Effect of ceramic reinforced Al-3Mg composite fabricated by stir-casting and wear behavior

Jayatirtha M Patil [1], Mahendra K V [2], Mohan kumar T S [1]

[1]Assistant Professor, Dept. of Mechanical Engineering, JIT Bengaluru-560082, affiliated to VTU Belagavi, Karnataka, India.

[2] Principal, RRIT Bengaluru-560090, affiliated to VTU Belagavi, Karnataka, India.

Corresponding Author: pmjayatirtha@gmail.com

Abstract: - The current research gives an insight on Al-3Mg, Silicon carbide, and graphite composite on wear behavior under dry sliding atmosphere. The stir-casting method is cost-effective way of producing composites was adopted. The ceramic reinforcement components like silicon carbide and graphite were added to Al-3Mg from 2-8 Wt. % with an increase in the step of 2wt. % to quantify its potential as better hardness & self-lubricating reinforcement in a dry sliding condition. Desired properties like the hardness of as-cast, density, tensile strength, the volume loss of specimen due to wear were evaluated. A wear test was performed on a pin-on-disc wear test rig to evaluate the tribology behavior of composites to establish the optimum wt. % of graphite for least wear rate. The experimental results of the dry wear test reveal that with the addition of graphite, wear resistance was initially enhanced and descending further with 8wt. % of graphite particulates. The tensile strength & hardness of the hybrid metal matrix composites (HMMC's) found to be slightly decreasing with an increase in Graphite 6wt. %. The microstructure was analyzed using SEM. The inclusion of 6wt. % graphite composite leads to lower wear rate when compared to the base alloy.

Key Words: — ***Al-3Mg, Ceramic, Stir-casting, Hybrid Metal Matrix Composites (HMMC's).***

I. INTRODUCTION

Aluminum Metal Matrix composites are tailor-made to meet the challenges of Industrial/commercial application, due to their good combination of excellent corrosive/wear resistance properties. Sharma et.al.-1999 In recent times, ceramic-reinforced alloys (MMCs) have found a promising future for both the academic community and the industrial sector.[1] G. F. V. Voort et.al.-20O9 conclude that Aluminum is preferred as a material system due to its lightweight, higher strength, higher temperature, receptivity in surplus, ease of composition, and competitive cost.[2] M. Nagaralet.al. 2018 from his research work that aluminum and its alloys elements are widely used as matrix composites for hybrid metal matrix composites. Silicon, Magnesium, Copper, Zinc, Manganese, etc. are some of the major blending constituents used with aluminum. [3] Lots of many smart ceramic materials such as SiC, graphite, boron carbide, Zirconia, Alumina are often used as reinforcing materials for the aluminum matrix. G. B. V. Kumar et.al.- 2012 concluded that in the process of the production of metal-matrix elements, silicon carbide (SiC) improves energy structures such as hardness, strength, durability, wear, corrosion resistance, fatigue health, and high temperatures.[4] Most Hybrid Metal Matrix Composites (HMMC's) are engineered materials that are made by combining two or more dissimilar materials (at least one of which is a metal) to achieve improved characteristics. Mahendra K V et.al.-2015 analyzed casting is being considered to be an essential technology for producing composites in the automotive industry due to its low cost.[5] J.V.Mohanachari- 2018 revealed by his research, a composite is a combination of two or more different materials with different structures to produce new components of tailored properties. When two or more compact elements are combined to form a cohesive whole, some of the characteristics of each component are usually included.[6] U. K. Annigeri et.al. - 2017 discloses that Stir casting process is more economical technique used to produce a particulate reinforced aluminum metal matrix composites (PMMC). K Ananda Babu et.al.- 2018 give out from their research work that SiC certainly improves composite

