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Research Article

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Mechanical and tribological studies on nano particles reinforced hybrid aluminum based composite

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Abstract – Hybrid metal matrix composites are new class of materials due to their better mechanical properties which can be achieved through proper selection and combination of materials. The work reported in this paper is based on fabrication of hybrid composites by using nano particles as reinforcements. The hybrid composites were fabricated by reinforcing them with nano sized SiC and Al_2O_3 particles in order to study mechanical and tribological properties of these enhanced materials. A stir casting method was used to obtain hybrid composites. LM 6 aluminum alloy was used as a matrix material. The results shown increase in hardness as well as in ultimate tensile strength of the composites with small wt.% of nano-sized hybrid reinforcements. The composites produced also exhibit better tribological properties.

Key words: Hybrid composites, Nano-sized reinforcement, Mechanical properties, Tribology

1. Introduction

Aluminum based composite system has been studied over last three decades where micro sized reinforcements were used commonly. Only few research work available so far on nano sized particle reinforcement aluminium matrix composite [1, 7]. Hybrid metal matrix composite are new class of composite materials that gained the attention of scientist and researchers recently [2, 10]. Hybrid metal matrix composites are engineered combination of two or more reinforcements. Hybrid reinforcement gives us high degree of freedom in material design [3]. It was reported that the properties of hybrid composites are superior to those of single reinforcement composite. Their have been very few studies carried out on hybrid composites [4].

It was reported that use of hybrid composites helps to improve strength, stiffness, modulus, wear resistance and decreased the coefficient of thermal expansion [5–11]. Aluminum matrix composites are one of the advanced engineering material developed for variety of applications [4]. Reinforcing the aluminium alloy with nano particle have a significant influence on the overall strengthening [7].

This paper presents the work carried out on nano hybrid aluminium matrix composite to study the effect of nano hybrid reinforcement on mechanical and tribological properties of nano hybrid composite.

2. Experiment

To develop nano hybrid aluminium matrix composite, procured aluminium alloy billet (LM6) cut into small pieces. The weight of each piece is recorded. The nano particles of SiC and Al_2O_3 in equal ratio are measured on micro balance having wt.% of 0.5, 1.0, 1.5 and 2 with respect to cut Al alloy pieces. A piece of LM6 alloy is placed in graphite crucible, which is heated with the help of induction furnace to melt Al alloy. The temperature of molten Al alloy raised 10–20 °C above melting point (LM6 Al alloy have melting point of 580 °C). The nano particles are preheated to a temperature of around 100 °C to make them free from moisture and to improve its wettability with Al alloy. The nano particle are then feed manually into crucible containing molten Al alloy. Then the stirring is carried out at constant speed of 400 rpm to mix the nano particles into Al alloy for 4–5 min. The stirrer is made of low carbon steel. To avoid oxidation and contamination to hybrid composites argon inert gas envelope is used. After stirring the molten metal mixed with nano particles poured into preheated metallic mould to get rods of circular cross section after solidification. The preheating of metallic mould to a temperature of around

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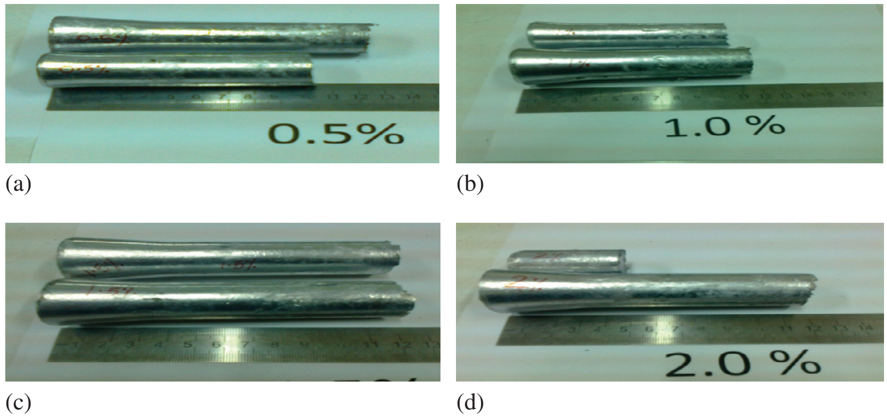


Figure 1. Hybrid composite stir cast rods with different wt.%. (a) 0.5 wt% reinforcement, (b) 1% reinforcement, (c) 1.5 wt% reinforcement, (d) 2 wt% reinforcement.

