Wear and Mechanical Properties Assessment of Al-Si/Al_2O_3 Nano Composites Processed by Stir Casting

Anand Badiger[1], Ajay Krishan V S[2], Sumandas D[3], Vinayaka H L[4]

[1234]*Department of Mechanical Engineering, Dayanada Sagar College of Engineering, Bangalore, India*

***Abstract*— Aluminum matrix composites (AMCs) finds significant application in Automobile, Mining and Mineral sectors due to their excellent properties such as Lightweight, low coefficient of thermal expansion and high abrasion wear resistance coupled with high hardness, strength and stiffness. Light weight with high specific strength is the main criteria in the automotive and aerospace industry which has accelerated the demand and development of Metal Matrix Composites (MMCs). The interest in nano particles as reinforcements for Aluminum (Al) has been growing considerably due to their excellent properties. Efforts have been largely focused on investigating their contribution to the enhancement of the mechanical properties of the composites. The present work is carried out to explore the possible properties of nanoparticles as reinforcements to the maximum extent. In this study, Al based Al_2O_3 reinforced composite materials were manufactured by stir casting and their Tribological properties were investigated using pin-on-disc wear test rig at dry conditions. Mechanical properties such as Ultimate Tensile strength, hardness were also investigated. In addition to that, the microstructures of these materials were investigated by optical and Scanning Electron Microscopy (SEM). Tribological and hardness properties of composites significantly improved by the use of particle reinforced into LM25 alloy.**

***Keywords*—Metal Matrix Composites, Nano particles, Stir casting, Microstructure, Hardness, Ultimate Tensile Strength, LM25.**

I. INTRODUCTION

The structures and machine components of aerospace and automobile industries demands use of material selection with good mechanical properties for higher service life. Selection of suitable material to meet such requirements is the main criteria for design engineers. The evolution of composite materials which exhibits superior properties than base metals led to the usage for different applications and has been the focus of researchers [1].

Composite materials are classified as Polymer matrix composites (PMCs), Metal matrix composites (MMCs) and Ceramic matrix composites (CMCs). MMCs are most promising in achieving enhanced mechanical properties such as Hardness, Young's modulus, 0.2% yield strength and ultimate tensile strength due to the presence of nano and micro-sized reinforcement particles into the matrix [2, 3]. Addition of reinforcements into the matrix leads to enhancement of desirable properties at the cost of some ductility [4].

AMCs reinforced with particles and whiskers are widely used for high performance applications such as in automotive, military, aerospace and electricity industries due to their improved physical and mechanical properties [5,6]. In the composites, relatively soft alloy like aluminum can be made highly resistant by introducing predominantly hard but brittle particles such as Al_2O_3 and SiC.

LM25 is the most preferred material to obtain mechanical properties [7]. The alloy is also used where resistance to corrosion is an important consideration, particularly where high strength is also required. It has good weldability. Consequently, LM25 finds application in the food, chemical, marine, electrical and many other industries and above all, in road transport vehicles where it is used for wheels, cylinder blocks and heads, and other engine and body castings. Its potential uses are increased by its availability in four conditions of heat treatment in both sand and gravity die castings. It is, in practice, the general purpose high strength casting alloy, whose range of uses is increased by its availability in the ascast and partially heat-treated condition as well. It is used in nuclear energy installations and for aircraft pump parts [8, 9]. LM25 may be superior for castings, particularly in gravity dies, which are difficult to make to the required standard of soundness. It offers better machinability and mechanical properties.

Several techniques have been employed to prepare the composites including powder metallurgy, melt techniques and squeeze casting. There are two types of melting methods to fabricate composites, depending on the temperature at which the particles are introduced into the melt. In the liquid metallurgy process, the particles are incorporated above the liquid temperature of the molten alloy, while in compo-casting method the particles are incorporated at the semi-solid slurry temperature of the alloy. In the both processes, the vortex occurs and the composites have high porosity [10].

In this study, Al based Al_2O_3 reinforced composite materials were manufactured by stir casting. Tribological properties of these composite materials were investigated by wearing on a pin-on-disc wear test rig at dry conditions [11]. Mechanical properties were investigated. The effects of reinforced materials on tribological and mechanical properties were investigated. In addition to that microstructures of these materials were investigated by optical and SEM, to evaluate the Tribological and hardness properties of composites significantly improved by the use of particle reinforced into LM25 alloy.

