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Development & Fabrication of AL-3Mg Based SiC & Gr. Hybrid Metal Matrix Composite by Stir Casting Method

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Abstract **Original Research Article**

The congregation of ceramic particulates in Aluminum hybrid metal matrix composites induces a greater significance in marine and automotive engineering applications because of its strength to weight ratio, good anti-corrosive properties, and high-temperature resistance. The research work focuses on the fabrication of hybrid metal matrix composite with influences of hard ceramic particulates like silicon carbide and dispersoid of graphite in Al-3Mg matrix material, and tribology behavior routed through the liquid metallurgical vortex method. The characterizations of conglomerate like, tensile properties, hardness, compression tests were investigated. The wear resistance increases with assorted graphite compositions. Microstructural examination shows the dispersoids of graphite and silicon carbides are uniformly distributed. The test results of Al-3Mg conglomerates reveal that tensile and hardness properties were enhanced with the addition of Gr. & SiC, as silicon carbide being a harder constituent mixed with a ductile matrix.

Keywords: Hybrid Metal Matrix Composites HMMC's, Silicon Carbide -SiC, Graphite-Gr., Al-3Mg.

1. NTRODUCTION

The overall performance of the day-to-day engineering applications has given significant demand for materials that possess better strength, are cost-effective, lightweight, competitive, meeting industrial & commercial requirements. Material weight reduction is one of the crucial areas of research that has groomed aluminum hybrid metal matrix composites commercially. Hybrid metal matrix composite (HMMC) is a homogenous metallurgical mixture of two or more metals as a matrix and by dispersing hard ceramic particulates as reinforcement in the matrix, towards achieving desired properties of strength and stiffness, etc. Stir casting process is cost effective and simple to fabricate the hybrid metal matrix composites [1]. The fabrication of aluminum hybrid metal matrix composite is the combination of the useful aspects of the reinforcement added to the matrix. The addition of hard particulates of silicon carbide in soft alloy of aluminum satisfactorily contributes to the hardness of the composite. [2]. Achieving good wettability among matrix and constituents of reinforcement particulates is a challenge, is a major concern [3]. Which can be achieved by adding 2 to 4 wt. % of magnesium in the molten metal. Uniform distribution of reinforcement within the matrix is one such challenge, which affects directly the properties and quality of composite material [4]. The density of the composite was found lesser than the base matrix. The porosity of the composite can't be avoided in the casting process i.e. should be minimized or negligible. The desired property of the composite can be achieved by reducing the pouring time of the molten composite for casting and cooling time.[3] The sliding end of the pin and the disc surface was cleaned with acetone before testing [5]. The thermal conductivity of ceramic particulates improves with temperature and decrease with increase of particle size [6]. It was noticed that the volume loss of the composite under dry wear test ,the wear resistance was increased significantly with the increase in SiC as reinforcement hard particulates of composites [7]. The difference between the theoretical and experimental density of each composite specimen was used to estimate porosity using equation (1).

$$\text{Porosity} = \frac{\text{Theoriotical Density} - \text{Expiremental Density}}{\text{Theoriotical Density}} \quad (1)$$

The investigation of the current research work is to fabricate an Al-3Mg conglomerate by augmenting dispersoids of silicon carbide and varying the weight fraction of graphite to the aluminum-magnesium matrix. The changes in mechanical characterization and microstructure for different compositions of graphite were recorded experimentally and analyzed. The finding of investigation helps society to commercialize material used as flooring in the form of sheets, the structure of shipbuilding, construction, automobile structures, components, and forming processes like rolling, extrusion, forging, etc.

2. EXPERIMENT PROCEDURE

Enhanced quality of the hybrid metal matrix composite being the main objective, resulting in distinct mechanical properties and microstructure. These variations in the properties are bound to the weight percentage of constituents mixed in the matrix, uniform distribution of the constituents, stirring time for molten metal by vortex method, pouring temperature of the molten composite, and cooling time after pouring.

