RESEARCH ARTICLE OPEN ACCESS

Investigation of Mechanical Properties of Aluminium Based Metal Matrix Composites Reinforced With Sic & Al_2O_3

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ABSTRACT
Present study is focused on the fabrication of aluminium 6061 based metal matrix composites, Reinforced with silicon carbide and Al_2O_3 by stir casting technique. The percentage of one reinforcement particulate is kept constant and varying other and vice versa, namely typeI and typeII composites. The various mechanical tests like tensile strength test, hardness test, wear test and Impact strength performed on the samples obtained by stir casting technique for comparison purpose. The result indicated that the developed method is quite successful and there is an increase in the value of tensile strength, hardness value and Impact strength of newly developed composite having (SiC + Al_2O_3) particulates in comparison to the Aluminium.
***Keywords* -** Aluminum 6061, SiC, Al_2O_3, Metal matrix composite, Mechanical properties.

I. INTRODUCTION

Aluminum alloys are widely used in automobile industries and aerospace applications due to their great mechanical properties, low density, low coefficient of thermal expansion, better corrosion resistance and wear as compared with conventional metals and alloys. The low production cost and better mechanical properties of composites makes them very useful for various applications in many areas from technological point of view. The reinforcements Al_2O_3 and SiC enhance the density of the base alloy when they are added to the base alloy to form the composite. Moreover, the theoretical density values match with the measured density values of these composites. Further, Miyajima et.al. [1] reported that the density of Al2024-SiC particle composites is greater than that of Al2024-SiC whisker reinforced composites for the same amount of volume fraction. From the above the increase in density can be reasoned to the fact that the ceramic particles possess higher density. Further, the increased volume fraction of these particles contribute in increasing the density of the composites, also they have stated that the theoretical and measured density values of these composites match to each other. Additionally, the above discussions can be reasoned to the fact that the ceramic particles possess higher density.

The Al6061-SiC and Al7075-Al_2O_3 particulate reinforced composites were developed by liquid metallurgy technique (stir casting route). The cast alloy and composite specimens were subjected to density test by two methods, i.e. weight to volume ratio and another being the rule of mixture, the obtained results [2].

Among the variants of reinforcements, the low aspect ratio particle reinforcements are of much significant in imparting the hardness of the material in which they are dispersed (the hardness of fiber reinforced MMC < whisker reinforced MMC < particle dispersed MMC) [1]. The particulate reinforcements such as SiC, Al2O3 and aluminide [3-4] are generally preferred to impart higher hardness. The coating of reinforcements with Ni [4] and Cu [5], also leads to good quality interface characteristics and hence contribute in improving hardness. TiC when dispersed in Al matrix, increases the hardness to weight ratio. Moreover, it imparts thermodynamic stability to the composites [6-7]. Abdulhaqq et.al. [10-13], explored the significance of hard ceramic particles in increasing the bulk hardness of Al-MMCs. Howell et.al. [12] reasoned the improvement of the hardness of the composites to the increased particle volume fraction. [15-16] attributed this increase in hardness to the decreased particle size and increased specific surface of the reinforcement for a given volume fraction. Deuis et.al. concluded that the increase in the hardness of the composites containing hard ceramic particles not only depends on the size of reinforcement but also on the structure of the composite and good interface bonding [16]. The micro-hardness is a direct, simple and easy method of measuring the interface bonding strength between the matrix and reinforcement [17].

From the application point of view, the mechanical properties of the composites are of immense importance. The modified rules of mixture proposed by several researchers [18] are effective in predicting upper and lower bound values of the modulus and strength properties of the composites. An optimized combination of surface and bulk mechanical properties may be achieved, if Al-MMCs are processed with a controlled gradient of reinforcing particles and also by adopting a better method of manufacturing [19]. Although there is no clear relation between mechanical properties of the composites, volume fraction, type of reinforcement and surface nature of reinforcements [14], the reduced size of the reinforcement particles [20] is believed to be effective in improving the strength of the composites.