II. OBJECTIVES

From the extensive literature survey it has been found that, different processing techniques were employed in the manufacture of composites. Also it was found that many researchers have used Al_2O_3,Si,Gr,TiO_2 etc., as reinforcement in Aluminum based matrix which ensures enhancement of Microstructural, Mechanical and Tribological properties.The present investagition is carried out with the following objectives.

i. To synthesize the Al_2O_3 reinforced MMCs using liquid metallurgy stir casting technique, as this technique is versatile and economical.
ii. To use Aluminum oxide (Al_2O_3) Nano particles as reinforcement upto 3 wt% in step of 1 wt% .
iii. Evaluation of tensile and hardness behavior by using ASTM-E8 and ASTME10 test standards.
iv. Evaluation of wear behavior of base alloy LM25 and LM25- Al_2O_3 MMCs in ascast and composites by using ASTM-G99 testing standards.
v. To analyse the microstructure of the composite using SEM.

III. METHODOLOGY

Stir casting: Stir casting processing involves the addition of reinforcement particles into liquid aluminum melt which is further cooled due to solidification. Good wettability between the reinforcement particles and liquid melt plays an important role. To achieve this, the simple technique known as stir casting or vortex technique is employed.

Lloyd (1999) reports that vortex-mixing technique for the preparation of ceramic particle dispersed aluminum matrix composites was originally developed by Surappa & Rohatgi (1981) at the Indian Institute of Science. Subsequently several aluminum companies further refined and modified the process which are currently employed to manufacture a variety of AMCs on commercial scale. Micro structural inhomogeneties can cause notably particle agglomeration and sedimentation in the melt and subsequently during solidification. Inhomogeneity in reinforcement distribution in these cast composites could also be a problem as a result of interaction between suspended ceramic particles and moving solid-liquid interface during solidification. Generally it is possible to incorporate up to 30% ceramic particles in the size range 5 to 100 μmin a variety of molten aluminum alloys.

The melt–ceramic particle slurry may be transferred directly to a shaped mould prior to complete solidification or it may be allowed to solidify in billet or rod shape so that it can be reheated to the slurry form for further processing by technique such as die casting, and investment casting. The process is not suitable for the incorporation of sub-micron size ceramic particles or whiskers. Another variant of stir casting process is compo-casting. Here, ceramic particles are incorporated into the alloy in the semi solid state.

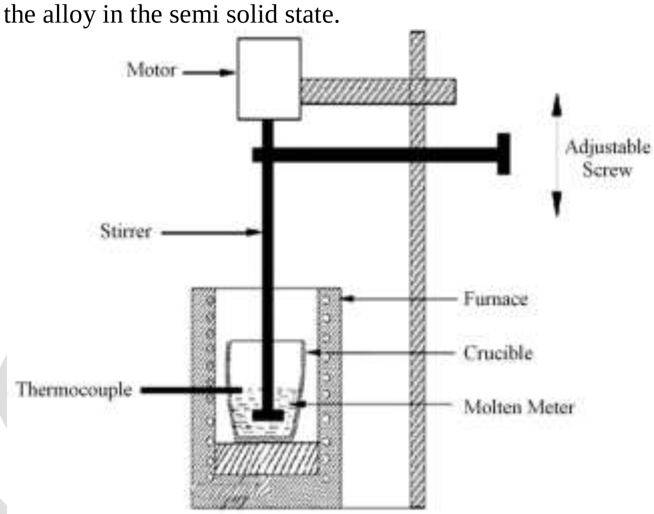

Fig 1.Stir casting assembly

IV. EXPERIMENTAL

In the preparation of MMCs, LM25 is used as base matrix material. The Al_2O_3 Nano particles are used as reinforcement up to 3 wt% in steps of 1 wt%. Table 1 shows the chemical composition of LM25.

