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Recent developments in hypoeutectic Al–Si A-S4G alloy

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The effect of adding Sr in the form of the Al–5 Sr master alloy to commercial A-S4G and high purity Al–4Si alloys on the modification process has been investigated. The volume fraction of the eutectic matrix decreased by modification due to the movement of the eutectic point to the higher Si content side. The tensile properties, especially elongation, have been increased by modification. The elongation of the A-S4G alloy is increased from a value of 0.9 to 15% by modification. Additionally, the elongation of the modified high purity alloy reached a value of 34%. The fracture path of the modified alloys circumvents the α-phase while it is not yet known if it propagates intergranularly or transgranularly through the eutectic matrix. The fracture surface revealed dimple and smooth ripple patterns reflecting the high ductility of the modified alloys.

1. Introduction

It is now well known that the addition of sodium (Na) [1–4] or antimony (Sb) [5] or strontium (Sr) [2–4, 6–9] to aluminium–silicon alloys affects their structure and hence their mechanical properties. Na has numerous drawbacks such as its high volatility and rapid rate of burn-out from the melt, its gassing tendency, its reaction with and damage to the crucible and the inconsistent resulting structure caused by its burn-out. Although Sb has some advantages over that of Na, however, it has the disadvantage of "not using the antimony modified alloys for food contact applications [5]". Sr is a superior modifier to both, however, its addition as a metallic element showed some problems [9]. The addition of Sr in the form of Al–Sr master alloy has proved to be the most powerful and easy method of modification of hypoeutectic [10–13] and eutectic [14] alloys. Up till now, there is a lack of research on the commercial A-S4G alloy and on the high purity Al–4% Si alloy in spite of their practical importance. These alloys are mainly used in; electrical appliances, automobiles, buildings, chemistry, mining, motorcycles, textile and cooking utensils. The present investigation aims at clarifying the effect of addition of Sr in the form of Al–Sr master alloy on the structure, tensile properties and fracture of the A-S4G commercial alloy and Al–4% Si high purity alloy.

2. Experimental procedure

Two types of ingots, about 30 g each, have been prepared from A-S4G and Al–4% Si high purity alloys. The chemical analysis of the former alloy is given in Table I. Casting temperature of about 1025 K was used for both modified and nonmodified alloys. Ingots of both chill-casting (copper mould) and sand-casting have been produced to study the effect of cooling rate on both the modification process and the mechanical properties. Accurately balanced amount of Al–5Sr master alloy, in the form of slender rods 5 mm diameter was added, as a modifier, to the molten metal.

Cylindrical tensile test specimens were machined from the ingots for tensile testing. The shape and dimensions of these specimens are shown in Fig. 1. Tensile tests were carried out at room temperature of about 295 K and at a constant crosshead speed of 0.42 mm min^{-1}.

The structures of the modified and nonmodified alloys have been optically revealed using the well known techniques of metallography for Al–Si alloys [4, 11, 15]. The fracture surfaces, after tensile testing, were observed using the scanning electron microscopy [13, 16].

3. Results and discussion

Referring to the phase diagram of the Al–Si system [4, 15] it can be seen that the eutectic composition is 12.5 mass % Si and the eutectic temperature is 850 K. Now, if we locate the 4% Si and 4.2Si alloys on this diagram, the volume fraction of the eutectic matrix V_e can be estimated, by the lever rule, (for thermodynamically equilibrium conditions) as 21.7 and 23.5% respectively. Table II delineates the volume fraction of the eutectic matrix V_e which was determined using the point counting technique for the present alloys for both chill-cast and sand-cast conditions. From

TABLE I Chemical analysis of the A-S4G alloy

Element	%	Element	%
Fe	0.40	Zn	0.08
Si	4.20	Ti	0.20
Cu	0.05	Co	0.10
Mg	0.40	Pb	0.05
Mn	0.45	Sn	0.03
Ni	0.40	Al	Balance

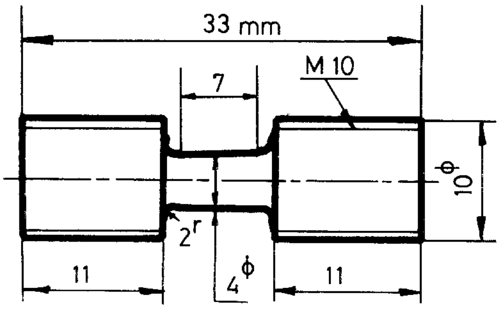

Figure 1 Tensile test specimen.

