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ORIGINAL CONTRIBUTION

Mechanical Properties of SiC, Al_2O_3 Reinforced Aluminium 6061-T6 Hybrid Matrix Composite

S. Senthil Murugan[1] · V. Jegan[1] · M. Velmurugan[1]

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Abstract This paper contains the investigation of tensile, compression and impact characterization of SiC, Al_2O_3 reinforced Aluminium 6061-T6 matrix hybrid composite. Hybrid matrix composite fabrication was done by stir casting method. An attempt has been made by keeping Al_2O_3 percentage (7%) constant and increasing SiC percentage (10, 15, and 20%). After fabricating, the samples were prepared and tested to find out the various mechanical properties like tensile, compressive, and impact strength of the developed composites of different weight % of silicon carbide and Alumina in Aluminium alloy. The main objective of the study is to compare the values obtained and choose the best composition of the hybrid matrix composite from the mechanical properties point of view.

Keywords Stir casting · AMCs · UTM · Hybrid

Introduction

The interest in Metal Matrix Composites (MMCs) are on account of their attractive physical and mechanical properties and they are most promising materials in achieving enhanced mechanical properties such as: hardness, Young's modulus, yield strength and ultimate tensile strength due to the presence of micro-sized reinforcement particles in the matrix. MMCs possess combination of metallic properties of matrix alloys with ceramic properties of reinforcements that leads to superior strength and higher service temperature capabilities. Aluminum, magnesium, titanium, and their alloys are commonly used metallic matrices for the production of MMCs [1, 2]. Aluminium Matrix Composites (AMCs) have found wide applications in our daily life. There are some advantages of using particle reinforced AMC materials rather than unreinforced materials; such as greater strength and high specific modulus, improved stiffness, better strength to density ratio, light weight, low thermal expansion coefficient, high thermal conductivity, tailored electrical properties, increased wear resistance and improved damping capabilities. Reinforcing constituents can be incorporated within the matrix in the form of particles, short fibers, continuous fibers or mono filaments. Nowadays, it is used in aerospace, thermal management areas, industrial products, automotive applications such as engine piston, brake disc etc. [3]. In AMC the matrix phase is of pure aluminium or its alloy and the reinforcement used is a non-metallic ceramic such as SiC, Al_2O_3, SiO_2, B_4C, and Al–N. Aluminium alloys are widely used due to the properties of good corrosion resistance, high damping capacity, low density and good electrical and thermal conductivities. AMCs have been tested and found useful in different engineering sectors including functional and structural applications [4].

In most cases, hard ceramic particulates such as Zirconia, Alumina (Al_2O_3) and Silicon Carbide (SiC) have been introduced into aluminium-based matrix in order to increase the strength, stiffness, wear resistance, corrosion resistance, fatigue resistance and hardness. Among these reinforcements, SiC is chemically compatible with aluminium (Al) and has other advantages such as excellent thermal conductivity, high machinability and good workability. The demand for lightweight, inexpensive and energy efficient

✉ S. Senthil Murugan
gctsegan@gmail.com

[1] Department of Mechanical Engineering, Mepco Schlenk Engineering College, Sivakasi 626005, Tamil Nadu, India

Fig. 1 Aluminium alloy (6061)

materials has led to the development of cast Al alloy matrix composites containing hard ceramic dispersed particles [5]. Among the manufacturing processes, the conventional stir casting is an attractive processing method for producing AMCs as it is relatively inexpensive and offers a wide selection of materials and processing conditions. Stir casting offers better matrix particle bonding due to stirring action of particles into the melts. The recent research studies report that the homogeneous mixing of reinforcement and matrix and good wetting can be obtained by selecting appropriate processing parameters like stirring speed, time, and temperature of molten metal, preheating temperature of mould and uniform feed rate of particles [6].

The aim of the present investigation is to study the mechanical characterization of Al 6061 alloy discontinuously reinforced with two different types of particles such as SiC and Al_2O_3 and to study the effect of reinforcements on the mechanical properties of prepared Al matrix composites. Stir casting method is the apt one for the manufacturing of hybrid metal matrix composites [7]. Mechanical properties are evaluated as per ASTM standards using computerized Universal Testing Machine (UTM).