Table 1.Chemical composition of LM25

Element	Si	Cu	Mg	Ni	Fe	Mn	Ti	Zn	Cr	Aluminum
Weight %	6.5-7.5	0.1	0.2-0.6	0.1	0.5	0.3	0.1	0.1	0.05	Balance

Table 2. Wt% ratio of reinforcement and their designation

Materials	Matrix	Reinforcement (Wt %)	Weight (gm)		Designation
			LM25	Al_2O_3	
Base alloy	LM25	-	1400	0	LM2500
MMCs	LM25	1	1560	15.60	LM2501
		2	1460	29.20	LM2502
		3	1680	50.04	LM2503

Table 3.Physical and Thermal properties of LM25

Density	2.7 gm/cm^3
Melting point	Approx 580^{0}C
Modulus of elasticity	70-80 GPa
Poisson’s ratio	0.33

Coefficient of thermal expansion	23.5×10^{-6} m/m.^{0}C
Thermal conductivity	173 W/m.K

Aluminum oxide Nano particles are used because of their excellent capability showed on the mechanical, electronic, magnetic and optical properties in comparison with their bulk counterparts [12]. It can be considered as one of the high-function materials, and can be widely used in catalyst, fine ceramics, complex materials, fluorescent materials, waterish sensor and infrared-absorb materials. Nanoparticles are being used more and more often in research and in industry due to their enhanced properties compared to bulk materials. The benefit of nanoparticles includes increased electrical conductivity, toughness and ductility and increased hardness and strength of metals and alloys. The Physical properties of Al_2O_3 are shown in table 4.

Table 4.Physical properties of Al_2O_3

Density	3.9 gm/cm^3
Melting point	2040^{0}C
Boiling point	2977 ^{0}C
Molar mass	101.96 gm/mol

The chemical properties of Al_2O_3 particles are as shown in table 5.

Table 5.Chemical properties of Al_2O_3

Commercial name	Al_2O_3
Appearance	White liquid
Crystal structure and type	Alpha
PH value	6-8
Original particle size	30 nm
Morphology	Spherical
Al_2O_3 purity	99.99%
Group	Aluminum 13, Oxygen 16

V. RESULTS AND DISCUSSIONS

A. Microstructure: The samples for microstructure examination were prepared by following standard metallurgical procedures, etched in etchant prepared using 90ml water, 4ml HF, 4ml H_2SO_4 and 2gm CrO_3 and were examined using Optical Microscope.

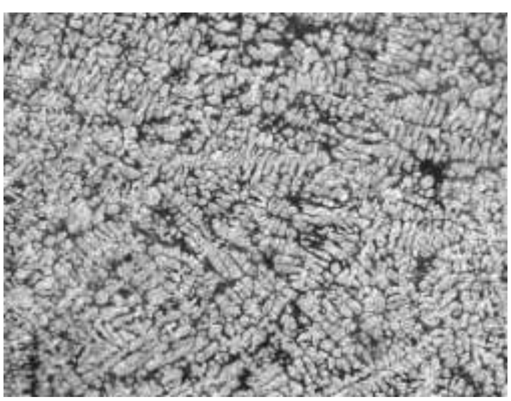

Fig 2.1(a)

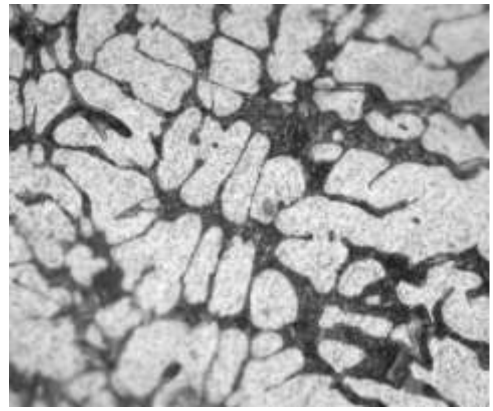

Fig 2.1(b)

Fig 2.1 (a) and (b) shows Microstructure of ascast LM2500 for 100x and 500x magnification Optical microstructure respectively (Keller's reagent), which clearly shows distribution of the primary dendrite alpha phase (Aluminum rich phase) which is predominant in the matrix.

It is observed that Microstructure consists of fine unmodified eutectic silicon needles dispersed in the matrix of dendrites of aluminum solid solution and fine precipitates of alloying elements dispersed in the matrix.

