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Experimental investigations on mechanical and microstructural properties of Al₂O₃/SiC reinforced hybrid metal matrix composite

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Abstract. Aluminium alloy metal matrix composites (MMCs) have obtained wide spread acceptance in automotive and aerospace applications because of its high strength, low density and good structural rigidity. This work studies the mechanical and microstructural properties of hybrid metal matrix composite reinforced with Al₂O₃/SiC prepared by using powder metallurgy technique. Hardness and compressive strength of aluminum matrix composite increased with increase in wt% of SiC. The characterization results showed the improvement in mechanical properties with addition of hybrid reinforcement.

Keywords: powder metallurgy; automobile; stiffness; weight percentage; microstructural study; X-ray; SEM

1. Introduction

Good strength to weight ratio is an essential requirement in the selection of material for automotive and several applications where improved mechanic efficiency and reduced fuel consumption are critical conditions to be satisfied. The materials that are used in currently developed modern infrastructure equipment and machineries have a good combination of properties to match service demand. Aluminium matrix composite (AMC) represent a different diversity of properties that can match through the design necessities of particular of the overhead applications [1]. The ceramic materials (SiC, Al₂O₃, EC, B₄C, TiO₂, BN) are primarily reinforced in the aluminium matrix composite (AMC). These metal composites are produced by solid route processing such as powder metallurgy [2]. Single reinforced composites have been improved over the years for use in several mechanical applications but have been followed to have disadvantages in some material property and cost related factors [3]. In order to optimize the variation of single reinforced MMCs and to minimize the processing cost, these efforts have paved way for the development of hybrid reinforced AMCs [4]. In recent times, the performance and properties of hybrid reinforced AMCs have attracted the interest of researchers and different design concepts have been adopted to select the attached combination of reinforcing materials [5]. The properties and processing cost of the composites are impacted by the combination of reinforcing materials [6]. In recent times, hybrid reinforced AMCs have engaged the



interest of researchers and different design concepts have been affected to select the suitable combination of strengthening materials. Adding reinforcements of SiC and Al₂O₃ in aluminium hybrid composites agreed to dominating crack growth resistance in the lower stress intensity factor range compared with the composite having only alumina as the reinforcement [7]. These reinforcements are having higher density compared to aluminium and hence increase the weight of the composite establishing the reinforcement's content [8]. The ceramic reinforcements in the Aluminium matrix composite possess excellent strength than any other types of reinforcements [9]. Aluminium-based composites have been evolved as a group of supported materials blending the good mechanical properties of Al and several properties of the ceramic reinforcements [10]. In this research, alumina (Al₂O₃) and silicon carbide (SiC) are used as reinforcements in the development of Aluminium based hybrid composites. The microstructural characterization, x-ray diffraction characterization, hardness test, compression test, density test and were investigated to ascertain the feasibility of using Al₂O₃ and SiC as reinforcing materials in the development AMC.

2. Experimental procedure

2.1 Material powder

The sample preparation was carried out for different compositions with pure aluminium used as the base metal matrix. Al₂O₃ and SiC was used as the reinforcements. The composition of alumina was fixed at 5 wt% and silicon carbide varied from 0-8 wt.% with corresponding composition of pure aluminium. Powder metallurgy technique was implemented for the synthesizing of aluminium metal matrix composites. Reinforcement powders were selected with average size of 20µm [11].

2.2 Preparation of Composite

Reinforcement and matrix powders with their weight composition were loaded into the die. Compaction was carried out in the UTM machine with a capacity of 50KN. Uni-axial pressing was carried out with 300 Mpa pressure up to 45 seconds. Zinc stearate was coated in the die walls for lubrication. The lubricant was used in the powder mixture helps in strengthening the green compact density [12].

2.3 Sample designation

The composites produced were based on the weight percent of the reinforcing phase of SiC and Al₂O₃ [13]. The samples were compacted in the 40mm of diameter die. Figure 1 shows the samples with different compositions used in this research. Table 1 show the composition used in this work.

