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Characterization and Property Evolution of A356.1 Aluminium Alloy Reinforced With MgO Nanoparticle

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***Abstract*— Aluminum matrix composites (AMCs) reinforced with Nano-sized MgO particles are widely used for high performance applications such as automotive, military, aerospace and electricity industries because of their improved physical and mechanical properties. In this research, Magnesium Oxide (MgO) Nano particles were synthesized by Solution Combustion Synthesis process. The Nano particles were characterized by Powder X-ray diffraction (PXRD) and Transmission Electron Microscopy (TEM). A356.1 Aluminium alloy was reinforced with 0.5, 1.0, 1.5 and 2.0 Wt.% of the Synthesized Magnesium Oxide Nanoparticle, via stir casting Technique. The composites were then characterized by scanning electron microscopy (SEM). Hardness and Wear tests were carried out at Varying Wt. % ratios with varying Conditions of Speed, Load and Time. The results reveal that the Nano Metal Matrix Composite (NMMC)'s containing 2.0 Wt.% reinforcement particle has improved mechanical properties.**

Keywords*— Nano Metal Matrix Composite, MgO/A356.1 Composite, SEM

1.INTRODUCTION

The attention of material scientists and engineers has shifted from monolithic materials to composite materials for the development of light weight, environment friendly and high performance appliances.As aerospace technology continues to advance, there is a rapidly increasing demand for advanced materials with high mechanical and thermal capabilities for such ultra high applications [1]. Its application also stretched to automobile, electronic and computer industries to replace the existing materials including plastics [2].The early 1990s are considered to be the renaissance for Aluminium as structural material due to environmental concerns, increasing safety and comfort levels .A significant improvement in the properties of Aluminium alloys, reduced fuel consumption because of light weight has made huge demand from automobile industry [3,4]. This growing requirements of materials with high specific mechanical properties with weight savings has fueled significant research activities in recent times targeted primarily for further development of Aluminium based composites[5–7]. A recent industrial review revealed that there are hundreds of components from structural to engine in which Aluminum alloy is being developed for variety of applications [8]. It is also predicted that for Aluminium alloys demand increased globally attain average rate of 20% every year [9]. It is noticed that the limited mechanical properties (strength and hardness) of Aluminium and its alloys adversely affect its applications in automobile and aerospace industries [10,11]. This remains one of the major concerns in its fabrication to suit its application in recent days. Search of open literature indicates that for number of Aluminium based MMCs(Metal Matrix Composites) including chilled MMCs [12–15] are being developed but no work has been done in this field. Hence the present research is undertaken to fill the void and to investigate the integrated properties of A356.1alloy/MgO NMMCs(Nano Metal Matrix Composite). Among all the reinforcements used in Aluminium based composites only Nano-size particulates has shown their potential superiority in improving mechanical properties, such as wear, hardness and microstructure with noticeable weight savings [16].

Liquid metallurgy technique is one of the most economical of all the available routes for Nano metal–matrix composite production and generally can be classified into four categories: pressure infiltration, stir casting, spray deposition and in situ processing [17]. Compared to other routes, melt stirring process has some important advantages ,e.g., the wide selection of materials, better matrix–reinforcement bonding, easier control of matrix structure, simple and inexpensive processing, flexibility and applicability to large quantity production and excellent productivity for near-net shaped components[18]. However, there are some problems associated with stir casting of AMCs such as: poor wettability and heterogeneous distribution of the reinforcement material. Poor wettability of reinforcement in the melt means that the molten matrix cannot wet the surface of reinforcement particles. Therefore, when the reinforcement particles are added into the molten matrix, they float on the melt surface. This is due to the surface tension, very large specific surface area and high interfacial energy of reinforcement particles, presence of oxide films on the melt surface and presence of a gas layer on the ceramic particle surface. Mechanical stirring can usually be applied in order to mix the particles into the melt, but when stirring stops, the particles tend to return to the surface. There are some methods to improve the wettability of the reinforcement particles within the molten matrix alloy, for example heat treatment of the particles before dispersion into the melt caused removal of the adsorbed gases from the particle surface [19]. Another problem is distributing of reinforcement particles uniformly in molten matrix.