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strength as well as corrosion and wear resistance.[8] Jaswinder SINGH, et.al. - 2016 it has been pointed out in his article that in the use of liquid metal, the agglomeration of solid particulates and the wettability of molten matrix alloy is a major problem. The additions of SiC particulates to Al composite enhance mechanical strength and wear properties. Graphite particles contribute to the formation of a thick and diffused layer of the coating surface. Under certain conditions, this layer reduces direct contact between the rubbing surfaces, reducing the wear rate. A set of Isotropic properties can be obtained by successfully installing a hybrid reinforcement in the Al matrix employing a liquid extract.[9] S. Balasivanandha Prabu et.al.- 2006 concludes with his in-depth study that stirrer speed and time provided a better hardness of MMC integration compared to the as-cast situation. The best hardness concentration obtained from 600 rpm and 10 min stimulate the processing time.[10] Prashant S N et.al. - 2012 observed that the hardness of Al6061-SiC composite increases with increased wt. % of reinforcement while in Al6061- Graphite composite the hardness decreases with increasing wt. % of reinforcement. After evaluating SiC and Graphite composites, it can be seen that SiC reinforced composites exhibit wt. % of Reinforcement better wear resistance properties than that of Graphite reinforced composites.[11] M.Nagaral et.al. - 2014 Loss of volume wear is governed by load and delivery speed. The increase in loads and the speed of delivery lead to a significant increase in wear loss.[12] Increasing the speed reduces wear by supporting the machine-bound tribology layer and increasing load increases wear by reducing the role of the tribology layer. Wear increases due to sliding distance and is a prominent feature that affects the wear of both combinations. the best stabilization of about 7.5% than any faster distance, delivery, and loading speed within the range observed in the investigation.[13]

The present article is aimed at fabrication of Al-3Mg alloy – 3wt. % of Sic & 0-8 wt. % of graphite addition in steps of 2wt. % of Gr. particulates produced by stir-casting technique. 2wt. % of Magnesium was added to improve the wettability of the hybrid metal matrix composites. Al-3Mg composite compositions are also intended to test the wear properties of composites at different loads and wt. % Graphite composite. The hybrid metal matrix composite produced having good ductile properties can help forming processes like extrusion, rolling which can have control on production cost and commercialized.

II. MATERIALS AND METHODS

A. Materials

A combination of Aluminum & Magnesium alloy "Al-3Mg" with a theoretical density of 2660 kg / m3 is used as the matrix, while graphite particle size 30 to 150 µm, density 2200 kg / m3 in combination with silicon carbide particulate size ranging from 100 to 200 µm. and a maximum of 3210 kg / m3 used as reinforcement. The chemical composition of the matrix is shown in Table 1, determined using the atom-absorbing spectrometry from Ragavendra laboratory, Bangalore. Silicon carbide particle with an average size of 150 µm and Graphite particles with a size of 125 µm were varied in the ratio of 2 to 8wt. % as secondary particulates in the preparation of HMMC's.

Table.1. Chemical Composition of Al-3 Mg alloy

Constituents	Si	Cu	Fe	Mn	Mg
% by weight	0.04	0.01	0.14	< 0.01	3.21
Constituents	Cr	Ti	V	Zn	Al
% by weight	0.02	0.02	0.01	< 0.02	Balance

B. Methodology

The Al-3Mg reinforced with SiC & Gr hybrid metal matrix composites have been produced by liquid gravity die casting method mounted with stirring attachment and auto cut-off arrangement. A stirrer attachment is enclosed with a three-phase induction motor along with a speed controlling device. The distribution of reinforcement constituents uniformly in the molten matrix is a challenging task. [9] To start with, the calculated Al-3Mg matrix material is weighed on a digital weighing machine and charged in a graphite crucible, and superheated around 780 °C in a resistance electric furnace with gravity pouring arrangement. The furnace temperature was controlled to an accuracy of + 25 °C using a digital temperature controller. Once the desired temperature is attained, Hexachloroethane tablets were added for degassing of the molten metal mixture to evacuate trapped gases. The calculated weight of the reinforcement was weighted using a digital weighing machine with an accuracy of 0.001 grams, in aluminum foil. The reinforcement constituents SiC and Gr. are free from moisture by heating arrangement around 400 °C to enhance the wettability for uniform dispersion of the reinforcement particulates in the matrix. The rapped aluminum foil along with the reinforcement was plunged into the molten metal and stirred with a mechanical stirrer coated with zirconium for a fine vortex around 8 minutes at a speed of 500 rpm to avoid agglomeration. The melt was gravity die-casted at 760°C having dimension 200mm length x ϕ25, ϕ50 & ϕ75mm preheated cast-iron mold as shown in fig. 1(a) respectively. The stir casted composites were obtained successfully for different wt. % of graphite particulates keeping SiC as constant as depicted in the fig. 1(b).