Table 1. Sample composition

Sample code	Al wt%	Al ₂ O ₃ wt%	SiC wt%
AI87	87	5	8
AI89	89	5	6
AI90	90	5	5
AI92	92	5	3
AI95	95	5	0

2.4 Sintering Technique

Sintering was carried out at 450°C for 45 minutes under neutral atmosphere in the furnace, the sintered specimens were allowed to cool up to 250°C inside the furnace to avoid atmospheric contamination and the air cooled [14]. It carried out at controlled atmosphere to form strong bonds. Bonding occurs mainly by transmission of atoms. The sintering was done at 70% of melting point of materials to strengthen the specimen in order to obtain good densification that occurs during the process and aids in enhancement of physical and mechanical properties [15]. The prepared specimens were tested for its density using Archimedes principle, phase composition analyzed using XRD, and hardness measurement using micro hardness tester and the compression properties in a universal testing machine (UTM).



Figure 1. (a) Sample Al87

(b) Sample Al90

(c) Sample Al95

3. Results and Discussion

3.1 Density Measurement

According to Archimedes' Principle, the density of the prepared green samples was determined using ASTM B962-15. Standard test procedures were adopted to measure the density of compacted or sintered powder metallurgy [16]. Archimedes' Principle assists in measuring the density by providing a convenient and accurate method for controlling the volume of an irregularly shaped object. It is known also as hydrostatic weighing [17].

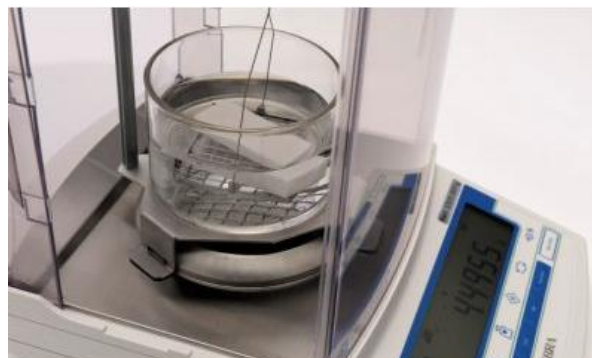


Figure 2. Density measuring apparatus [17]

P = Density, **m** = Weight or Mass in Air, **m₂** = Weight in Water, **m₂ - m** = Volume of object (V)
p = **m/v** density of the object.

Sample 1: (Al- 87%, Al₂O₃ – 5%, SiC – 8%)

$$\text{Density} = 2.7565 \text{ g/cm}^3$$

Sample 2: (Al- 90%, Al₂O₃ – 5%, SiC – 5%)

$$\text{Density} = 2.7453 \text{ g/cm}^3$$

Sample 3: (Al- 95%, Al₂O₃ – 5%, SiC – 0%)

$$\text{Density} = 2.727 \text{ g/cm}^3$$

From the density calculation, we can observe that the density of aluminium composites increases with respect to increase in the reinforcement wt.% (Al₂O₃ and SiC).

3.2 Hardness Test

According to ASTM E384-16, standard test method is followed for micro indentation of Vickers hardness tester to measure the powder metallurgy of samples [18]. The hardness of the Al/SiC/Al₂O₃ composites sample was measured using a Vickers hardness tester at 200gm for 30 seconds. Hardness measured on the sintered composite is shown in Table 2. The results showed that the addition of (0-8% of SiC and 5% Al₂O₃) cause an increase in hardness of aluminium metal matrix composite and the values obtained were averaged by measuring the hardness and five different locations [19]. The results clearly show that increase in hardness is influenced by the varying wt% of reinforcement.

Table 2. Hardness Measurement

Sample	Sintering Temperature (°C)	Sintering Time (min)	Sintering Density (g/cm ³)	Load (gm)	Hardness (HV)
A187	450	45	2.7565	200	159.56
A189	450	45	2.7509	200	161.03
A190	450	45	2.7453	200	162.00
A192	450	45	2.7361	200	162.50
A195	450	45	2.7270	200	161.01

3.3 Compression Test

The prepared aluminium matrix composite samples were subjected to compression test. The compressive load on aluminium metal matrix composites is carried out using ASTM E8 standard [20] and the maximum load applied on the sample is 400KN. The obtained results were analyzed by studying the load vs elongation curve of compression test (Figure 3) and load vs cross head travel (Figure 4). The result showed that compressive strength increased with increase in percentage of silicon carbide reinforcement. Table 3 shows that the various samples of compression test values and

