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Study on hardness and microstructural characteristics of sand cast Al–Si–Cu alloys

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Abstract. **In this study, the influence of Cu content on the hardness and microstructural characteristics of sand cast Al–Si–Cu alloys have been investigated. Al–Si alloys with 2% and 5% Cu have been utilized for this purpose. Solidification of Al–Si–Cu alloys have been realized by melting in a gas furnace with a crucible and casting in green sand molds at 690°C. The solution treatment has been performed at 500°C for 7 h and then specimens were quenched in water. The samples have been aged at 190°C for 15 h to observe the effect of aging on mechanical properties.**

Keywords. **Al–Si–Cu alloys; Cu content; microstructure; heat-treatment.**

1. Introduction

Aluminium and its alloys represent an important category of materials due to their high technological value and wide range of industrial applications, especially in aerospace and household industries. Mainly because of their good specific strength, excellent formability and corrosion resistance, Al–Si base alloys are most commonly used in commercial aluminum casting alloys and have been used extensively in automotive, aerospace and transportation industries. Al–Si–Cu alloy system has great importance in casting industry. Copper is a potent precipitation-strengthening agent in aluminium. Cu additions up to about 5% lead to alloys with very high strength and good toughness when subject to natural or artificial aging. The addition of Cu increases considerably the strength of Al–Si alloys, due to precipitation of dispersed Al_2Cu (θ) phase during aging. The strengthening contribution from precipitation is typically a function of both precipitate size and fraction (Haque and Maleque 1998; Wang *et al* 2003; Li R X *et al* 2004; Li X *et al* 2004; Guo and Shah 2005; Zeren 2005; Kim and Buchheit 2007; Rosliza *et al* 2008).

Determining the influence of Cu content on the hardness and microstructural characteristics of sand cast Al–Si–Cu alloys is the aim of this study.

2. Experimental

Two different Cu containing Al–Si alloys were utilized for this study. The chemical compositions of these alloys can be seen in table 1. The melting operation was carried out on a gas furnace in a crucible, and the molten metal was cast into green sand molds at 690°C.

For understanding heat treatment effect on microstructure and mechanical properties, solution and aging heat treatments were applied to the solidified specimens. Solution heat treatment was performed at 500°C for 7 h. After that specimens were water quenched to obtain super saturated solid solution structure. The specimens were then aged at 190°C for 15 h. All heat treatments were carried out with a resistance heating furnace.

To obtain the transition temperatures of the equilibrium phases, differential thermal analysis (DTA) was performed with a NETZSCH STA 409 PC7PG. The cooling rates during the DTA was constant at 30 K/min. And all tests were applied under argon atmosphere.

Specimens were prepared in usual manner for metallographic observations. Microstructural investigations were made by a Zeiss optical microscope and Jeol 6063 type Scanning Electron Microscope (SEM) with an Energy Dispersive X-ray Spectroscopy (EDX) attachment.

3. Results and discussion

3.1 *Microstructure*

Figure 1 shows the optical micrographs of as-cast A2 alloy. As seen in figure 1(a) alloy has dendritic α-Al matrix with dispersed needle-like eutectic silicon particles. In figure 1(b) some dark contrasted intermetallic particles are seen. To identify these intermetallic phases back-scattered electrons are used in SEM, which can be seen in figure 2 for A5 alloy. In SEM micrographs Cu containing intermetallic precipitates appear in white contrast and can easily be separated.

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Figure 3 shows the EDX analysis of the precipitate arrowed in figure 2(b). The EDX analysis proves that the precipitate contains Cu. The chemical composition of the intermetallic particle is Al_2Cu which is generally named as θ phase for Al–Cu alloys.

3.2 *Differential thermal analysis (DTA)*

Figures 4 and 5 show the DTA curves for Al–Si–2Cu and Al–Si–5Cu, respectively. In the DTA curve of alloy containing 5% Cu there is a peak (marked as 1) which is caused by the formation of polynary eutectic phases with low melting points. This type of eutectic phases are present in the material when the copper content is higher than 2%. Increasing the amount of copper in the alloy causes increase of these phases (Wang *et al* 2003).

