

PRODUCTION OF ALUMINIUM-SILICON CARBIDE CAST PARTICLE COMPOSITES WITHOUT MAGNESIUM

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Abstract

To produce Al matrix cast particle composites, wettability of the ceramic particles by liquid Al is essential. To improve wettability, elements such as Mg, Ce etc. are added into Al alloy prior to incorporation of the ceramic particles. In other methods, ceramic particles are incorporated into solid-liquid slurry of Al alloy; metal-ceramic powder compacts are slowly dissolved into the Al alloy or particles are preheated before incorporation into Al alloy.

In the present study, silicon carbide and alumina particles were mixed with Al-Cu (50:50) master alloy powder in a required proportion to produce Al-4.5 Cu alloy-15 wt% particle composites by vortex method. Success was achieved to incorporate SiC particles in an Al melt without Mg, whereas in case of alumina particles, the viscosity of the melt was too high after addition of about half of the required amount of particles. The fluidity of the Al alloy-SiC composite melt was sufficient to pour in graphite moulds. The mechanism of this novel approach of production of cast ceramic particle composites by vortex method without Mg is discussed.

Introduction

Aluminium alloys reinforced with ceramic particles exhibit superior mechanical properties to unreinforced Al alloys and hence are candidate materials for structural, automotive, aerospace and other applications [1-3]. The Al matrix-particle composites are produced either by casting route or by powder metallurgy. The former has advantages of producing the composites by casting route are lower cost of production and possibility of producing larger components. However, the inherent difficulties of casting route are non-wettability of the ceramic particles by liquid Al [4], segregation of particles, higher porosity level and extensive interfacial reaction due to higher processing temperature. Nonwettability of the particles can be improved by coating the particles with metals such as Ni, Cu, addition of surface active elements such as Mg into liquid Al or preheating of the particles before addition into liquid Al [4] . Most convenient method of production of the composites by casting route is

vortex method, where the liquid Al containing 2-4% Mg is stirred with an impeller and the ceramic particles are incorporated into the vortex formed by stirring of the liquid metal. Addition of Mg into liquid Al reduces its surface tension [1] and thereby avoids rejection of the particles from the melt. Without addition of Mg, the recovery of the particles into the melt is quite low [5]. Hence 2-4% Mg is generally added into the Al melt before incorporation of the particles. However, the chemistry of an Al alloy is changed with the addition of Mg that can be deleterious to the mechanical properties of the composites.

Production of Al matrix particle composites by casting route without addition of Mg is possible by using Ni-coated ceramic particles. However Ni-coating on ceramic particles is a costly process. Preheating the particles at around 800°C for 1-2 hrs before incorporation into liquid Al is another route [4] for production of the composites without Mg. However, this approach requires an additional step of preheating the particles.

The present work considers the production of Al matrix SiC particle composites without Mg where the SiC particles are mixed with Al-Cu master alloy powder and the particle mix is incorporated into commercially pure liquid Al by vortex method.

Particle-matrix interface characteristics have significant effect on the mechanical properties of the composites, as good bonding promotes load transfer to the higher strength ceramic particles. On the other hand, extensive interfacial reaction may deteriorate the mechanical properties of the composites [1]. Hence another objective of the present study was to compare the particle - matrix interfacial characteristics of Al-SiC particle composites without and with 1.5% Mg in Al - 4.5% Cu alloy. The effect of holding the composite melt at 730°C upto 1h on the interface has also been studied. The density and hardness of the composites have been correlated with the interface characteristics and porosity.

Experimental Procedure

Al-SiC particle composites were prepared by vortex method. Commercially pure aluminium of about 500g was melted in an electrical resistance furnace. To prepare Al-4.5Cu-15 wt% SiC particle composite, required amount of Al-Cu master alloy powder (Al:Cu - 50:50, <180 μm) was mixed with as-received SiC particles of average size 43 μm . The molten Al in the crucible was stirred with a graphite impeller revolved at 1200rpm. The particle mix was slowly added into the vortex formed in the melt. After complete addition of the particles, the melt was stirred for another two minutes for uniform distribution of the particles in the melt. The composite melt was poured at 730°C into graphite moulds of 12mm and 15mm diameter.