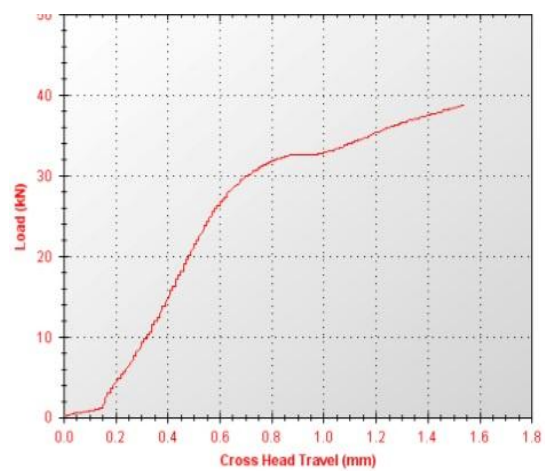
the peak load appears on the sample Al87. The maximum achieved compressive strength is 77.611N/mm^2 .

Table 3. Compression Test (Al 95%-87%)

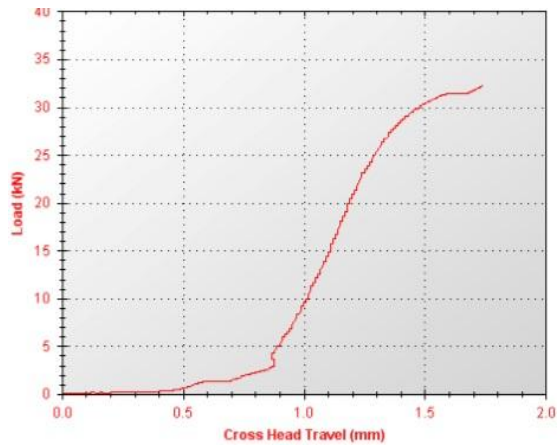
Sample	Load at Peak KN	C.H. Travel at Peak Mm	Compressive strength N/mm ²
Al87	54.860	3.170	77.611
Al89	40.340	2.290	57.069
Al90	38.760	1.540	54.834
Al92	33.640	2.350	47.591
Al95	32.180	1.740	45.525