Table 1. Chemical composition of alloys.

	Composition (wt.%)				
Alloy	Si	Cu	Mg	Fe	Al
A2	10·8	2	0·1	0·8	Balance
A5	10·6	5	0·1	0·6	Balance

3.3 *Hardness*

To understand the effect of copper content and heat treatment, hardness values of alloys were measured both in as cast and heat treated conditions. The dimensions of the hardness specimens were $2 \times 2 \times 2$ cm and all the specimens were prepared in the usual metallographic manner, 3 μm diamond particles were used for final polishing. Figure 6 shows the graphical representation of hardness values of the alloys, all the given values are average of 5 measurements. It is obvious that increasing the Cu amount in the alloys increases the hardness with or without heat treatment. Figure 6 also shows that aging heat treatment increases hardness nearly 100% for alloy

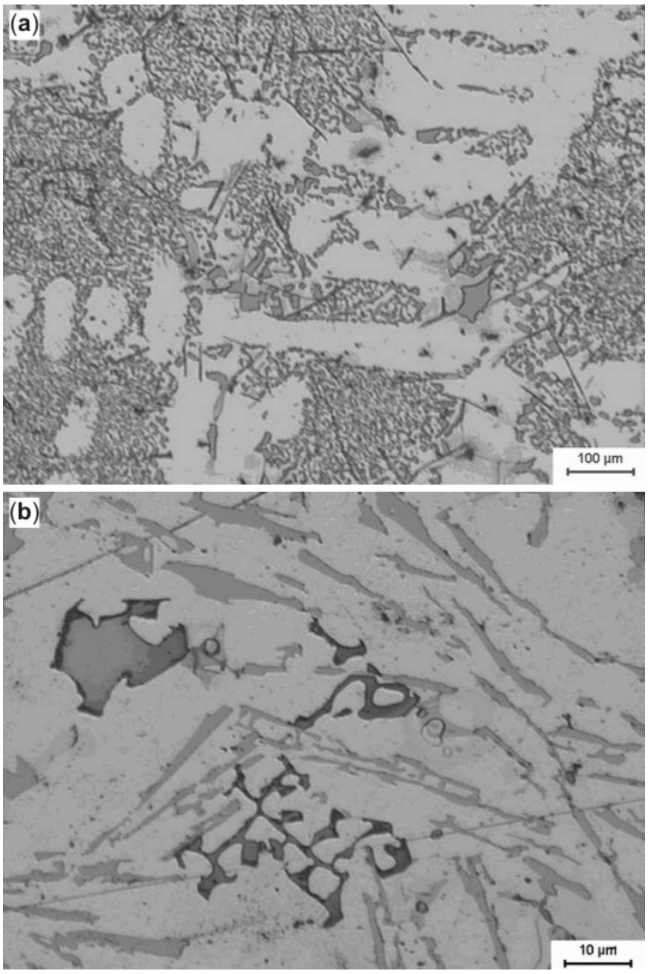

Figure 1. Microstructure of as-cast A2 alloy (**a**) dendritic structure and (**b**) distribution of silicon platelets (grey) and fine intermetallic particles.

