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# On the nature of $T(Al_2Mg_3Zn_3)$ and $S(Al_2CuMg)$ phases present in as-cast and annealed 7055 aluminum alloy

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**Abstract**

Aluminum alloys, encompassed by AA 7055 alloy composition, having the nominal zinc content (i.e. 8 wt.%) but varying copper and magnesium contents across the alloy composition range were examined in the as-cast form by a combination of light microscopy, scanning electron microscopy (SEM), electron probe micro analysis (EPMA) and X-ray diffraction (XRD). It is observed that for all compositions, the second phases based on $\eta(MgZn_2)$, $T(Al_2Mg_3Zn_3)$ and $S(Al_2CuMg)$ are present. The T phase dissolves copper up to 28 wt.%, whilst the S phase shows metastable solubility of zinc that may range up to 30 wt.%. In alloys with magnesium at the lower limit and the copper contents approaching the upper limit of the alloy composition, the θ phase ($Al_2Cu$) of the constituent binary Al–Cu system is further observed. The θ phase ($Al_2Cu$) does not dissolve either zinc or magnesium. Below the nominal composition, the alloys could be homogenized substantially using a commercially viable homogenization treatment leaving small amounts of undissolved S phase that does not contain any zinc.
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*Keywords:* Aluminum alloy 7055; Ingot casting; Annealing; $T(Al_2Mg_3Zn_3)$ and $S(Al_2CuMg)$ phases; Electron probe microanalysis; X-ray diffraction

## 1. Introduction

In the past several decades, considerable commercial interest has been shown in the development of high strength Al–Zn–Mg–Cu base 7XXX series aluminum alloys aiming at a superior combination of high specific strength, fracture toughness and stress corrosion cracking resistance that renders them suitable for use predominantly in aircraft structures [1–5]. This led to the design and development of the Al–Zn–Mg–Cu–Zr base AA 7055 alloy produced by Alcoa in the early 1990's. This high solute alloy evokes the highest strength aluminum alloy produced by ingot metallurgical route and finds application as upper wing structural material in the state-of-the-art Boeing 777 aircraft [6]. It is well known that the superior combination of properties promised by this alloy is largely determined by the stability, morphology as well as the chemistry of the strengthening precipitates, the dispersiods and the various constituent (insoluble) phases present in the alloy. The nature of the secondary alloy phases present in this complex alloy system is not fully understood in that the chemistry of many of the secondary phases in the constituent binary and ternary systems [such as Al–Cu, Al–Cu–Mg, Al–Zn–Mg, etc.] may be modified when such phases form in multi-component alloy systems. Such modifications in the nature of the secondary alloy phases may directly affect both mechanical properties and corrosion behavior of the alloy.

Existing literature suggests that below solidus temperature, four major intermetallic phases, viz. $\eta(MgZn_2)$, $T(Al_2Mg_3Zn_3)$, $S(Al_2CuMg)$ and $\theta(Al_2Cu)$ can occur in Al–Zn–Mg–Cu alloys [3,5]. Whilst, η and T phases have extended solubility of copper in them, θ and S are essentially binary and ternary phases in the constituent Al–Cu and Al–Cu–Mg systems, respectively [5]. The Zn:Mg ratio plays a crucial role in controlling the nature of zinc-bearing constituents. Copper behaves synchronously with zinc in this respect, and up to 2.5 wt.% copper additions, most of the copper remains dissolved in the above two intermetallic phases

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i.e. η and T [5]. Above 2.5 wt.%, however, copper tends to form S phase rather than dissolving in the matrix or in η and T phases [5]. Furthermore, eutectic phases involving η dissolve fast during homogenization, whilst, the dissolution rate of T and S phases is rather sluggish [7]. Given the varying nature of the secondary alloy phases (in terms of their compositions and their response to homogenizing annealing process), it is important that the chemistry of the coarse intermetallic phases present in the as-cast form of these alloys be characterized in details.

Studies have further shown that the chemistry of the coarse, equilibrium alloy phases present in the as-cast microstructure is similar to that of the same phases when formed as fine precipitates during aging following solution treatment and quenching [8–10]. Such studies demonstrated that the as-cast alloy may often contain metastable phases, and studies involving such phases may provide a basis for further understanding of the solid-state phase transformations that occur in these alloys [8–10]. Evaluation of the exact chemistry of the second phases, when present as coarse particles in the as-cast and/or annealed microstructure, also becomes much easier using conventional micro-analytical techniques [8–10].