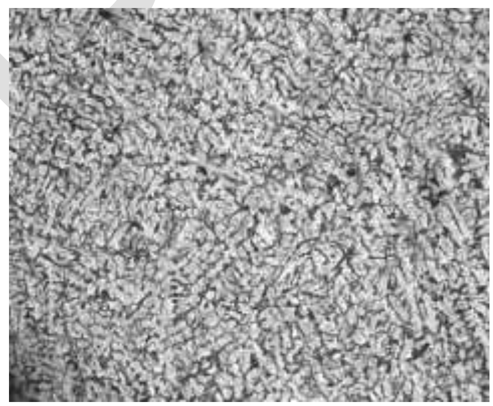

Fig 2.2(a)

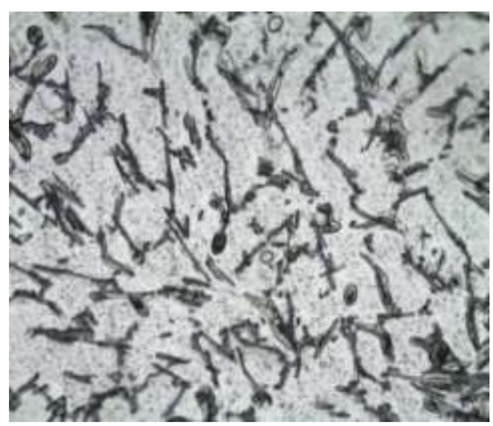

Fig 2.2(b)

Fig 2.2 (a) and (b) Microstructure of 100x and 500x magnification Optical microstructure respectively (Keller's reagent) of LM2501 composite.

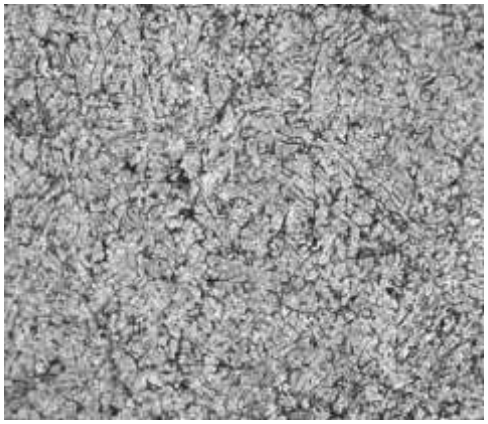

Fig 2.3(a)

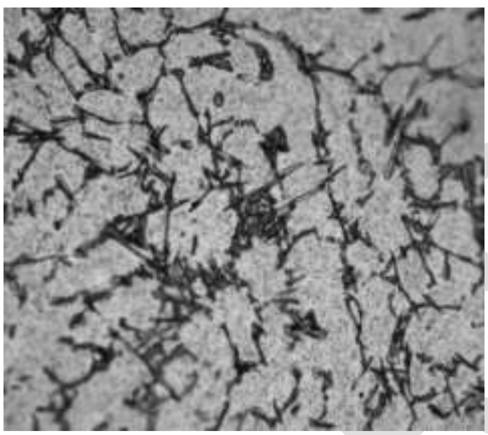

Fig 2.3(b)

Fig 2.3 (a) and (b) shows Microstructure of 100x and 500x magnification Optical microstructure respectively (Keller's reagent) of LM2502 composite.

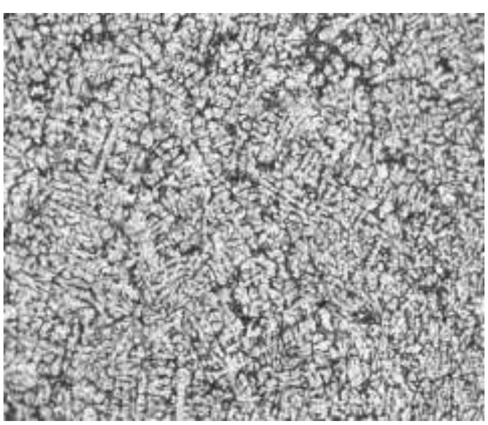

Fig 2.4(a)

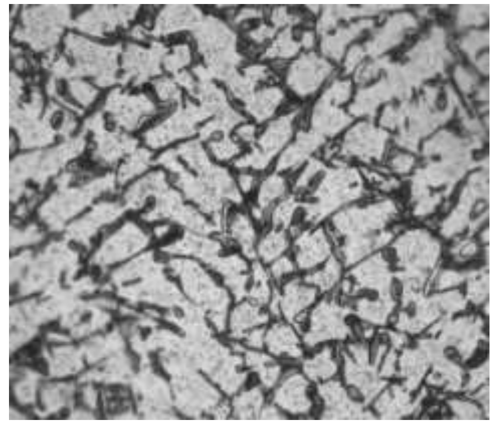

Fig 2.4(b)

Fig 2.4 (a) and (b) shows Microstructure of 100x and 500x magnification Optical microstructure respectively (Keller's reagent) of LM2503 composite.

