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Effect of Minor Additions of Al and Si on the Mechanical Properties of Cast Mg-3Sn-2Ca Alloys in Low Temperature Range

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Abstract. The Mg-Sn-Ca alloys have shown superior creep properties compared to the creep resistant alloy AE42. In the present study, the effects of small amounts of Al and Si additions on the mechanical properties have been investigated on a Mg-3Sn-2Ca (TX32) alloy. The Al content in the selected alloys was 0.4 wt% and the Si content was varied from 0–0.8 wt% in steps of 0.2 wt.%. The alloys were cast in pre-heated permanent molds. Cylindrical specimens machined from the cast billets were tested in compression in the temperature range 25–250 °C at a strain rate of 0.0001 s^{-1}. The alloy with 0.4 wt% Al shows an increased strength at all test temperatures compared with the TX32 base alloy. This is attributed to a solid solution strengthening of Al in Mg. The alloy with 0.4 wt% Al and 0.2 wt% Si has compressive strength that is closer to that of the TX32 alloy. However, increased additions of Si (from 0.4–0.8 wt%) reduce the strength, more significantly at higher temperatures.

Introduction

Magnesium (Mg) alloys have low density and hence are very much useful in automobile and aerospace parts, materials handling equipment, and portable tool housings. Mg alloys offer moderate room temperature mechanical properties and creep resistance [1]. An alloy system that has potential to offer superior creep properties is Mg-Sn-Ca (TX). Sn forms solid solution with Mg in this system and thus imparts corrosion resistance whereas Ca forms intermetallic particles in the matrix that augment the creep resistance of the alloy [2,3]. The alloys formed from this system could match the strength levels of AZ31 alloy which is the most popular among wrought magnesium alloys but with low corrosion resistance.

It is essential to develop newer alloys using Mg-Sn-Ca as a platform and by further minor alloying additions. Among the several compositions being considered, Mg-3Sn-2Ca alloy (TX32) is identified to be the most promising since it offers better creep resistance than the commonly recommended alloys AE42 and AZ91 [4,5]. In the present study, a series of Mg-3Sn-2Ca alloys was developed by adding minor amounts of Al and Si. Al was added to impart better solid solution strengthening, while Si could improve the creep resistance by forming intermetallic particles. The mechanical properties of cast Mg-3Sn-2Ca alloys with Al and Si additions were investigated.

Experimental Setup and Methodology

In this study Sn and Ca in the range of 3 and 2 wt% respectively were selected for the base Mg-Sn-Ca alloy (TX32). Additional alloying elements of Al and Si were added in small quantities to obtain a series of alloys based on TX32 system. The alloys were prepared using 99.99% pure Mg, 99.96% pure Sn and 98.5% pure Ca. The Al content was maintained at a level of about 0.4 wt% as greater amounts are detrimental to corrosion. The Si content was varied from 0-0.8 wt% in steps of 0.2 wt%. The alloys were molten at about 720 °C under a protective cover of Ar + 3% SF_6 mixed gas atmosphere. They were then cast in pre-heated permanent molds to acquire cylindrical billets of 100 mm diameter and 350 mm length.

For compression testing cylindrical specimens of 10 mm diameter and 15 mm height were machined from the cast billet. A 0.8 mm diameter hole was machined at mid height to the centre of the specimen for inserting a thermocouple. This was done to measure the specimen temperature.

Compression tests were conducted at a low strain rate of 0.0001 s^{-1} in the temperature range 25–250 °C using a computer-controlled servo-hydraulic testing machine. Graphite powder mixed with grease was used as the lubricant in all the experiments. Details of the experimental set-up and testing procedure are described in an earlier publication [6]. Using standard equations the load-stroke data were converted into true stress - true strain curves.

Results and Discussion

The true stress - true strain curves obtained from compression tests for TX32 alloys with Al and Si additions at various temperatures (25-250 °C) and low strain rate 0.0001 s^{-1} are shown in Fig. 1(a-f) and their ultimate compression strengths (UCS) are given in Table 1. Referring to Fig. 1 (a) and (b), the alloy with only 0.4 wt% Al has shown increased strength compared to their TX32 base Al free alloy at almost all the test temperatures. Aluminum is an alloying addition often utilized to improve room temperature mechanical properties by solid solution strengthening (α-Mg) and precipitation of (β-$Mg_{17}Al_{12}$) intermetallic phase [7]. Therefore, the TX32 alloy with 0.4 wt% Al has exhibited higher strengths in the tested temperature range.

