J Mater Sci (2006) 41:6087–6089
DOI 10.1007/s10853-006-0643-1

LETTER

Observations of microstructural refinement in Mg–Al–Si alloys containing strontium

A. Srinivasan · U. T. S. Pillai · J. Swaminathan · S. K. Das · B. C. Pai

Received: 15 February 2006 / Accepted: 5 July 2006 / Published online: 12 August 2006

Magnesium is the lightest of all metals used as the basis for constructional alloys. It finds applications in the automobile, aerospace, electronics industries as well as in household equipment [1]. Various Mg alloys have been developed for different applications by alloying with major elements such as Al, Zn, Mn, Zr, RE, Y, etc depending on the specific requirement in properties. Among various Mg alloy systems Mg–Al alloy system such as AZ91 and AM60 are the most commercially used magnesium alloys. These alloys have good room temperature and foundry properties. However, the major problem in using these alloys is their inferior properties at high temperature, especially the creep properties at elevated temperature, which is due to the presence of the low melting point $Mg_{17}Al_{12}$ intermetallic phase [2]. Alloying additions such as RE, Sb, Ca, etc. are normally made to improve the creep properties of these alloys. Silicon (Si) is one such important alloying element added to the Mg–Al alloy system to improve the high temperature properties. The addition of silicon leads to the formation of the thermally stable intermetallic Mg_2Si phase. Alloys like AS21 (Mg–2Al–1Si), AS41 (Mg–4Al–1Si) have superior creep resistance to that of alloy AZ91 due to the above said reason. However, the Si addition is effective only with die castings; it is not suitable for sand castings due to the formation of coarse Chinese script Mg_2Si precipitates. These coarse precipitates lead to poor mechanical properties due to the fact that cracks can easily nucleate and develop at the interface between the ductile Mg matrix and the coarse Chinese script Mg_2Si precipitates [3].

Ca and P are normally added in Si-containing Mg alloys to refine the Mg_2Si precipitates so as to improve the mechanical properties [4]. Kim et al. [4] have reported that when Ca and P are added, $CaSi_2$ and $Mg_3(PO_4)_2$ particles form respectively, and these particles act as a nucleation sites for Mg_2Si precipitates. Recent studies report that a Sb addition also modifies the morphology of Mg_2Si precipitates [3, 5]. Generally, Ca, P, Sb are normally added to modify the eutectic or primary Si particles in Al–Si alloys and Sr is a well-known modifier of Si particles in hypoeutectic Al–Si alloys [6, 7]. Based on this behavior, it is believed that Sr also can change the morphology of Mg_2Si precipitates in Si-containing Mg–Al alloys. Hence, the present study aims to investigate the effect of Sr addition on the refinement of Mg_2Si precipitates in the Si-containing AZ91 alloy.

Initially, a master melt of AZ91 (Mg–9Al–1Zn–0.2Mn) alloy was prepared. Subsequently, castings of Mg–9Al–1Zn–0.2Mn–0.5Si alloy were made by adding required quantity of an Al–20Si master alloy so as to get 0.5Si in the casting. In order to study the ability of Sr to refine the Mg_2Si precipitates, castings of Mg–9Al–1Zn–0.2Mn–0.5Si–0.1Sr were made by adding the appropriate quantity of Al–10Sr master alloy so as to get 0.1Sr in the casting. The detailed procedure for casting the above alloys is reported elsewhere [3]. The

A. Srinivasan
Metal Extraction and Forming Division, National
Metallurgical Laboratory, Jamshedpur 831 007, India

J. Swaminathan · S. K. Das
Material Science and Technology Division, National
Metallurgical Laboratory, Jamshedpur 831 007, India

U. T. S. Pillai (✉) · B. C. Pai
Materials and Minerals Division, Regional Research
Laboratory (CSIR), Thiruvananthapuram 695 019, India
e-mail: utspillai@rediffmail.com