The structure and properties of the reinforcements control the mechanical properties of the composites. Increase in elastic modulus and strength of the composites are reasoned to the strong interface that transfers and distributes the load from the matrix to the reinforcement [18]. Further, the improved interface strength and better dispersion of the particles in the matrix can also be achieved by preheating the reinforcements [17]. The strength of SiC, Al_2O_3, TiC [9], and TiB2 particulate reinforced Al-MMCs is found to increase at the cost of reduced ductility, by increasing the volume percentage of ceramic phase and by decreasing the size of the reinforcement in the composite [19-20]. In general, the particle reinforced Al-MMCs are found to have higher elastic modulus, tensile and fatigue strength over monolithic alloys. In case of heat treatable Al-alloys and their composites, the yield strength of composites increase after heat treatment. The composites, before fabrication process, are heat treated to an under aged condition as the materials can be shaped more easily and after fabrication, these materials are heat treated to the peak aged condition so as to provide improved mechanical properties [18].

II. MATERIALS USED

Aluminum alloy 6061 is a medium to high strength heat-treatable alloy with strength higher than 6005A. It has very good corrosion resistance and very good weld ability although reduced strength in the weld zone. It has medium fatigue strength. It has good cold formability in the temper T4, but limited formability in T6 temper. Not suitable for very complex cross sections.

Table 3.1 Chemical Composition of Al6061

Element	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	Bal

3b. Reinforcing material

In the present investigation Silicon Carbide and alumina were used as reinforcing elements. Alumina or Al_2O_3 (Young's Modulus = 375 GPa, poison ratio = 0.21) [57] is easily available, cost effective ceramic reinforcement, having good thermal properties so that it could be used as refractory material. The strong ionic inter-atomic bonding imparts excellent dielectric properties and higher hardness, higher strength and higher stiffness. Silicon Carbide or SiC (Young's Modulus = 410 GPa, poison ratio = 0.19) [22] Al_2O_3 has moh's hardness of 9-9.2, nearly equal to that of SiC. It remains inert to many chemical solutions and does not have any sharp melting point, although it softens at a temperature range of 1140-1280 °C. Among many ceramic materials, SiC and Al_2O_3 are widely in use, due to their favorable combination of density, hardness and cost effectiveness. When these reinforcements are combined with Al-MMCs, the resulting material exhibits significant increase in its elastic modulus, hardness, strength and wear resistance [21].

III. EXPERIMENTAL METHODOLOGY

The Aluminium 6061 alloy based ceramic reinforced composites were designed as per Table 3.2, amounting to 100% by weights and prepared using Stir casting technique. Stir casting is a liquid state fabrication method; in which dispersed phase (ceramic particles) is mixed with molten 6061 alloy (melting temperature of 800^0C achieved using furnace and graphite crucibles) by manual stirring for ~ 30 s. The mixture is then poured into a sand mold and allows cooling to room temperature. Thereafter, specimens were cut as per standard size for characterizing physical and mechanical analysis.

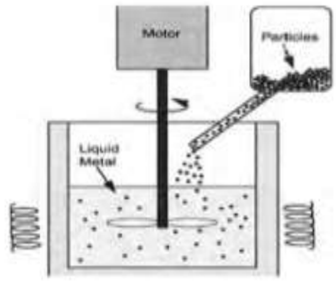

Fig. 3.1 Stirring of composite melt with ceramic particles to minimize settling of the particles during processing [15].

Figure 3.2 Fabrication process of composites materials

Table 3.2 Design of fabricated ceramic particulate filled Al6061 alloy composites

Composites	Material	Weight (%)			
PMMCs-I	Al6061	100	90	85	80
	SiC	---	7	12	17
	Al_2O_3	---	3	3	3
PMMCs-II	Al6061	100	90	85	80
	SiC	---	3	3	3
	Al_2O_3	---	7	12	17

3.2. Mechanical and physical characterization

3.2a. Density and Void

Archimedes Principal says that the apparent weight of an object immersed in a liquid decreases by an amount equal to the weight of the volume of the liquid that it displaces.

The void content of the said composites are computed using equation 1. The rule of mixture (equation 2) is used for calculating theoretical density [1] while the actual density is calculated by Archimedean principle of weighing the sample first in air and then in water.

$$void\ fraction = \frac{theoretical(\rho_t) - \exp erimental(\rho_e)}{theoretical(\rho_t)} \quad \ldots (1)$$

$$\rho_t = \frac{1}{\frac{w_p}{\rho_p} + \frac{w_m}{\rho_m}} \quad \ldots\ldots (2)$$

Where ρ represent the density of composite.

