MATRIX Al-ALLOYS FOR ALUMINA PARTICLE REINFORCED METAL MATRIX COMPOSITES

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The mechanical properties of different metal matrix composites have been determined. Al 6061, Al 6063 and Al 7072 matrix alloys are reinforced with alumina particulates. The yield strength, ultimate strength, and ductility of Al/Al_2O_3 metal matrix composites are in the downhill order of Al 6061, Al6063 and Al 7072 matrix alloys. Alumina is highly reactive to the Mg content in the matrix alloys. The fracture mode is predominantly ductile in nature.

1. INTRODUCTION

A composite is a material that is produced through a physical combination of materials to obtain a new material with unique properties when compared to the monolithic material properties. This definition distinguishes a composite from other multiphase materials. Composite materials have been of interest to aerospace and defense markets for many decades as they sought to obtain continuous performance improvements. The material selection criteria involve the requirement of high strength, and good corrosion resistance aluminum alloys for the matrix materials.

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, Fe Al_3, Mg_5Al_8, and Mg_2Si during the fabrication process (Seleznev et al., 1998). Alumina is known to be stable in pure aluminum, but reacts with magnesium to form $MgAl_2O_4$ (spinel). MgO may form at high magnesium levels and lower temperatures whereas the spinel will form even at very low magnesium levels (Lioyd et al., 1990). In the as-cast conditions, the matrix is multiphase. Even small quantities of brittle second phases, particularly if these are located along the matrix-reinforcement interface, affect the toughness and tensile ductility of metal matrix composites [Dutta etal., 1994 and Reddy 2003). Some Al_2O_3 particles aggregated to form coarse clusters in the matrix. According to a previous study (Manoharan, and Lewandowski, 1990), if the agglomeration appears to be well bonded to the matrix, the agglomeration can contribute to the strengthening of the composites.

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In the present work, Al-alloy based matrix materials have been considered for alumina (Al_2O_3) particulate reinforced metal matrix composites. Three Al-alloys namely Al 6061, Al 6063 and Al 7072 alloys were chosen. The effect of matrix materials on the mechanical properties and fracture behavior has been investigated.

Table-1: Chemical composition of matrix 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	0.0051
6063	98.8	0.271	0.325	0.0047	0.0376	0.52	0.0076	0.076	<0.0005
7072	97.8	0.387	0.464	0.013	0.0053	0.396	0.0082	0.85	0.012

2. EXPERIMENTAL PROCEDURE

The matrix alloys and composites were prepared by stir casting process in Tapasya Casting Private Limited – 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 Al_2O_3 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

2.1 Preparation of Melt and 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. The temperature of the melt was measured using a dip type thermocouple. The dross removed melt was finally gravity poured into the preheated cast iron mould.

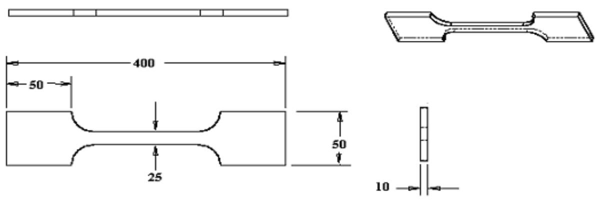

Figure 1: Tensile specimen, all dimensions are in mm

2.2 Tensile Test

The samples were machined to get dog-bone specimen for the tensile test. The shape and dimensions of the tensile specimen are shown in Figure 1. The computer-interfaced UTM (Universal Testing Machine) was used for the tensile test. The loads at which the specimen has reached the yield point and broken were noted down. The extensometer was used to measure the elongation.

2.3 Optical and Scanning Electron Microscopic Analysis

Microscopic analysis of the cast composite samples was performed by the optical microscopy. An image analyzer was used to examine the distribution of the reinforcement particles within the aluminum matrix. 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 (SEM) to determine the macroscopic fracture mode and to 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 (Indian Institute of Chemical Technology - Hyderabad).

3. RESULTS AND DISCUSSION

The tested tensile specimens are shown in figure 2. Three samples were tested for each trial. The average values of yield strength, ultimate tensile strength, and ductility in terms of tensile elongation.