2.1. Material selection

The fabrication of pre-factory hybrid metal matrix composites AL-3MG/SiC/Gr. incorporates ceramic particles like silicon carbide and graphite with aluminum-magnesium alloy. AA5754 and AA5154A alloys, containing 2.5 to 4 wt.%magnesium with minor additions of manganese or chromium, are widely used in construction, public works, transport, and mechanical industries [8]. The size of SiC particulates varies in the range of 100 to 200 µm with wt. % of 97.85 carbon and silicon as chemical compounds, an excellent abrasive material of high-quality technical grade ceramic possessing good mechanical properties. Graphite particulate has sizes varying between 30 to 100 µm and an immaculate of 93.63 by weight percent, has an ash content of lesser than 0.5% by weight with volatile combustible matter close to 6 % by weight. Heat treating SiC particulates forms surface oxides enhances wettability with molten matrix material hence SiC particulates were heated in an oven up to 800 °C for 8 hours to improve wettability [1]. The hybrid matrix material has aluminum as the main alloying element and 3.21 % of magnesium enhances the wettability and hardness of soft material Al, which can help the ceramic constituents to disperse uniformly in the matrix bearing load as a property of particulates in the matrix. To achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix alloy must be uniform, and the wettability or bonding between these substances should be optimized [4]. The casted rods from the vortex method are shown in Fig No.1 and Fig No.2 replicates the hybrid metal matrix composite Al-3Mg uniformly blend with SiC and Gr. in a graphite crucible liquefied at 760°C as pouring temperature. The increase in weight percentage of graphite particulates as reinforcement in the matrix alloy was in the step of 2% from 3 – 7% by weight and maintaining the weight percentage of Silicon carbide a 5 % in the molten matrix.

Fig-1: Al-3Mg/ SiC/Gr. in liquefied pouring temperature of 760 °C.

Fig-2: As-Casted rod for three different diameters 25, 50, 75mm

2.2 Design of as-cast workpiece

The Al-3Mg hybrid metal matrix composite reinforced with 3, 5, and 7 wt.% of graphite and 5 wt. % of SiC was fabricated by liquefied vortex method. The graphite was varied by different weight percentages in aluminum and was tested for three different diameters of the casting produced i.e ϕ25, ϕ50, and ϕ75mm. The current investigation is focused broadly on the fabrication and development of the bottom pouring technique for HMMC's of Al-3Mg with SiC and Gr. constituents. The demonstration of the bottom pouring resistance furnace used in the die-casting process of composite is shown in Fig.3. The furnace is equipped with a single-phase resistance heating element made of Nickel-Chromium with 1.5 kW to achieve the melting temperature around 1250 ^{0}C. The furnace is integrated with a hopper for preheating of constituents to avoid thermal distortion of the composite and adding the constituents in parallel while melting Al-3Mg matrix alloy. The stirring mechanism is actuated by a 3-phase induction motor of 0.25 HP integrated with a variable frequency drive for the different speeds of the stirrer. The motor is actuated with a timer unit for the stirring time, the stirrer blades are made of Nickel chromium steel with 5mm in thickness coated with zirconium for proper dispersion of the constituents in the matrix uniformly. The furnace is also equipped with a gate valve which is actuated i.e. open / close for bottom pouring of the composite for the time set in the trimmer after completing the stirring process after attaining pouring temperature.