To study the effect of addition of Mg and effect of holding on the characteristics of particle-matrix interface, required amount of Mg was plunged inside the melt so that the matrix composition was Al-4.5Cu-1.5Mg. Another set of sample was poured into the moulds after five minutes of addition of Mg. The melt was held at 730°C and other two sets of samples were cast at the end of 30 minutes and 60 minutes after alloying with Mg.

To study the microstructures and density of the composites, 12mm dia samples were used, whereas 15mm dia samples were used for hardness measurements. Specimens for microstructures were polished by conventional method and were etched with Keller's reagent. Density of the specimens was measured by water displacement method. Hardness was evaluated in a Brinell Hardness Testing machine with 500 kg load. Average of two readings of hardness was taken.

Results and Discussion

One objective of the present work was to produce Al-SiC particle composite by liquid metallurgy by using Ni-without Mg. Al-Cu (50:50) master alloy powder of required amount was mixed with SiC particles to produce Al-4.5Cu alloy-15 wt% SiC particle composite. During addition of the particle mix through a funnel into the vortex of liquid Al, no rejection of the particles was observed. All the particles could be incorporated successfully into the Al melt.

Ceramic particles generally have poor wettability by liquid metal and hence it poses difficulty in production of metal-ceramic composites and joining of metals to ceramics. For example, wetting of carbon, SiC, B₄C and Al₂O₃ by Al and its alloys have been measured and found to be poor below 950°C [6]. Wettability can be improved by decreasing contact angle through :

- i) Increasing the surface energy of the ceramic
- ii) Decreasing the solid-liquid interfacial energy and
- iii) Decreasing the surface tension of the liquid metal.

The coating of ceramic particles by Ni, Cu etc. increases the surface energy of the ceramic particles by changing the interface from metal-ceramic to metal-metal. Thus Ni- or Cu-coated graphite particles have been successfully incorporated into Al-alloy [7].

Addition of reactive elements such as Cu, Si, Mg [8] Ca, Ti, Zr, P [4] improves the wetting characteristics of metal-ceramic systems through a reduction in solid-liquid interfacial energy and the surface tension of the liquid metal. For exam-

ple, addition of 3 wt% Mg into Al melt reduces the surface tension of it from 0.760 to 0.620 Nm⁻¹ [1]. The solid-liquid interfacial energy is changed through the presence of reaction products at the interface. The reactions of interface for Al-Mg alloy - Al₂O₃ and Al-SiC systems are :



The reaction products such as MgAl₂O₄, Al₄C₃ etc. at the interface change the solid-liquid interfacial energy.

Heat treatment of ceramic particles before incorporation is another approach to produce Al-ceramic particle composites by liquid metallurgy technique [4]. In this case the wettability of the ceramic particles by liquid Al is improved through desorption of adsorbed gases from the surface of ceramic particles.

In the present work, the Al-SiC particle composites are produced by a different approach. The schematic diagram of the mechanism of incorporation is shown in Fig. 1. The particles were a mixture of nonwetable SiC particles and wettable Al-Cu master alloy particles. It may be noted that when the particle mix is added into liquid Al, a cluster rather than individual particles are dropped into the vortex of liquid Al. These clusters contain both wettable as well as non-wettable particles. Since wettable particles are easily dispersible into the melt, Al-Cu particles carry the SiC particles inside the melt and subsequently both are dispersed uniformly by agitation.