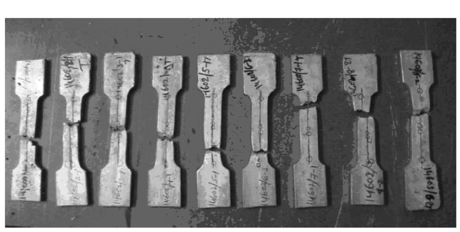

Figure 2: Tested tensile Al/SiC Composite specimens

3.1 Effect of Matrix Alloy on the Mechanical Properties

Figure 3 shows the influence of matrix alloy on the yield strength (YS) of Al/Al_2O_3 composites. It can be seen that the Al 6061 matrix alloy displays larger YS than Al 6063 and Al 7072 matrix alloys. The YS of Al 6063 matrix alloy is superior to that of Al 7072 matrix alloy.

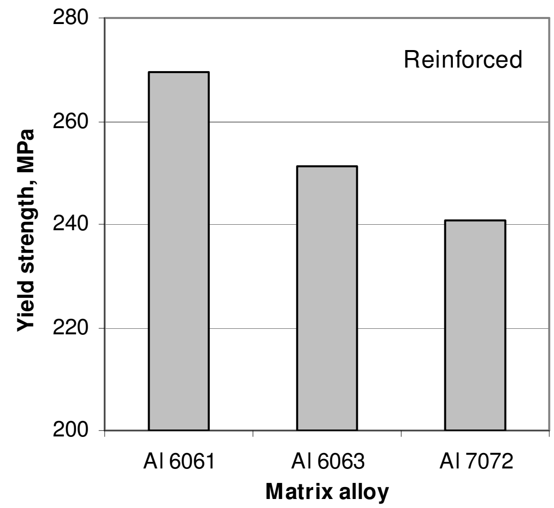

Figure 3: Influence of matrix alloy on the yield strength of Al/Al_2O_3 composite

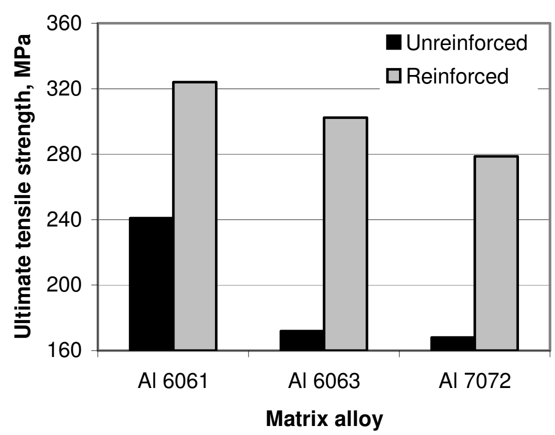

Figure 4: Influence of matrix alloy on the UTS of Al/Al_2O_3 composite

The influence of matrix alloy on the ultimate tensile strength (UTS) of metal matrix composites and unreinforced alloys is shown in Figure 4. It is observed that the Al 6061 matrix alloy exhibits larger UTS than Al 6063 and Al 7072 matrix alloys. The UTS of Al 7072 matrix alloy is inferior to that of Al 6063 matrix alloy. The UTS of metal matrix composites is very much privileged than the unreinforced Al-alloys.

Figure 5 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 influenced by the change in matrix alloy. The ductility of Al-Al_2O_3 composites is much lesser than that of un-reinforced Al-alloy. The ductility is in the downhill order of Al 6061, Al6063 and Al 7072 matrix alloys.

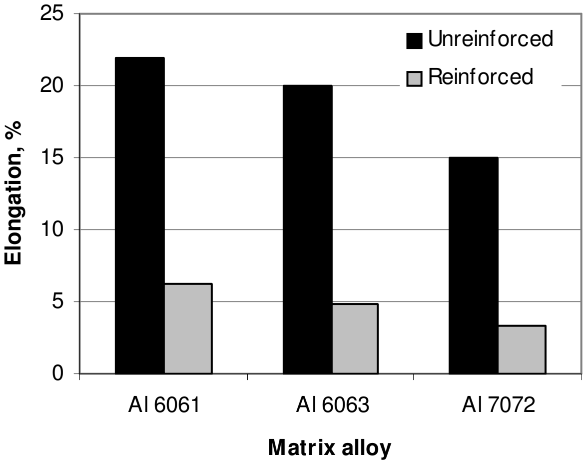

Figure 5: Influence of matrix alloy on the ductility of Al/A$_{l2}$O$_3$ composite