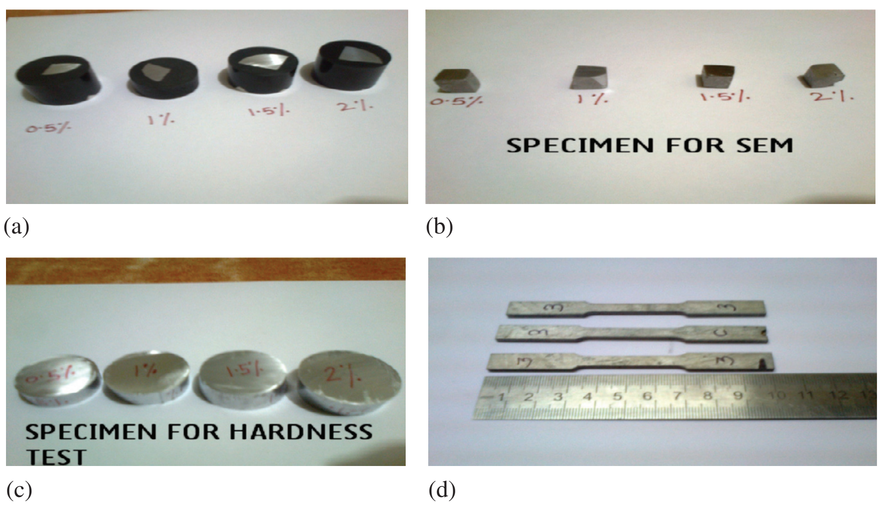


Figure 2. Specimen for (a) optical microscopy, (b) SEM, (c) hardness test and (d) tensile test.

Table 1. Chemical composition of LM6 (Al-12Si alloy) wt.%.

Si	Mg	Cu	Ni	Fe	Mn	Zn	Al
11–13	0.8–1.5	0.5–1.5	0.5–1.5	<0.2	<0.04	<0.02	Balance

100 °C is carried out to reduce humidity effect. Nano hybrid composites cylindrical rods thus obtained consist of 0.0 wt.%, 0.5 wt.%, 1.0 wt.%, 1.5 wt.%, 2.0 wt.% nano sized hybrid reinforcements in equal ratio. Figure 1 shows stir cast rods of hybrid composite with 0.5 wt.% to 2 wt.%. Further samples for characterization are prepared as shown in Figure 2.

Characterization studies included investigation of density, ultimate tensile strength, hardness, microstructure and wear test.

Material: Aluminum alloy LM6 was used as matrix (Table 1).

Nano sized SiC (>98.6% purity) and Al_2O_3 (>99.8% purity) powers were purchased from Reinste Nano Venture Pvt. Ltd. company New Delhi, India. The average particle size is 25–50 nm and 40 nm for SiC and Al_2O_3 nano reinforcement respectively.

Density measurement was carried out by using Archimedes principle technique. To examine microstructure and distribution of nano sized reinforcements in aluminium matrix optical microscopy and SEM were used respectively. All samples were polished to obtained mirror like surface with no visible scratches followed by etching. Micro hardness test was carried out by using Vickers hardness tester with ASTM E384-99 standard. Tensile test was done using ASTM E8 standard. Pin on disc test was used to study wear behaviour of composite.

3. Results and discussion

3.1. Processing

The Figure 1 shows the stir cast rod with different wt.% of hybrid reinforcement (nano sized SiC and Al_2O_3 particles) in

Table 2. Results of density and porosity measurements.

Materials	Nano sized SiC (wt.%)	Nano sized Al_2O_3 (wt.%)	Theoretical density (kg/m^3)	Experimental density (kg/m^3)	Porosity (%)
LM6 alloy	0	0	2700	2663	1.37
LM6 + 0.25% SiC + 0.25% Al_2O_3	0.25	0.25	2703	2667	1.33
LM6 + 0.5% SiC + 0.5% Al_2O_3	0.5	0.5	2706	2570	5.02
LM6 + 0.75% SiC + 0.75% Al_2O_3	0.75	0.75	2710	2610	3.69
LM6 + 1.0% SiC + 1.0% Al_2O_3	1.0	1.0	2713	2573	5.27