The optical micrograph of Al-4.5 Cu alloy-15 wt % SiC particle composite is shown in Fig. 2 (a). The distribution of the SiC particles is reasonably uniform. No particle segregation is observed in the composite. On addition of 1.5% Mg and after holding for 1 hr at 730°C, the particle distribution is similar as shown in Fig. 2 (b) and 2 (c) respectively. It is interesting to note that the particles are darkened on addition of Mg, that can be attributed to severe interfacial reaction. Al and SiC forms Al₄C₃ and Al₄SiC₄ [1] as given in reaction (2) earlier. In presence of Mg in Al alloy, MgO, CuMgAl₂ and CuAl₂ form at the interface. Since Mg is much more reactive than Al, it can be concluded that more interfacial reaction and change in composition of the surface of the particles due to reaction at the interface make the particles darker. This effect is also clear in the optical micrographs at higher magnification shown in Fig. 3(a), (b) and (c).

The specimens were observed at higher magnification primarily to study the interfacial zone. In case of Al-4.5Cu -15 wt% SiC particles without Mg, the interfacial bonding appears to be poor [Fig.3(a)]. On addition of Mg, the bonding is clearly

improved [Fig.3(b)]. After holding for 1hr at 730°C, interfacial reaction continued and the reaction products are decorated at the interface as shown with arrow marks in Fig.3(c). Both continuous layers or isolated precipitates can form at the interface [1]. In the present work, isolated precipitates have formed at the interface.

The density and hardness of the composites are presented in Table-I. On addition of Mg, the density is reduced from 2.63 to 2.61, since Mg has lower density than Al. On holding at 730°C for 30 min and 1 hr, the density gradually reduces. The primary reason for reduction in density is absorption of hydrogen from atmosphere by liquid Al during holding. Dissolved hydrogen precipitates as microporosity in the matrix of the composites and hence reduces its density. Since the interfacial reaction is minimum as observed in Fig. 3(c), the change in density due to formation of product phases at the interface would be negligible.

TABLE - I
Physical and mechanical properties of Al-SiC composites

Material	Density(g/cc)	Hardness(BHN)
Al - 4.5 Cu - 15 SiC (Without Mg)	2.63	38
Al - 4.5 Cu - 1.5 Mg - 15 SiC (5 min after Mg addition)	2.61	69
Al - 4.5 Cu - 1.5 Mg - 15 SiC (30 min after Mg addition)	2.60	65
Al - 4.5 Cu - 1.5 Mg - 15 SiC (60 min after Mg addition)	2.58	61

The hardness of Al - 4.5 Cu alloy matrix composite is 38 BHN, whereas that of Al-4.5Cu-1.5 Mg alloy matrix composite has increased to 69 BHN. Alloying of Al-4.5Cu alloy with Mg and probably better interfacial bonding increases the hardness. On holding the composite melt at 730°C reduces the hardness gradually. The primary cause of reduction in hardness is the increased microporosity on holding the composite melt. Another factor to reduce the hardness is possibly the reaction at the interface. Although some interfacial reaction is helpful for load transfer from matrix to the strong ceramic particles, excessive interfacial reaction is detrimental to the mechanical properties of the composites [1]. Thicker interfacial zone facilitates debonding. However, this effect is more probable in case of tensile loading at the interface, whereas in hardness test the loading is mainly compressive in nature. Therefore it can be concluded that absorption of hydrogen by liquid Al due to holding the melt at 730°C and the resultant microporosity in the matrix of the composite reduce hardness of the composite.

Conclusions

- 1) An alternative method of production of Al - SiC particle composite by vortex method without Mg is established.
- 2) The interfacial bonding between the Al matrix and SiC particles is poor without Mg. Addition of 1.5% Mg improves interfacial bonding.
- 3) Holding of the composite melt at 730°C causes gas porosity in the matrix and hence reduces density and hardness of the composite.