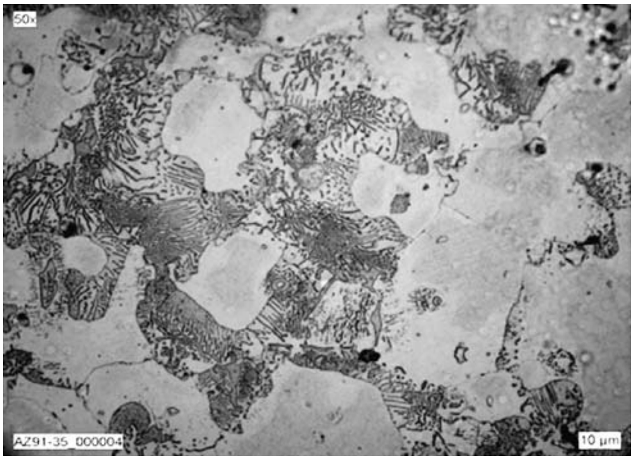

Fig. 1 Typical microstructure of the permanent mould cast AZ91 alloy

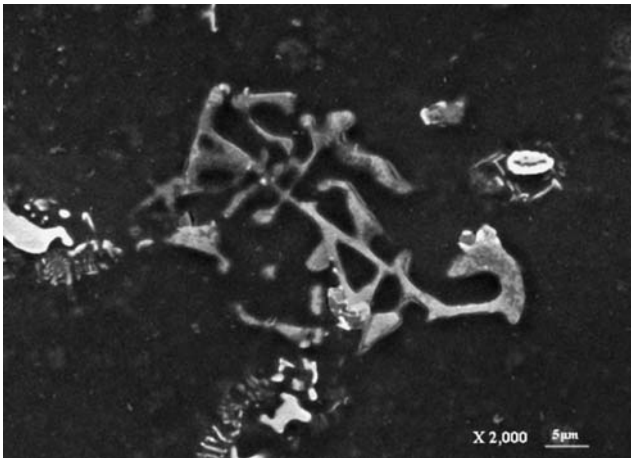

Fig. 3 SEM photograph highlighting the Mg_2Si Chinese script phase

above castings were made in cast iron mould. The microstructures of these alloys were evaluated by light optical metallography using a Leica DMRX Microscope. The compositions of intermetallic phases in these alloys were examined using JEOL JSE 35C Scanning Electron Microscope (SEM) interfaced with an Energy Dispersive X-ray Spectrometer (EDX).

Figure 1 shows the typical microstructure of the permanent mould cast AZ91 alloy. It consists of an α-Mg solid solution containing Al and Zn, and a divorced eutectic comprised of the massive $Mg_{17}Al_{12}$ phase and a supersaturated Mg solid solution. Discontinuous precipitation of $Mg_{17}Al_{12}$ is also observed in the vicinity of the massive eutectic $Mg_{17}Al_{12}$ phase. The microstructure of the 0.5Si-containing AZ91 alloy is shown in Fig. 2. When 0.5% Si is added to AZ91 alloy, a new Mg_2Si phase appears at the grain boundaries, in addition to the massive $Mg_{17}Al_{12}$ particles. It is further observed from the microstructure that the morphology of the Si bearing phase is a well defined Chinese script. Figure 3 contains a scanning electron micrograph, which explicitly highlights the Mg_2Si Chinese script phase. Both the EDX and X-ray diffraction analyses confirmed the presence of the Mg_2Si particles; the morphology of these particles is consistent with the one reported in the literature [3, 5]. It is further noted from the microstructure that the addition of Si to AZ91 alloy does not change the quantity or the morphology of the $Mg_{17}Al_{12}$ phase. The constant quantity of the $Mg_{17}Al_{12}$ phase is expected since no other compounds containing Al and Si are formed. The microscopic examination also indicates that the silicon addition does not change the morphology of $Mg_{17}Al_{12}$. The EDX analysis performed across the $Mg_{17}Al_{12}$ phases indicates that there is no Si present in