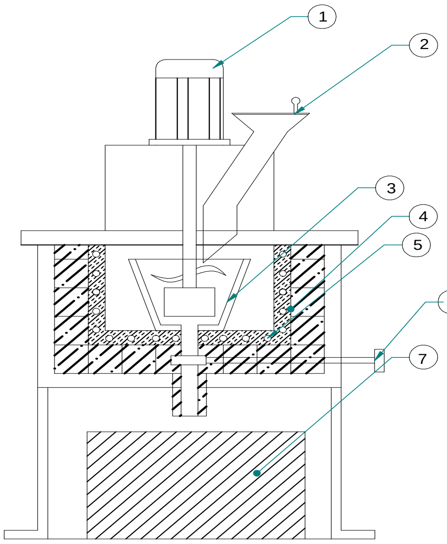

Fig-3: Schematic View of Gravity Feed setup for Fabrication of Composite

1. Motor Drive with Plunging and Stirrer attachment.
2. Hopper for adding reinforcement
3. Graphite Crucible
4. Heating element
5. Glass wool insulating material
6. Regulating steel valve
7. Casting die

The billets of Al-3Mg of size 30 x 30mm of weight 4 Kg were added to a graphite crucible and liquefied to 760 °C. in parallel the 5 % by weight of SiC and Gr. varied by 3, 5, and 7% by weight was pre-heated in owen at 250 °C. The stirrer coated with zirconium was preheated and immersed into liquefied alloy at 660 °C. The stirring speed was set at 350 rpm and the stirring time for 10 minutes. The blend of the liquefied molten metal was then poured into a pre-heated die cavity at 760 °C for three different diameters of 25, 50, and 75 mm. the dies were let for cooling naturally. The casting of Al-3Mg hybrid metal matrix composite was further used to prepare the specimens for Tensile, hardness, wear, Compression, density as per the ASTM standards.

2.3 The density of Al-3Mg composite

The density of the Al-3M hybrid metal matrix composite was calculated by the Archimedes method. The specimens were prepared as per the ASTM C20 87 standard and the density of Al-3Mg composite was calculated by immersing the specimens into a beaker containing 200cc of distilled water. The initial and final readings of the rise in the water level of the beaker were noted down. The density of the material is calculated with the difference of these readings by the Archimedes method experimentally. The density of the composite was further compared with the base alloy and analyzed.

2.4 Tensile test

The tensile specimen was prepared as per ASTM E8 standard for a micro tensile test specimen to analyze the effect of graphite and silicon reinforced in aluminum-magnesium composite for the as-casting of three different diameters. The specimens were prepared in an EDM wire cutting machine and tested further on a tabletop tensometer. The load of 10KN was applied with a cross-head speed of 2 mm/ min. three specimens of the same composition were carried and the average of all three values was considered to eliminate error.

2.5. Brinell Hardness Test

The hardness of Al-3Mg HMMC's specimens was measure using Brinell's hardness tester. The specimens were turned prepared as per ASTM E10 18 standard, a load of 250 Kgf was applied using a ball indenter of 5mm diameter at room temperature for a dwell time of 15 sec. The reinforcement constituents used in Al-3Mg composites, 5 % of SiC as constant by weight and varied graphite in the step of 2 wt. % i.e. 3, 5, and 7 % for three different diameters.

The average value of the hardness in each specimen was obtained by performing indentations at five different positions on the surface exposed.

2.6. Compression test

The compression strength of the Al-3Mg hybrid metal matrix composite was tested on a universal testing machine. The specimens were prepared as per ASTM E9 standard and tested at room temperature. The specimens were prepared from the same as-cast compositions used for testing similar properties as mentioned for three different diameters.

2.7. Wear test

The Tribometer from Ducom was used to analyze the wear of Al-3Mg hybrid metal matrix composite material. The specimens were machined to the standards of ASTM G99 and the dimensions for the specimen preparation are demonstrated in Fig No. 4. The non-lubricating dry sliding of wear test was performed for the track diameter of 70 mm with a travel time of 1200 sec, and the sliding distance of 1.64 m/sec. The disc is made of EN31 material rotating at speed of 450 revolutions per minute and loads of 5, 10, and 15 N were applied to check the wear of the composite.