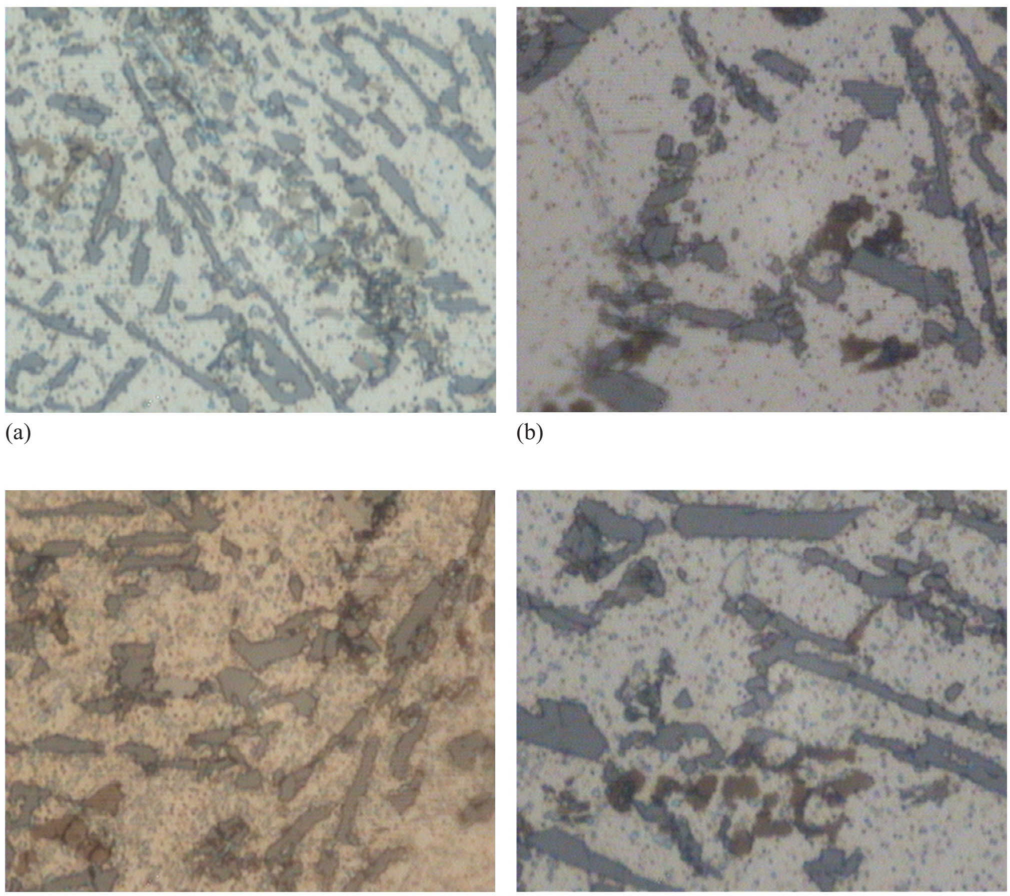


Figure 3. (a)–(d) show optical microscopic images of hybrid composite specimens. (a) Optical microscopic image of 0.5 wt.% nano particles composite, (b) optical microscopic image of 1.0 wt.% nano particles composite, (c) optical microscopic image 1.5 wt.% nano particles composite, (d) optical microscopic image 2.0 wt.% nano particles composite.

equal ratio. The fabrication of al based hybrid composites was done by using stir casting method. It is one of the most economical techniques available to produce large near net shaped parts of composite materials [12].

3.2. Density measurement

The Table 2 shows the theoretical and experimental density of composite specimens. They are very close to each other showing consistency in density. The samples used in this experiments were randomly cut from the stir cast rods, which confirms uniform distribution of hybrid reinforcement. The low amount of porosity indicates better densification of composites.

3.3. Micro-structural characterization

3.3.1. Optical microscopy

Figures 3a–3d show optical microscopic images of hybrid composites. These shows the microstructure of composites specimens.