TABLE II Experimentally determined eutectic volume fraction

Alloy	Casting condition		Eutectic volume fraction, V_e
A-S4G	Chill-cast	Nonmodified	0.209
	Sand-cast	Nonmodified	0.240
		Modified	0.225
Al-4Si	Chill-cast	Nonmodified	0.195
	Sand-cast	Nonmodified	0.220
		Modified	0.210

Table II, it can be seen that while V_e of the chill-cast nonmodified A-S4G alloy is 20.9% that of the sand cast is 24%. The latter value is very near to the value determined from the phase diagram for the binary Al–4.2% Si alloy (23.5%). While the addition of Al–5 Sr master alloy could not modify the chill-cast alloys it did modify the sand-cast one. Modified sand-cast A-S4G alloy showed V_e of 22.5% (cf. Table II). The decrease of V_e in both chill-cast and modified A-S4G alloy is believed to stem from the shift of the eutectic point, into the coupled region [3], to the higher Si content side of the phase diagram. Similarly, the high purity Al–4Si alloy showed $V_e = 22\%$ for the non-modified sand-cast condition (cf. Table II); this V_e value is close to that mentioned above of 21.7% determined theoretically from the phase diagram. Again the chill-cast and the modified alloys showed V_e of 19.5 and 21% respectively. By the same reasoning, mentioned above, these lower V_e values refer to the movement of the eutectic point [3, 4]. Taking into consideration that the movement of the eutectic point to the higher Si content side by an amount of 1 mass % Si results in a decrease of V_e to values of 19.8 and 21.5% for the 4 and 4.2% Si alloys respectively, the present values of V_e for the chill-cast and modified alloys can thus be explained.

Figure 2a and b shows the microstructure of the commercial alloy A-S4G as chill-cast (a) and as sand-cast (b). The primary α-phase is embedded in a eutectic matrix. In general, finer structure can be observed in (a) rather than in (b) due to the higher cooling rate in the former. Owing to the relatively small V_e in both photos the silicon morphology is obscured, however, it can be detected at higher magnification as will be seen later.

Figure 3 exhibits the microstructure of the sand-cast-modified A-S4G commercial alloy. It illustrates the primary aluminium phase embedded in a refined-eutectic matrix. Additionally, the microstructure of the sand-cast-modified Al–4Si high purity alloy is shown in Fig. 4a. The well refined silicon morphology of the latter case is illustrated at a higher magnification in Fig. 4b. The microstructure shown in Fig. 4b resulted in the highest ductility among all alloys tested in the present investigation as will be seen in detail later.

Now, the tensile properties of both modified and nonmodified alloys used in the present investigation are presented in Table III. It can be noted that modification by Al–5 Sr master alloy produces, in general, a limited increase in strength but the increase of ductility is substantial, especially in sand castings. For sand-castings, elongation of the commercial alloy has increased by modification from a value of 0.9 to 15%. For the high purity modified sand-cast alloy the elongation reached a value of 34%. The last row of Table III delineates that the modified high purity Al–4% Si sand-cast alloy showed the highest tensile properties among others. In this respect, it is known [4] that the mechanical properties are mainly controlled by the amount and structure of the Si, as affected by modification produced by Sr addition.