When the particles were wetted in the metal melt, the particles will tend to sink or float to the molten melt due to the density differences between the reinforcement particles and the matrix alloy melt, so that the dispersion of the magnesium Nano particles is not uniform and the particles have high tendency for agglomeration and clustering. Mechanical Stirring is preferred. In addition to mechanical stirring, there are some other techniques for introducing particles into the matrix. One of them is injection of the particles with an inert carrier gas into the melt. It has been reported that the technique is helpful in improving the distribution of the reinforcement particles within the melt [20]. Wettability and distribution of reinforcement particles becomes more difficult when the particle size decreases to the Nano scales. This is due to the increasing surface area and surface energy of Nano particles which cause an increasing tendency for agglomeration of reinforcement particles. Moreover, several structural defects such as porosity, particle clusters, oxide inclusions and interfacial reactions arise from the unsatisfactory casting technology [21].

Primary aim of the present investigation is to fabricate A356.1 alloy based composite reinforced with magnesium Nano particle using stir casting technique at a speed of 100 rpm. The Nano metal matrix composites thus obtained were casted using Die cast technique and characterized for their micro structure, hardness and wear properties.

2. EXPERIMENTAL PROCEDURE

2.1. Materials

In the presence study, elemental composition of A356.1 Aluminum alloy Specimens are listed in the Table 1.These alloys were used as matrix material with the reinforcement of Magnesium Nano material with an average particle size of 80 nm and is reinforced using die casting method at the stirring rate of 100 rpm.

TABLE1.CHEMICAL COMPOSITION OF A356.1

Elements	*Al*	*Si*	*Fe*	*Cu*	*Mg*	*Mn*	*Zn*	*Ni*
Wt.%	*91.73*	*7.23*	*0.32*	*0.18*	*0.38*	*0.02*	*0.05*	*0.05*

2.2. Process

Magnesium Nano material was prepared using Combustion Synthesis method using a base material of Magnesium nitrate ($Mg(NO_3)_2$),with fuel as Crystal sugar ($C_6H_{12}O_6$).

A356.1 Aluminium alloy was reinforced with Magnesium Nano materials at different wt. % ratios (0.5,1.0,1.5,2.0) of samples.It was fabricated using a Resistance furnace equipped with a stirring system. Stirring process was carried out at constant speed of 100 rpm with a stirring duration of 15-30 min ,and at casting temperature of 850 ± 5º C.

Specification of the stirring process including the position of ceramic coated stirrer in the molten alloy,the size and the shape of the blades of ceramic stirrer and the rate of stirrer were adopted according to the result of the literature and the previous works[23,24-26]. Fig.1 Shows Schematic diagram of Stir Casting technique.

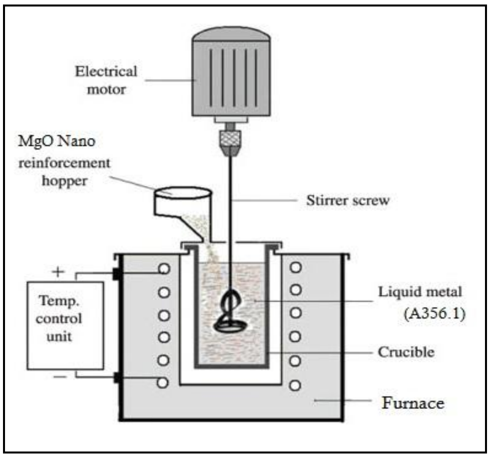

Fig.1. Schematic diagram of Stir Casting technique

Composite slurry was poured into the Cast Iron mould and samples were shaped in the form of cylindrical rod of 12 mm diameter and with the height of 170 mm.

To study the microstructure of the samples the specimens were grinded through 240 up to 2500 grit papers followed by polishing with 0.3μm Alumina paste, and etched with Keller's reagent. Microscopic examination were carried out using (SEM: JEOL, Japan, JSM 840A) Scanning electron microscope. To study the hardness variations in longitudinal sections of the cylindrical Nano composites, the specimens were prepared as per ASME G91 standard of dimension 12 x 8 mm cylindrical samples .The Brinell hardness values of the samples were measured on the polished sections (250 grit size papers), the hardness samples were measured on varying Wt.% reinforcements and at different temperature conditions, with a ball indenter diameter of 2.5 mm at a constant load of 187.5 Kgf. Each value of hardness for variation of Wt.% reinforcement and temperature conditions is reported with an average of at least five randomly obtained readings. For the evaluation of wear properties of the NMMC's the cylindrical samples were machined according to the ASTM G99 standards of dimension 30 x 8 mm. Wear test is carried out on a Pin-on-disc Tribometer. The disc is made up of high carbon EN31 steel having a hardness of HRC60.The radius of the sliding track on the disk surface was 100 mm, wear test were performed under dry sliding condition and with three different varying conditions of Load, Speed, Time.