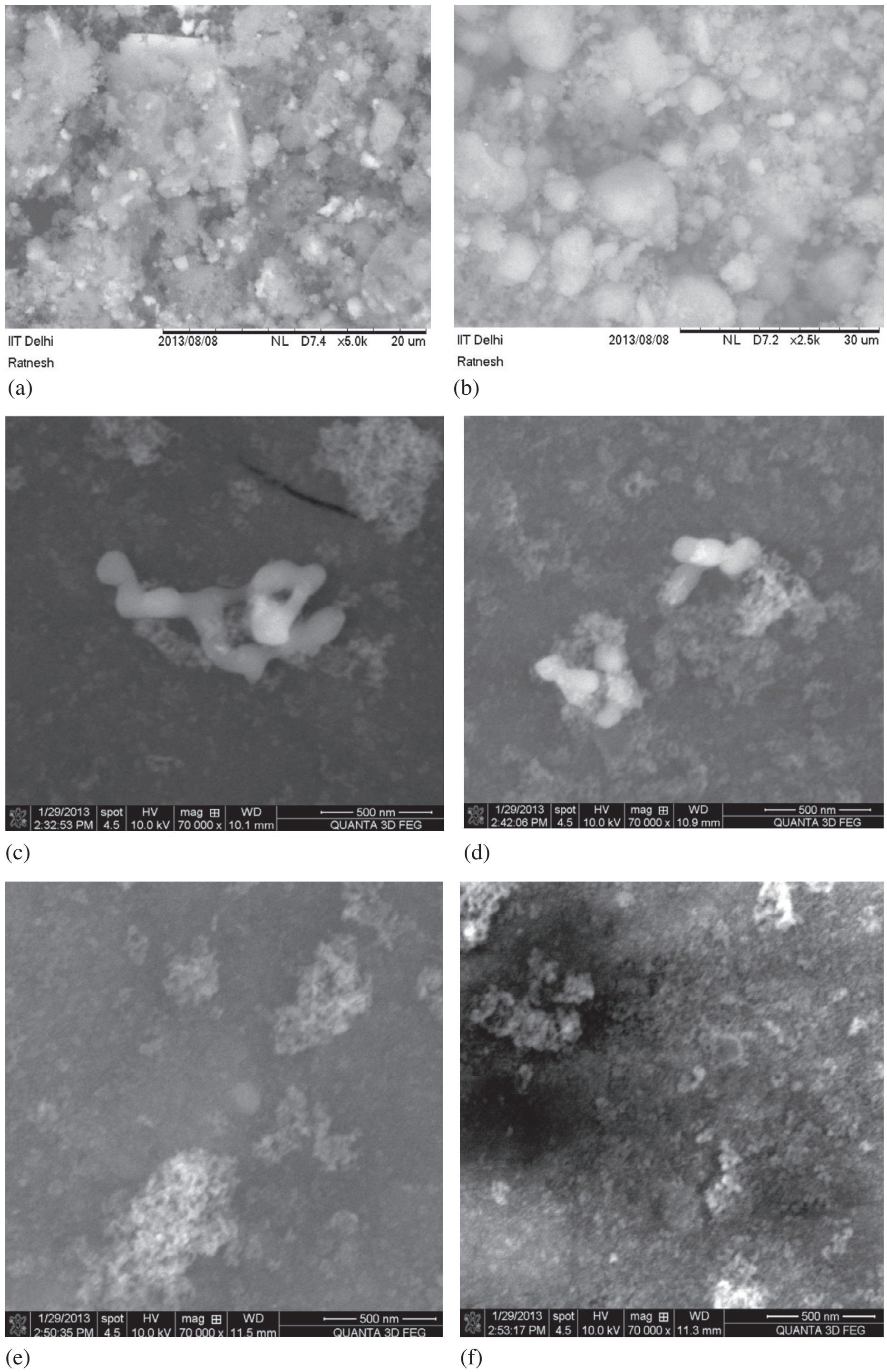


Figure 4. SEM images of nano particles and hybrid composites with different wt.%. (a) SiC nano particles, (b) Al_2O_3 nano particles, (c) 0.5 wt.% nano particles composite, (d) 1.0 wt.% nano particles composite, (e) 1.5 wt.% nano particles composite, (f) 2.0 wt.% nano particles composite.

3.3.2. SEM

Figures 4a and 4b show SEM image of SiC and Al_2O_3 nano particles respectively.

Figures 4b–4f show SEM images of the hybrid composite specimens shows uniform distribution of reinforcement with small amount of clustering. An uniform distribution of reinforcement is necessary in improving mechanical properties of composites. Some amount of clustering and agglomeration of nano-sized particles observed this can be attributed to high surface energy associated with nano-sized particles.

