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Mechanical Engineering

Elixir Mech. Engg. 72 (2014) 25462-25465

ISSN: 2229-712X

Exploration of mechanical behavior of Al_2O_3 reinforced aluminium metal matrix composites

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ARTICLE INFO

Article history:
Received: 31 May 2014;
Received in revised form: 19 June 2014;
Accepted: 2 July 2014;

Keywords
Aluminium oxide reinforcement,
Aluminium metal matrix composites,
Stir casting,
Mechanical behavior.

ABSTRACT

The Present research has focused on mechanical behaviour of aluminium oxide reinforced aluminium metal matrix composites. Aluminium metal matrix composites are fabricated using stir casting process by varying the reinforcement percentage volumes between 0 and 10, with 30 μm particles size. To study the mechanical behaviour through the effect of weight percentage of aluminium oxide, the fabricated specimens are tested for the mechanical and physical properties such as tensile strength, hardness and density and these values are compared with theoretical values which are obtained through the rule of mixtures. The mechanical properties of the composites are found to be greatly influenced with increasing the percentage volume of the reinforcement. Also it was observed that the experimental values of mechanical behaviour of AMMCs are nearer to the theoretical values.

Introduction

Now a day the modern automotive and aerospace industries are looking towards light weighted and high strength materials to increase their overall efficiency. As in present scenario the Aluminum metal matrix composites will secure the requirements of such industries, due to their low weight, high strength, thermal resistant, and corrosion resistance properties. The reinforcements used in these composites, may be in the form of continuous or discontinuous fibers, whiskers, and particles.

The metal matrix composites can be produced either by melting process or powder metallurgy. Over the powder metallurgy, the melting process has a few imperative advantages such as healthier bonding between matrix and particles, easier control of MMC structure, and low cost of processing. Among the various types of MMCs, the aluminium metal matrix composites (AMMCs) have been increase their significances in various engineering applications such as cylinder block liners, vehicle drive shafts, automotive pistons, bicycle frames, etc. [12-16].

[1] Studied the salient features of experimental as well as analytical and computational characterization of the mechanical behaviour of MMCs. The main focus is on wrought particulate reinforced light alloy matrix systems, with a particular emphasis on tensile, creep, and fatigue behaviour. [2] Investigated the structure and mechanical properties of Al MMC, fabricated by stir casting method. The influences of weight fraction of SiCp reinforcement on tensile strength and fracture toughness have been evaluated. [3] Compared the Powder Metallurgy method and stir casting method for producing the AMMC through testing for mechanical properties and conclude the stir casting method is best suitable for preparation of AMMC. [4] Studied the metal matrix and ceramic matrix composites and their process technologies, and applications. [5] Investigated the effect of heat treatment on the hardness, wear behaviour, and friction properties of Al 6061 composite reinforced with sub-micron Al_2O_3 (10% vol.) produced by powder metallurgy. [6] Developed the aluminium metal matrix composites reinforced with aluminium nitride by stir casting process, and investigated the morphology of the composite and particle distribution by optical microscopy. [7] Developed and studied the tensile properties of 6063/Al_2O_3 Particulate Metal Matrix Composites fabricated by Investment Casting Process. The yield strength and fracture strength increase with increase in volume fraction of Al_2O_3, whereas ductility decreases. The fracture mode is ductile in 10% volume fraction composite and the brittle fracture is observed in 20% and 30% volume fraction composites. [8] Investigated the mechanical properties like hardness and tensile strength and the wear resistance properties of Al6061/SiC and Al7075/Al_2O_3 composites prepared by using the liquid metallurgy technique. Reinforcement of the SiC and Al_2O_3 resulted in improving the hardness and density of their respective composites. [9] Developed Al/SiC MMC by investigating the mechanical properties of different metal matrix composites produced from Al6061, Al6063 and Al7072 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 Al6061, Al6063 and Al7072 matrix alloys. [10] Developed the aluminium metal matrix composites by different processing temperatures with different holding time to understand the influence of process parameters on the distribution of particle in the matrix and the resultant mechanical properties using the stir casting process. The distribution is examined by microstructure analysis, hardness distribution and density distribution. [11] Studied the Preparation, microstructure and properties of Al/Al_4C_3 system produced by mechanical alloying.

The literature reveals that the little research is done on the mechanical behaviour of Al_2O_3 reinforced aluminium metal matrix composites. Hence, the present research is focused on experimental investigation to study the microstructural and mechanical behavior of Al6061/Al_2O_3 and Al7075/ Al_2O_3 AMMCs.