B. Hardness test: The hardness tests were conducted as per ASTM E10 norms using Brinell Hardness tester. Tests were performed at randomly selected points on the surface by maintaining sufficient spacing between indentations and distance from the edge of the specimen.

Table 6.Hardness value of LM25 alloy and its composites

Sl no	Specimen designation	Hardness (BHN)
1	LM2500	62.8
2	LM2501	62.4
3	LM2502	72.9
4	LM2503	66.6

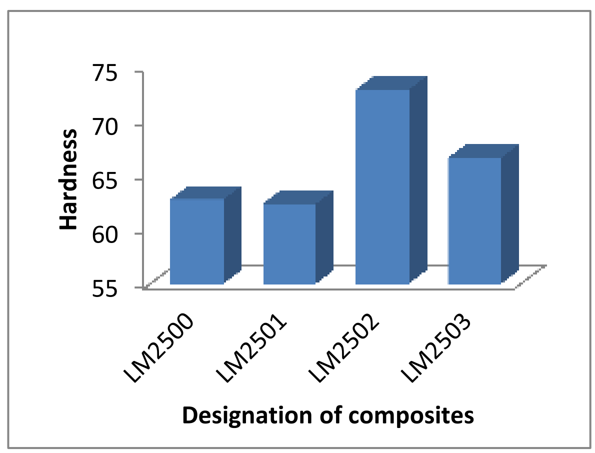

Fig 3.Hardness values of LM25 alloy and its composites

Remarks:

Hardness of the Al_2O_3 reinforced AMCs is found to be in line with literature survey.

C. Tension test: The tension test specimens machined as per ASTM E8 standards were tested at room temperature in a Universal Testing Machine. The mechanical properties such as YS (Yield strength), UTS (Ultimate tensile strength), and % Elongation (ductility) were obtained from the data acquisition system of the machine.

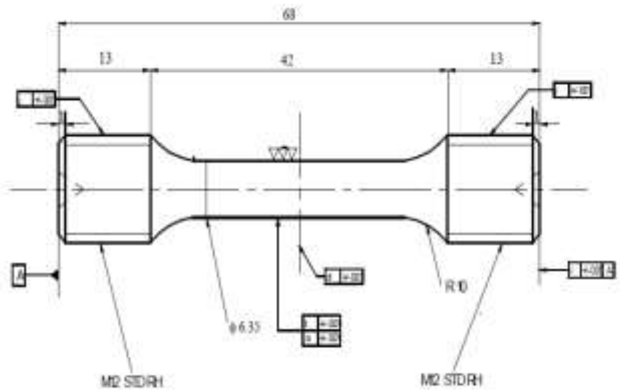

Fig 4a. Tension test ASTM E8 specimen sketch

The ultimate tensile strength obtained is as shown in table 7.

Table 7.UTS values of LM25 alloy and its composites

Specimen designation	UTS in MPa
LM2500	143.00
LM2501	141.64
LM2502	170.44
LM2503	144.40

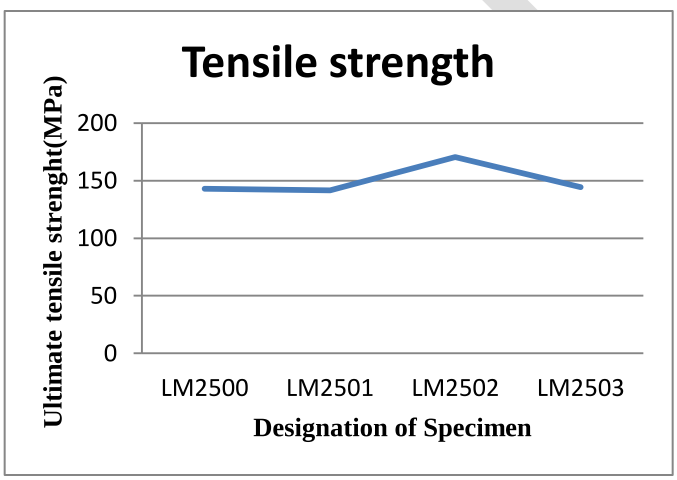

Fig 4b.UTS values of LM25 alloy and its composites

The % Elongation values obtained are as shown in table 8.