3.2b. Hardness

To evaluate Brinell harness of the said composites, Balance Instruments and Equipment Private Limited, Model No. TSM, SR. No. 014. Bombay is used. The diamond indenter of 1/16" diameter and load of 100kg is specified for the measurement. Red dial on scale B is used for measuring the readings.

3.2c. Tensile Test

To determine the global material parameters tensile tests following ASTM D 3039-76 is as shown in Figure 3.5a, with span length of 28 mm, at 2mm/s cross-sectional speed. For the test, Kudale Instruments make electronics Tensometer testing machine of 20-KN capacity is used.

Figure 3.5 (a) Tensile tests specimen

(b) Electronics Tensometer testing machine

Table3.3. Dimension for the Tensile test specimen

Specimen	Dimensions in mm Tensile Specimen
G - Gauge length	28.00±0.06
D - Diameter	5.00±0.10
R - Radius of fillet	5.5
	34

Figure 3.4 a Specimens for Hardness test

Figure 3.4 b Hardness testing machine

3.2d. Impact strength

The tests are done as per ASTM D-256 using impact tester. The pendulum impact testing machine ascertains the notch impact strength of the material by shattering the V-notched specimen with a pendulum hammer, measuring the spent energy, and relating it to the cross section of the specimen. The standard specimen for ASTM D-256 is 64 × 12.7 × 3.2 mm^3 and the depth under the notch is 10.2 mm. The machine is adjusted such that the blade on the free-hanging pendulum just barely contracts the specimen (zero position). Since there are practically no losses due to bearing friction, etc. (<0.3%), the testing conditions may be regarded as ideal. The specimens are clamped in a square support and are struck at their central point by a hemispherical bolt of diameter 5 mm. The respective values of impact energy of different specimens are recorded directly from the dial indicator.

Figure 3.6 a Impact test machine

IV. RESULT & DISCUSSION

4.1 Effect of Type-I Al6061 alloy composites on density & void fraction

From the Table 4.1 below, 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 by addition 7%SiC & 3% Al_2O_3. 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. The results of the several investigations [2] regarding the density of the Al_2O_3/ SiC particle reinforced Al6061 and other aluminum alloys can be summarized as follows: the reinforcements Al_2O_3 and SiC enhance the density of the base alloy when they are added to the base alloy to form the composites.

Table 4.1 Density & Void of composites using by experimental and analytical result

($SiC+Al_2O_3$) filled Al-6061 alloy composites	**ρ_{th} (gm/cc)**	**ρ_{exp} (gm/cc)**	**Void**
Al-6061	2.7	2.65	0.01851
Al-6061+ 7%SiC+3%Al_2O_3	2.75	2. 70	0.01818
Al-6061+ 12%SiC+3%Al_2O_3	2.99	2.85	0.04682
Al-6061+ 17%SiC+3%Al_2O_3	3.17	3.05	0.03785

4.2 Effect of Type-I Al6061 alloy composites on hardness

The Table 4.2 presents hardness characteristics of said composites as evaluated experimentally. The hardness reveals that its magnitudes improve (linearly) appreciably with appreciation in the content of silicon carbide and alumina ceramic reinforcement relative to Al6061 alloy. It can be observed that the hardness of composites were 3.3%, 8.3% and 16% greater than that of its base alloy. This may be attributed to presence of harder silicon carbide and alumina ceramic phases then Al6061 alloy phases in the composite. Abdulhaqq et.al. [9,10], Hutchings [11] and Lloyd et.al. [12], explored the significance of hard ceramic particles in increasing the bulk hardness of Al-MMCs. Vencl et.al. reasoned the improvement of the hardness of the composites to the increased particle volume fraction.

Table 4.2 Hardness of ($SiC+Al_2O_3$) filled Al-6061 alloy composites

($SiC+Al_2O_3$) filled Al-6061 alloy composites	**Hardness (BHN)**
Al-6061	60
Al-6061+ 7%SiC+%Al_2O_3	68
Al-6061+ 12%SiC+3%Al_2O_3	75
Al-6061+ 17%SiC+3%Al_2O_3	86