Preparation of AMMCs

The aluminum alloys Al6061 and Al7075 are used as the matrix metal for the fabrication of the composites that has been reinforced with 2 wt. %, 4 wt. %, 6wt. %, 8 wt. % and 10 wt. %

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of Al_2O_3 of average 30 µm size. The chemical composition, mechanical and thermo physical properties of the matrix material (Al6061 and Al7075) and reinforcement material (Al_2O_3) are given in Tables 1 and 2. The composite was fabricated by the stir casting technique. The melting was carried in a stir casting furnace in a range of 750±20^{0}C. A schematic view of the stir casting set up and metallic mold is shown in Fig.1. The melt has mechanically stirred by using a graphite stirrer with motor, during this the pre-heated aluminum oxide particles (about 800^{0}C to make their surfaces oxidized) and 1% of magnesium as a wetting agent (to reduce the surface tension of aluminium and to increase the wetting property between matrix and reinforcement material) were added gradually into the molten metal. The stirring process is carried out at a temperature of 750^{0}C with a stirring speed 600 rpm and time of 10min. One K-type thermocouple has inserted into the graphite crucible to measure the temperature variation of the molten metal. Finally, the mechanical properties Al6061/ Al_2O_3 and Al7075/ Al_2O_3 composites are compared with the unreinforced Al6061 and Al7075 matrix alloys. The micro structural characteristics, tensile strength, hardness and density of the composites are evaluated.

Figure.1 Experimental Setup

Table 1. Chemical Composition of Al6061 and Al7075 by Weight percentage

Elements	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Al6061	0.62	0.23	0.22	0.03	0.84	0.22	0.10	0.1	Balance
Al7075	0.4	0.5	1.6	0.3	2.5	0.15	5.5	0.2	Balance

Table 2. Mechanical and thermo physical properties of Al6061, Al7075 and Al_2O_3

Properties	Al6061	Al7075	Al_2O_3
Elastic Modulus (Gpa)	70-80	70-80	300
Density (g/cc)	2.7	2.81	3.69
Poisson's Ratio	0.33	0.33	0.21
Hardness (HB500)	30	60	1175
Tensile Strength(T)/ Compressive strength (C) (Mpa)	115(T)	220(T)	282.55(T)
Average particle size (Mesh)	-	-	400
Thermal conductivity (W/m, ^{0}K)	167	130	100
Liquidus temperature (^{0}C)	652	635	2072

Exploration of Mechanical Properties

The composite specimens are evaluated for Tensile strength, Hardness and Density by theoretical (Rule of Mixture) and Experimental methods.

Tensile strength

Theoretical values of tensile strength are obtained by Rule of Mixture (Eq.1) and experimental values are obtained by conducting experiments using the computer interfaced universal testing machine on AMMC samples which are machined as per ASTM D 3039-76 specifications (Fig.2). From the Table 3&4 and Fig.3 the experimental result shows that the tensile strength of the produced AMMCs is somewhat higher than that of the non reinforced Aluminium alloys. It can be noted that the addition of aluminum oxide particles (Al_2O_3) enhanced the tensile strength of the composites. It is apparent that an increase in the weight percentage of aluminum oxide particle results in an increase in the tensile strength. The tensile strength of Al 6061 and Al 7075 in non-reinforced condition is 115 and 220 Mpa and this value increases to a maximum of 130.89 and 226.1 Mpa for Al 6061/Al_2O_3/10 wt. % and Al 7075/Al_2O_3/10 wt. %.

$$\sigma_c = \sigma_f v_f + \sigma_m v_m \qquad (1)$$

Where σ_C, σ_f and σ_m are the tensile strength of composite, reinforcement and matrix materials and V_f and V_m are volume fractions of reinforcement and matrix materials.