(a) 87% Al

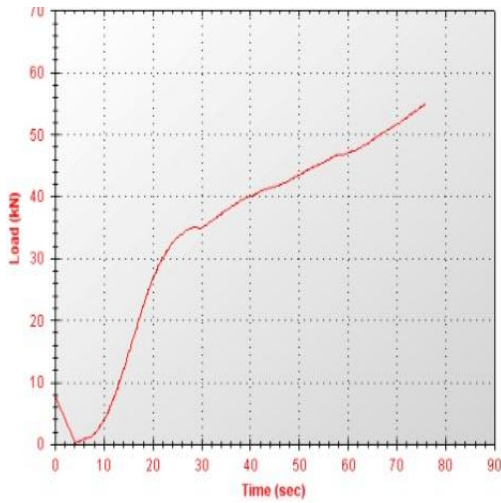


(b) 91% Al

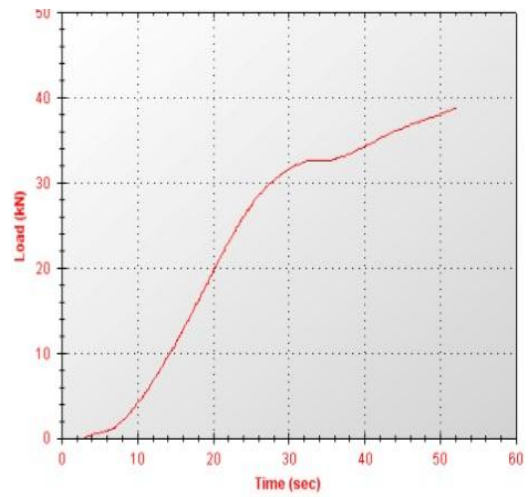


(c) 95% Al

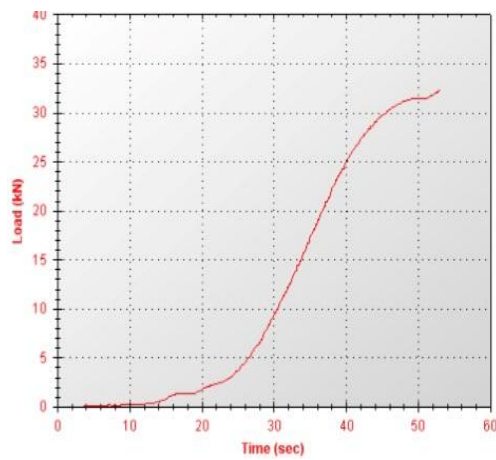
Figure 3. Load vs elongation curve



(a) Sample A187



(b) Sample A191



(c) Sample A195

Figure 4. Load vs time curve

3.4 X-Ray Diffraction

Figure 5 shows XRD result of the prepared aluminum matrix composite samples. The sintered samples were subjected to XRD in SEIFURT diffractometer. X-ray photons that reach the atoms, on interactions subject to various absorption and scattering effects on the samples [21]. The theory of these methods is based on the diffraction of X-rays by periodic atomic planes and the angle or energy-resolved observation of the diffracted signal. The diffraction pattern shows the presence of aluminum represented by high intensity peaks compared to alumina and silicon carbide. The peak at 58 and 63° correspond to the presence of SiC in the sample. XRD study is carried out to confirm the presence of SiC and Al_2O_3 , in order to study the improved mechanical properties.