Table 8. % Elongation values of LM25 alloy and its composites

Designated Composite	% Elongation
LM2500	1.7
LM2501	3.43
LM2502	2.17
LM2503	1.5

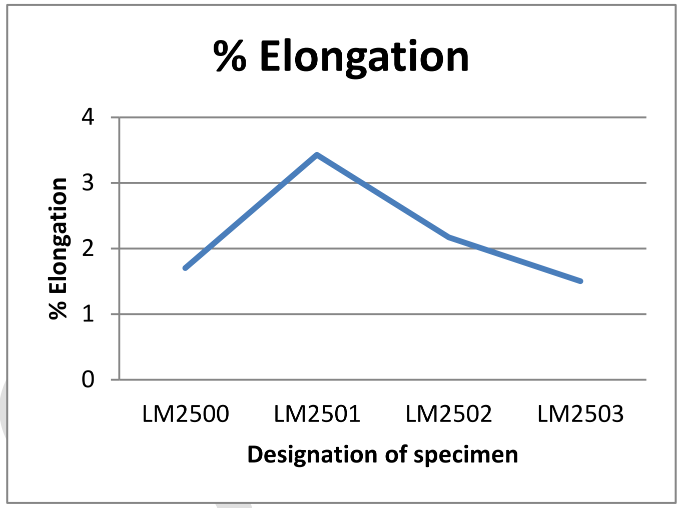

Fig 4c. % Elongation of LM25 alloy and its composites

Remarks:

i. The % elongation test for all 4 composites shows they are less than 5% .Thus indicating brittle in nature.

ii. It is also found that the variation (increase or decrease) in UTS and % of elongation properties is not linear which may be attributed to the problem of the dispersion of Al_2O_3 Nano particles into matrix material.

D. Wear test (Adhesive wear): Dry sliding wear tests were conducted as per ASTM-G99 norms using Pin-on-Disc machine driven by a D.C motor with counter face disc of the machine having diameter of 190 mm and thickness 30 mm. A pivoted steel lever supporting a loading pan on one end has a universal clutch provided at the other end to hold cylindrical specimen. The specimen presses against the counter face when weights are placed in the pan. The track radius of specimen was varied by sliding the support of the pivoted lever along the guide ways provided on the table top of machine. The pressure was varied by placing the load in Pan. A new specimen and freshly prepared counter face were used in every test. The wear rates of specimens were computed using weight loss method by dividing the weight lost in sliding by the sliding distance. Each specimen was weighed before and after every test using an electronic weighing machine to an accuracy of 0.0001gm. Each point on the graph represents one wear test result.

Fig 5a. Wear test specimen

Table 9.Wear test results of LM25 alloy and its composites

Composition designation	Percentage of weight loss for different speeds		
	100 rpm	200 rpm	300 rpm
LM2500	0.279	0.304	0.342
LM2501	0.242	0.259	0.267
LM2502	0.163	0.169	0.176
LM2503	0.137	0.149	0.15

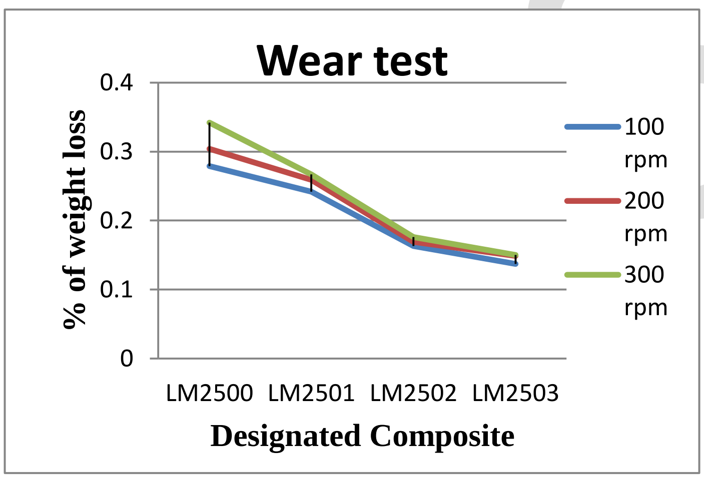

Fig 5b.Wear test results

Remarks:

The wear loss values of casting specimen shows the lowest weight loss occurred in reinforced Composite specimens. The highest wear loss occurred for pure Al specimen. Wear resistance of particle reinforced Al specimens was about 1.5–2 times (50–100%) better than that of pure specimen. Wear resistance has significantly improved with particle reinforcement.

