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Influence of Cu on the mechanical properties and precipitation behavior of AlSi7Mg0.5 alloy during aging treatment

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Abstract

The influence of Cu on the mechanical properties of AlSi7Mg0.5 alloy after T6 heat treatment has been studied. The tensile strength and peak age hardness increase while the elongation decreases with increasing Cu content in the alloy. The investigation of the precipitation behavior of dispersoids during aging by transmission electron microscopy (TEM) and high resolution TEM shows that Cu addition increases the density of the β″ precipitates and induces the precipitation of precursors of Q phase at the peak aged condition. When the Cu content is high, θ′-Al_2Cu phase also precipitates during artificial aging.

Keywords: Al–Si–Mg foundry alloy; Cu; Precipitation; Q-phase; Artificial aging

1. Introduction

Al–Si–Mg foundry alloys with a low Fe content (<0.15 wt.%) are widely used in the automotive industry for making high integrity castings with a combination of high elongation, high strength and good corrosion resistance. The most commonly used alloys are the A356 and A357 alloys. It is well known that Cu addition increases the strength of Al–Si–Mg alloys, which is due to the influence of Cu on the precipitation behavior of the alloys during the age-hardening treatment. So a further optimization of the mechanical properties of these foundry alloys can be expected by addition of Cu and optimized heat treatment.

Numerous investigations have been carried out on the influence of Cu on the precipitation behavior in 6xxx Al–Mg–Si alloys [1–7]. It has been found that addition of Cu has the effect of increasing the precipitation kinetics of β″ during artificial aging [5] and refining the precipitates in the alloys [1,7]. The addition of Cu also changes the precipitation sequence of dispersoids in the alloys during artificial aging. It has been found that Q′ phase, which has a lath-shaped morphology and a hexagonal unit cell with $a = 1.04$ nm and $c = 0.405$ nm, will precipitate in the alloy with Cu addition during artificial aging [1–4,6]. The Q′ phase has the same crystal structure as Q phase ($Al_5Cu_2Mg_8Si_6$) and is considered to be a precursor of the Q phase. L phase [8,14], QP (hexagonal, $a = 0.395$ nm, $c = 0.405$ nm) and QC (hexagonal, $a = 0.67$ nm, $c = 0.405$ nm) [9] have also been reported to precipitate as precursors of the Q′ phase in Cu-containing Al–Mg–Si alloys. The QP phase and lath-shaped L phase are reported to precipitate in the peak aged condition, while the Q′ phase is usually observed on over aging in the alloys [1–4,6,9,14].

There have been few investigations into the influence of Cu on the precipitation behavior of Al–Si–Mg foundry alloys. Usually, it is considered that the strengthening of Cu-containing Al–Si–Mg foundry alloys is due to the precipitation of β″ phase and θ′(Al_2Cu) phase [10–13]. According to the investigation of Eskin [10], no Q phase or its precursors will be present during artificial aging in

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Al–Si–Mg–Cu foundry alloys. However, Yao et al. have reported the presence of precipitate similar to the L phase besides the β″ and θ′ phases in the A320 alloy after 72 h of aging at 175 °C [11]. The aim of the present work is to study the influence of Cu content on the mechanical properties and precipitation behavior of AlSi7Mg foundry alloys.

2. Experimental

The materials used in the present work were direct chill (DC)-cast Al–Si–Mg–Cu ingots with a diameter of 95 mm. Before casting, the aluminium melts were degassed, grain refined with Al–Ti–B and modified by Sr. The chemical compositions of the alloys are shown in Table 1. A T6 heat treatment was conducted for the alloys. In order to have the maximum Mg content in solid solution before artificial aging and, at the same time, to avoid the incipient melting, different solution treatment temperatures and holding times were applied for the alloys, as shown in Table 1. All the specimens were quenched into cold water after solution treatment and then immediately aged at 175 °C in an oil bath for different times followed by quenching into cold water. The age-hardening curve was achieved by measuring the microhardness of the samples after artificial aging. The mechanical properties of the test bars were examined after 6 h of artificial aging.

