloys show a poor thermal stability and their operations are limited to temperatures below approximately 120 °C [2]. At higher temperatures, mechanical properties of AZ alloys rapidly degrade.

Two approaches have been adopted so far to improve the thermal stability of Mg-based alloys. In the first approach, rare earth elements (RE) are added to magnesium to form thermally stable Mg–RE precipitates which represent effective

* *Corresponding author*. Tel.: +420 220444055.
E-mail address: Jiri.Kubasek@vscht.cz (J. Kubásek).

1044-5803/$ – see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.matchar.2013.09.018

obstacles for dislocation slip at low as well as elevated temperatures. Among Mg–RE alloys, the casting WE43 (Mg–4Y–2Nd–1RE–0.5Zr) alloy is a well known representative developed for applications up to 250 °C [3–8]. Final mechanical properties of this alloy are generally achieved by T6 heat treatment including solid solution annealing at 525 °C/8 h, water quenching and artificial aging at 250 °C/16 hours [3,9]. However, high costs of rare earth elements prevent widespread use of these materials. The second, and also less expensive, approach adopted to enhance the thermal stability of Mg alloys consists in alloying by alkaline-earth metals, like Ca or Sr, together with Al. A high affinity of alkaline-earth metals to aluminum leads to the formation of Al_2Ca or Al_4Sr intermetallic phases whose congruent melting points are 1079 °C and 1040 °C, respectively [1], indicating a high thermal and structural stability of these phases. One representative of this type of alloys is the recently developed AJ62 alloy (Mg–6Al–2Sr) combining a superior thermal stability at 150 °C, a good die-castability, hot-tear and corrosion resistance. This alloy is actually used in series production of BMW I6 Mg/Al composite crankcase [10,11].

In the scientific literature, the number of reported studies on the AJ62 alloy is limited [10–13] because of the novelty of this material. For this reason, the present study is aimed to contribute to the knowledge of structural and compressive mechanical properties of the AJ62 alloy. The influence of the cooling rate on the structure and mechanical characteristics is determined. In addition, the thermal and structural stability of this alloy is compared with the most widely used die-casting AZ91 alloy and with the commercial thermally stable WE43 casting alloy.

2. Experiment

The investigated AJ62, AZ91 and WE43 alloys were supplied by an inductrial supplier in the form of ingots with dimensions of 500 × 150 × 100 mm. Chemical compositions of the alloys are summarized in Table 1.

All the alloys were then re-melted in an induction furnace under argon and gravity cast into a brass mold to prepare ingots of 100 mm in length and 30 mm in thickness. The alloys were investigated in the as-cast state. To explore the influence of the cooling rate on the structure and mechanical properties of the AJ62 alloy, it was also processed by gravity casting into brass cylindrical molds of 100 mm in length. Diameters of mold cavities varied between 10 and 50 mm to achieve different average cooling rates during solidification which were determined by thermocouples placed in the middle of the mold cavities. Cooling rates were identified from the change of the temperature over time in the interval from 630 °C to 450 °C which correspond to the solidification interval for AJ62 alloy. Cooling rates increased from 10 to 120 K/s with decreasing the mold cavity diameter from 50 to 10 mm. The mold with a cavity diameter of 30 mm used for casting all the investigated alloys corresponds to a cooling rate of 30 K/s for AJ62. However, the cooling rates measured for AZ91and WE43 differed only slightly; therefore, the cooling rate of 30 K/s can be considered for all studied alloys.

Mechanical properties were characterized by room temperature (RT) Vickers hardness measurements with a loading of 5 kg (HV 5) and by RT compressive mechanical tests performed at a deformation rate of 1 mm/min. Thermal stability of mechanical properties was determined by RT hardness measurements after various periods (0–150 hours) of heat-treatment at 250 °C and also by compressive mechanical tests at elevated temperatures of 150, 200 and 250 °C. Study of the elevated temperature behavior was completed by compressive creep tests at a temperature of 250 °C and constant compressive stresses of 60, 100 and 140 MPa.

All the investigated alloys in the as-cast, as-heat-treated and as-crept states were subjected to detailed structural examination with the use of light (LM) and scanning electron microscopy (SEM, Tescan Vega 3), energy dispersive spectrometry (EDS, Oxford instruments) and x-ray diffraction (XRD, X'Pert Pro, Cu K_α radiation).

3. Results

3.1. *Structures and Mechanical Properties of the as-cast Alloys*

Figs. 1 and 2 illustrate structures and x-ray elemental maps of the as-cast alloys solidified at a rate of 30 K/s. The AJ62 (Fig. 1A) alloy is dominated by dendrites of an α-Mg phase (dark). In addition, there is also an almost continuous interdendritic network (light). An x-ray map in Fig. 2A shows that the interdendritic network is enriched in Al and Sr and depleted in Mg in comparison with the α-Mg dendrites. A more detailed view in Fig. 1A together with the x-ray map in Fig. 2A indicate that the interdendritic network comprises two components: the first one is characterized by a lamellar morphology. Al, Sr and Mg contents in lamellae are 27.1, 7.4 and 65.5 at. %, respectively, according to EDS. Therefore, the light lamellae correspond to the Al_4Sr phase [1]. The measured content of Mg in the lamellae is caused by their small dimensions and by the influence of surrounding α-Mg phase on the EDS analysis. The second component of the interdendritic network forms homogeneous particles appearing as slightly darker in comparison with the Al_4Sr lamellae. Concentrations of Al, Sr and Mg in these particles determined by EDS are 18.1, 8.1 and 73.8 at. %. Occurrence of ternary phases, mostly identified as $Al_3Mg_{13}Sr$ in the structure of AJ alloys has already been reported in literature [12,14]. It was also shown that the composition of

Table 1 – Chemical compositions (in wt. %) of the investigated alloys.

	Al	Zn	Sr	Fe	Cu	Mn	Y	Nd	Zr	Other RE	Mg
AJ62	6.1		2.1			0.32					Bulk
AZ91	8.8	0.67		0.002	–	0.22	–	–	–	–	Bulk
WE43	–	0.01		–	<0.03	0.15	3.98	2	0.33	0.727	Bulk