The alloy with 0.4 wt% Al and 0.2 wt% Si (Fig. 1(c)) has shown compressive strengths that are similar to TX32 base alloy (Fig. 1(a)) up to a temperature of 150 °C. However, with increased additions of Si (from 0.4–0.8 wt%), the alloys have exhibited reduction in strength, in particular with increase in temperature. This reduction is likely due to the formation of Mg_2Si particles. It is the only stable compound to form in the Mg-Si System. The Si addition often promotes the precipitation of Mg_2Si particles which forms during solidification and is quite detrimental to the mechanical properties of Mg alloys [8,9]. As can be seen in Table 1, the compression strength of alloy TX32 + 0.4 wt % Al increases with Si addition (0.2 and 0.4 wt%) at room temperature. At 250 °C, stress - strain curves exhibited steady state flow in all the alloy cases.

Table 1. Ultimate compression strength (UCS) of TX32 alloys and with Al and Si additions

Temperature [°C]	UCS [MPa]					
	TX32 Base	TX32 + 0.4 wt% Al	TX32 + 0.4 wt% Al, 0.2 wt% Si	TX32 + 0.4 wt% Al, 0.4 wt% Si	TX32 + 0.4 wt% Al, 0.6 wt% Si	TX32 + 0.4 wt%Al, 0.8 wt% Si
25	198	195	207	207	179	181
50	182	195	194	179	167	176
75	175	186	169	162	163	154
100	164	180	176	166	142	139
125	168	169	162	148	138	119
150	164	170	161	138	141	108
175	161	169	144	135	121	99
200	136	156	138	134	119	84
250	80	93	92	89	80	56

