Matrix Al-alloys for silicon carbide particle reinforced metal matrix composites

A. Chennakesava Reddy and Essa Zitoun
Department of Mechanical Engineering, JNT University College of Engineering, Hyderabad-515002, AP, India
dr_acreddy@yahoo.com, essajessus@yahoo.com

Abstract

The material selection criteria involve the requirement of high strength and good corrosion resistance aluminum alloys for the matrix materials. The mechanical properties have been determined for different metal matrix composites produced from Al 6061, Al 6063 and Al 7072 matrix alloys reinforced with silicon carbide particulates. The yield strength, ultimate strength, and ductility of Al/SiC metal matrix composites are in the descending order of Al 6061, Al6063 and Al 7072 matrix alloys. Mg has improved the wettability between Al and SiC particles by reducing the SiO_2 layer on the surface of the SiC. The fracture mode is ductile in nature.

Keywords: Aluminum alloys, silicon carbide, matrix composites, fracture mode.

Introduction

Composites are materials in which two phases are combined, usually with strong interfaces between them. They usually consist of a continuous phase called the matrix and discontinuous phase in the form of fibers, whiskers or particles called the reinforcement. Considerable interest in composites has been generated in the past because many of their properties can be described by a combination of the individual properties of the constituent phases and the volume fraction in the mixture. Composite materials are gaining wide spread acceptance due to their characteristics of behaviour with their high strength to weight ratio. The interest in metal matrix composites (MMCs) is due to the relation of structure to properties such as specific stiffness or specific strength. Like all composites, aluminum matrix composites are not a single material but a family of materials whose stiffness, density and thermal and electrical properties can be tailored. The elements of Si, Fe, Cu, Mn, and Mg in Al-alloys are known to increase tensile properties by forming precipitates such as Al_2Cu, $FeAl_3$, Mg_5Al_8 and Mg_2Si during the fabrication process (Seleznev *et al.,* 1998; Chennakesava & Sundararajan, 2005). During the plastic deformation of the composite, the nature of the chemical bond is very vital and it depends on the alloying elements. For instance, addition of Mg to composite matrix lead to the formation of MgO and $MgAl_2O_3$ at the interface and this enhances the wettability, which is otherwise poor. Mg has also improved the wettability between Al and SiC particles, by reducing the SiO_2 layer on the surface of the SiC (Zlaticanin *et al.,* 2004). The grain sizes of the Al-alloy matrix are sensitively dependent on the fabrication process and the composition (Zhou & Xu, 1997). Generally, the reinforcing particles are more or less non-uniformly dispersed in the metal matrix composites (Qu *et al.,* 2007; Chennakesava, 2003). In the as-cast conditions, the matrix is multiphase. The intermetallics are brittle in nature. Such brittle phases can form at various stages of composite processing by reaction between the matrix and the reinforcement during solidification (Rohatgi *et al.,* 1990).

Table 1. Chemical composition of alloys

Alloy	Composition determined spectrographically (%)								
	Al	Si	Fe	Cu	Ti	Mg	Mn	Zn	Cr
6061	97.6	0.68	0.61	0.021	0.053	0.92	0.044	0.072	0.005
6063	98.8	0.271	0.325	0.005	0.037	0.52	0.008	0.076	0.001
7072	97.8	0.387	0.464	0.013	0.005	0.396	0.008	0.85	0.012

The material selection criteria involves the requirement of high strength and good corrosion resistance aluminum alloys for the matrix materials, and the inexpensive reinforcement particles which can result in increased yield strength and elastic modulus at little expense of ductility. The matrix materials used in the present work are Al 6061, Al 6063 and Al 7072 alloys. The reinforcement materials are silicon carbide (SiC) particulates.

Experimental procedure

The matrix alloys and composites were prepared by stir casting process in Tapasya casting pvt. Ltd., Hyderabad. The chemical composition of alloys is given in Table 1. The properties of the matrix materials are given in Table 2. The volume fraction and particle size of SiC reinforcement are 20% and 10 μm respectively.