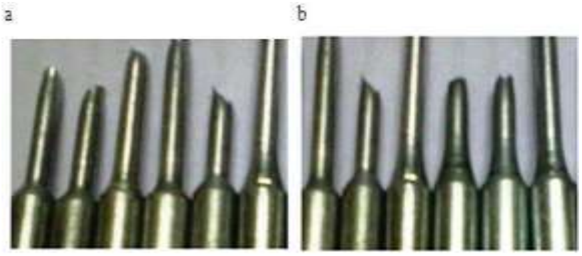

Figure 2. Tensile tested specimens (a) Al6061-Al_2O_3 composite; (b) Al7075- $Al2O_3$ composite

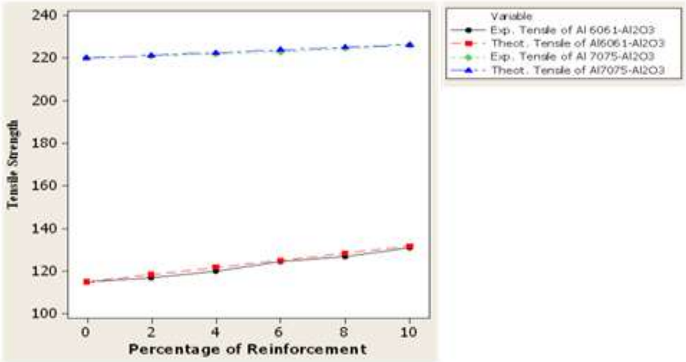

Figure.3 Experimental and Theoretical Tensile strength of Al6061-Al_2O_3 and Al7075- $Al2O_3$ composites

Hardness

Hardness is one of the important mechanical properties in case of composite material as the hardness of matrix metal is very low, which limits its wide application. The hardness of matrix metal enhances due to reinforcement of Al_2O_3 particles with it. Hardness test has conducted on each AMMC specimen using ASTM E10-12 standards. These experimental values are compared with theoretical values of hardness obtained by the Eq.2 and shown in Table.3&4.

$$H_c = H_f V_f + H_m V_m \qquad (2)$$

Where, H_C, H_F and H_M are the Brinell hardness number of composite, reinforcement and matrix materials and V_F and V_M are volume fractions of reinforcement and matrix materials.

From Table 3&4 and Fig. 4, the hardness value increases with the increase of weight percentage of Al_2O_3 particles. The maximum hardness value obtained at 10 wt. % of Al_2O_3.

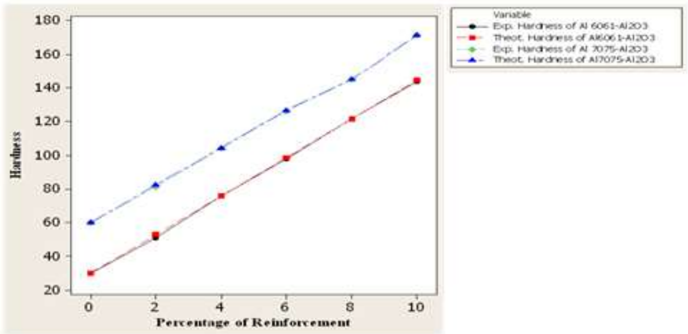

Figure 4. Experimental and Theoretical Hardness of Al6061-Al_2O_3 and Al7075- $Al2O_3$ composites

Density

Density is an important factor which is considered in material selection for several engineering applications to improve their efficiency. Theoretical values of density are obtained by the Eq.3 and the most common experimental method of density measurement simply involves dividing the object's mass by its volume. Hence to determine the experimental value of density, the AMMC samples of measured volume are weighed using a digital balance. From Table 3& 4 and Fig.5 it can be observed that the density of the composite is higher than the base matrix. Also, the density of the composites increased with increase in filler content. Further, the theoretical and experimental density values are in line with each other. The increase in density of composites can be attributed to higher density of reinforcement particles.

$$\rho_c = \rho_f v_f + \rho_m v_m \qquad (3)$$

ρ_C, ρ_F and ρ_M are the densities of composite, reinforcement and matrix materials and V_F and V_M are volume fractions of reinforcement and matrix materials.

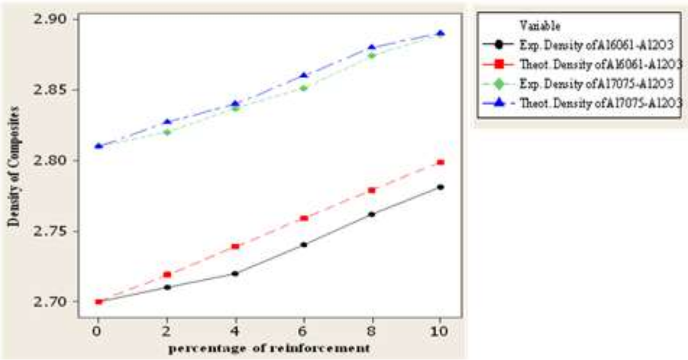

Figure 5. Experimental and Theoretical Density of Al6061-Al_2O_3 and Al7075- Al2O_3 composites