Experimental Procedure

Matrix and Reinforcements

Aluminium alloy (6061-T6), which is shown in Fig. 1, is used as matrix in this experimental study and its chemical composition (in weight %) is listed in Table 1. Al 6061 is a precipitation hardening aluminium alloy, containing Magnesium and Silicon as its major alloying elements. The chemical composition of matrix and reinforcement is estimated by optical emission spectroscopy and the average values of major compositions have been given in tables. Al. 6061 has good mechanical properties and is one of the most common wrought Aluminium alloys for general purpose use.

Alumina (Al_2O_3) particles of size 20 μm and silicon carbide (SiC) particles of size 30 μm are used as the reinforcement in this AMC fabrication. Figure 2a, b shows the reinforcements. Table 2 shows the chemical

Table 1 Chemical composition of matrix alloy Al-6061

Elements	Al	Mg	Si	Mn	Cu	Fe	Ti	V
(wt%)	97.3	1.08	0.63	0.52	0.32	0.17	0.02	0.01

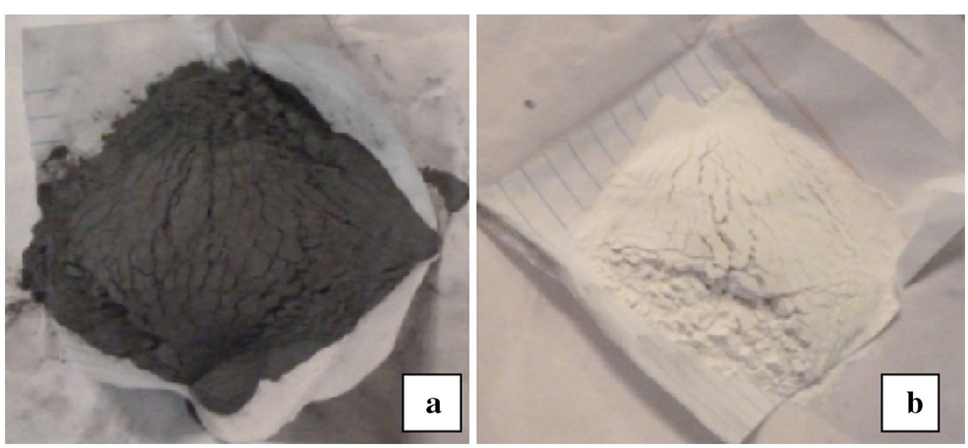

Fig. 2 Reinforcement powder: SiC (**a**) and Al_2O_3 (**b**)

Table 2 Chemical Composition

SiC	Elements	SiC	Si	SiO_2	Fe	Al	C
	wt%	98.5	0.3	0.5	0.08	0.1	0.3
Al_2O_3	Elements	Al_2O_3	TiO_2	SiO_2	MgO	Fe_2O_3	–
	wt%	95.69	2.66	0.83	0.29	0.28	–

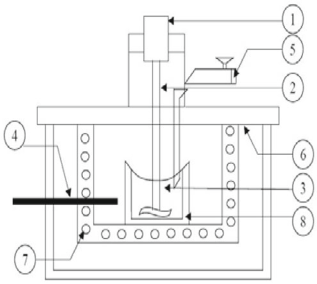

Fig. 3 Stir casting setup

composition. Alumina (Al_2O_3) is highly wear resistant and also has good properties such as good thermal conductivity, high strength and stiffness, excellent size and shape capability, resistance against strong acid and alkali attack at elevated temperatures and better thermal shock resistance.

SiC particle-reinforced aluminium alloy composites are particularly sought after owing to their superior stiffness, strength and wear resistance. Silicon carbide (SiC), also known as carborundum, is a compound of silicon and carbon with chemical formula SiC. Many studies have shown that the increase of SiC particles will improve the strength, so an attempt was made to do experiment with randomly chosen SiC in the range of 10, 15 and 20 wt% and mixed with the 7 wt% of Al_2O_3 in the preparation of composites.