Table 2. Mechanical properties of matrix materials

Matrix Material	Density (g/cc)	Modulus of elasticity (GPa)	Ultimate tensile strength (MPa)	Elongation (%)
Al 6061	2.7	68.9	241	22
Al 6063	2.7	68.9	172	22
Al7072	2.72	68.0	168	15

Preparation of metal matrix composites

Al alloys were melted in an oil-fired furnace. The melting losses of alloy constituents were taken into account while preparing the charge. The charge was fluxed with coverall to prevent dressing. The molten alloy was degasified by tetrachlorethane (in solid form). The crucibles were made of graphite. The preheated reinforcement particles were added to the liquid melt. The molten alloy and reinforcement particles are thoroughly stirred using a mixer to make the melt homogenous as shown in Fig.1. The temperature of the melt was measured using a dip type thermocouple. The dross removed melt was

Fig. 1. Charge preparation in the stir casting process

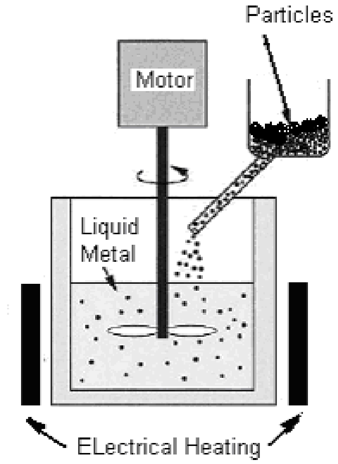


Fig. 2. Tensile specimen (all dimensions are in mm).