Now, to illustrate clearly the improvement of tensile properties due to modification the engineering stress–strain diagrams are plotted in Fig. 5. For the sake of comparison the curves of modified and nonmodified commercial and high purity alloys are shown together. As can be seen both the strength and ductility have

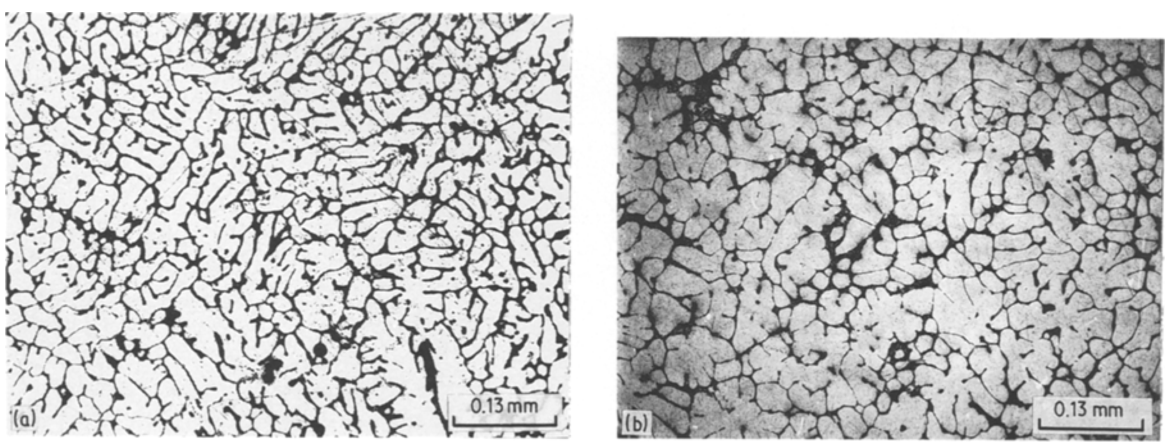

Figure 2 Microstructure of A-S4G alloy (a) as chill-cast, (b) as sand-cast. (reagent: dilute solution of sodium hydroxide).

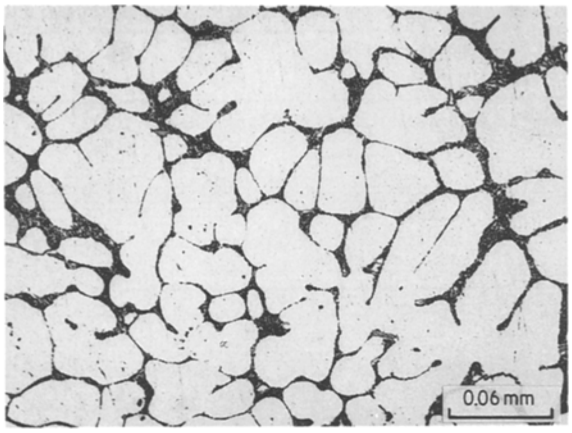

Figure 3 Microstructure of modified A-S4G commercial alloy. (reagent: dilute solution of sodium hydroxide).

increased due to modification. The tendency of the present results is in a good agreement with those reported previously [4].

Figure 6 shows an optical fractograph for a longitudinal section near the fracture surface of a modified alloy. Refined eutectic-silicon can be clearly seen at this, relatively, high magnification. The fracture path clearly circumvents the α-primary phase, however, it cannot be detected whether it propagates intergranularly or transgranularly through the eutectic matrix.

Figure 7a shows the general features of the fracture surface of nonmodified high purity as chill-cast alloy. It delineates complex pattern reflecting in general a brittle fracture. To the left of the photo dendrite lobes of primary α-phase are observed. Figure 7b shows this area at a higher magnification. The trace of the interaction between the fracture surface and the lobes can be observed as those indicated by arrow.

On the other hand the fracture surface of the modified high purity sand-cast alloy, Fig. 8a, shows dimple and smooth ripple patterns. These features are better clarified in Fig. 8b at higher magnification. It therefore, reflects the higher ductility observed (cf. Table III) [16].

4. Conclusions

1. The volume fraction of the eutectic-matrix is influenced by the modification process. The eutectic silicon content moves to the higher silicon side.

2. Modification of the structure of A-S4G and high purity Al–4 Si alloy has been successful only for sand-cast alloys (slow cooling rate).