The objective of the present study is to provide an understanding of the nature of secondary alloy phases present in as-cast and subsequently annealed microstructure of 7055 aluminum alloy with a particular attention to T and S phases.

## 2. Experimental procedure

7055 aluminum alloys having the average zinc content (i.e. 8 wt.%), zirconium content of 0.16 wt.% and varying magnesium and copper contents across the composition range (1.8–2.3 wt.% Mg and 2.0–2.6 wt.% Cu) were prepared via ingot metallurgical route. The alloy samples were taken from the equivalent position of the moulds in order to maintain uniformity of cooling rate. For each composition, 15 kg of the alloy was cast in a bottom pouring, tapered mild steel mould of dimension 310 mm × 310 mm × (50–40) mm. After casting, a slice of as-cast alloy of dimension 310 mm × 10 mm × (50–40) mm was machined from the surface of each ingot. All the specimens were collected from the middle of such slices, where the average local cooling rate [in the temperature interval of 710 °C i.e. the pouring temperature of the alloy to 200 °C] was measured to be ∼15 °C/min. The cooling rate was calculated from an experimental temperature-time plot obtained by placing a suitable thermocouple close to the said region.

The mass compositions of the alloys examined in the present investigation (designated A through E) are given in Table 1. The alloys were given a commercially viable homogenizing annealing treatment at 450 °C for 35 h. The homogenization temperature was selected on the basis of results of thermal analysis (by differential scanning calorimetry) of as-cast, high zinc containing (>8 wt.%) Al–Zn–Mg–Cu–Zr alloy showing the presence of non-equilibrium solidus at 460 °C [11].

Table 1
Compositions (wt.%) of the 7055 Aluminum Alloys used in the Investigation

| Alloy | Zn | Mg | Cu | Zr | Fe | Si | Al |
|---|---|---|---|---|---|---|---|
| A | 8.0 | 2.3 | 2.6 | 0.16 | 0.06 | 0.05 | Balance |
| B | 8.0 | 2.0 | 2.3 | 0.16 | 0.04 | 0.05 | Balance |
| C | 8.0 | 1.8 | 2.6 | 0.16 | 0.06 | 0.06 | Balance |
| D | 8.0 | 1.8 | 2.0 | 0.16 | 0.06 | 0.05 | Balance |
| E | 8.0 | 2.3 | 2.0 | 0.16 | 0.05 | 0.06 | Balance |

A combination of optical microscopy, scanning electron microscopy (SEM) and electron probe micro-analysis (EPMA) was carried out to characterize as-cast and annealed microstructures of the alloys. SEM, in the back scattered electron imaging mode, was carried out on the SEM attached to the EPMA instrument, operating at 20 kV. EPMA was performed on a CAMECA CAMEBAX micro-analyzer operating at 20 kV. A quantitative X-ray wavelength dispersive spectroscopy (WDS) system attached to the EPMA instrument was used to analyze the chemistry of the phase particles present in as-cast and annealed microstructures. The instrument was equipped with the MAGIC-IV analytical program for ZAF corrections [12]. For each type of phase, at least five particles from different locations were analyzed and the average values of such analyses are reported here. The analyses were carried out on polished but unetched samples. X-ray diffraction studies (XRD) were undertaken in order to identify the alloy phases present in as-cast and annealed materials. XRD was further used to measure the lattice parameter of certain alloy phases; alloy E (see Table 1) was utilized only for this purpose. X-ray diffraction studies were performed on a PHILIPS PW 1710 automatic diffractometer.

## 3. Results and discussion

### 3.1. General description of microstructure

For all the alloys, optical microscopy and SEM revealed a typical cored dendritic microstructure of primary α(Al)-solid solution surrounded by inter-dendritic secondary phases. The predominant eutectic structure of the alloys is understood to be consisting of a ‘quasi-binary reaction’ products, evolving from parallel solidification of three quasi-binary eutectic reactions viz. α-Al/η[$MgZn_2$], α-Al/T[$Al_2Mg_3Zn_3$] and α-Al/S[$Al_2CuMg$] [7]. Apart from being a part of eutectic structure, T-base and S-base phases are also present as ‘*divorced*’ phases. Compared to η- and T-base phases, the S-base phase is present in relatively smaller volumes, although the volume fraction of S phase is found to increase with increasing copper and magnesium contents of the alloys. The θ($Al_2Cu$) phase of the constituent Al–Cu system is also observed in alloys with magnesium toward the lower limit and copper contents approaching the upper limit of the composition range.

Fig. 1(a) through (d) represents optical micrographs showing as-cast microstructures of 7055 aluminum alloys having

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