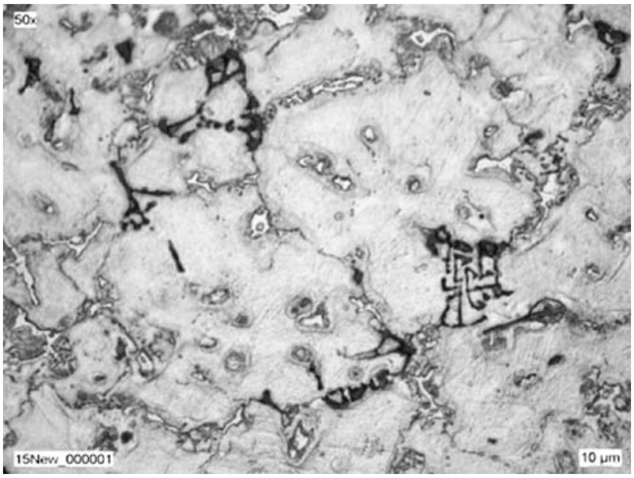

Fig. 2 Optical micrograph of Si-containing AZ91 alloy

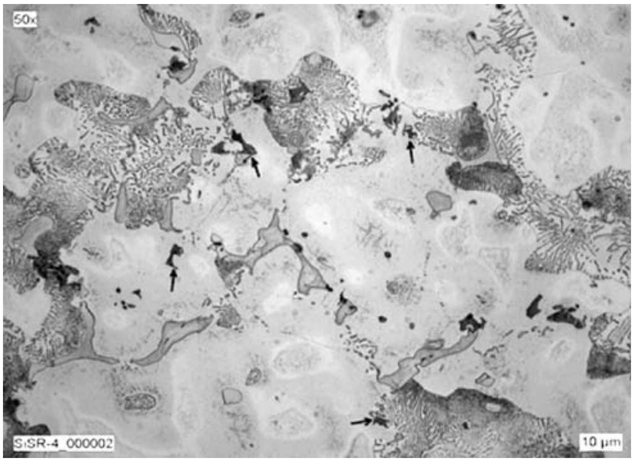

Fig. 4 Microstructure of AZ91 alloy containing 0.5Si and 0.1Sr

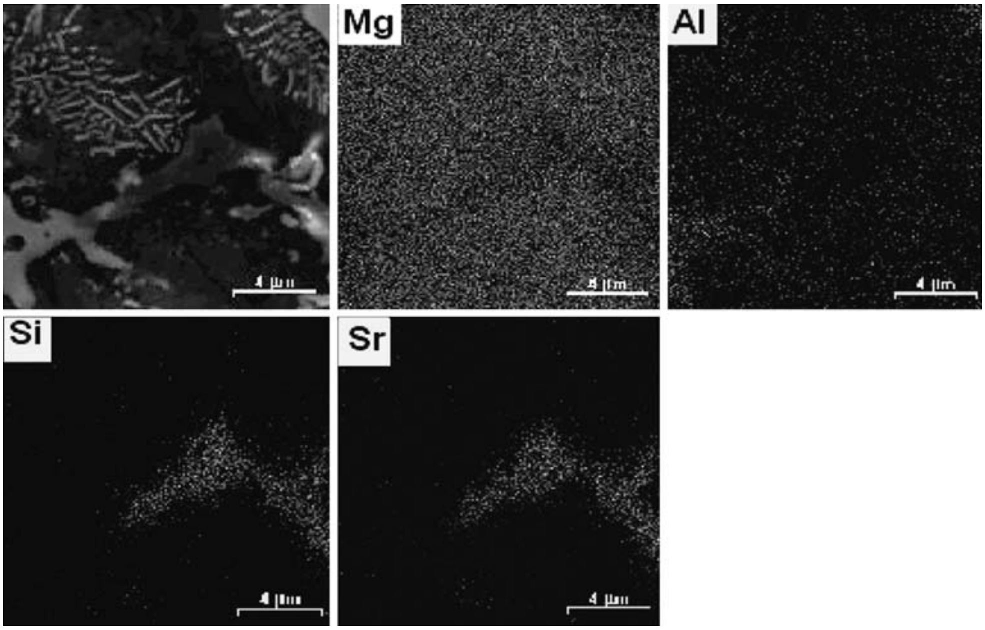

Fig. 5 X-ray maps showing a refined Mg_2Si precipitate

that phase. These facts indicate that Si does not act as a refiner or modifier for the $Mg_{17}Al_{12}$ phase.

Figure 4 shows the microstructure of the AZ91 alloy containing 0.5Si and 0.1Sr. From this figure it can be observed that 0.1Sr additions effected an interesting microstructural change. The morphology of the massive Chinese script Mg_2Si phase morphology has been refined but to an irregular shape. The exact measurement of size Mg_2Si phase is difficult because of its complex shape. However, the average size (in terms of area) of the precipitates measured before refining is 320 μm^2 and after refining its average size is 75 μm^2. The grain size of the AZ91 alloy containing the Sr addition is significantly finer (45 μm) than the base AZ91 alloy (80 μm). However, the amount of Sr required to optimize (refine) the microstructure requires further investigation. In order to explore further the nature of precipitates, analyses were performed using SEM and EDX spectroscopy. The spot EDX analyses obtained from the precipitates suggest that Sr may be incorporated in the precipitates. X-ray mapping was also performed as shown in Fig. 5. These qualitative EDX maps suggest that Sr may be incorporated in the Mg_2Si precipitates. However, a detailed TEM study is required for clear understanding the mechanism.

In conclusion, the addition of Sr to a Si-containing AZ91-Mg alloy appears to refine the microstructure by promoting a finer grain size. The coarse Chinese script Mg_2Si precipitates also appear to be smaller and more uniformly distributed in the alloy containing Sr. Further research is needed to understand the mechanism for the observed refinement in structure.

Acknowledgement The authors thank the CSIR, New Delhi, for its financial support to the first author to carry out the work.

References

1. Mordike BL, Ebert T (2001) Mater Sci Eng A302:37
2. Pekguleryuz MO, Arslan Kaya A (2003) Adv Eng Mater 5:866
3. Srinivasan A, Pillai UTS, Pai BC (2005) Metall Mater Trans A 36A:2235
4. Kim JJ, Kim DH, Shin KS, Kim NJ (1999) Scripta Matera 41:333
5. Yuan GY, Liu SL, Wang QD, Ding WJ (2002) Mater Lett 56:53
6. Closset B, Gruzleski JE (1982) Metall Mater Trans A 13A:945
7. Byczynski GE, Cusinato DA (2002) Int J Cast Metals Res 14:315