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Synthesis and characterization of AA5083 and AA2024 reinforced with SiO_2 particles

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Abstract. Among the types of different particulates, silica is a standout as one of the the cheapest and low-density particulates accessible in substantial amounts. The present study has been centered around the synthesis and study of aluminum matrix composite strengthened with nano-sized SiO_2 particles of various weight percentage by means of the stir casting technique. The EDX emphasized the presence of various elements and augmented the *in situ* reaction. The tensile strength and wear studies were also carried out. The reinforcement materials percentage variation was one of the important factors for the present studies. The Aluminum Alloy 5083 and 2024, which are magnesium and copper-based alloys, had a significant effect on the material characterization.

Key words: *in situ* reaction, SEM, wear rate, stir casting, tensile strength, EDX.

1. Introduction

Particulate reinforced aluminum matrix composites are gaining significance these days due to their isotropic properties and the likelihood of secondary processing facilitating fabrication for secondary components. Superior mechanical and physical properties and changes in morphology and interfacial characteristics can be obtained by reinforcement of submicron or nano-sized particles with aluminum matrix yields [1]. To increase wettability 5% Mg is added. For better stirring and to reduce agglomeration, the stirrer setup is also changed. The decrease in tensile strength is observed due to the hardness of SiO_2 but aging could increase the impact strength [2]. Reinforcement of particles by friction stir vibrational welding could decrease the grain sizes and increase the homogeneity of particles [3]. Density tensile strength and elongation increase from 165 MPa and 3.95% to 187 MPa and 7.18%, respectively, for composites prepared with the Al-SiO_2 system [4]. Wear resistance of the composite increases for the 5% weight percentage of fly-ash particles SiO_2 [5]. The rate of reduction in wear rate with growing distance is relatively more for the matrix alloy than for the composite [6]. These findings confirmed that addition of SiO_2 nanoparticles modifies deposit morphology through grain refinement, reduction in surface roughness and minimization of surface porosity in nanocomposite coatings [7]. SiO_2 nanoparticles are agglomerated at pH 3 but well dispersed at pH 4. Nano-SiO_2 has been not only absorbed onto the Ni–W layer but also through it. It improves the mechanical and electrical proprieties of Cu [8]. Hot extrusion of the discontinuously reinforced AMMCs can lead to break-up of particle agglomerates, reduction of porosity, and improved bonding, all of which contribute to improving the mechanical properties of these materials. Aluminums can be considered ideal reinforcements, due to their high strength, high aspect ratio, and thermo-mechanical properties. The objective of this work is to reinforce 0, 3, 6, 9 and 12 wt% of Al_2O_3 particles with the Al 1100 (Mg) alloy by means of the melt stirring method to make aluminum-based composites [9]. Al_2O_3 particles were observed to refine the grains and were distributed homogeneously in the aluminum matrix. Al_2O_3 particles clusters were also seen in a number of places. Al_2O_3 particles were properly bonded to the aluminum matrix. The reinforcement of Al_2O_3 particles improved the microhardness and ultimate tensile strength of AMMC [10]. With 10 wt% SiO_2, the mechanical properties such as uniaxial compressive strength (UCS) and hardness increased [11]. A reduction in dendrite cell size that was 1.5–2 greater than for the matrix alloy cast using the same conditions with the α-Al2O3p/A356 composite. The yield stress, tensile strength, elongation and microhardness amounted to 132 MPa, 268 MPa, 5.1% and 107.2 HV at 10% volume fraction of 11 wt% RM-Al. HMMC showed a maximum of 90% improved wear resistance as compared with the Al6061/Alumina/Graphite Hybrid Metal Matrix Composite (AlHMMC) [12, 13]. Reinforcing the ZA-27 alloy by fly ash or Al_2O_3 particles forms a weak micro galvanic couple between matrix and reinforcement particles thus reducing the potential for uniform corrosion [14]. This study evaluates the effect of the reinforcement of SiO_2 particles on the matrix of Aluminum 5083 and Aluminum 2024. This attempt is based on the motivation of the desired properties of magnesium and copper along with the base metal aluminum.

2. Materials and methods

For the fabrication of MMC, aluminum alloys 2024 and Al5083-O were used as the base metal. Element composition

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and material properties of both the alloys are shown in Table 1 and 2, respectively. A ceramic particle, silica (SiO_2), was used to synthesize the Al_2O_3 reinforcement and an Al/Al_2O_3 composite was produced based on the variation given in Table 3.