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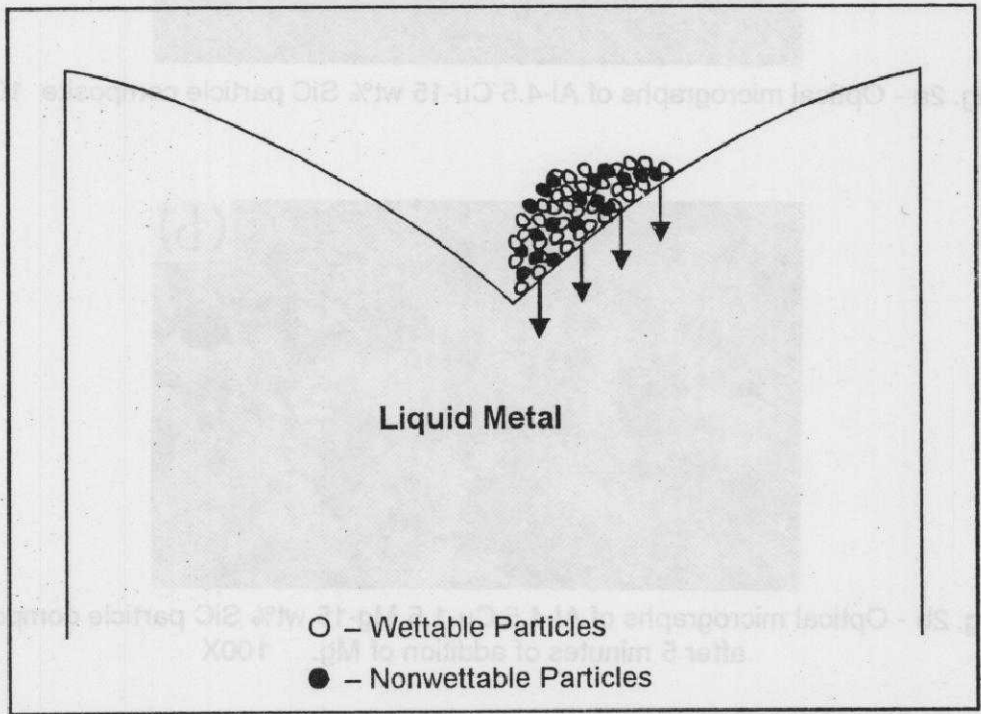


Fig.1 - Schematic diagram of mechanism of incorporation of SiC particles in liquid Al

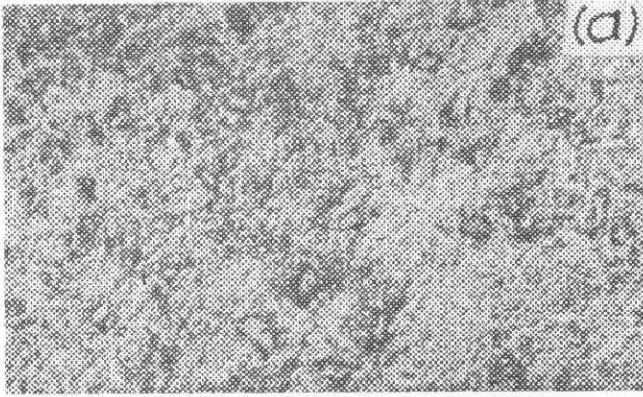


Fig. 2a - Optical micrographs of Al-4.5 Cu-15 wt% SiC particle composite 100X

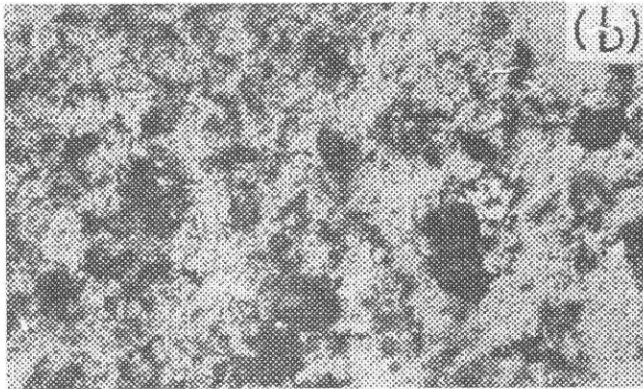


Fig. 2b - Optical micrographs of Al-4.5 Cu-1.5 Mg-15 wt% SiC particle composite after 5 minutes of addition of Mg. 100X