E. SEM: In scanning electron microscopy (SEM) an electron beam is focused into a small Probe and is raftered across the surface of a specimen.

i. Several interactions with the sample that result in the emission of electrons or photons occur as the electrons penetrate the surface.
ii. These emitted particles can be collected with the appropriate detector to yield valuable information about the material.
iii. The most immediate result of observation in the scanning electron microscope is that it displays the shape of the sample.
iv. The resolution is determined by beam diameter.

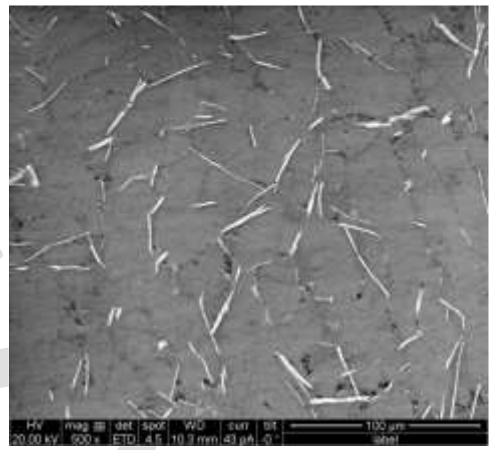

Fig 6a.SEM image of LM2500

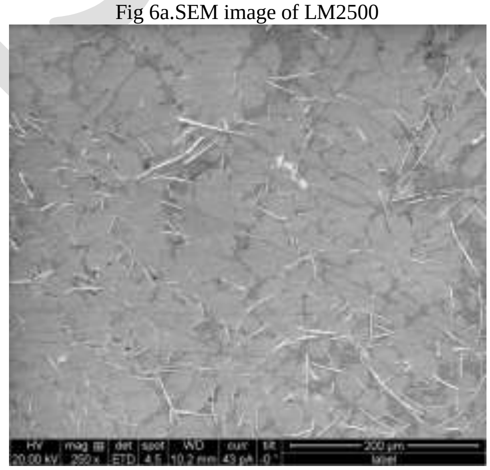

Fig 6b.SEM image of LM2500

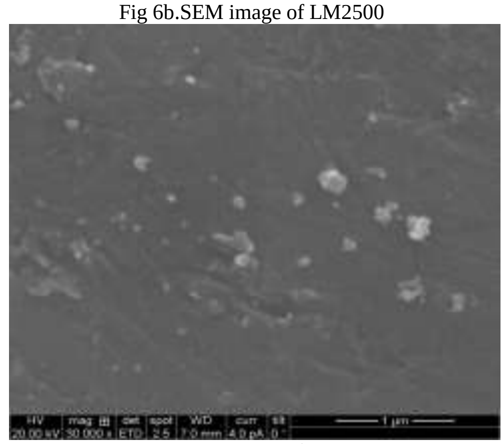

Fig 6c.SEM image of LM2501

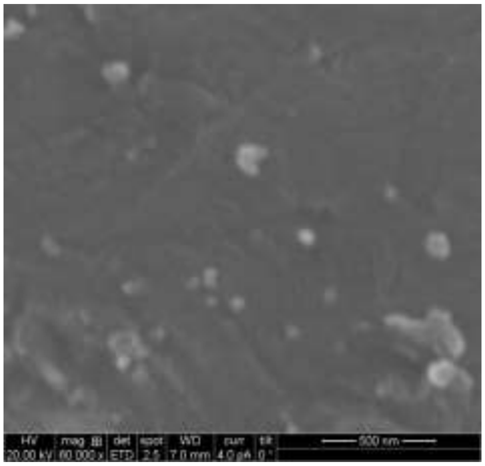

Fig 6d.SEM image of LM2501

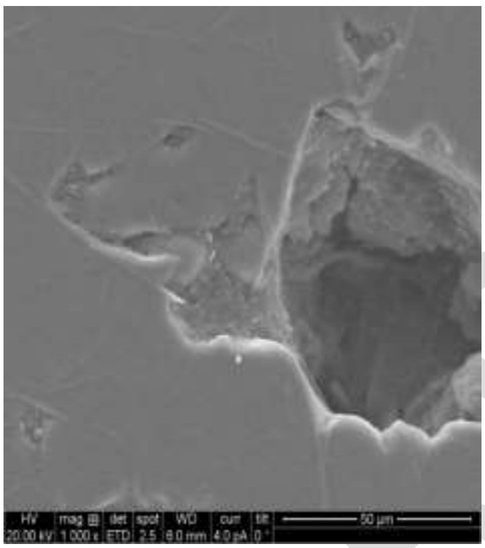