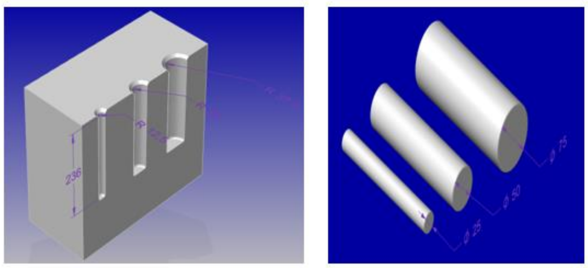

Fig.1 (a) Fig. 1(b)

Fig.1. (a) Die casting mold arrangement for Al-3Mg composite castings for ϕ 25, ϕ 50, ϕ 75 mm. (b) Al-3Mg/SiC/Gr. Stir casting specimens

III. RESULTS AND DISCUSSION

A. Density

The theoretical density of the composite was calculated using a rule of mixture. The density of base alloy, SiC, and graphite were found to be 2.66 g/cc, 3.21 g/cc, and 2.2 g/cc respectively.

The experimental density of the base alloy and composites of HMMC's were calculated by the principles of Archimedes. The density of composite specimens was measured by weighing them in air and known density fluid e.g. distilled water. The density of the alloy and the HMMC's was calculated from the eqn.1 as shown below.

$$\text{"}\rho\ \text{HMMC"} = \frac{\text{ma}}{(\text{ma}-\text{mw})} * \rho\text{w}[14] \qquad (1)$$

Where specimen mass is measured in the air as "ma", Sample mass is measured in distilled water as "mw" & "ρw" water density (998 kg/m3). The base alloy and composite sample's density were measured from the above equation. It was also seen that the density of the composite samples measured were found to be lesser than the density of the base alloy. The porosity of the composite was found to be minimum which is unavoidable in the process of casting.

$$\text{Porosity} = \frac{(\rho\text{th}-\rho\text{m})}{(\rho\text{th})} \qquad (2)$$

Where "ρth" as theoretical density, and "ρm" as measured composite specimen density. "ρth" the theoretical density is obtained by rule of mixture as shown in eqn. 3

$$\text{"}\rho\text{th"} = \rho\text{m}.\text{Vm} + \rho\text{r}.\text{Vr}[14] \qquad (3)$$

Where, the matrix density is "ρm", Vm the matrix volume fraction, "ρr", the reinforcement density and Vr the reinforcement volume fraction. The theoretical density for Al-3Mg/SiC/Gr. HMMC's using rule of mixture can be rewritten as

$$\text{"}\rho\text{th"} = \rho\text{Al}.\text{VAl} + \rho\text{Mg}.\text{VMg} + \rho\text{SiC}.\text{VSiC} + \rho\text{Gr}.\text{VGr}. \qquad (4)$$

Where "ρAl, ρMg, ρSiC, ρGr." are the density of matrix "Al, Mg", and density of reinforcement "SiC, Gr.", " VAl, VMg, VSiC, VGr.", the volume fraction of Al,Mg,SiC,Gr.