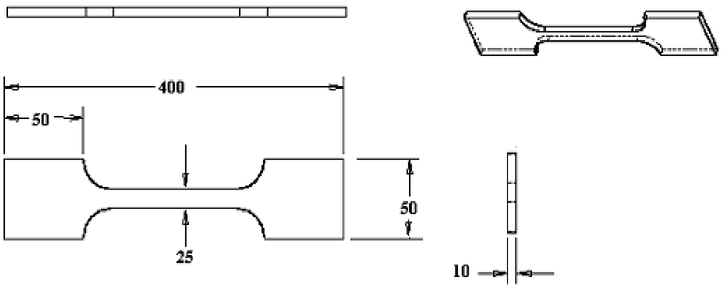


Fig. 3. Tested tensile Al/SiC composite specimens

Fig. 4. Influence of matrix alloy on the yield strength Al/SiC composite

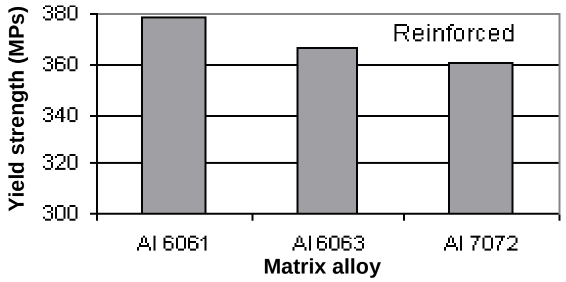


Fig. 5. Influence of matrix alloy on the UTS of Al/SiC composite

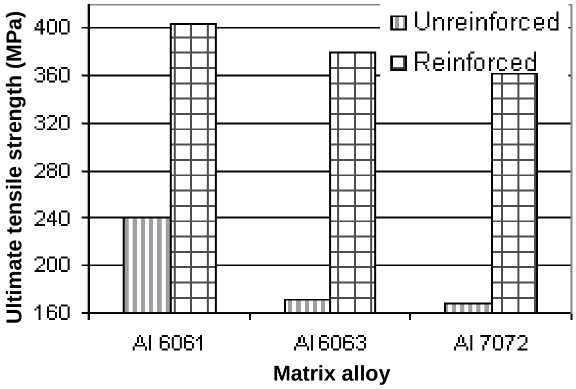


Fig. 6. Influence of matrix alloy on the Ductility of Al/SiC composite

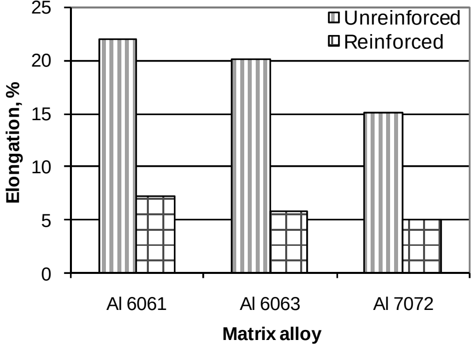


Fig. 7. Microstructure of Al 6061/SIC metal matrix composite, 200X

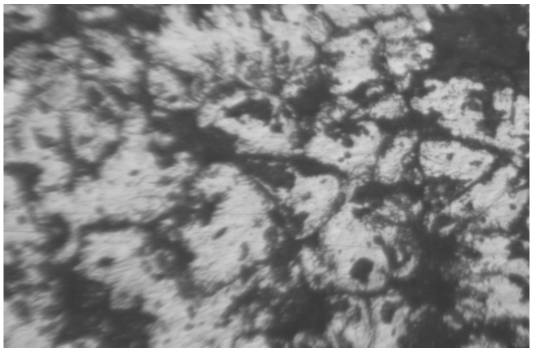


Fig. 8. Microstructure of Al 6063/SIC metal matrix composite, 200X

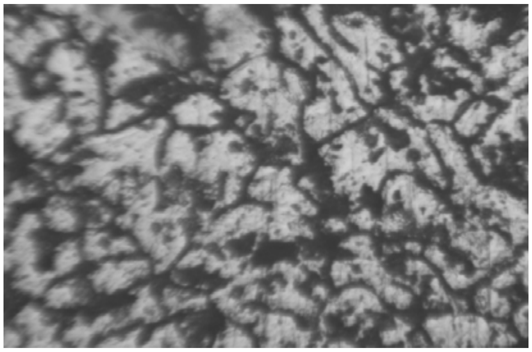


Fig. 9. Microstructure of Al 7072/SIC metal matrix composite, 200X

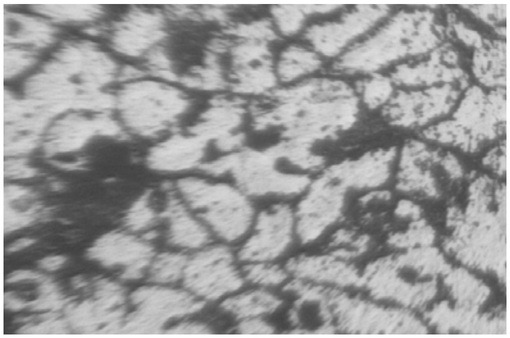


Fig. 10. SEM of fracture surface of SiC/Al6061 metal matrix composite, 1000X

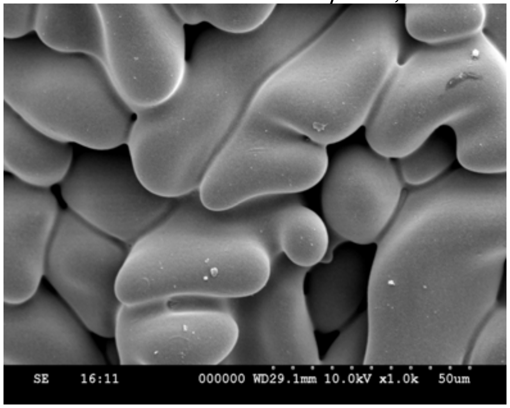


Fig. 11. SEM of fracture surface of SiC/Al6063 metal matrix composite,1000X

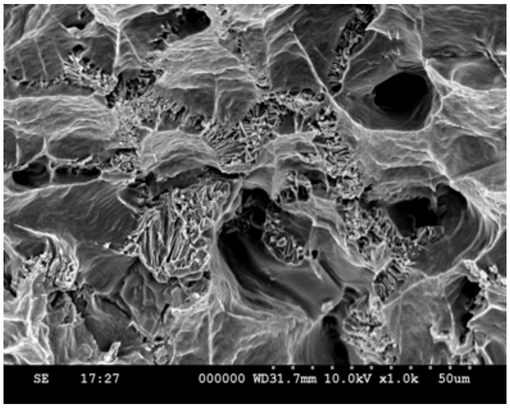
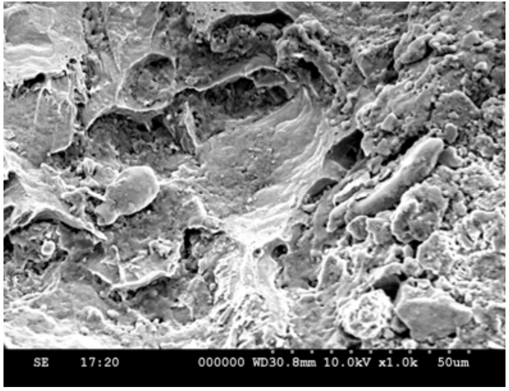