4.3 Effect of Type-I filled Al6061 alloy composites on tensile strength

It can be seen that as the silicon carbide and alumina particulate content increases the UTS of the composite material. There is an increase of 24.8% for an addition of 7% silicon carbide and 3% of alumina added to Al6061. However on further addition of silicon carbide and alumina particulate, it drops by 20.7% and 16.62%. It has been reported that the addition of silicon carbide and alumina particulate to Al6061alloys improves the UTS of the composites, whereas the strain to failure decreases as the weight percentage of silicon carbide and alumina. Improvement in the strength of Al-MMCs can be reasoned to the presence of ceramic particles. The possible reasons for such dropping behavior could be, poor/improper interface adhesion or bonding between matrix and particulates may be because of insufficient matrix to adhere properly the particulates hence deteriorates effectiveness of stress transfer. Similar, results are reported by Further, the studies on Al-MMCs are mainly concentrated on Al–SiC, Al–Al_2O_3 based systems with limited studies on Al–TiO_2 composites, though TiO_2 particles have excellent mechanical properties. The ultimate tensile strength has also enhanced with increase in Fly Ash weight percentage and compared to base metal it has increased by 23.26% [22].

4.4 Effect of Type-I filled Al6061 alloy composites on impact strength

The impact strength (in terms of impact energy absorbed in Joules during the Izod impact test) of the said composites improves with addition of silicon carbide and alumina. This may attribute to embitterment effect; the silicon carbide and alumina particulate in Al6061 alloy ceases dislocation movement in the matrix, thereby decreases the number of local stress concentration sites. The effect of alumina particulates is expected to be mechanical in nature since the particulates are properly mechanical bonded with the matrix phase.

4.5 Effect of Type-II Al6061 alloy composites on density & void fraction

Theoretical and experimental density listed in Table 4.6, it is indicates that the density of particulate filled Al6061 alloy composites consistently increase in the range of 11%, 31% & 51% with increasing the volume fraction of reinforcing material and nearly equal to the theoretical density of the composite. Although the general distribution of the reinforcement particles is generally uniform, there still exists particle clustering in some local areas.

4.6 Effect of Type-II Al6061 alloy composites on hardness

The change in the hardness of composites with increased content of reinforcement shown in 5.2 represents the variation in hardness evaluated at a load of 500kg with increasing percentage of Al_2O_3 and constant value of SiC in Al6061. It is observed that the hardness of Al6061 composites increases with increased content of the Al_2O_3 reinforcement.

4.7 Effect of Type-II Al6061 alloy composites on tensile strength

From the fig 5.3 tensile strength increases with increasing percentage in the term of 7%, 12% & 17% of Al_2O_3 and value 3%SiC is constant. The tensile strength of the composites is higher than that of the Al6061 alloy. This improvement in tensile strength of the composites may be attributed to the fact that the filler SiC and Al_2O_3 possesses higher strength and also may be due to the better bonding strength due lower fineness of dispersed particulates. The similar results were obtained when the Aluminium alloy was reinforced with ceramic particulates [2, 10, and 18].

4.9 Effect of Type-II Al6061 alloy composites on impact strength

The impact strength also increases with increasing increase Al_2O_3 and constant value 3% SiC content. This may be due to the presence of hard SiC+Al_2O_3 particulates. The impact strength shows higher values for 20% and 10% of SiC+Al_2O_3 filled Al6061 alloy composites than the base alloy.

4.10 COMPARISON OF MECHANICAL & PHYSICAL PROPERTIES BETWEEN PMMCS-I AND PMMCS-II :-

It is observed that from the Figure 5.1 density of both Al6061 alloy composites material increases with increasing volume fraction of ceramic particle in matrix materials. In PMMCs-II density of reinforcing Al6061 alloy composite greater than the PMMCs-I.

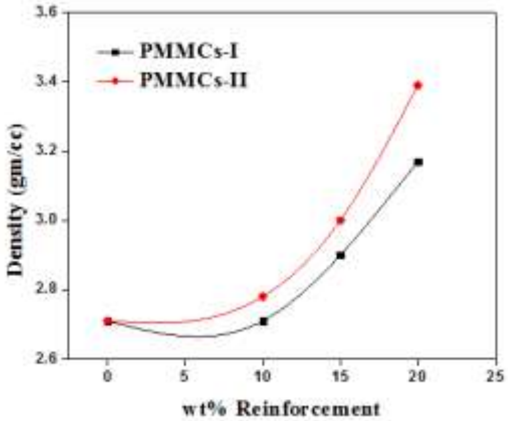

Fig. 5.1 Comparison of Density in both PMMCs-I and PMMCs-II

The results show in Figure 5.2 that the hardness varies linearly with volume fraction in both the PMMCs-I and PMMCs-2 conditions. However, the effect is about 22%greater for the material in the PMMCs-I as comparative to PMMCs-II addition of 17% and 3% ceramic particle addition respectively.

