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Microstructure studies in Al–6% Si–1.9% Cu–x% Mg alloys

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The nature of precipitates formed in the aged Al–6% Si–1.9% Cu–x% Mg alloys (where x varies from 0.2 to 1.13) was investigated using scanning and transmission electron microscopy. Vickers hardness and grain size were measured. Results showed peak hardness around 4 and 10 h ageing time for 0.54% Mg and 1.13% Mg alloy, respectively. Hardness was found to increase with increasing magnesium content except for the 1.13% Mg alloy aged for 10 h. Q-phase particles have been observed and these are most probably responsible for the variation of hardness.

1. Introduction

Aluminium alloys (Al–Si–Cu–Mg) have many applications especially in the automotive and aircraft industries because of their light weight and good mechanical properties. The mechanical properties of these alloys may respond sensitively to any change in chemical composition. Their characteristics are significantly influenced by the presence of precipitates. Depending on the alloy composition, possible phases may be Si, Mg_2Si (β'), $CuAl_2Mg$ (S), and $Al_5Mg_8Cu_2Si_6$ (Q) [1, 2]. In the present study, results are given of the investigation of these quarternary alloys (Al–Si–Cu–Mg) with the magnesium content varying from 0.2 to 1.13%. The variation in hardness with ageing time is reported and the nature of the precipitates is discussed.

2. Experimental procedure

Three alloys designated A1, A2 and A3 were prepared by melting primary binary alloys in a vacuum induction furnace. Table I gives the chemical composition of these alloys; the magnesium content was varied from 0.2 to 1.13 wt %. These alloys were solution treated at 530° C for 8 h, then hot rolled at 500° C for 70% reduction. After hot rolling, they were again solution treated at 530° C for 4 h. Samples were then aged at 190° C for 1, 4 and 10 h. The unaged and aged samples were polished in the usual way and then etched with the following etchants before examining in the scanning (Jeol JSM-35CF) and transmssion (Jeol JEM-120C) electron microscopes: (a) for SEM, 30% HCl, 30% HNO_3, 10% HF, 30% H_2O; (b) for TEM, 20% HNO_3 in methanol.

TABLE I Chemical composition of the alloys (wt %)

Alloys	Si	Cu	Mg	Fe	Zn	Mn	Al
A1	6.0	1.84	0.2	0.34	0.08	0.01	Bal.
A2	6.85	1.95	0.5	0.33	0.1	0.01	Bal.
A3	6.93	2.02	1.13	0.32	0.1	0.01	Bal.

TABLE II Vickers hardness

Samples	Time (h)	A1	A2	A3
a	0	65	98	109
b	1	75	109	112
c	4	84	114	116
d	10	–	113	97

The Vickers hardness was measured using a Matsuzawa DMH-1 Micro-indentation tester. Grain size was also measured for all the alloys. The composition of different particles was determined using an electron microprobe analyser equipped with a microprocessor LINK 860-2.

3. Results and discussion

Table II gives values of Vickers hardness for unaged and aged samples for the three alloys. This table shows the trend of an initial increase in hardness, followed by a decrease in the value, with increasing ageing time. In

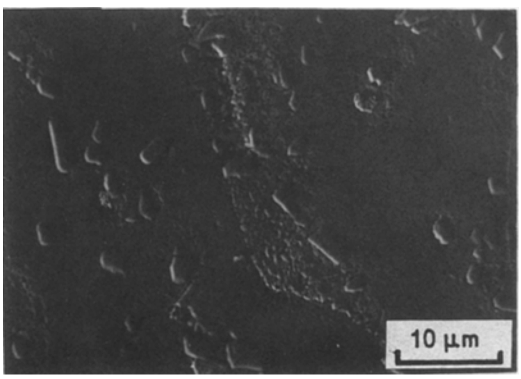

Figure 1 Scanning electron micrograph showing silicon particles present along the grain boundaries and within the grain.

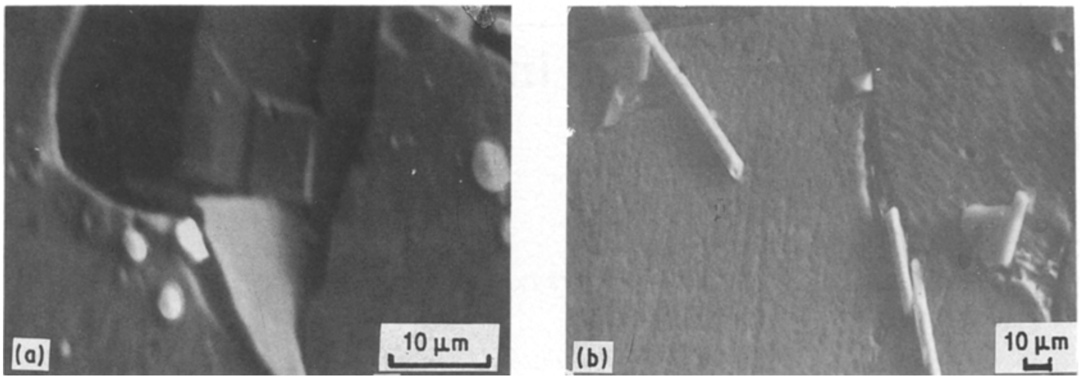

Figure 2 Scanning electron micrographs of the iron-containing particles in Al–Si–Cu–Mg alloy. (a) α precipitates, (b) α_3 precipitates.