Al_2O_3 particles aggregated to form coarse clusters in the matrix. The agglomeration can add to the strengthening of the composites. Alumina reacts with magnesium to form MgO and $MgAl_2O_4$. Al_2O_3 is not thermodynamically stable in most aluminum alloys. There is also possibility of forming intermetallics such as $Al_5Cu_2Mg_8Si_6$ and $Al_4CuMg_5Si_4$. These are brittle in nature. The Mg content in Al 6061, Al 6063, and Al 7072 is respectively 0.920%, 0.520%, and 0.396%. The YS and UTS of Al/Al_2O_3 metal matrix composites are larger than the unreinforced alloys in consequence of the load transferred to the reinforcement Al_2O_3 particles.

The various intermetallics can be revealed in the microstructures shown in figures 6-8. In the as-cast conditions, the matrix is multiphase. Even small quantities of intermetallics, particularly if these are located along the matrix-reinforcement interface affect the YS, UTS and tensile ductility of metal matrix composites. 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. A non-uniform distribution of Al_2O_3 particulates through the Al-alloy metal-matrix with evidence of clustering, or agglomeration is observed. MgO and $MgAl_2O_4$ are also seen along the grain boundaries. The phases Al_2Cu, Mg_2Si, $Al_5Cu_2Mg_8Si_6$ and $Al_4CuMg_5Si_4$ are also observed in the microstructures. The percentage of intermetallics in Al 7072/Al_2O_3 is higher to that in Al 6063/Al_2O_3 and Al 6061/Al_2O_3 metal matrix composites.

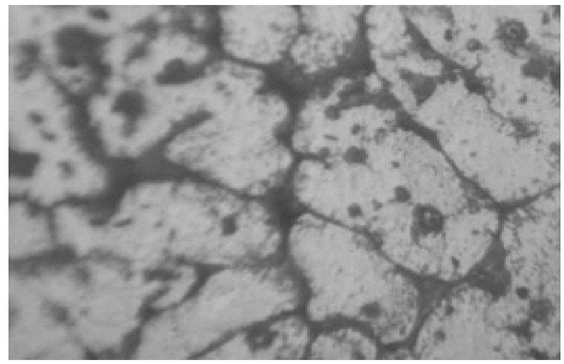

Figure 6: Microstructure of Al 6061/ Al_2O_3 metal matrix composite, 200X

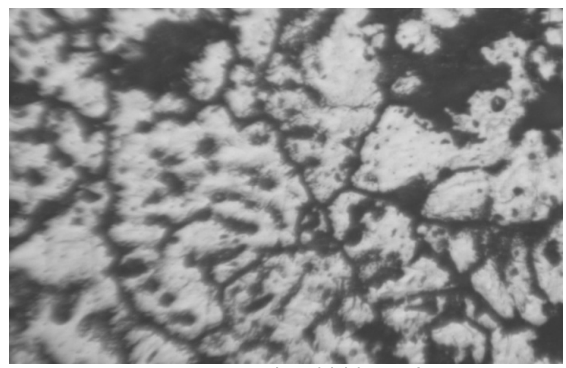

Figure 7: Microstructure of Al 6063/ Al_2O_3 metal matrix composite, 200X

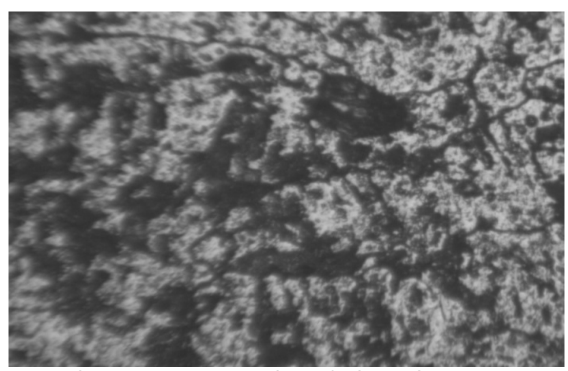

Figure 8: Microstructure of Al 7072/ Al_2O_3 metal matrix composite, 200X

3.2 Fracture Behavior

The fractured surfaces of the tensile specimens are shown in figures 9 – 11. The fracture of Al_2O_3 particles is not seen in Al 6061/Al_2O_3 metal matrix composite (figure 9). The fracture is only due to the matrix in Al 6061/Al_2O_3 composites. The failure mode in Al 6063/Al_2O_3