Hybrid Composite Fabrication

The liquid metallurgy route (stir casting technique), which is shown in Fig. 3, was adopted to prepare the cast composites as described below. A batch of 1 kg of 6061Al was melted to 660 °C in a graphite crucible using resistance furnace. The melt was agitated with the help of stirrer to form a perfect vortex. At the temperature of 800 °C in furnace, preheated SiC and Al_2O_3 particles of vol. wt% were added at the rate of 1 gm/20 s into the vortex with mechanical stirrer at 350 rpm. Before adding the reinforcements, a degassing agent, solid dry Hexacholoroethane tablet was added into the molten metal for removal of dissolved gas to overcome the porosity problems in the cast. Preheated reinforcements (SiC and Al_2O_3) were added into matrix. The molten metal at a temperature of 830 °C was then poured into the permanent mould of 20 mm diameter and 110 mm height, which was preheated at 300 °C and allowed to solidify. Figure 4 shows the samples of prepared composites. The mechanical tests were planned to be carried out on these samples.

However, there was some concern over the possible chemical reaction between the SiC particles and the aluminium matrix, as it can have a significant effect on the interfacial characteristics [8]. In the composite system, silicon carbide is thermodynamically unstable at temperatures above the melting point of aluminium (660 °C) and reacts with the liquid aluminium to form aluminium carbide and silicon according to the following reaction:

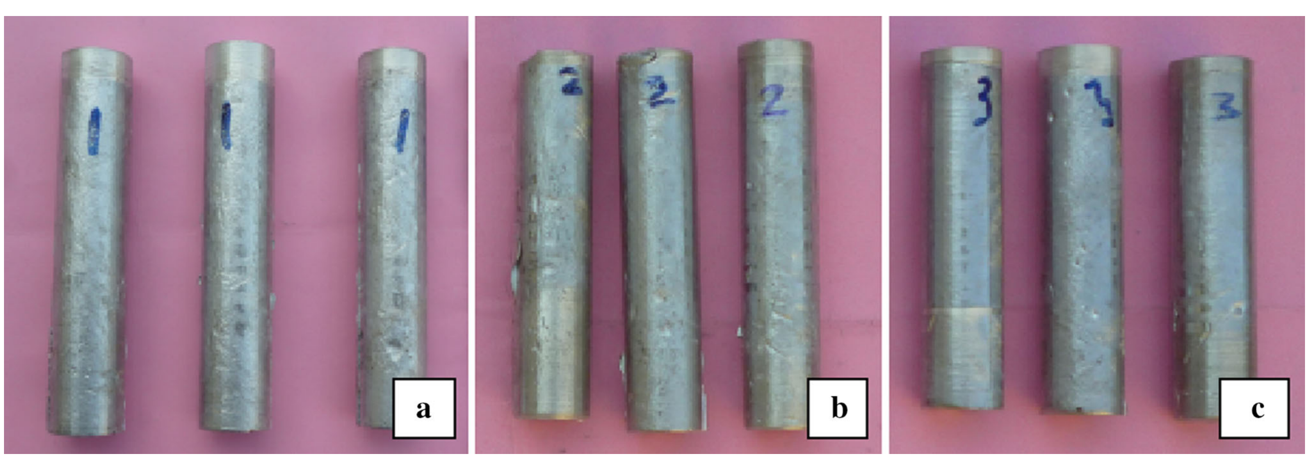

Fig. 4 Samples prepared from composite with 7 wt% of Al_2O_3: **a** 10% SiC, **b** 15% SiC, **c** 20% SiC