TABLE III Chemical composition (wt %) of precipitates

Phase	Composition	Al	Si	Cu	Mg	Fe
α	Al_8Fe_2Si	58.6	9.04	–	–	30.98
α_3	Al_4Fe_3Si	50.55	12.65	–	–	36.80
Q	$Al_5Mg_8Cu_2Si_6$	22.52	27.58	19.73	30.27	–

the case of alloy A3, a decrease in hardness after ageing 10 h is significant. In alloy A2, hardness seems to saturate after 4 h ageing. Such a behaviour is similar to that observed by Bonfield and Datta [3] who reported peak hardness after 13 h ageing at 190° C in an Al–4Cu–0.8Si–0.8Mg. It is also obvious from Table II, that hardness increases with increasing magnesium content.

Increase in hardness with ageing time may be due to a decrease in grain size or to precipitate formation within grains. Measurements of grain size in unaged and aged samples show that, within experimental error, there is no change in the grain size.

The effect of precipitates on the hardness of the alloy is discussed next. Examination by SEM shows three types of phase whose compositions are given in Table III. These phases are: (i) silicon particles; (ii) Al–Fe–Si with two different compositions, α (Al_8Fe_2Si) and α_3 (Al_4Fe_3Si); and (iii) particles containing all four elements, i.e. Q-phase ($Al_5Mg_8Cu_2Si_6$).

Silicon particles observed on grain boundaries and within the grains are illustrated in Fig. 1. On average, the size and density of these particles is found to be almost constant and hence a change in hardness is not expected to be due to these particles. The presence of these particles at the grain boundaries would inhibit grain-boundary migration [1, 4].

Alpha particles have a geometrical shape, as shown in Fig. 2a and their size varies from 30 to 80 μm. α_3 particles are rod shaped (Fig. 2b) and their size varies from 25 to 100 μm. The electron diffraction pattern of these particles indicates that these have fcc structure with the lattice parameter equal to 1.7 nm compared to 1.6 nm reported by Pearson [5].

Previous studies [6] have shown that iron-containing phases in aluminium alloys appear during their solidification. It is also observed that ageing does not have any effect on the size, density and composition of these particles. Therefore it can be concluded that these phases are not responsible for any change in hardness.

SEM examination has revealed small Q-phase particles in alloy A3 whose size varies from 1 to 7 μm. These are found to lie along the grain boundaries (Fig. 3) for unaged and aged samples. The density of these particles increases with increasing ageing time. In the case of samples which were aged for 10 h these particles were also observed within grains.

Some of the phases in aluminium alloys are Mg_2Si, Al_2CuMg and $CuAl_2$, but there possibility is ruled out in the present case because of the composition and low ageing temperature [7, 8].

It is concluded that the change in hardness of the alloys investigated is most probably due to Q-phase particles. At lower ageing times, Q-phase particles just nucleate and their size is small. TEM examination of the three alloys shows some very small particles about

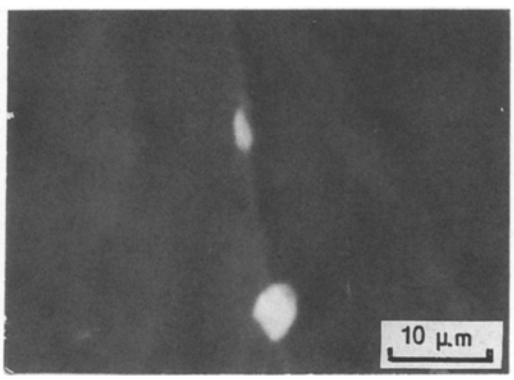

Figure 3 Scanning electron micrograph showing the $Al_5Mg_8Cu_2Si_6$ (Q) phase along the grain boundaries.

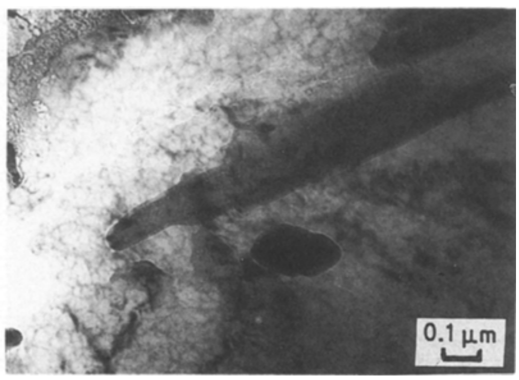

Figure 4 Transmission electron micrograph showing very small particles in the alloy A1.

0.1 μm in size (Fig. 4) which are most likely Q-phase particles. It is assumed that these particles grow with ageing and a stage is reached (e.g. at 10 h ageing) when these particles grow to a size which makes them non-coherent causing a decrease in hardness. Work is continuing on the characterization of the growth stage of the particles in the transmission electron microscope.

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