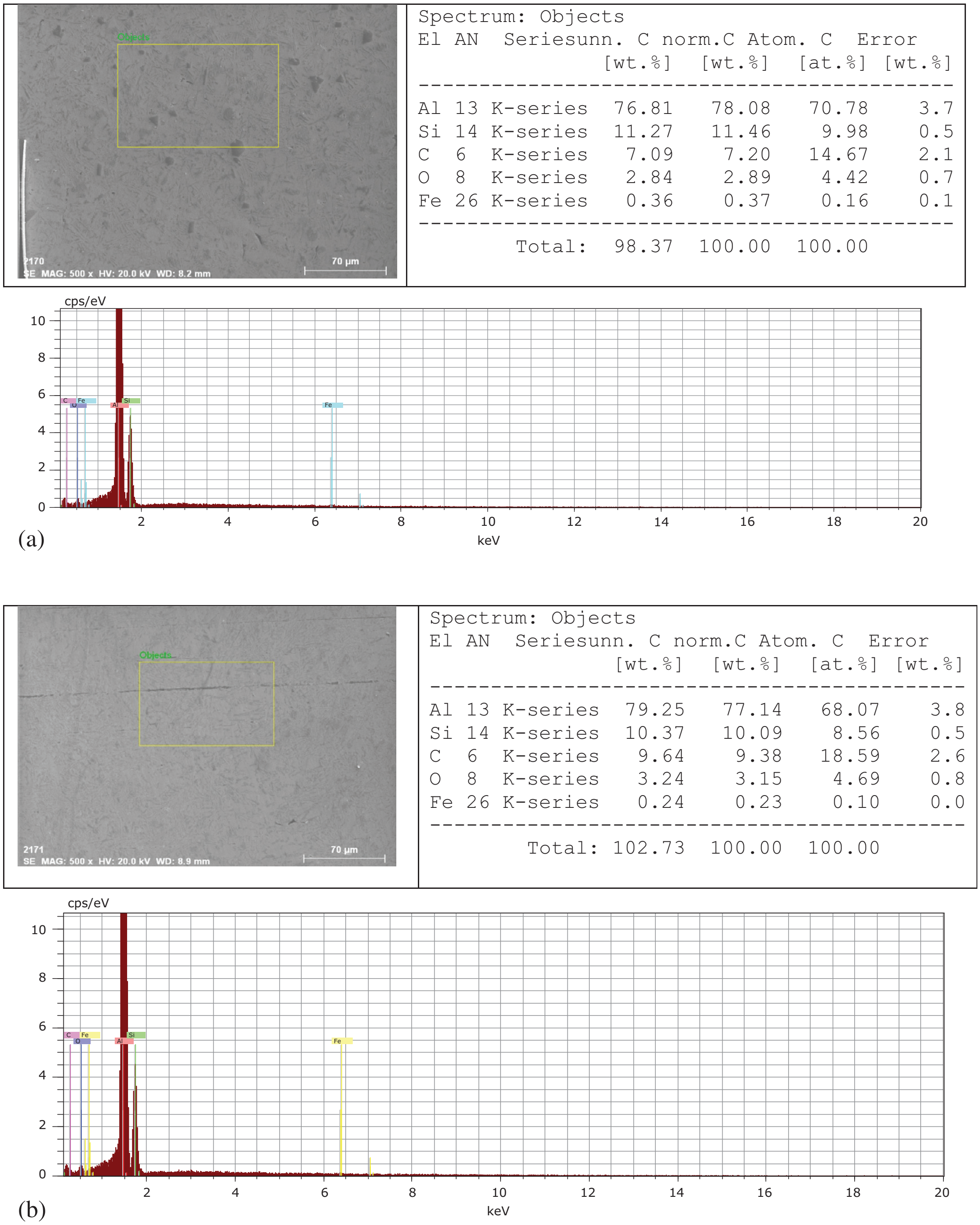


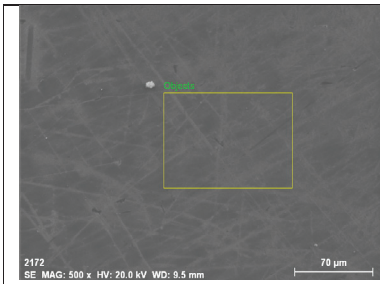
Figure 5. (a)–(d) show EDAX results of hybrid composites. (a) 0.5% nano hybrid composite, (b) 1.0% nano hybrid composite, (c) 1.5% nano hybrid composite, (d) 2.0% nano hybrid composite.

3.3.3. EDAX

It confirm presence of SiC and Al_2O_3 in hybrid composites. Figures 5a–5d show EDAX of various wt.% hybrid composites.

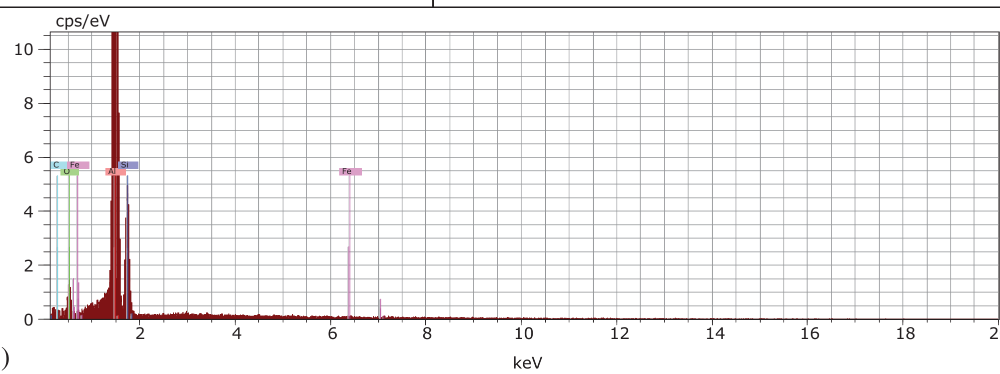
3.4. Hardness test

Figure 6 shows the results of Vickers micro hardness test. It was observed that the hardness increased with increase in reinforcement quantity. The hardness is higher than LM6 Al alloy. This can be attributed to the presence of hybrid reinforcement particles. The presence of reinforcement imposed higher degree of constraint to the localised matrix deformation during hardness test; which obstructed the motion of dislocations and resisted the deformation of matrix. Increase in the residual stresses induced due to the mismatch of thermal expansion between the matrix and reinforcement resulted in higher dislocation density, increased hardness of composites [1].