The transmission electron microscopy (TEM) specimens, with a diameter of 3 mm, were first thinned by jet-polishing in a solution containing one part nitric acid and two parts methanol at −30 °C with a voltage of 20 V and then thinned by ion milling. The TEM foils were observed at 200 kV accelerating voltage in JEOL2010 and JEOL2010F (with a field emission gun) TEM. A Noran energy dispersive spectroscopy (EDS) system attached to the JEOL2010F TEM was used to measure the compositions of the precipitates.

3. Results

3.1. Age-hardening curve

Fig. 1 shows the evolution of the Vickers hardness of the alloys with time during artificial aging at 175 °C. As can be seen, the hardness of all the three alloys increases fast with increasing aging time and approaches peak values after approximately 6–9 h. The peak aged hardness increases with increasing Cu content in the alloys, showing that the addition of Cu has the influence of improving the peak age hardness of the ASi7Mg foundry alloy.

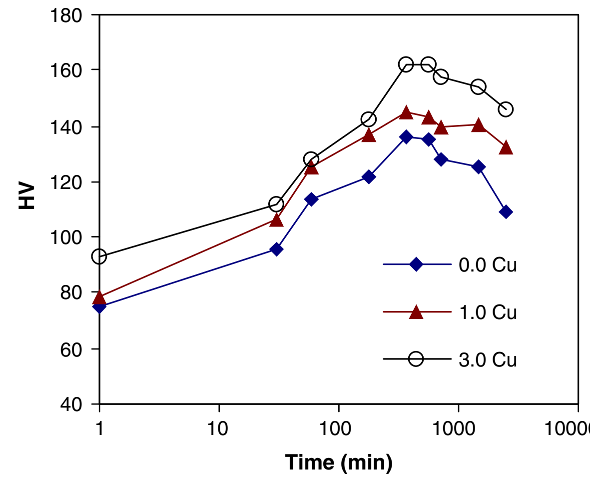

Fig. 1. Evolution of hardness with time during aging at 175 °C for alloys with different Cu contents.

3.2. Mechanical properties

The mechanical properties of the alloys after 6 h of artificial aging at 175 °C are shown in Fig. 2. The tensile strength (UTS) increases with Cu content in the alloys. A significant improvement of the tensile strength has been achieved in the alloy with addition of 3.0 wt.% Cu. The 3.0 Cu alloy has also a much higher yield strength (YS) than the 0.0 Cu alloy. However, the yield strength of the 1.0 Cu alloy is a little lower than the 0.0 Cu alloy. This is probably due to the lower solution treatment temperature

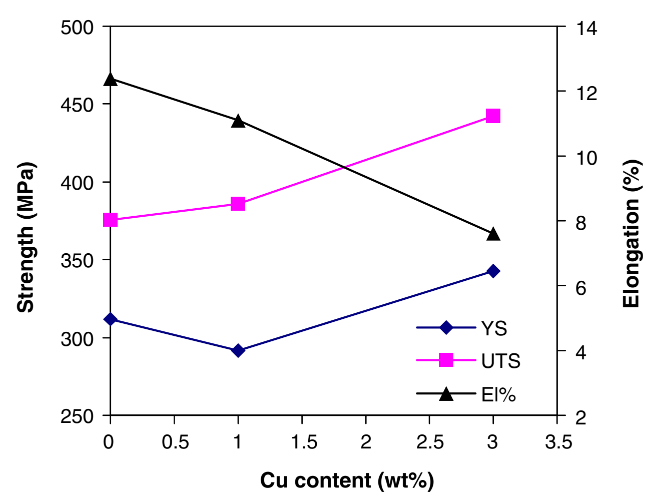

Fig. 2. Mechanical properties of the AlSi7Mg alloy with different Cu contents after 6 h aging at 175 °C.

Table 1
Chemical compositions (wt.%) and solution treatment of the alloys

Alloy	Si	Mg	Cu	Fe	Ti	Al	Solution treatment
0.0 Cu	7.0	0.47	0.01	0.12	0.09	Bal.	550 °C, 3 h
1.0 Cu	7.0	0.45	1.04	0.13	0.09	Bal.	525 °C, 8 h
3.0 Cu	7.0	0.45	2.99	0.13	0.09	Bal.	515 °C, 16 h