Table 1
Element compositions

Element	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn	Al
AA 2024	0.28	4.90	0.50	1.80	0.90	0.50	0.15	0.25	Bal
AA 5083	0.05	0.10	0.40	4.90	0.40	0.40	0.15	0.25	Bal

Table 2
Material properties

Mechanical properties	Hardness, Vickers	Tensile yield strength(MPa)	ultimate tensile strength (MPa)
AA5083 0	137	324	469
AA 2024	87	97	210
SiO_2	1000	165	180

Table 3
Sample preparations

SAMPLE No.	Al 2024 (gm)	Al 5083 O (gm)	SiO_2 (gm)
SAMPLE 1	278	278	0
SAMPLE 2	346	346	27.68 (4%)
SAMPLE 3	398	398	47.76 (6%)
SAMPLE 4	424	424	67.84 (8%)

Casting parameters:
- Preheat temp. for SiO_2: 464°C
- Casting temp.: 820°C
- Stirring speed: 650 rpm for 2 min.

The ceramic reinforcement is incorporated into the matrix by the chemical reaction of the salt with molten metal matrix. These are referred to as *in situ* composites. The *in situ* arrangement gives more tangible control of size and level of reinforcement, and also the matrix support interface. On the other hand, the making of *in situ* reinforcement requires the use of an appropriate reaction. The strength and other mechanical properties are reduced when the aluminum alloy is used at high temperatures. The above problem can be solved by incorporating SiO_2 reinforcement into the aluminum matrix.

$$4Al + 3SiO_2 \longrightarrow 2Al_2O_3 + 3Si$$
$$2Mg + O_2 \longrightarrow 2MgO$$
$$2Cu + O_2 \longrightarrow 2\,CuO$$

Fig. 1. Tensile specimen

3. Mechanical characterization techniques

3.1. Tensile test. The samples were tested for tensile strength as per the American Society for Testing of Material (ASTM E8). UTS and the percentage of elongation were assessed utilizing the computerized universal testing machine (HITECH TUE-C-1000). Tensile test specimens are presented in Fig. 1.

3.2. Hardness test. Microhardness was measured using a microhardness tester (MITUTOYO-MVK-H1) at a 500 g load applied for 15 seconds along the cross-section of a specimen obtained, perpendicular to the welding direction. The indentation was made at up to 10 mm (one indentation/mm) on either side of the weld line of specimens.

3.3. Wear test. A pin on disc tribometer consists of a stationary "pin" under an applied load in contact with a rotating disc. The pin can have any shape to simulate a specific contact, but spherical tips are often used to simplify the contact geometry. The coefficient of friction is determined by the ratio of the frictional force to the loading force on the pin. The amount of wear is determined by measuring appropriate linear dimensions of both specimens before and after the test, or by weighing both specimens before and after the test. In this experiment, the test was conducted with the following parameters:

1. Load 2. Speed 3. Distance

In the present experiment, parameters such as speed, time and load are kept constant throughout all the experiments.

4. Results and discussion

In the following sections, microstructure structural analysis, hardness, tensile strength and wear resistance strength of all the samples examined are presented and discussed.

4.1. Tensile strength. Based on the experiments conducted using the UTM machine, the following values were obtained The magnesium and copper-based alloys have affected the strength of the composite. This is tabulated in Table 4. There is a reduction in strength, which might be due to the percentage of copper in the composite, as shown in Fig. 2. The incorporation of nanoparticles improves the hardness values and by increasing the content of SiO_2 nano-particles the tensile strength and ductility values are also increased. The tensile strength of the described composites may have increased under high temperature while their plasticity remains high. This might be

Table 4
Tensile strength

Sample	Composition	Tensile Load (Kg)	Tensile Strength (MPa)	% of Elongation
1	Al2024+ Al5083-O	476.5	111.262	11.5
2	Al2024+ Al5083-O+ SiO_2 (4%)	740.8	172.976	14.5
3	Al2024+ Al5083-O+ SiO_2 (6%)	833.0	194.500	16
4	Al2024+ Al5083-O+ SiO_2 (8%)	639.2	149.262	14