Fig. 12. SEM of fracture surface of SiC/Al7072 metal matrix composite, 1000X



finally gravity poured into the preheated cast iron mould.

Tensile test

The samples were machined to get dog-bone specimen for tensile test. The shape and dimensions of the tensile specimen are shown in Fig. 2. The computer-interfaced UTM (universal testing machine) was used for the tensile test. The specimens were loaded hydraulically. The loads at which the specimen has reached the yield point and broken were noted down. The extensometer was used to measure the elongation. The load vs. deflection graph was also obtained for each specimen from the computer attached to the machine.

Optical & SEM analysis

Microscopic analysis of the cast composite samples was performed by optical microscopy. An Image analyzer was used to examine the distribution of the reinforcement particles within the aluminum matrix. The mechanical properties of any particle reinforced metal matrix composites depend on the particle distribution, particle size, particle flaws, surface irregularities and particle-matrix bonding. It is therefore, necessary to conduct a microscopic analysis on the new material in order to gain better understanding of its micro structural characteristics. The polished specimens were ringed with distilled water and etched with 5% HF solution. Fracture surfaces of the deformed (under tensile loading) test samples were examined in a scanning electron microscope to determine the macroscopic fracture mode and to characterize the fine-scale topography and establish the microscopic mechanisms governing fracture. Samples for SEM observation were obtained from the tested specimens by sectioning parallel to the fracture surface and the scanning was carried in IICT, Hyderabad (S-3000N Toshiba).

Results and discussion

The tested tensile specimens are shown in Fig. 3. Three samples were tested for each trial. The average values of yield strength, ultimate tensile strength, and ductility in terms of tensile elongation.

Effect of matrix alloy on mechanical properties

Fig. 4 shows the influence of matrix alloy on the yield strength (YS) of Al-SiC composites. It can be seen that the Al 6061 matrix alloy exhibits larger YS than Al 6063 and Al 7072 matrix alloys. The YS of Al 6063 matrix alloy is greater than that of Al 7072 matrix alloy. The influence of matrix alloy on the UTS of metal matrix composites and unreinforced alloys is shown in Fig. 5. It is observed that the Al 6061 matrix alloy contributes larger UTS than Al 6063 and Al 7072 matrix alloys. The UTS of Al 7072 matrix alloy is lower than that of Al 6063 matrix alloy. The UTS of metal matrix composites is very much higher than the unreinforced Al-alloys. Fig. 6 shows the effect of matrix alloy on the ductility (measured in terms of tensile elongation) of metal matrix composites and unreinforced alloys. The variation in the ductility of composites is largely effected by the change in matrix alloy. The ductility of Al-SiC composites is much lower than that of un-reinforced Al-alloy. The ductility is in the descending order of Al 6061, Al6063 and Al 7072 matrix alloys.

The contents of alloying elements such as Si, Fe, Mg, and Cu in Al 6061 are higher than those in Al 6063 and Al 7072. Secondly, contents of alloying elements such as Si, Fe, and Cu in Al 7072 are greater than those in Al 6063 except Mg content. Therefore, it is expected that the YS and UTS of Al 6061 are higher than those of Al 6063 and Al 7072. Even though the contents of Si, Fe, and Cu in Al 7072 are higher than those of Al 6063, the YS and UTS of AL 7072 are lower than those of Al 6063. Mg has improved the wettability between Al and SiC particles by reducing the SiO_2 layer on the surface of the SiC in case of Al 6063 matrix alloy. Mg leads to the formation of MgO and $MgAl_2O_3$ at the matrix-reinforcement interface. The YS and UTS of Al/SiC metal matrix composites are greater than the unreinforced alloys on account of the load transferred to the reinforcement SiC particles.