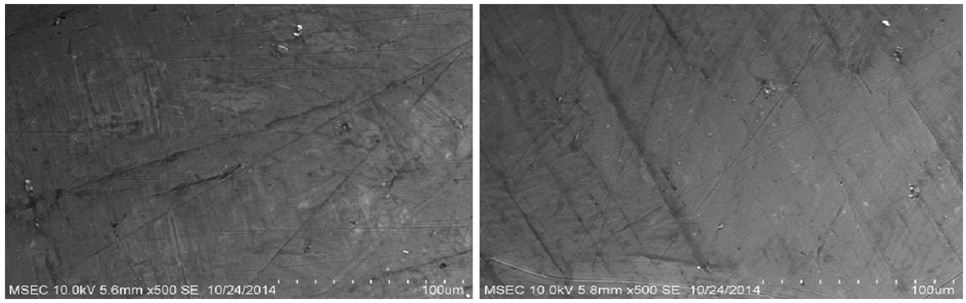

Fig. 5 SEM image of Al + SiC + Al_2O_3

$$4Al + 3SiC \rightarrow Al_4C_3 + 3Si \quad (1)$$

Results and Discussions

SEM Analysis

Scanning electron microscopy (SEM) uses a focused electron probe to extract structural and chemical information point-by-point from a region of interest in the sample. The high spatial resolution of an SEM makes it a powerful tool to characterize a wide range of specimens in the nanometer to micrometer length scales. Figure 5 shows the SEM images of developed composite. The microstructural characterization studies have revealed that developed composites were virtually defect free and contained practically identical volume fractions of SiC particles distributed homogeneously throughout the aluminium matrix.

Tensile Test

In this study computerized UTM was used to evaluate the tensile strength of the composites fabricated with x % wt of SiC (X = 10, 15, 20%) and alumina % wt was kept constant at 7%. The specimens were prepared for tensile tests as per ASTM standard. The standard specimen size for tests is given in Fig. 6. After completing the tensile test, the values are reported and properties such as tensile strength, yield strength, fracture stress and % of elongation are obtained from the graph. Table 3 shows the values of tensile properties against the wt% of SiC. Figure 7 shows the before and after tensile test specimens.

The results indicate the enhanced interfacial bonding because of the small change in the silicon concentration resulting from the Al–SiC chemical reaction. The interface plays a crucial role in determining the overall properties of metal-matrix composites [8]. Strengthening by the hard particle reinforcement depends critically on the interfacial bond. A well-bonded interface facilitates the efficient transfer and distribution of load from the matrix to the reinforcing phase, which leads to improved composite strengths.

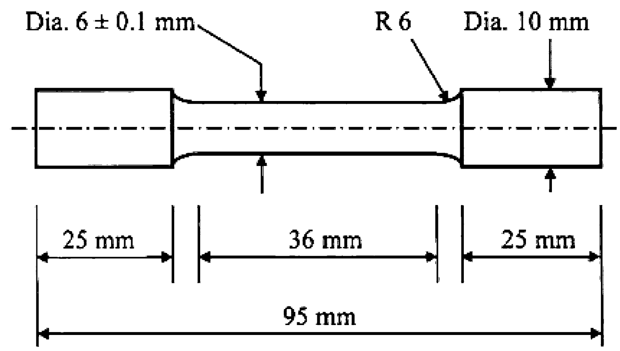

Fig. 6 Tensile test standard specimen (ASTM E8 M)

Table 3 Wt% SiC versus tensile properties

wt% SiC	Average values in N/mm^2			% Elongation
	Tensile strength	Yield strength	Fracture stress	
10	110	94	87.9	6.867
15	114	96	94.2	6.8
20	124	97	110.18	5.17

It is observed from the graph (Fig. 8) that by increasing the wt% of SiC from 10 to 20%, the tensile strength value increases from 110 to 124 N/mm^2. The ceramic nature of SiC particles make bond with the matrix and improves the strength of the composites.

Figure 9 shows the variation of yield strength with SiC content. From the graph, it it is observed that by increasing the wt% of SiC from 10 to 20%, the yield strength value increases from 94 to 97 N/mm^2.

Figure 10 shows the variation of % elongation with SiC content. The graph shows that the value of % elongation initially increases from 6.867% at 10% wt of SiC and then decreases to 6.8% at 15% wt of SiC and finally decreases to the value of 5.167% at 20% wt of SiC.

Figure 11 shows the graph of the experimental fracture stress of the composites according to the SiC content in the composite. It is observed that the fracture stress of composites gradually increases from 87.90 N/mm^2 at 10% wt of SiC to 110.18 N/mm^2 at 20% wt of SiC.