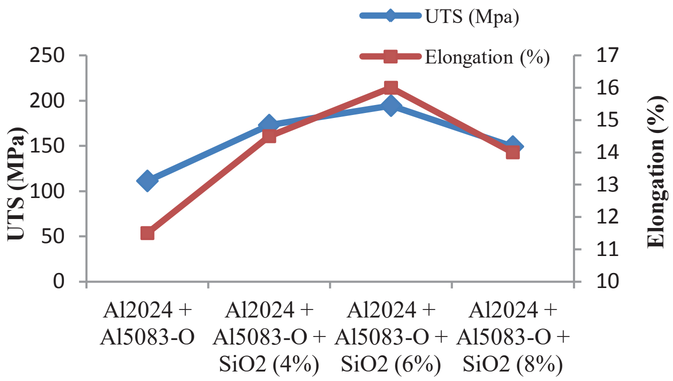


Fig. 2. Effect of weight percentage on tensile strength and elongation

due to matrix alloy, aging conditions, and the failure mechanisms. And also due to increased dislocation density near the matrix-reinforcement interface, grain refinement, and strengthening effects. The Si content of an Al alloy infiltrated into the SiO_2 matrix composites affected the strength of the SiO_2 matrix composites.

4.2. Microhardness. Table 5 shows the effect of SiO_2 reinforcement on the hardness of cast Al2024-Al5083O-SiO_2 particulate composites. For the 4% wt composition, there was an increase in the hardness value while for 6% a slight reduction of hardness might be observed. The same applies to 8% wt, as shown in Fig. 3. A drastic reduction of hardness value infers that hardness of material increases only from 0–4% and then decreases. This might be due to a variety of factors such as dispersion and increase in lattice strain. Particles block the movement of dislocations, thus increasing hardness. The hardness of the hybrid composites increased due to the strengthening effect of reinforcements.

Table 5
Hardness

Samplee	Composition	Hardness
1	Al2024+Al5083-O	130.7
2	Al2024+Al5083-O + 4% SiO_2	156.5
3	Al2024+Al5083-O + 6% SiO_2	117.7
4	Al2024+Al5083-O + 8% SiO_2	96.7

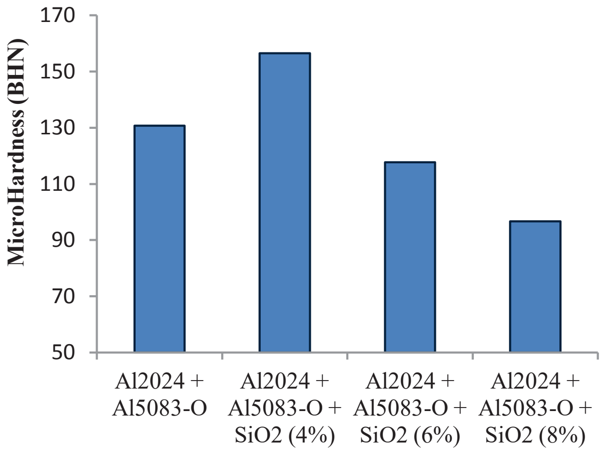


Fig. 3. Effect of weight percentage on microhardness

4.3. Wear rate. The results for composite specimens containing 4%, 6% and 8% of SiO_2 in Al2024+ Al5083-O under an applied load of 20 N with a constant speed of 300 rpm, respectively, are as shown in Table 6. The Al2024+ Al5083-O with the 8% wt SiO_2 composite manifests superior wear performance under different conditions. Al-composites reinforced with ceramic materials reveal that there is a reduction in the wear rate due to the formation of oxide layers on the wear surface. Hard ceramic particles like aluminums as hybrid reinforcements and solid lubricant particles can effectively improve the wear properties. The wear resistance of the composites is found to be higher than that of pure Al. Cumulative wear for all composites increases with increasing sliding distance whereas the coefficient of friction will show a fluctuating tendency.