3. RESULTS AND DISCUSSION

3.1. Synthesis of MgO Nano Material :

Magnesium Nano material was prepared by dissolving Magnesium nitrate ($Mg(NO_3)_2$) and Crystal sugar ($C_6H_{12}O_6$)(acts as Fuel) in distilled water , taken in a Ceramic(Silica) crucible. The crucible containing this solution was introduced into a muffle furnace maintained at a temperature 850 ± 5° C. The solution initially boils and undergoes dehydration followed by decomposition with the evolution of large amount of gases. The solution boiled resulting in a transparent gel. The gel then formed white foam, which expanded to fill the vessel. Shortly thereafter, the reaction was initiated somewhere in the interior and a flame appeared on the surface of the foam and proceeded rapidly throughout the entire volume, leaving a white powder with an extremely porous structure.

The entire combustion process for producing MgO powder takes place. The reaction for combustion synthesis in the present case can be written in equation (1)

$$MgO + C_6H_{12}O_6 + H_2O \rightarrow MgO + N_2 + 6CO + 7H_2O \quad (1)$$

3.2. Powder X-ray Diffractometer (PXRD) Studies**.**

The Powder X-ray diffraction studies were carried out using Phillips X-Ray Diffractometer (Model PW 3710) with Cu Kλ radiation (λ = 1.5405 A˚) The X-ray diffraction pattern of Nano-MgO powder confirms the crystalline phase and mean crystal size determined was around 80 nm. In the XRD observations three Strongest peaks shown in Fig.2 were detected with Miller indices(Intensity Values) of (80), (78), (102), and (50) corresponding to Bragg angles 22.48°, 30°, 42.74°and 62.298°respectively. The characteristic peaks higher in intensity indicates that the products are of good crystalline nature. No peaks corresponding to impurities are detected, showing that the final product is purely MgO Nano powder.

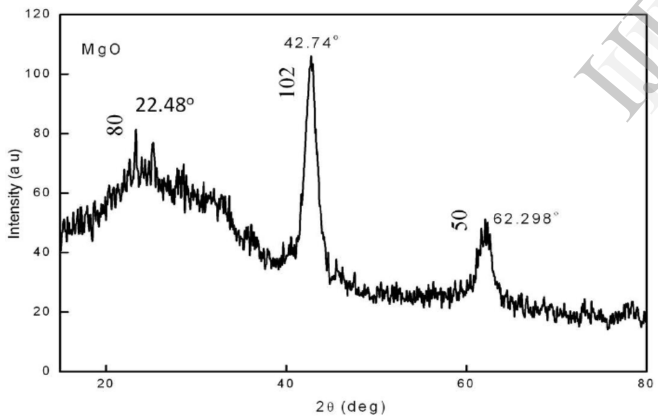

Fig.2. *PXRD pattern of MgO Nano powder fabricated at 850± 5°C*

It is observed that intensity of the peaks increases with thermal treatment due to Agglomeration, which means that the crystalline structure has been improved. The full width at half maxima of major peaks decrease and confirms the grain size growth.

3.3. Micro structural Studies

Micro structural studies were conducted to determine the presence and the distribution of reinforcement and interfacial integrity between matrix and reinforcement.