Spectrum: Objects

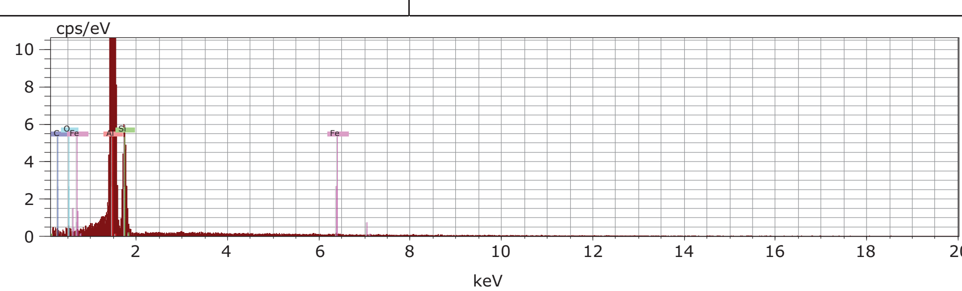
El	AN	Series	unn. C [wt.%]	norm.C [wt.%]	Atom. C [at.%]	Error [wt.%]
Al	13	K-series	76.17	71.44	60.68	3.7
O	8	K-series	10.17	9.54	13.66	1.8
Si	14	K-series	10.08	9.46	7.72	0.5
C	6	K-series	9.97	9.36	17.85	2.5
Fe	26	K-series	0.22	0.21	0.09	0.0
		Total:	106.62	100.00	100.00	



(c)

Spectrum: Objects

El	AN	Series	unn. C [wt.%]	norm.C [wt.%]	Atom. C [at.%]	Error [wt.%]
Al	13	K-series	86.36	75.43	67.61	4.2
Si	14	K-series	14.38	12.56	10.82	0.7
C	6	K-series	8.83	7.71	15.52	2.5
O	8	K-series	4.45	3.88	5.87	1.0
Fe	26	K-series	0.47	0.41	0.18	0.1
		Total:	114.49	100.00	100.00	



(d)

Figure 5. Continued.

3.5. Tensile Test

Figure 7 shows results of ultimate tensile strength of hybrid composites. The ultimate tensile strength of the hybrid composites increases with increase in nano particle wt.% percentage. The tensile test is carried out as per ASTM standard. The specimens for tensile test (as shown in Figure 2d) were cut along the length of cast rod by wire cut EDM machine. The increase in the tensile strength can be attributed to obstruction to dislocation motion, higher dislocation density, induced internal stresses due to thermal expansion mismatch between matrix and reinforcements and effective load transfer from matrix to better bonded and uniformly distributed reinforcements [1, 7, 9].

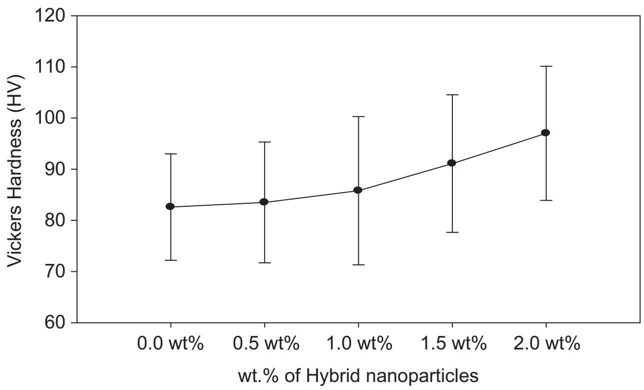


Figure 6. Vickers micro hardness.

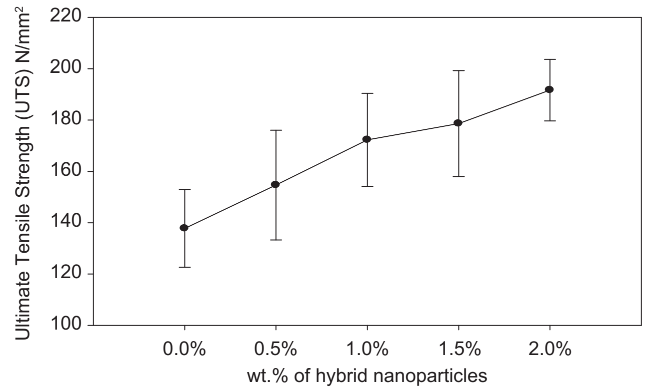


Figure 7. Ultimate Tensile Strength (UTS) of hybrid composites.