Table 6
Wear rate

Sample	Composition	Wear rate $\times 10^{-5}$
1	Al2024+Al5083-O	639
2	Al2024+Al5083-O + 4% SiO_2	474
3	Al2024+Al5083-O + 6% SiO_2	360
4	Al2024+Al5083-O + 8% SiO_2	294

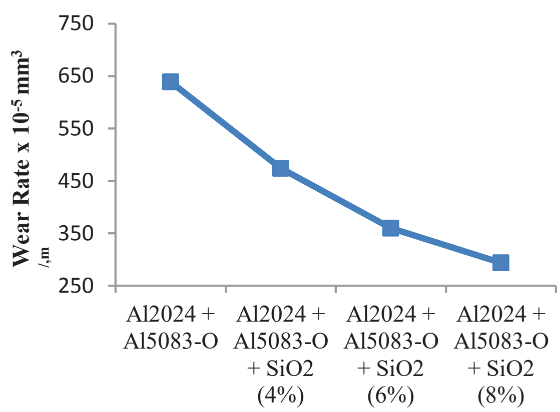


Fig. 4. Effect of weight percentage on wear rate

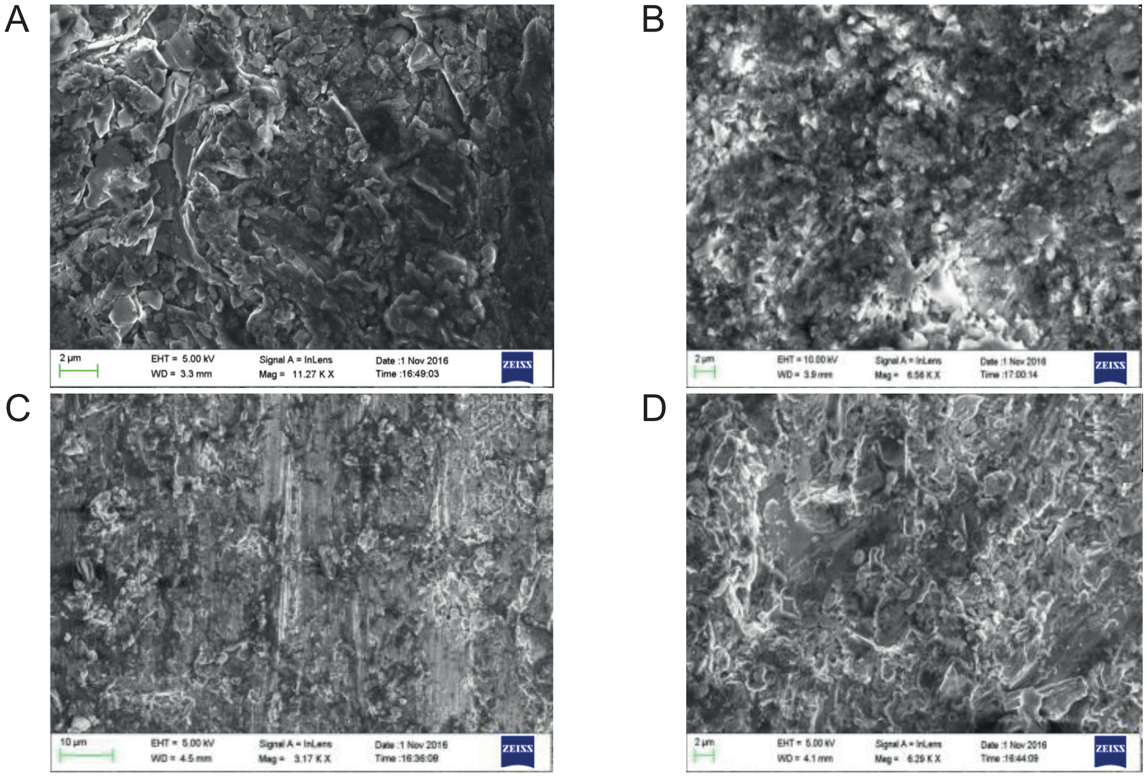


Fig. 5. SEM images a) Al2024+Al5083-O; b) Al2024+Al5083-O + 4% SiO_2; c) Al2024+Al5083-O + 6% SiO_2; d) Al2024+Al5083-O + 8% SiO_2

4.4. Microstructure SEM analysis. Figure 5 a–d shows the SEM images of Al2024+Al5083-O alloy reinforced with 0%, 4%, 6% and 8 wt% of SiO_2 composites, respectively. Micrographs reveal that there is an uniform distribution of SiO_2 particulates throughout the matrix alloy and that porosity is reduced. It is reported that higher hardness is always associated with lower porosity of the MMCs. Also, it can be observed that there is good bonding between the matrix and the reinforcement particulates resulting in better load transfer from the matrix to reinforcement material. This may be due to the presence of magnesium in AA5083-O which is a good wetting agent for reinforcement of aluminum alloys.