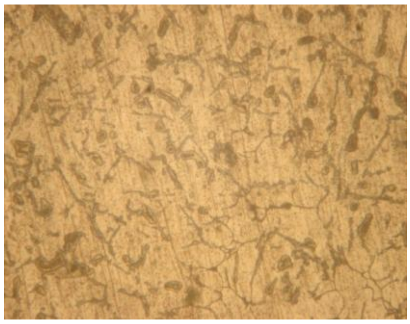

Fig.3. Optical microstructure of metal mould casted NMMC *containing 2.0wt.% of reinforcement at 200X Magnification*

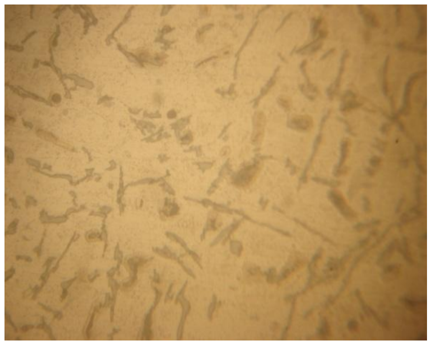

Fig.4. Optical microstructure of metal mould casted NMMC containing 2.0wt% of reinforcement at 400X Magnification

3.4.Hardness Studies

Hardness is the measure of a material's resistance to surface indentation, also it is a function of the stress required to produce some specific types of surface deformation. The Hardness test were performed with a Brinell Hardness Tester with a load of 187.5Kgf and with a Ball Indenter Diameter of 2.5mm. The influence of Magnesium Nano particle content on the hardness of various Wt. % reinforcements (0.5,1.0, 1.5, 2.0) for varying temperature and T6[29,30] condition of heat treatment is depicted in the Fig.5and Fig.6.

The Fig.6 shows that the Hardness Number (BHN) for As cast A356.1 Aluminium alloy at room temperature (28^0 C) is 73.61, then hardness gradually increases to 89.97 at 540^0C for As cast material, after heat treatment. Similarly the Hardness Number for 2 Wt.% reinforced A356.1 Aluminium alloy at room temperature (28^0 C) is 79.53 and for the same condition Hardness Number increases to 98.41 at 540 ^{0}C after heat treatment.

3.5. Wear Analysis

Wear test was conducted employing a Pin-on-Disc Tribometer as shown schematically in Fig.7 .Most requirements of the ASTM G99 standard on Wear Testing were followed. However, substantial modifications were considered, mainly regarding the Pin shape. Cylindrical Pins with dimension of 30 x 8 mm were made of the A356.1 Aluminium alloy reinforced with Magnesium Nano material at varying Wt.% ratios. A constant nominal area was maintained during the wear test. The counterpart disc was

made of high carbon EN31 steel having a hardness of HRC60. The radius of the sliding track on the disc surface was
100 mm. Before the wear test the surface of each Pin was ground using 240,320,400,600-grit SiC Abrasive papers. Wear testing was performed in a dry sliding condition for varying Wt.% ratios with varying speed, load and Time and varying sliding velocity. All worn-out Pins were cleaned in Acetone and weighed to an accuracy of ±1mg prior to testing. Wear rate and Wear weight loss was determined.

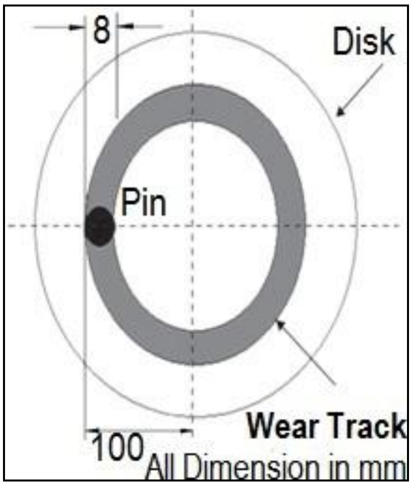

Fig.7. Schematic configuration of Wear Test

To investigate the size effect of reinforcing particulates reinforced with Nano sized Magnesium particles. Fig.8 shows the wear values for all specimens under applied load of 30N.It is generally believed contribution of Nano particles With Aluminium alloy increases the wear resistance of base alloy to great extent [27,28].Based on the results reinforcement of Nano particle into the base alloy, Wear rate gradually decreases with increasing reinforcement content (0.5,1.0,1.5,2.0%), as seen from the Fig.8 the wear loss for As cast A356.1 Aluminium alloy at a sliding distance of 314.15m and at a speed of 100rpm is 0.023g. By increasing the reinforcement to 2.0 Wt.% of Nano particles wear loss decreases to 0.007g for same speed and sliding distance. Similarly, for As cast A356.1 Aluminium Alloy for a sliding distance of 1570.79 m and at a speed of 500 rpm and load of 30N wear loss is 0.172 g and for same load and speed condition wear loss value decreases with the reinforcement of Nano particles to 0.122g.