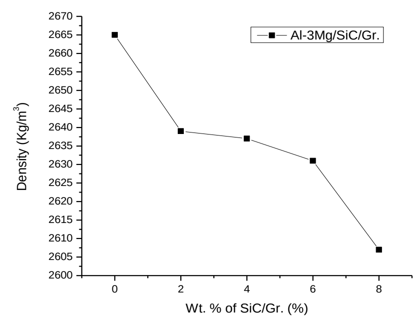

Fig.2. Density of hybrid metal matrix composite

The volume of Al is given by eqn. (5)

$$\text{"VAl"} = \left[\frac{(\text{WAl} / \rho\text{Al})}{\left(\left(\frac{\text{WAl}}{\rho\text{Al}}\right) + (\text{W Mg} / \rho\text{Mg})\right)}\right] \qquad (5)$$

Similarly, VMg. is calculated and the matrix Al-3Mg is substitute in eqn. 4 to obtain theoretical density respectively. Volume of Al-3Mg also can be obtained from the expression

$$\text{"VAl-3Mg"} = 1 - (\text{VSiC} + \text{VGr.}) \qquad (6)$$

Density of the Al3Mg composite has decreased with addition of reinforcement as shown in the Fig.2.

B. Tensile test

The Tensile Test of the as-cast sample was performed on UTM of 60 Ton capacity. The standard of ASTM E8 was adopted for producing the Al-3Mg composites specimens which are visualized in fig. 3(b), with the gauge length of 24mm and diameter of 6mm, and fillet radius of 6mm, with a speed across the head of 0.2 mm/min. The Tensile test results of the composite are shown in fig. 3(a) depicts that the increase in tensile strength with the addition of SiC & Gr composite as SiC being hard reinforcement which acts as an obstacle for the flow of dislocations, and descends further with the addition of 6wt. % Gr, as Gr. being soft material which acts as a lubricant hence the tensile strength decreases. As % of elongation being increased which improves the ductility of the material which plays a vital role in the secondary processing operations like roll forming and extrusion.

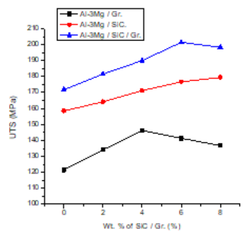

Fig. 3(a)

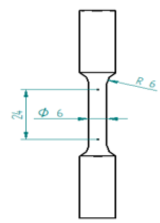

Fig. 3(b)

Fig.3. (a) Ultimate Tensile Strength of Al-3Mg /Gr., Al-3Mg / SiC, Al-3Mg / Gr. / SiC and 3(b) Specimen dimensions as per the ASTM E8 standard

C. Hardness test

The hardness test were carried out using Brinell's hardness testing machine, The BHN of base-alloy and composite specimens were measured, by using a ball indenter of 5mm, and considering the load 250Kgf, for a dwell time of 12 sec. Hardness base alloy and composite were measured at five different locations and the average was computed. The hardness results of Al-3Mg/SiC/Gr. HMMC's are shown in fig.4 reveals an increase in the hardness of composite with the addition of SiC and Gr to some extent hence further addition of Gr. i.e. 5 wt. % and more, hardness decreases due to Gr. particulate as Gr. being soft material which acts as a lubricant results in decrease in the hardness.

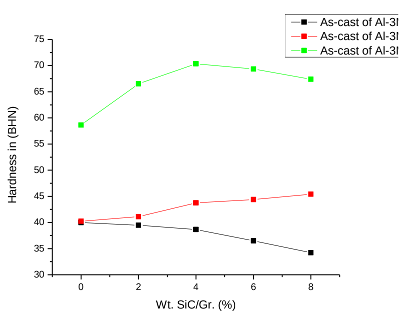

Fig.4. Hardness in BHN of as-cast of Al-3Mg / Gr, Al-3Mg /SiC, Al-3Mg / SiC / Gr.

The Scanning Electron Microscopy and Energy-Dispersive X-ray Spectroscopy reveals the microstructure of the tailor-made Al-3Mg and SiC/Gr. composite material contains the Al-3Mg dendrites and eutectic particulates of SiC and graphite. The stirring time, speed of the molten melt has a result of dendritic structure and addition of magnesium, which has enhanced distribution are reinforcement particulates in the matrix as seen in Fig 4(a) reveals the distribution of SiC and Gr. particles uniformly as observed in the matrix alloy. The presence of constituents is shown in energy-dispersive X-ray spectroscopy (EDX) images as depicted in fig 4(b).The presence of SiC particles is conformed to the compounds of Silicon and Carbon. The occurrence of graphite is observed as compound of carbon.