Optical micrographs of AMMCs

The mechanical properties of AMMCs are majorly influenced by the type of reinforcing particles and its distribution. It is necessary to distribute particles uniformly throughout the AMMC casting. The variable that directs the distribution of particles are solidification rate, fluidity, type of reinforcement and the method of casting process. The microstructures of the samples, cut from the casting at different locations are observed using optical microscope to study the particle distribution. The obtained optical micrograph (Fig.6 (a) & (b)) shows the uniform distribution of reinforcing particles. The particle distribution strongly influences the physical and mechanical properties of the composites.

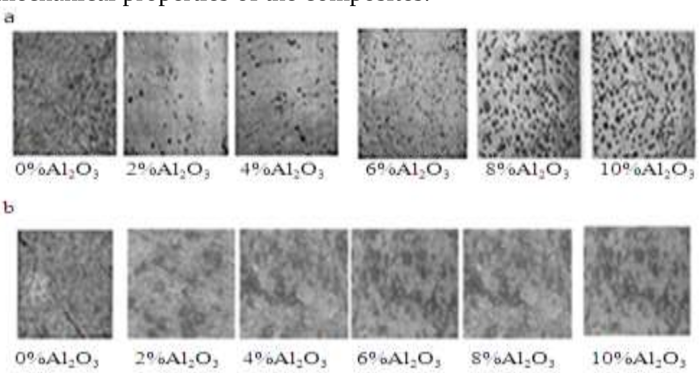

Figure.6 (a) Optical micrographs of Al6061 with 0 - 10% Al_2O_3; (b) Al7075 with 0 - 10% Al_2O_3

Conclusions

The following conclusions have been drawn based on the experimental investigation on Al_2O_3 reinforced AMMCs at different weight fraction:

1. Tensile strength is enhanced with increase of reinforcement percentage in matrix.
2. The hardness of the MMCs is higher than the unreinforced matrix metal and the hardness of the cast composites increases linearly with increasing the weight fraction of Al_2O_3.
3. Density of the composites has been improved by increasing the percentage of the reinforcement. It is found that, an Al6061/Al_2O_3 composite have lower density than the Al7075/Al_2O_3 composites. So Al6061/Al_2O_3 composite can be used in applications where lower weight is desirable.
4. Microstructural observation shows that the Al_2O_3 particles are well distributed in matrix material and there is a good particulate matrix interface bonding.

Scope of the future work

The study can also be extended by the addition of Al_2O_3 reinforce materials in aluminium composites other than Al6061 and Al7075. And also wear studies can be carried out.

Acknowledgments

The author would like to acknowledge Mr. G. Vijaya Kumar (Research scholar) and the staff of mechanical workshop of S. V. U. College of engineering, S.V. University Tirupati.

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Table 3. Mechanical properties of Al6061/Al_2O_3 composites

Properties		Al 6061	Al 6061/ Al_2O_3/2p	Al 6061/ Al_2O_3/4p	Al 6061/ Al_2O_3/6p	Al 6061/ Al_2O_3/8p	Al 6061/ Al_2O_3/10p
Tensile	Experimental	115	117	120	124.7	126.9	130.89
	Theoretical		118.351	121.702	125.053	128.404	131.755
Hardness	Experimental	30	51	76	97.89	122	143.98
	Theoretical		52.9	75.8	98.7	121.6	144.5
Density	Experimental	2.7	2.69	2.719	2.746	2.75	2.78
	Theoretical		2.71	2.73	2.75	2.77	2.79

Table 4. Mechanical properties of Al7075/Al_2O_3 composites

Properties		Al 7075	Al 7075/ Al_2O_3/2p	Al 7075/ Al_2O_3/4p	Al 7075/ Al_2O_3/6p	Al 7075/ Al_2O_3/8p	Al 7075/ Al_2O_3/10p
Tensile	Experimental	220	221	221.9	222.8	224.6	226.1
	Theoretical		221.251	222.502	223.753	225.004	226.255
Hardness	Experimental	60	81.29	104.2	126.5	144.98	171.3
	Theoretical		82.3	104.6	126.9	145.2	171.5
Density	Experimental	2.81	2.819	2.826	2.854	2.87	2.89
	Theoretical		2.82	2.84	2.86	2.88	2.89

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