One side of the sample were put in contact with rotating disc at Different Loading Conditions(10,20,30,40,50N respectively).The Fig.9 depicts a graph for Wear rate Vs load for As cast and different varying Wt. % of Magnesium Nano Metal Matrix composite(NMMC).It is seen that for A356.1 Aluminium alloy reinforced with 2.0 Wt.% of Magnesium Nano particles shows better wear rate compared to As cast and other Wt. % NMMC's .The Fig.9 shows when a Load at 10N the wear rate is $47.74x10^{-6}$g/m for As cast A356.1 Aluminium alloy, and for the same Load 2.0 Wt. % of Magnesium Nano particle added to the base alloy shows decrease in wear rate by$15.91x10^{-6}$g/m. Wear rate is severe in the region where the Nano particles were not present. Similarly, the graph shows when Load is at 50N ,the wear rate is $95.49x10^{-6}$g/m for As cast A356.1 Aluminium alloy, and for the same Load condition, 2.0 Wt. % of Magnesium Nano particle Reinforced to the base alloy shows significantly decrease in wear rate by $38.19x10^{-6}$g/m.

Based on results, as shown in Fig.10, when speed increases, wear rate also increases. For As Cast alloy at the speed of 100 rpm, Wear rate is $73.21x10^{-6}$g/m and for the same speed with 2.0 Wt.% reinforcements of Nano particle to base alloy the wear rate decreases to $22.28x10^{-6}$g/m. For As Cast alloy at the speed of 500 rpm Wear rate is 109.49 $x10^{-6}$ g/m and for the same speed with 2 Wt. % reinforcements of Nano particle to base alloy, the wear rate considerably decreases to $77.66x10^{-6}$ g/m. Operating Time is proportional to Wear rate, as shown in the Fig.11.Based on the this graph, for As Cast alloy at the Operating time of 300sec,Wear rate is $81.70x10^{-6}$g/m and for the same time with 2.0 Wt. % reinforcements of Nano particle to base alloy the wear rate decreases to $43.50x10^{-6}$g/m. For As Cast alloy at Operating time of 1500 Sec, Wear rate is 207.96 $x10^{-6}$ g/m and for the same operating time with 2 Wt. % reinforcements of Nano particle to base alloy, the wear rate considerably decreases to $129.35x10^{-6}$g/m.

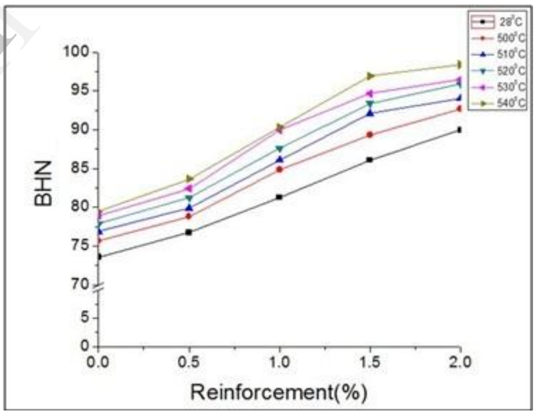

Fig.5. BHN Vs Wt. % Reinforcements at varying temperatures

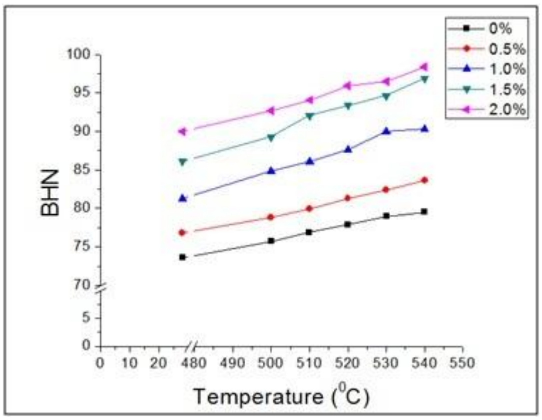

Fig.6.BHN Vs Temperature for Different Wt. % Reinforcements.