Tables 7 and 8 show the EDX results with various elements present in the sample, their weight, and compound percentage. The result also validates the presence of aluminums following the *in situ* reaction of SiO_2 with the base material.

Table 7
Sample 1 EDX

Element	Weight %	Atomic %	Compd %	Formula
C K	7.66	11.86	28.08	CO_2
Mg K	1.31	1.00	2.17	MgO
Al K	32.58	22.45	61.55	Al_2O_3
Si K	2.68	1.78	5.74	SiO_2
Mn K	0.18	0.06	0.23	MnO
Fe K	0.10	0.03	0.13	FeO
Cu K	0.87	0.26	1.09	CuO
Ag L	0.94	0.16	1.01	Ag_2O
O	53.68	62.39		
Total	**100.00**			

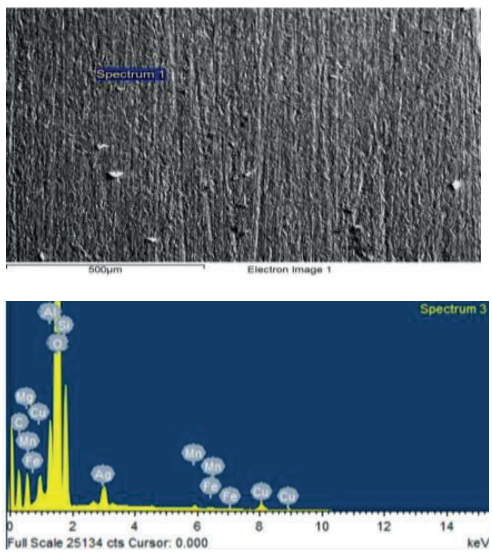
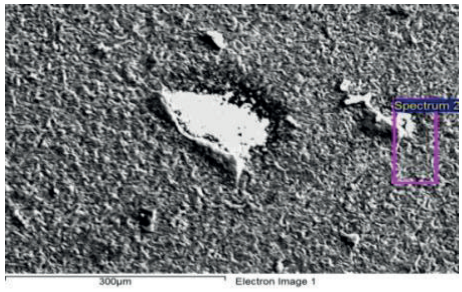
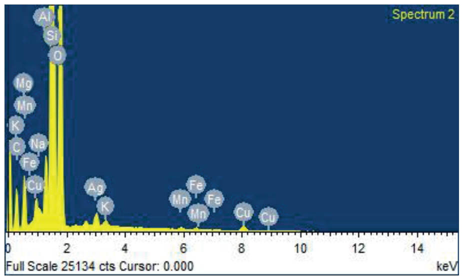


Table 8
Sample 1 EDX

Element	Weight %	Atomic %	Compd %	Formula
C K	6.37	9.99	23.33	CO_2
Na K	0.24	0.20	0.33	Na_2O
Mg K	1.08	0.84	1.80	MgO
Al K	30.77	19.40	52.46	Al_2O_3
Si K	6.24	6.20	19.76	SiO_2
K K	0.15	0.07	0.18	K_2O
Mn K	0.14	0.05	0.18	MnO
Fe K	0.15	0.05	0.20	FeO
Cu K	0.76	0.23	0.95	CuO
Ag L	0.75	0.13	0.81	Ag_2O
Totals	**100.00**			





5. Conclusions

Silica particulate reinforced Aluminum MMCs of different wt% (4, 6, and 8%) is successfully cast by means of the stir casting process and then results obtained from various experiments are compared with base material mechanical properties. This is a new attempt to have a MMC with two base aluminum alloys as matrix to which SiO_2 reinforcement is added. This attempt has yielded desirable properties in the matrix synthesized in this work. Conclusion derived from this research are listed below:

The composites with particle volume fraction of less than 4–6% show the best comprehensive mechanical properties, i.e. tensile strength, yield stress and percentage elongation. As the weight% of reinforcement increases, the wear loss decreases, suggesting that Al_2O_3 aluminum MMCs have good wear resistance as compared with the base material.

The hardness of the material increases only up to 4 wt% of SiO_2 reinforcement and then with increasing the wt% the hardness drastically decreases. This might be due to the uneven distribution of the particles caused by the increase in wt%.

Microstructure and mechanical properties deteriorate after excessive addition of particle reinforcement. EDX results show different elements and compounds present in the material and the volume percentage of Al_2O_3 in the matrix infers that *in situ* reactions have occurred in the material.

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