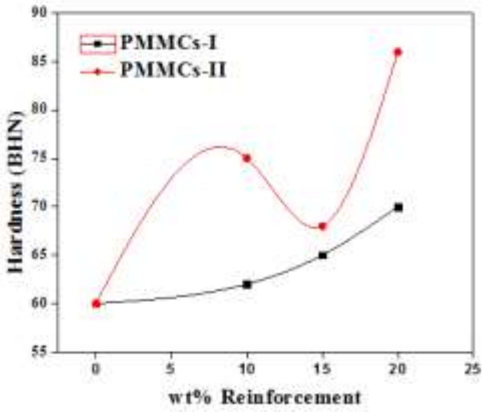

Fig. 5.2 Comparison of Hardness in both PMMCs-I and PMMCs-II

The observations form Figure 5.3 reveals that addition/increasing alumina ceramic particulates gradually improves the tensile characteristics of the Al6061, whereas it deteoriates with increase the SiC reinforcement. It may be attributed to better interface properties that enhance chemical bonding between ceramic variation of alumina ingredients and matrix responsible for proper transfer of tensile stress along tensile test direction as compare to SiC. It is found that addition of 5-30% the ultimate tensile strength has also enhanced with increase in ceramic particles by weight percentage and compared to base metal it has increased by 23.26% [22].

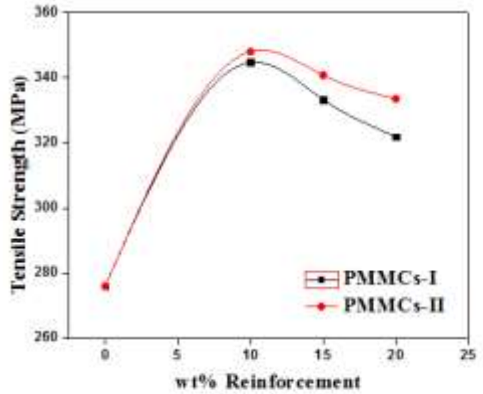

Fig. 5.3 Comparison of Tensile strength in both PMMCs-I and PMMCs-II

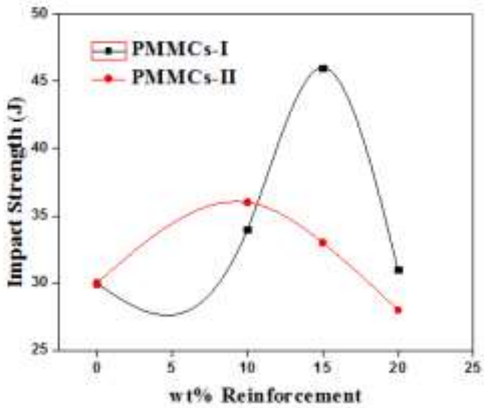

Fig. 5.4 Comparison of Impact Strength in both PMMCs-I and PMMCs-II

In this condition, the impact strengths were increased markedly by the addition of particulate, as shown in Figure 5.4 in both type of reinforcement Al6061 alloy composites; although a general increase occurred with increase in volume fraction. The influence of Al6061 alloy on the impact strength of Al6061 alloy composites and unreinforced alloys is shown in Fig. 5.5. It is observed that the SiC ceramic particulate contributes larger than alumina in Al6061 alloys composites at level 15% (12% SiC & 3% Al_2O_3).

V. CONCLUSIONS

The significant conclusions of the studies carried out on SiC & Al_2O_3 filled Al6061 alloy composites are as follows.

1. Cast SiC & Al_2O_3 filled Al6061 alloy composites were prepared successfully using conventional casting techniques. Density found increasing with increased SiC and Al_2O_3 content.
2. Hardness of the SiC & Al_2O_3 filled Al6061 alloy composites found increased with increased ceramic particulates content. Finer the grain size better is the hardness and strength of composites leading to lowering of wear rates.

The tensile strength and impact strength of the SiC & Al_2O_3 filled Al6061 alloy composites found increasing with increased reinforcements in the composites.

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