The various intermetallics can be revealed in the microstructures shown in Fig. 7-9 which show the distribution of the SiC particles in the composites. It is clear that the SiC particles are distributed less evenly in the as-cast composites. There is an evidence of clustering and agglomeration. In the as-cast condition, Al is present both in solid solution with the matrix and precipitated as $Al_{12}Mg_{17}$ phase that is present at and along the grain boundaries. MgO and $MgAl_2O_3$ are also seen along the grain boundaries. The phases Al_2Cu, Mg_2Si, Al_5Mg_8, Cu_2Si_6, Al_3Fe and Al_3FeSi are also observed in the microstructures. In the microstructure of composites, Si phase can also be seen apparently in the eutectic regions and intermetallic compounds such as Mg_2Si, iron-containing phases or spinels may also exist due to the secondary alloying elements and impurities present in the matrix alloy scraps.

Fracture behavior

The fractured surfaces of the tensile specimens are shown in Fig. 10-12. The fracture of SiC particles is not seen in Al 6061/SiC metal matrix composite (Fig. 10). The fracture is only due to the matrix in Al 6062/Sic composites. The failure mode in Al 6063/SiC and Al 7072/SiC metal matrix composites is predominantly by the particle-matrix interface cracking (Fig. 11 & 12). The overall fracture is ductile in nature.

Conclusion

The yield strength, ultimate strength, and ductility of Al/SiC metal matrix composites are in the descending order of Al 6061, Al6063 and Al 7072 matrix alloys. The contents of alloying elements such as Si, Fe, Mg, and Cu have played vital role on the mechanical properties Al/SIC composites. Mg has improved the wettability between Al and SiC particles by reducing the SiO_2 layer on the surface of the SiC. The fracture of SiC particles is not seen in Al 6061/SiC metal matrix composite. The fracture is only due to the matrix in Al 6062/Sic composites. The failure mode in Al 6063/SiC and Al 7072/SiC metal matrix composites is predominantly by the particle-matrix interface cracking.

Acknowledgements

The authors acknowledge with thanks All India Council for Technical Education (AICTE), New Delhi for providing financial assistance and Tapasya casting Pvt. Ltd., Hyderabad, Jyothi laboratories, Hyderabad and Indian Institute of Chemical Technology, Hyderabad for technical help.

References

1. Chennakesava Reddy A (2003) Studies on fracture behaviour of brittle matrix and alumina trihydrate particulate composites. *Ind. J. Engg. Materials Sci.* 9(5), 365-368.
2. Chennakesava Reddy A and Sundararajan S (2005) Influences of ageing, inclusions and voids on the ductile fracture mechanism of commercial Al-alloys. *J. Bull. Material Sci.* 28(1), 101-105.
3. Qu S, Geng L and Han J (2007) SiC/Al composites fabricated by modified squeeze casting technique. *J. Materials Sci. Technol.* 23(5), 641-644.
4. Rohatgi P, Asthana R and Yarandi E (1990) Solidification of metal matrix composites. In: *Minerals Metals Materials Soc.* pp:51-75.
5. Seleznev ML, Seleznev IL, Cornie JA, Argon AS and Mason RP (1998) Effect of composition, particle size and heat treatment on the mechanical properties of Al-4.5wt.%Cu based alumina particulate reinforced composites, SAE international congress and exposition, Detroit, MI, Feb 23-26, Paper no. 980700.
6. Zhou W and Xu ZM (1997) Casting of SiC reinforced metal matrix composites. *J. Materials Proc. Technol.* 63, 358-363.
7. Zlaticanin B, Filipovic M, Valcic A, Aleksic R, Nikolic S, Radonjic B and Bosnjak B (2004) The effect of magnesium and titanium addition on the microstructure and properties of as-cast Al-5%Cu alloys. *Materiali in Tehnologije.* 38, 1-2.