3.6. Pin on disc wear test

The pin on disc wear test was performed to study the tribological properties of the hybrid composites. Figure 8 shows the pins used in this study. The diameter of the pin is 10 mm and length is 30 mm. The counter surface disc of EN 31 material was used. The pin and disc surfaces were polished with emery paper. It was ensured that pin surface should be perfectly flat. To know wear loss, the difference between weight of the pin before and after wear test was calculated. The experiments were performed over load range of 10 N–50 N keeping sliding distance 1000 m constant and sliding speed of 1 m/s and 2 m/s was used. As the wt.% of reinforcement increased wear loss decreased (Figures 9 and 10). But with increased load the wear loss increased for 0.5 wt.% hybrid composite. For other composition with higher load there no much increase in wear loss. It is indicated that hybrid nano reinforcement reduced the wear loss. At the higher load (40 N and above) due to higher temperature between pin and disc, pin had tendency of being ceased. In Figure 10 as the sliding speed increased from 1 m/s to 2 m/s the wear loss increased for all wt.% hybrid composites but less than shown in Figure 9. It was reported that addition of SiC particles in matrix reduced the natural tendency for materials flow at the wear surface and formed iron reach (Fe_3O_4) layer on the surface of composite pin and the steel disc track which helps in reducing wear rate [13, 14, 17]. The well distributed SiC and Al_2O_3 particles acted as load bearing elements [14, 15]. In case of Al-Si alloys it was reported that when iron reach surface layers are formed on the composite the wear rate is low [16]. Some studies also shown that SiC particles subjected to tribo-chemical interaction during sliding process which forms SiO_2 which act like a lubricant and helps to reduce the wear. Further with increased volume fraction wear resistance reported to be enhanced [17]. The enhanced wear performance of hybrid composites can be attributed to improved hardness and strength of composite with the addition of nano Al_2O_3 particulates also as composites with improved hardness and strength exhibit better wear resistance [18]. The hybrid composite have better wear resistance than single reinforcement reinforced composites. The SiC particles are more effective than Al_2O_3 particles due to their high hardness. Also it was noted that porosity was mainly located around Al_2O_3 particles while it was less pronounced around SiC particles. This is due wetting behaviour of Al alloy. The SiC particles have better wettability and are more compatible with Al alloy than Al_2O_3 particles. The addition of mg improves wettability and reduces porosity. The SiC particles reacts with Al to produce Al_4C_3 precipitation at Al/SiC interfaces. However any reaction of Al melt and Al_2O_3 has not been reported [19]. It was reported that hybrid aluminium matrix composites are superior to unhybrid aluminium matix composites in wear performance. Mostly studies on hybrid composites are focussed on the form of reinforcements such as mixture of particles and fibers or fibers and whiskers. But information on hybrid composites reinforced with the nano particles is limited. It was reported that as the size of reinforcement increased from nano to micro the rate of wear increased, this is due to reduction in relative density, hardness and inter-particle spacing. The wear mechanism observed for nano particles was abrasion. In micro sized particles dominant wear mechanism is adhesion and particle cracking induced delamination. The tendency of particle cracking decreases with reducing particle size [20].

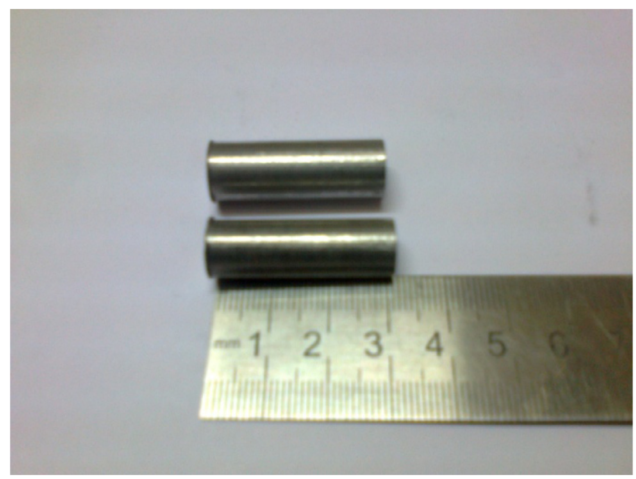


Figure 8. Pin for wear test.