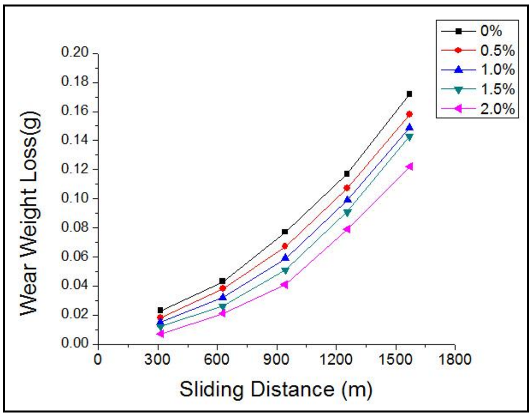

Fig.8.Wear Weight Loss Vs Sliding Distance for Different Wt. % Reinforcements for constant Load 30N and constant Time of 300 Sec.

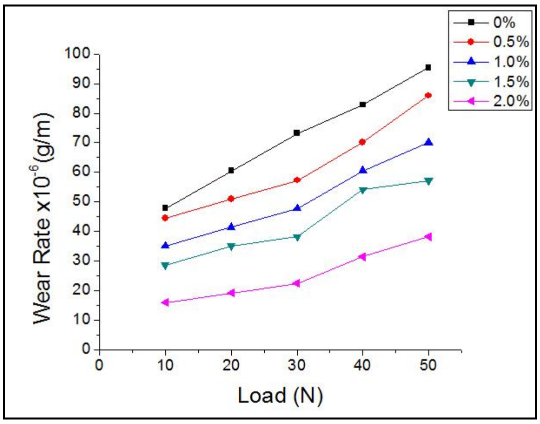

Fig.9.*Wear Rate Vs Load for Different Wt. % Reinforcements for constant Speed 300rpm and constant Time of 300 Sec*

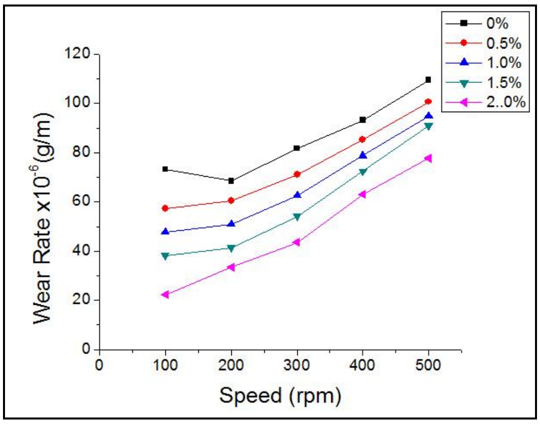

Fig.10.Wear Rate Vs Speed for Different Wt. % Reinforcements for constant Load 30N and Constant Time of 300 Sec

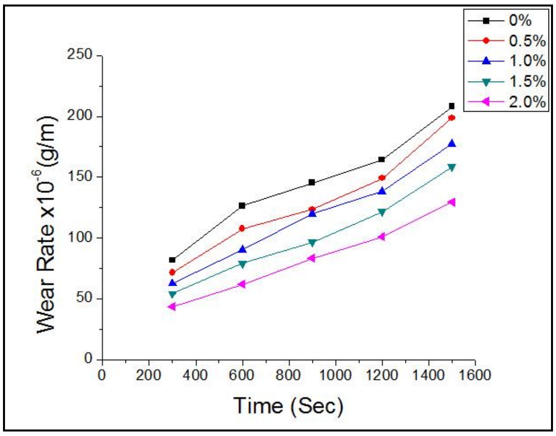

Fig.11.Wear Rate Vs Time for Different Wt. % Reinforcements for constant Load 30N and Constant Speed of *300rpm*

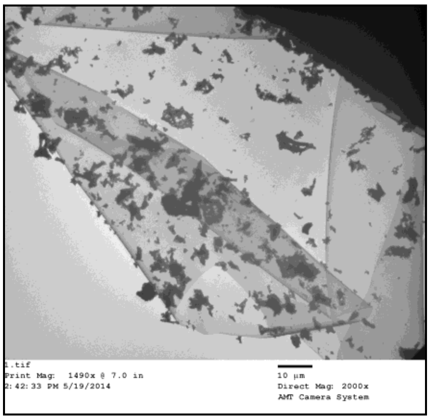

Fig.12.(a)