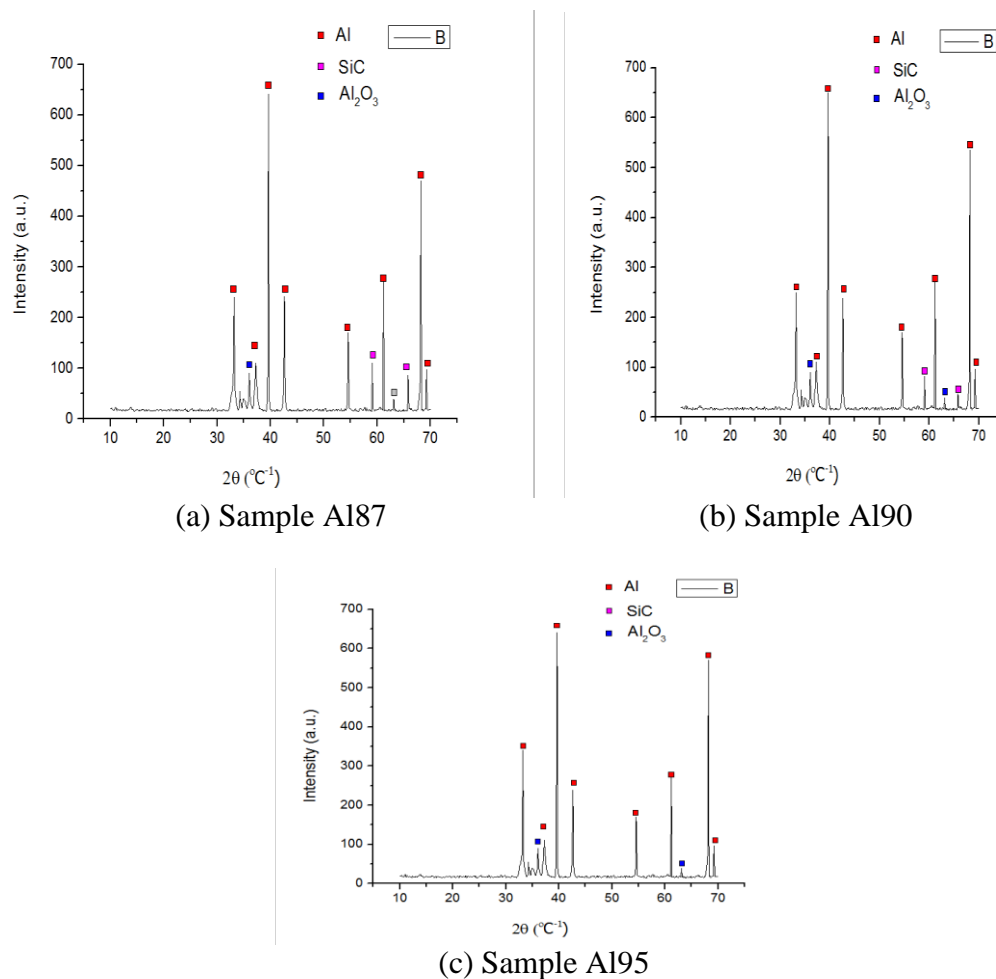


Figure 5. XRD pattern for Aluminium matrix Composites

3.5 Scanning Electron Microscope (SEM)

In order to perform the scanning electron microscopic analysis on the samples, the surface of the samples were cleaned and polished using appropriate grade sheets and thermally etched to give a clear surface. The samples were placed under scanning electron microscopic machine to obtain SEM micrograph at 750X magnification. The typical SEM micrograph is done to study the characteristic changes for the added reinforcements to the aluminium alloy [22]. Figure 6 (a and b) shows the micrograph of fracture surface of composite samples with the different composition. The properties of

MMCs are influenced by the reinforcements, morphology and distribution. Figure 6 (a) shows the uniform distribution of SiC and Al₂O₃ particles; it is due to less segregation compared to the micrograph of the other sample. Micrograph (b) indicates that the Al₂O₃ particles tend to segregate and cluster as the Al dendrites get solidified; the Al₂O₃ particles are rejected at the solid-liquid interface. The results clearly confirm that the uniform distribution of reinforcement particles lead to better mechanical properties

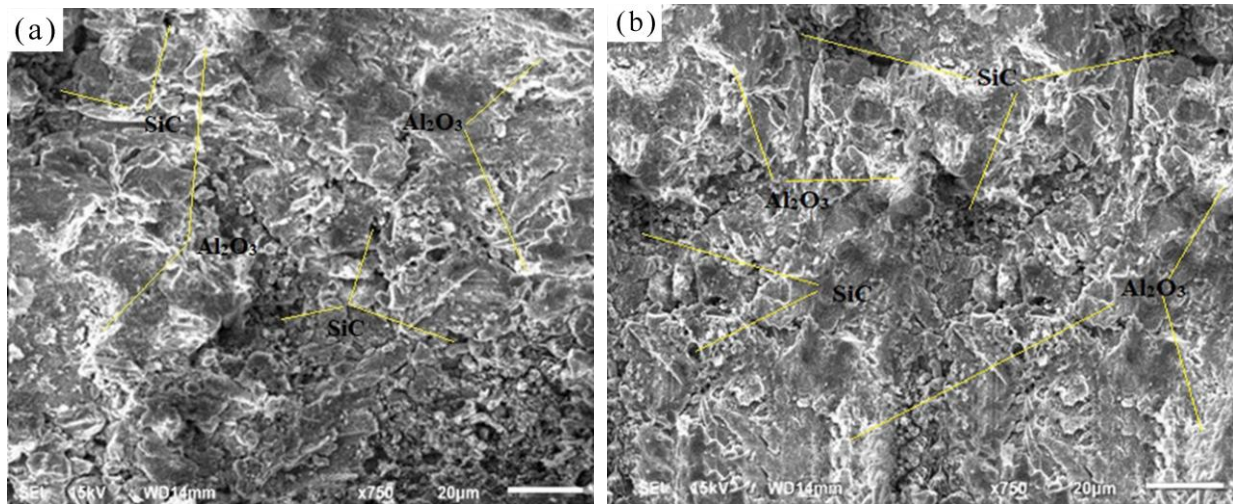


Figure 6. (a) SEM micrograph for sample Al87 **Figure 6.** (b) SEM micrograph for sample Al95

4. Conclusion

The SiC and Al₂O₃ particle dispersed in aluminium was successfully synthesized by powder metallurgy technique. The samples were subjected to measuring the density measurement, hardness and compression; analyzing the microstructural and XRD. The obtained results can be summarized as follows:

- SEM analysis showed homogeneous distribution of alumina and silicon carbide in the aluminum metal matrix composite.
- Hardness, compressive strength and density of aluminum matrix composite increased with increasing wt% of SiC (0-8%)

The results of this research confirm the improved mechanical properties with addition of reinforcement.

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