3. The tensile properties of chill-cast commercial and high purity alloys are not improved by the addition of strontium.

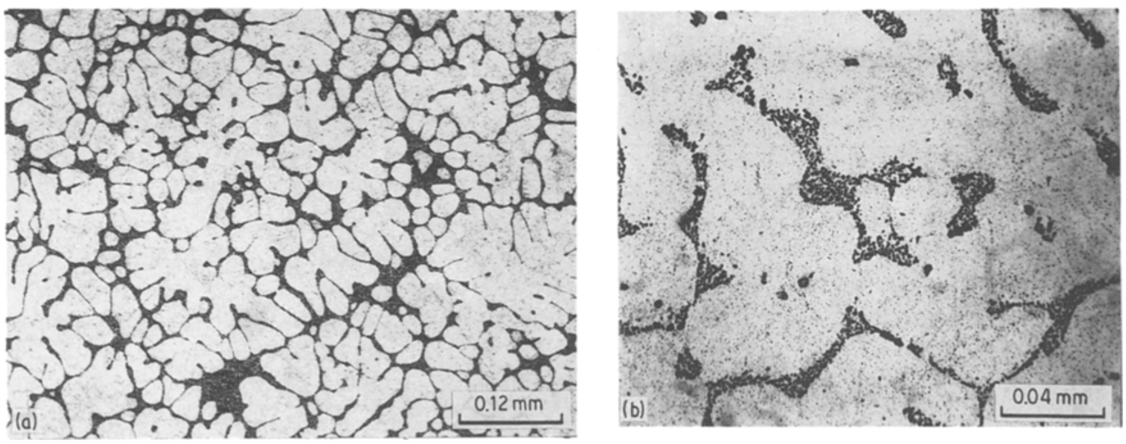

Figure 4 (a) Microstructure of modified high purity Al-4Si alloy, (b) same as in (a) but at a higher magnification. (reagent: dilute solution of sodium hydroxide).

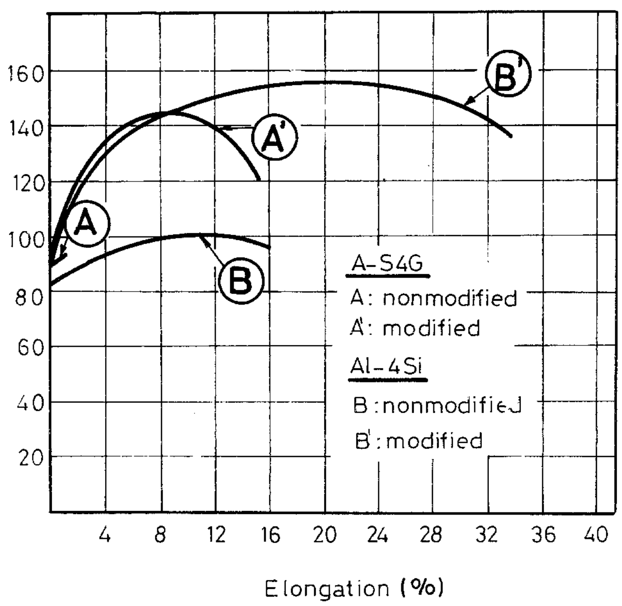

Figure 5 Engineering stress–strain curves.

TABLE III Tensile properties of modified and nonmodified A-S4G and Al–4% Si alloys

Alloy	Casting condition	Alloy condition	0.2% proof strength (MPa)	UTS (MPa)	Elongation (%)
A-S4G	Chill-cast	Nonmodified	82	160	1.8
	Sand-cast	Nonmodified	81	140	0.9
		Modified	90	142	15
Al-4 Si	Chill-cast	Nonmodified	80	116	8
	Sand-cast	Nonmodified	79	113	16
		Modified	82	154	34

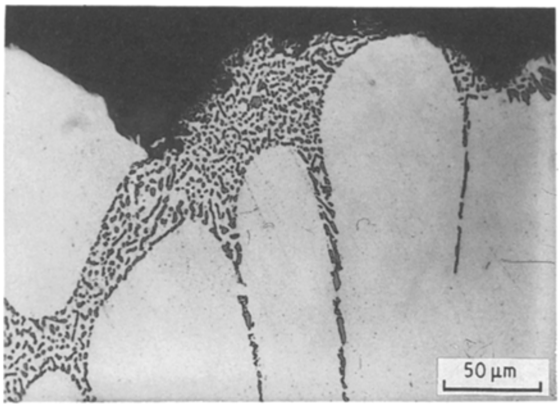

Figure 6 Optical fractography for a modified alloy.