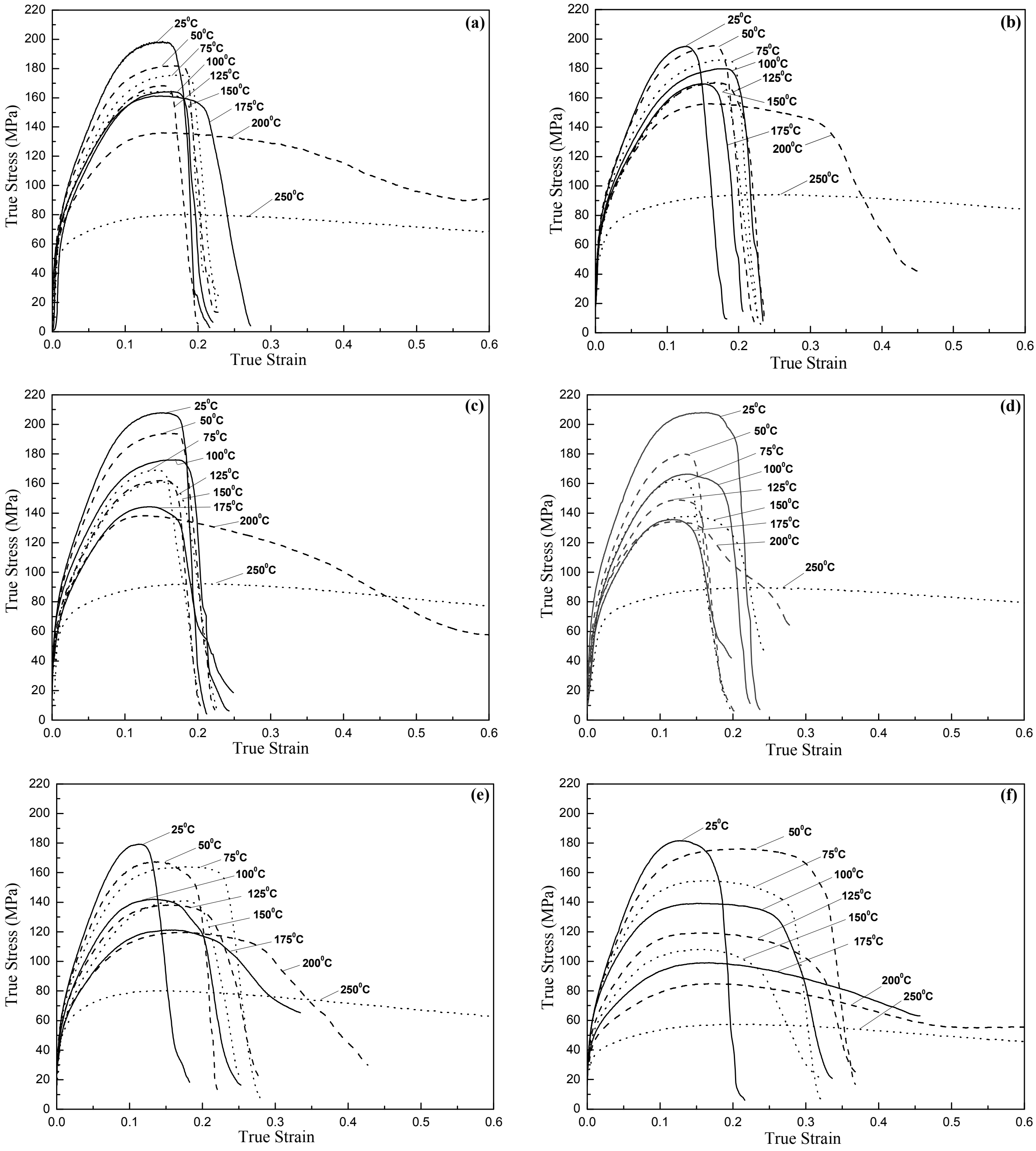

Fig. 1 Compressive true stress – true strain curves at (a) TX32 base alloy (b) TX32 + 0.4 wt % Al (c) TX32 + 0.4 wt % Al & 0.2 wt % Si (d) TX32 + 0.4 wt % Al & 0.4 wt % Si (e) TX32 + 0.4 wt % Al & 0.6 wt % Si (f) TX32 + 0.4 wt % Al & 0.8 wt % Si.

It can be seen that from the Fig. 1(c-f), in all the cases, increasing the addition of Si concentration reduces the compressive strength from room temperature to 250 °C compared to the TX32 base alloy (Fig. 1(a)). This may be due to the little solubility between Al and Si or Mg and Si while the amount of Mg_2Si increases with increase in Si content which reduces the strength. Therefore, Si does not seem to act as a refiner or modifier of the alloy to provide any benefit.

It is reported [10] that the addition of Si to AZ91 alloys does not change the quantity as well as the morphology of the $Mg_{17}Al_{12}$ phase. It may be due to negligible solid solubility of Si in Mg and the impossibility of the formation of any other compound containing Al and Si. On the other hand, Nanjunda Swamy et al. observed that, in cast Mg-Al-Si composites, ultimate tensile strength (UTS) decreases with increasing Mg_2Si content possibly due to increased casting defects such as porosity and segregation which may be counteracting the strengthening effect of increasing Mg_2Si content [11]. Asl et al. [7] have indicated that addition of Si to some aluminum containing magnesium alloys improves creep resistance while reducing the room temperature mechanical properties. With such differing observations, the role of Si on mechanical and creep properties of such alloy systems is not fully clarified.

TX32 alloy with 0.4 wt% Al and 0.8 wt% Si has shown higher levels of ductility in the tested temperature range. All the tested alloys have exhibited pronounced ductility at 250 °C indicating the beginning of hot workability temperature range.

Summary

Minor alloy additions of Al and Si have been made to Mg-3Sn-2Ca alloy system to develop a series of five cast alloys. The mechanical properties of these alloys have been investigated and compared with those of the base alloy. The following conclusions are drawn from this study.

(1) The alloy with only 0.4 wt% Al showed increased strength compared to their TX32 base Al free alloy. This is attributed to the solid solution strengthening of Al in Mg.
(2) The alloy with 0.4 wt % Al and 0.2 wt% Si showed compressive strengths that are somewhat closer to that of TX32 base alloy.
(3) Increased concentration of Si reduced the compressive strength at all the temperatures. Such reduction is primarily attributed to the formation of Mg_2Si particles though its role is not clear.
(4) TX32 alloy with 0.4 and 0.8 wt% of Al and Si addition exhibited higher ductility. All the alloys have shown excellent hot workability at 250 °C.

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