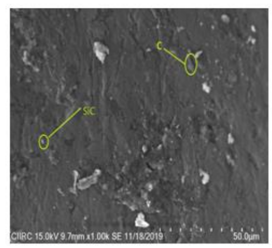

Fig 4(a)

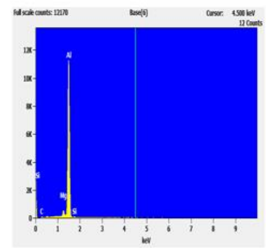

Fig 4(b)

Fig.4. (a) SEM image of the SiC/Gr. reinforced Al-3Mg and 4(b) percentage of constituents like SiC, Gr. present in the Composite as Al-3Mg(matrix)

IV. WEAR BEHAVIOR

The topic discussed relates to the investigation of sliding wear behavior without lubrication and its behavior of Al-3Mg/SiC/Gr composite tested as per ASTM G-99-95 standard procedure as shown in Fig. 5 (a). The testing was carried out on a computerized Pin-on-Disc wear test rig of Ducom make. The steel disc of 100 mm diameter made of EN-31 material with a hardness of HRC 60. The cylindrical specimen (ϕ 8mm x 30mm in length) was used for the wear testing at different normal loads i.e. 5, 10, 20 N by keeping the sliding speed of 450 rpm. Acetone was used for cleaning the wear track and the specimens during testing of composites. The weight loss of the sample was measured for every interval of 20 minutes for the sliding distance of 1500 m. We can reveal that from the figs 5b & fig 5c, the wear resistance decreased with the inclusion of Gr. and SiC in comparison with the base alloy and SiC reinforcement. It is observed that with addition of 3 wt. % of SiC & 8 wt. % graphite, it's found that the wear rate decreases and then increases because graphite acts as lubricant, with the rise in temperature the wear rate increases as it losses lubrication properties.

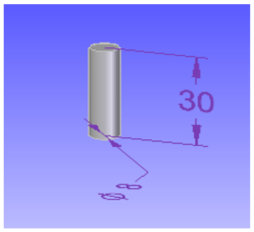

Fig. 5(a)

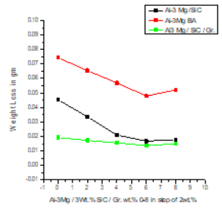

Fig. 5(b)

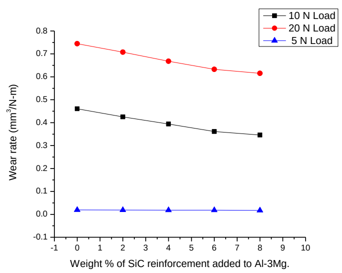

Fig.5(c)

Fig.5. (a) shows the wear specimen dimension as per ASTM G99-95 standard, 5(b) wt. % of Graphite as reinforcement in Al-3Mg. & 5(c) wt. % of SiC as reinforcement in Al-3Mg.

V. Conclusion

- The addition of constitutes like SiC / Gr. particulate in Al-3Mg by 2- 8 wt. % of Gr was successfully fabricated by liquid melt stirring technique.
- The hardness of the Al-3Mg HMMC's is increased with the addition of SiC & Gr. particulate and also seen that hardness descends beyond 8 wt. % of Gr.
- The addition of ceramic SiC & Gr. constituents in the Al-3Mg matrix enhances the composite's wear resistance up to 8 wt. % of Gr.
- The hardness of the hybrid metal matrix composite (with 3 wt. % of SiC and 4 wt. % of Gr) was increased by 54% when compared with the base alloy.
- The Tensile strength of the hybrid metal matrix composite (with 3 wt. % of SiC and 6 wt. % of Gr) was increased by 58% when compared with the base alloy.
- The wear rate of the hybrid metal matrix composite (with 3 wt. % of SiC and 6 wt. % of Gr) was decreased by 4% when compared with the base alloy.

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