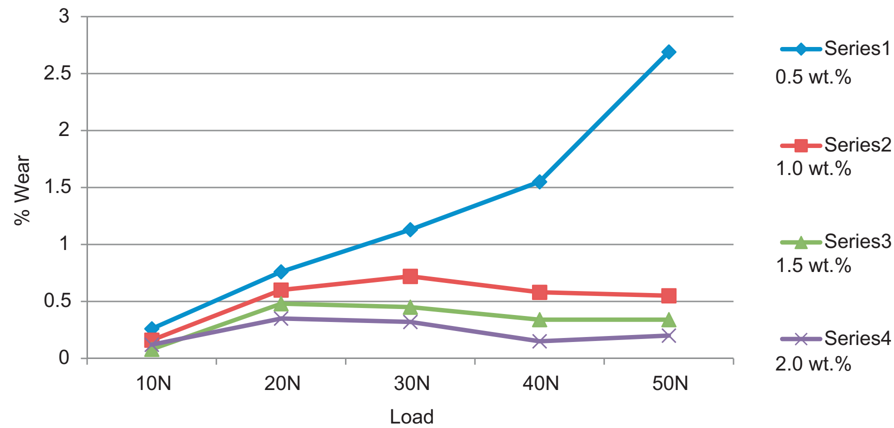


Figure 9. Load vs. wear (sliding speed 1 m/s and sliding distance 1000 m).

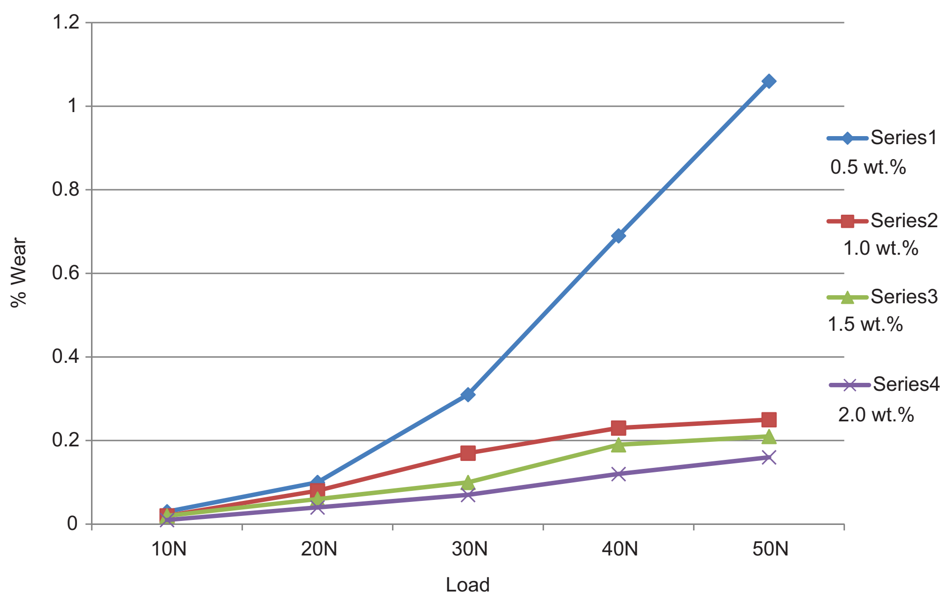


Figure 10. Load vs. wear (sliding speed 2 m/s and sliding distance 1000 m).

4. Conclusions

The following conclusions are drawn from the work reported above:

1. The stir casting method is simple and cheaper method for mixing reinforcement into matrix materials. But it has limitations when used for mixing nano particles, as nano particles have tendency of agglomeration. This results in clustering of nano particles and affect uniform distribution in matrix material. But continuous stirring at 400–600 rpm helps to distribute nano particles to a great extent.
2. The nano hybrid composites shown improved mechanical properties compared to LM6 alloy matrix. Vickers hardness for as cast LM6 matrix with 0 wt.% reinforcement is 84 Hv. With the addition of small wt.% of nano hybrid reinforcement it has shown increasing trend. For 2 wt.% of nano hybrid reinforcement it is increased to to 98 Hv. This increase in hardness is approx. 17%. Similarly the Ultimate Tensile Strength (UTS) also shown increasing trend. It is 138 N/mm^2 for 0 wt.% reinforcement and increased to 193 N/mm^2 for 2 wt.% nano hybrid reinforcement. This increase in UTS is approx. 39% compared to LM6 Al alloy. The further improvement in mechanical properties can be obtained by using suitable manufacturing method which helps to distribute nano particles uniformly in matrix and by using secondary processing techniques like hot extrusion.
3. The pin on disc wear test is carried out with aim to use nano hybrid composite for braking system application in automobile. The results shown that the nano hybrid composite exhibit reduced wear loss with increase in nano

hybrid reinforcement from 0.5 wt.% to 2 wt.%. The reduction in wear loss is approx. 80%. So nano hybrid composites have huge potential to enhance tribological property and can become most sought after material for tribological application.

The hybrid nano-composites exhibit better mechanical and tribological properties, compared to monolithic Al alloy. It has also have better properties than single reinforced composites. Because of its superior properties it can be a preferred material for many applications especially in braking system of automotive vehicles.

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