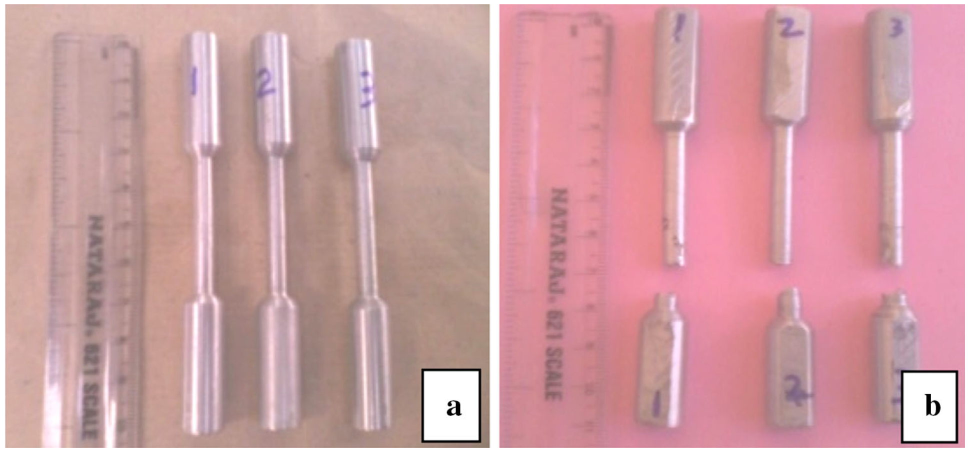

Fig. 7 Tensile test specimens **a** before tensile testing **b** after tensile testing

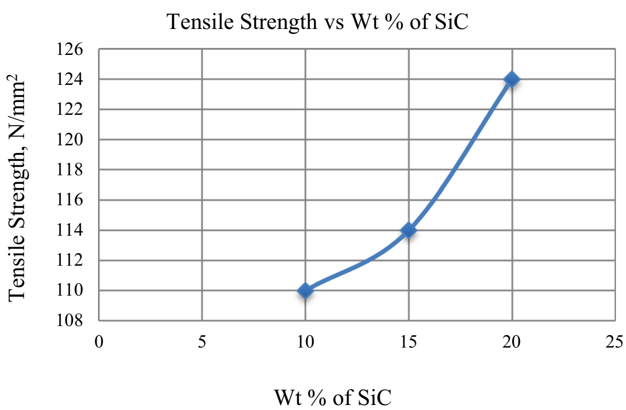

Fig. 8 Variation of tensile strength with SiC content

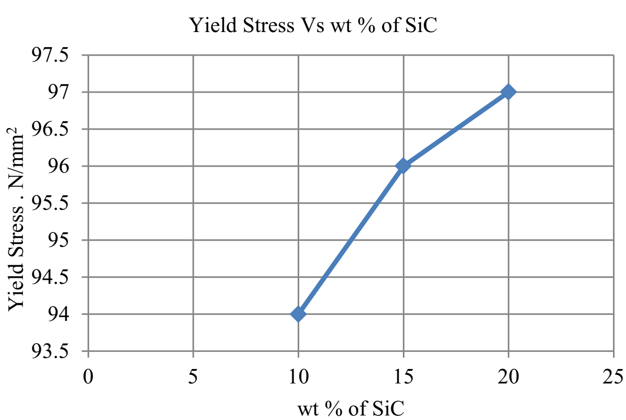

Fig. 9 Variation of yield stress with SiC content

Compression Test

The fabricated hybrid aluminium matrix composites were examined by UTM to test compressive strength. The specimens were prepared as per ASTM E8 M. The size of specimen was 25 mm in height and 10 mm diameter.