4. Elongation has been substantially increased by modification. For A-S4G alloy it reached a value of 15% while for high purity alloy it is 34%. Strength is slightly increased by modification.

5. The fracture path circumvents the α-phase while it is not detected if it propagates intergranularly or transgranularly in the eutectic matrix.

6. The fractography of the fracture surface by SEM reveals, for the modified alloys, dimple and smooth ripple patterns which reflect the high ductility of these alloys.

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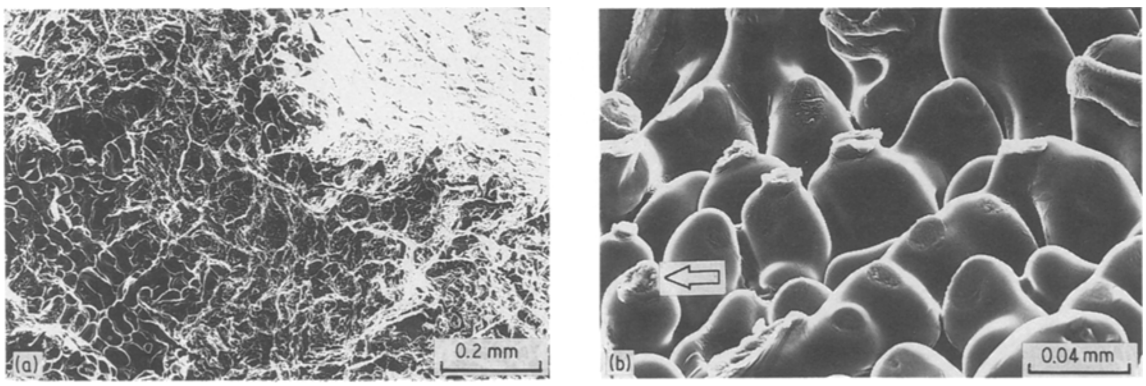

Figure 7 (a) General fracture features of nonmodified chill-cast Al–4Si alloy, (b) fracture traces on dendrite lobes.

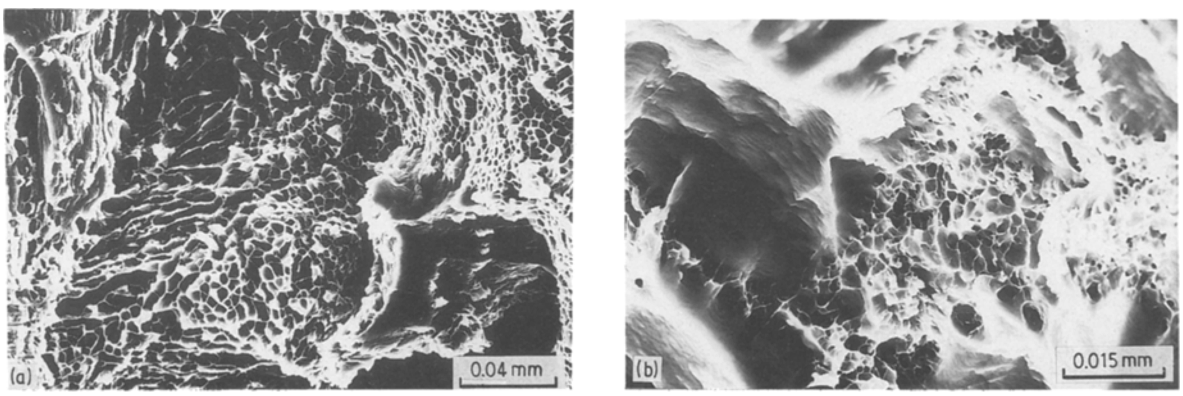

Figure 8 (a) Fracture features of modified Al–4Si alloy, (b) smooth and dimple patterns at a higher magnification.

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