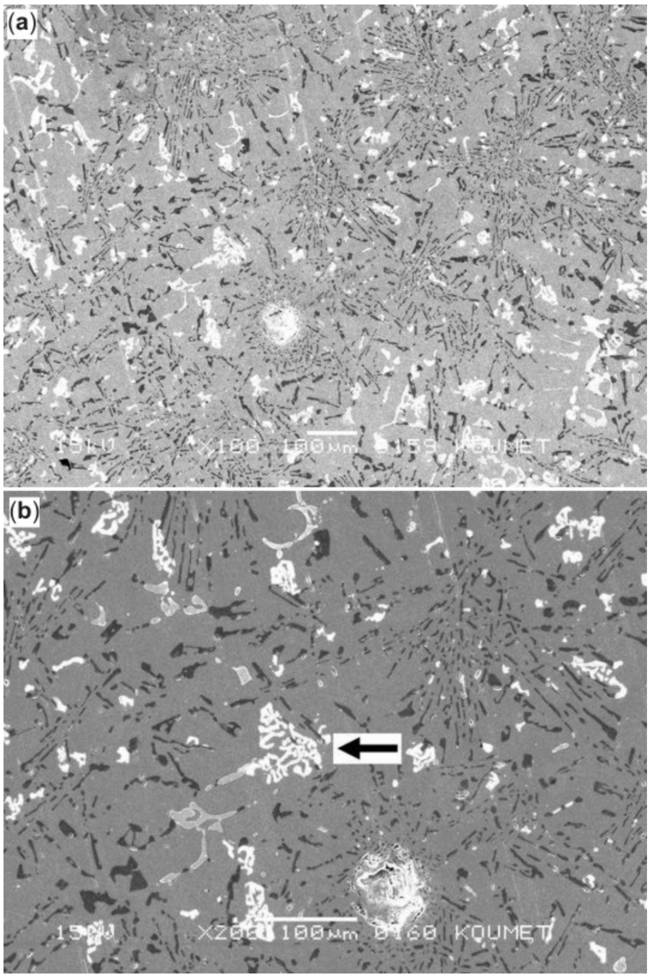

Figure 2. (**a**) SEM microstructure of as-cast A5 alloy and (**b**) white contrasted intermetallic phase.

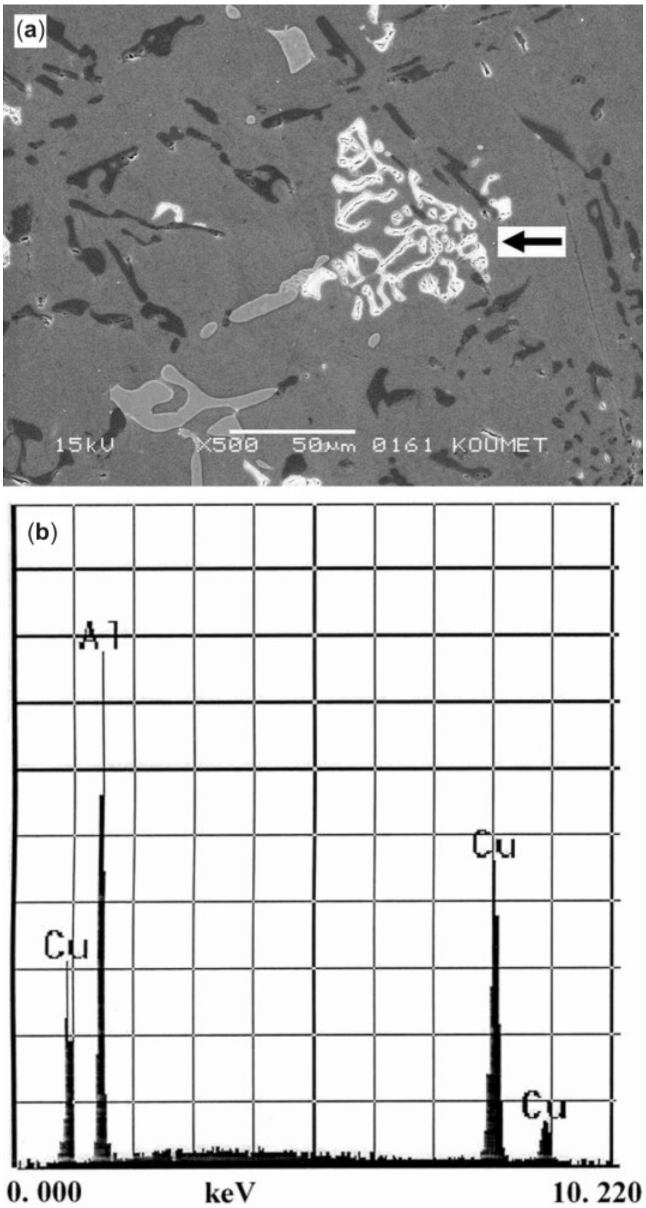

Figure 3. (**a**) Microstructure of the intermetallic particle and (**b**) energy dispersive X-ray analysis of the white contrasted particle in figure 2(b) (arrowed).