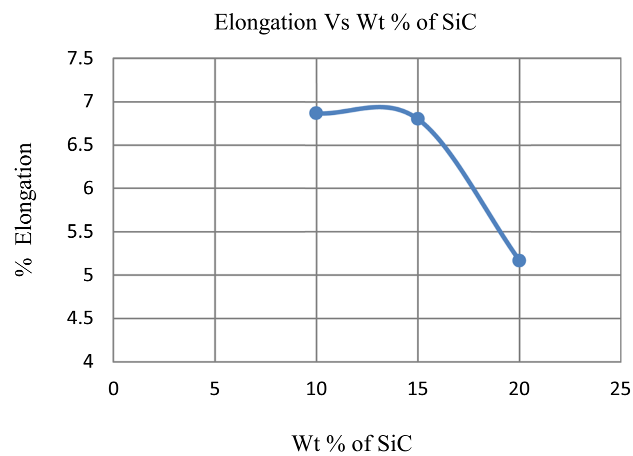

Fig. 10 Variation of % Elongation with SiC content

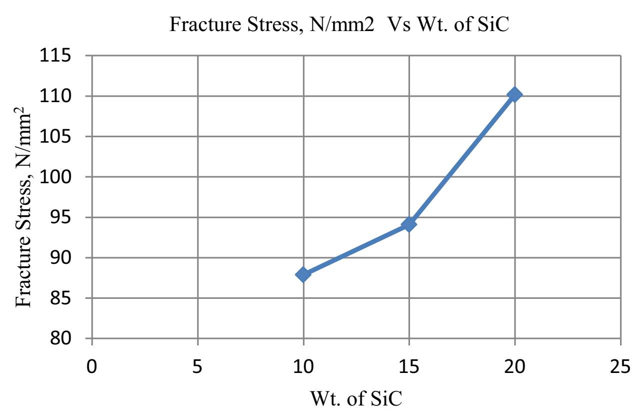

Fig. 11 Variation of fracture stress with SiC content

Figure 12 shows the variation of compressive strength with SiC content. From the Fig. 12, when the addition of SiC increases from 10 to 20 wt%, it was found that the compressive strength values increased from 287 to 300 N/mm^2 and the variation of compressive strength with % of SiC reinforcement was also observed. Table 4 gives the

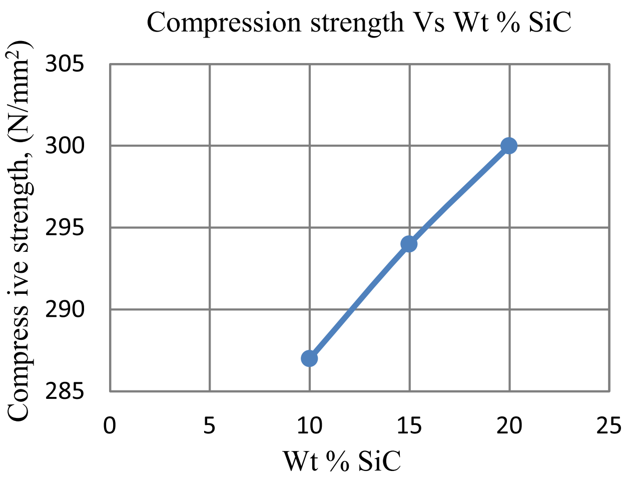

Fig. 12 Variation of compressive strength with SiC content

Table 4 Compressive strength and impact strength of composites

wt% of SiC in hybrid composite prepared	Compressive strength (N/mm^2)	Impact strength (N/mm)
10	287	80
15	294	88
20	300	100

compressive strength and impact strength of fabricated composites against the addition of silicon carbide.

Impact Test

The impact test is a method for evaluating the toughness and notch sensitivity of engineering materials. To study the impact behaviour of the hybrid composites, Izod impact tests were performed using impact testing machine. Izod impact testing is a standard method of determining impact strength. Figure 13 shows the impact test specimens before and after testing.

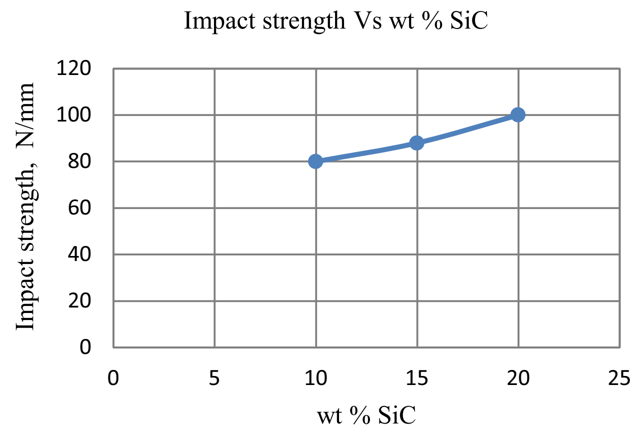

Fig. 14 Variation of impact strength with SiC content

The Izod test was conducted on notched sample. Standard square impact test specimens of dimension 75 mm × 10 mm × 10 mm with notch depth of 2 mm and a notch angle of 45° were prepared from composites. The machine should provide a range of impact energies from 0 to 160 J. From the results, the 20% of SiC of impact energy were better than of 10% SiC.