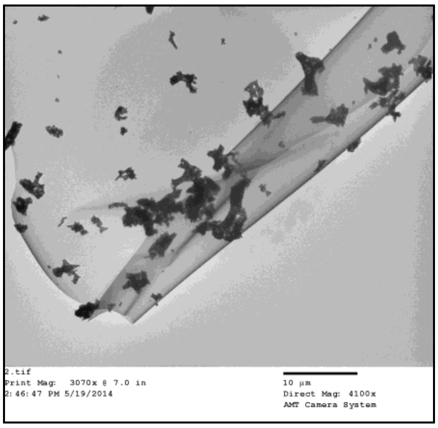

Fig.12.(b)

Fig.12. TEM images of MgO Nanoparticles under Magnification at (a)2000x (b) 4100x

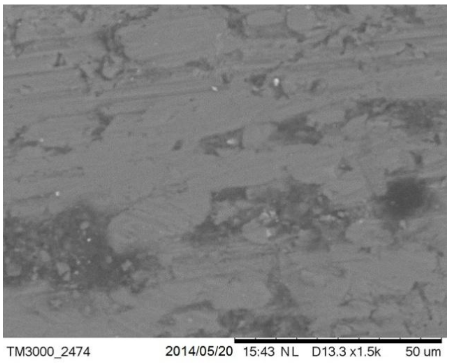

Fig.13.(a)

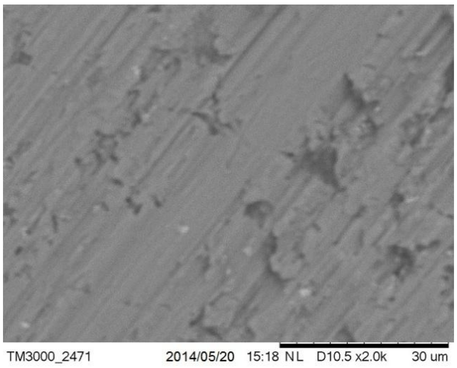

Fig.13.(b)

Fig.13.(c)

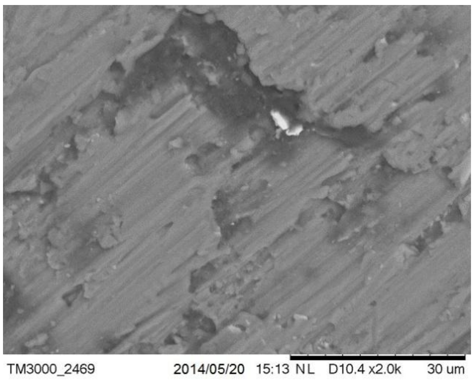

Fig.13.(d)

Fig.13.SEM Images of the A356.1 Aluminium Alloy reinforced with(a) 0.5 Wt.% of MgO Nanoparticles at *Magnification of 1500x(b) 0.5 Wt.% of MgO Nanoparticles at Magnification of 2000x(c) 2.0 Wt.% of MgO Nanoparticles at Magnification of 1500*x *(d)2.0 Wt.% of MgO Nanoparticles at Magnification of 2000*x.

4. CONCLUSION

In the current study A356.1 Aluminium alloy successfully reinforced with Magnesium Oxide NMMC's at varying Wt. % via Stir casting technique with the stirring speed of 100 rpm . To evaluate the effect of varying Wt. % reinforcement of Nano particles with the base alloy on mechanical properties of NMMC's ,the hardness ,Wear Test were carried out.

1. Solution combustion synthesis is suitable for preparation of Magnesium Nano particle at 850 ± 5º C
2. SEM micro graph indicated that Magnesium NMMC's particles are successfully reinforced with A356.1 Aluminium alloy and particles dispersed throughout the matrix.
3. Hardness of the Nano particle reinforced composites was higher than that of A356.1 Aluminium alloy, with increasing the Weight % of Nano particle hardness is consistently increased , result reveals that 2.0Wt.% of reinforcement content shows increased hardness compared to other reinforcements.
4. Wear resistance of the composite was found to be considerably higher than that of matrix alloy increased with increase Nano particle content. The hard particles resist against destruction action of the abrasive and the protect the surface. So, with increase with the Nano content the wear resistance enhances. By increasing the reinforcement content of 2.0 Wt.%

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