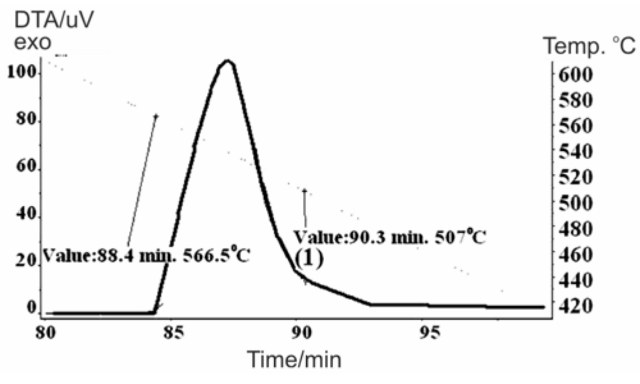

Figure 4. DTA curve for as-cast samples of Al–Si–2Cu alloys.

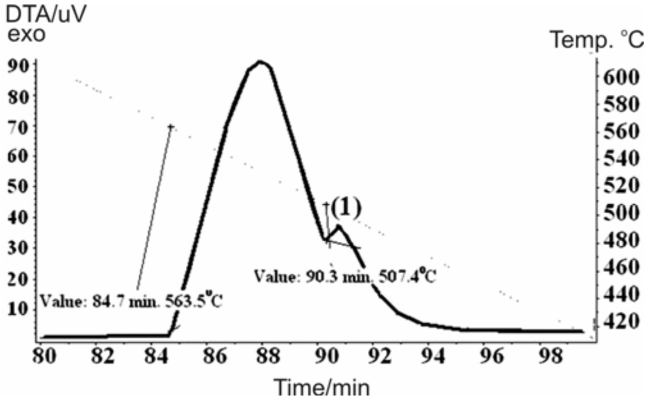

Figure 5. DTA curve for as-cast samples of Al–Si–5Cu alloys.

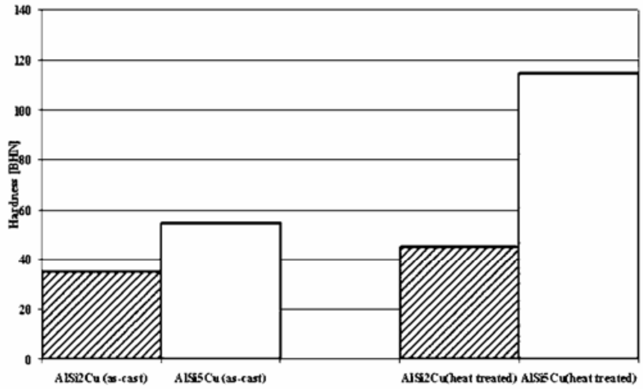

Figure 6. Graphical representation of hardness values of Al–Si–Cu alloys in as-cast and heat treated conditions.

containing 5% Cu. The increase of hardness after heat treatment is more effective when Cu content is high in alloy.

4. Conclusions

(I) Large precipitates of stable Al_2Cu phases were found in the solidified alloys.

(II) Mechanical properties of Al–Si–Cu alloys largely depend on the heat treatment. Thus, characteristics of heat treatment play a vital role for a good combination of microstructure and mechanical properties. Copper content in Al–Si–Cu alloys affect the mechanical properties. By increasing copper content, hardness increases due to precipitation hardening. It is found that increasing copper content from 2 to 5% increases from 55 HB to 115 HB.

(III) Peak 1 in DTA appears when Cu content is more than 2%. The height of peak 1 increases due to increasing Cu content. This means that polynary eutectic phases are formed when Cu content is more than 2% and its amount is increasing with increasing Cu content.

(IV) For Al–Si–Cu alloys, the restrictive solution temperature avoiding grain boundary melting decreases with increasing Cu content. For alloys with more than 2 wt.% Cu, suitable temperature is 500°C (Wang *et al* 2003).

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