From Fig. 14, it was observed that the impact strength of aluminium hybrid composites were 80, 88 and 100 N/mm for 10, 15 and 20 wt% of SiC respectively. The impact strength of AA 6061-7% of Al_2O_3- 20 wt% SiC hybrid composites was higher than AA 6061-7% of Al_2O_3- 10 wt % SiC hybrid composites.

Conclusion

In the present work, Aluminium Matrix Hybrid Composite of AA 6061 + 7% of Al_2O_3 + X wt% SiC (X = 10, 15, and 20%) was successfully fabricated by stir casting method. The effect of Al_2O_3 and SiC reinforcement in the matrix on tensile strength, compressive strength and impact

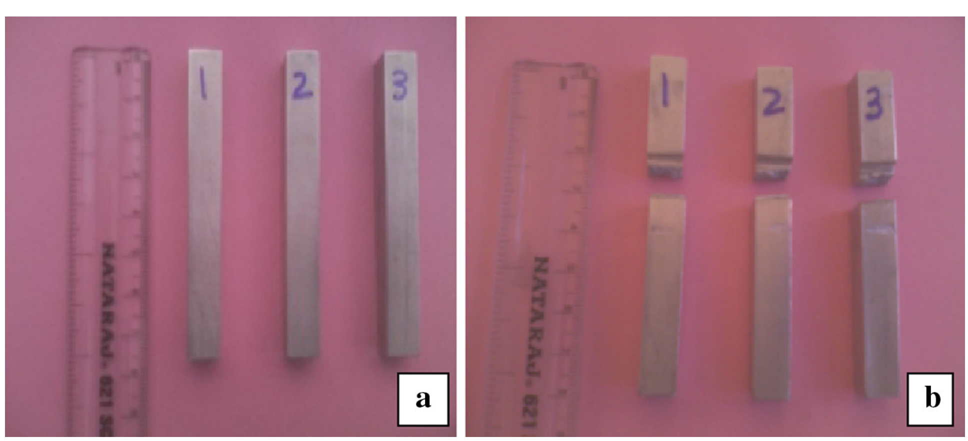

Fig. 13 Impact test specimens **a** before testing **b** after testing

strength of the developed composite were investigated and reported and the best composition AMMC matrix was determined. From the results of this study, the following conclusions were drawn:

- The tensile strength of aluminum composites was studied and the maximum tensile strength observed was 124 N/mm^2 at 20 wt% of SiC
- The yield strength and fracture stress of aluminium composites with different weight fractions were noted. The maximum yield strength observed is 97 N/mm^2 at 20 wt% of SiC and maximum fracture stress value observed is 110.18 N/mm^2 at 20 wt% of SiC
- The compressive strengths of hybrid composites are 287, 294 and 300 N/mm^2 for the addition of 10%, 15% and 20 wt% of SiC respectively. Compressive strength of AA6061-7% of Al_2O_3- 20 wt% SiC hybrid composites is higher than AA 6061-7% of Al_2O_3- 10 wt% SiC. This is due to the addition of more amounts of ceramic SiC particles into matrix
- The impact strengths of Al_2O_3, SiC reinforced hybrid composites are 80, 88 and 100 N/mm for the addition of 10%, 15% and 20 wt% of SiC respectively. It is reported that the improved impact strength of AA 6061-7% of Al_2O_3- 20 wt% SiC hybrid composites was higher than AA 6061-7% of Al_2O_3- 10 wt% SiC
- Highest tensile, compressive strength, and impact strength was obtained for AA 6061- 20% of SiC-7% of Al_2O_3 hybrid composite because of the ceramic nature of silicon carbide reinforcement. On increasing the amount of SiC into the matrix, the ceramic will develop a strong interface bond with the matrix and this bond, in turn, improves the properties of composites.

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