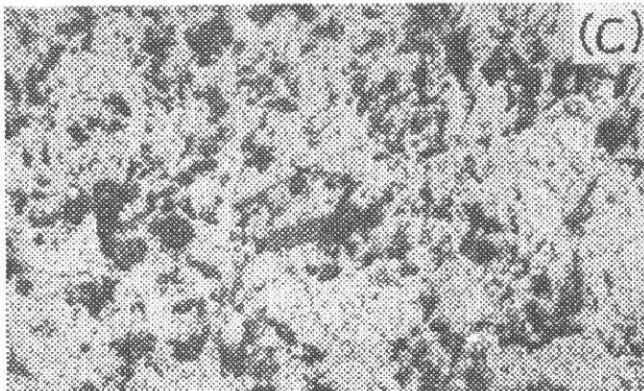


Fig. 2c - Optical micrograph of Al-4.5 Cu-1.5 Mg-15 wt% SiC particle composite after 60 min. of addition of Mg 100X

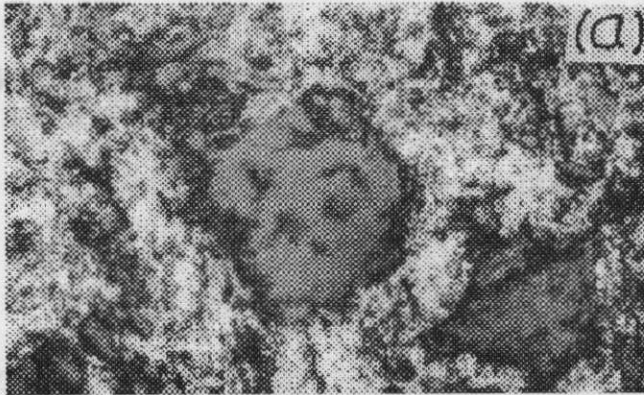


Fig. 3a - Optical micrograph of Al-4.5 Cu-15 wt% SiC particle composite. 1000X.

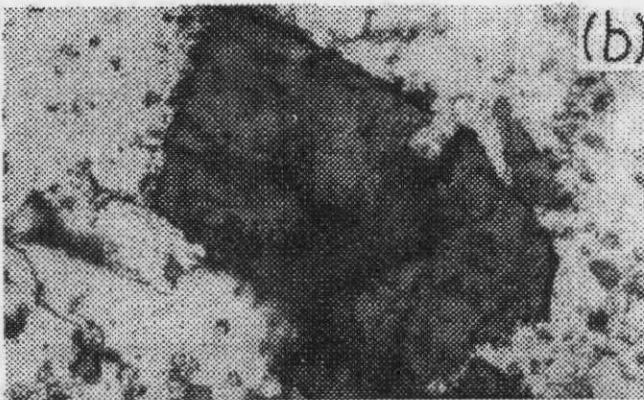


Fig. 3b - Optical micrograph of Al-4.5 Cu-1.5 Mg-15 wt% SiC composite after 5 min. of addition of Mg. 1000X.

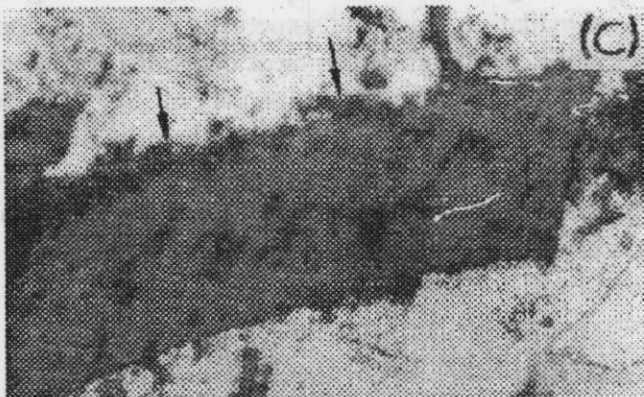


Fig. 3c - Optical micrograph of Al-4.5 Cu-1.5 Mg-15 wt% SiC composite after 60 min. of addition of Mg. Mag. 1000X.