metal matrix composites is as a result of the particle-matrix interface cracking (figure10). The rupture of Al_2O_3 particles and particle-interface cracking appear in the Al 7072/Al_2O_3 metal matrix composite. The overall fracture is ductile in nature.

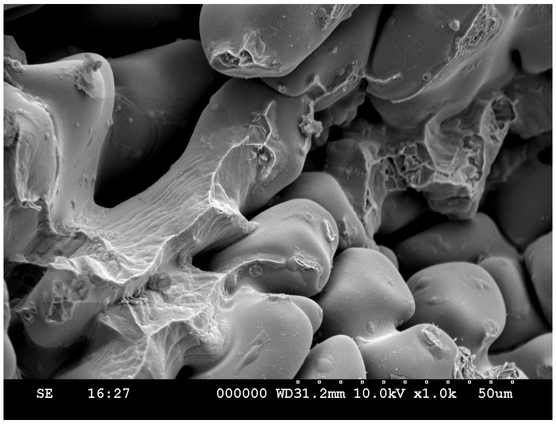

Figure 9: SEM of fracture surface of Al_2O_3/Al6061 metal matrix composite, 1000X

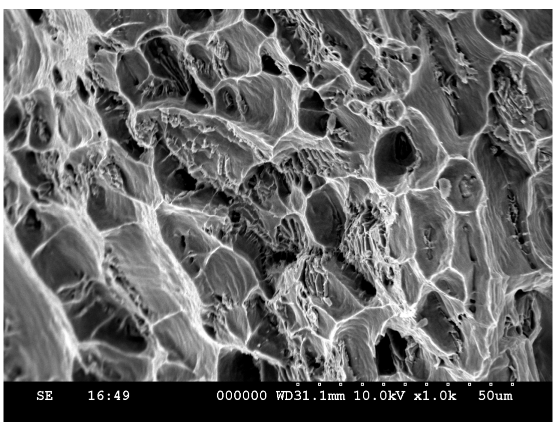

Figure 10: SEM of fracture surface of Al_2O_3/Al6063 metal matrix composite, 1000X

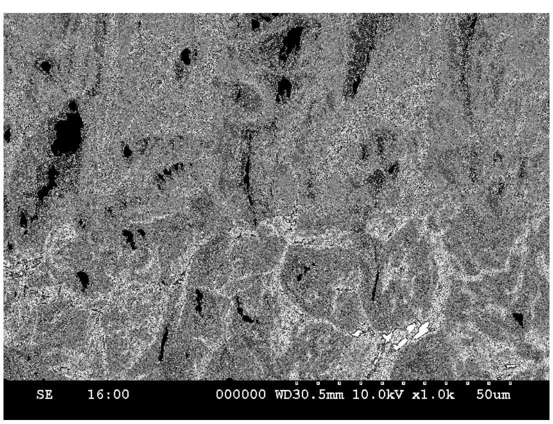

Figure 11: SEM of fracture surface of Al_2O_3/Al7072 metal matrix composite, 1000X

4. CONCLUSIONS

The yield strength, ultimate tensile strength, and ductility of Al/Al_2O_3 metal matrix composites are in the downhill order of Al 6061, Al6063 and Al 7072 matrix alloys. 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. The agglomeration can add to the strengthening of the Al/Al_2O_3 metal matrix composites.

The fracture of Al/Al_2O_3 particles is not seen in Al 6061Al/Al_2O_3 metal matrix composite. The fracture is only due to the matrix in Al 6061Al/Al_2O_3 composites. The failure mode in Al 6063Al/Al_2O_3 composite is on account of particle-interface cracking. The failure mode in Al 7072Al/Al_2O_3 composite is the resultant effect of particle rupture and the particle-matrix interface cracking.

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