Fig 6e.SEM image of LM2502

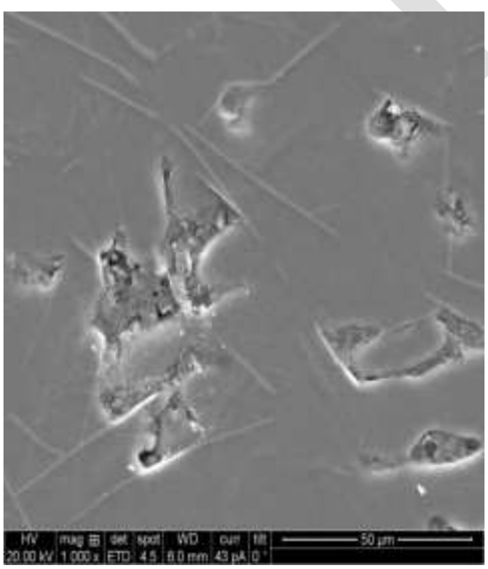

Fig 6f.SEM image of LM2502

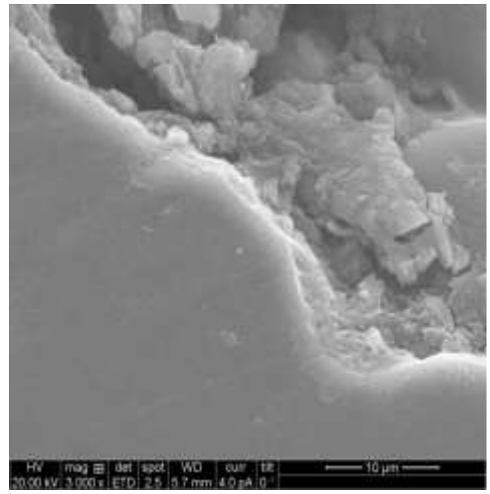

Fig 6g.SEM image of LM2503

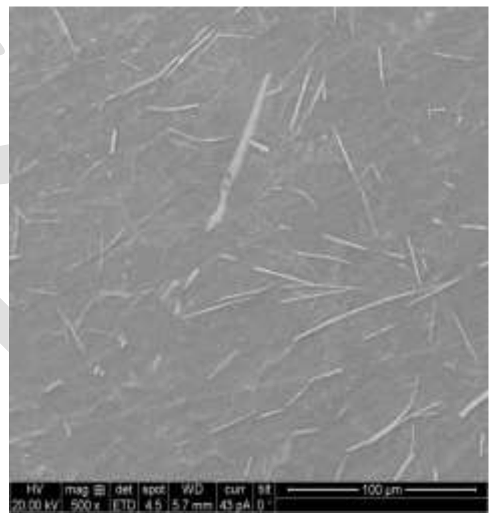

Fig 6h.SEM image of LM2503

VI. CONCLUSIONS

i. The SEM micrographs show good distribution of particles and very low agglomeration of alumina produced by stir casting method.
ii. The type of used processes for fabrication of composites in this research (stir casting) was an effective factor on the mechanical properties. Microstructure results showed the Good wettability of particles in stir casting process.
iii. The tendency of decrease in strength and hardness is observed up to 2 wt% reinforcement particles, and further increase in Al_2O_3 (3 wt%) content leads to the reduction in mentioned values.

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