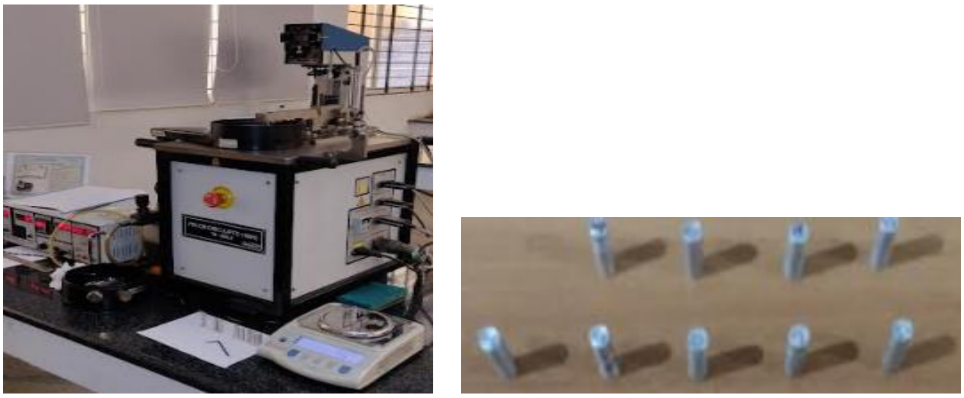

Fig-4: Specimens of Wear testing as Per ASTM G99 standard

2.8 Microstructure study

The microstructure of the Al-3Mg hybrid metal matrix and the reinforcement and their amalgamation were analyzed by scanning electron microscopic. The specimen of size ϕ 8 x 5 mm in cross-section including the wear-tested specimens were prepared by a standard metallographic procedure using a wire cut EDM machine and analyze under SEM. The Kelle agent solution was applied over the surface and buffed to a fine finish to study the microstructure of wear specimens.

3. RESULTS & DISCUSSION

3.1 Density

The theoretical and experimental density values of AL-3Mg hybrid metal matrix composite is demonstrated in fig No.4 and quantified based on the different weight fraction of the SiC and Gr. as reinforcement in Al-3Mg matrix material. The spikes of theoretical and experimental density from the graphs show the density for three as-cast diameters. It is observed that the experimental density of Al-3Mg hybrid metal matrix composite is less than the spikes of theoretical density in the current study which is of greater significance as compared with the previous experimental results. Literature citation. The density values are found to be high in the 25 mm diameter casting as compared to 75 mm diameter die casting specimens.

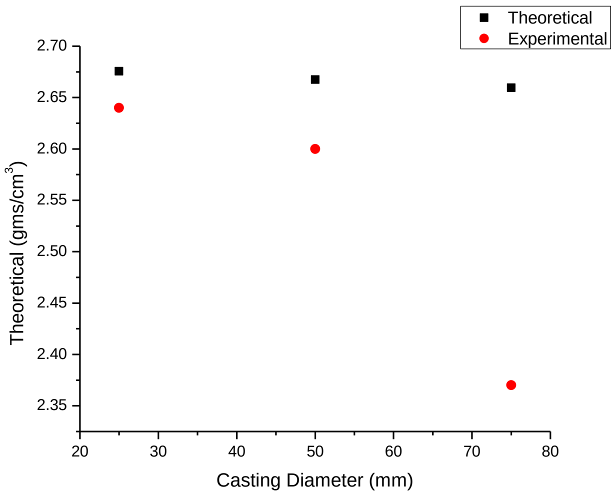

Fig-4: Theoretical and experimental density of Al-3Mg HMMC's

3.2 Tensile strength

The graph in fig No. 5 demonstrates the tensile strength of Al-3Mg hybrid metal matrix composite. The tensile strength of the as-cast rod was analyzed for three different diameters 25, 50 & 75mm. It can be observed from the graph shown in Fig. 5 that the tensile strength of the as-cast diameter 25mm is with an increasing trend in comparison with larger diameter rods with an increase in the weight percentage of SiC and Gr. It can also be seen as Gr. increased the tensile strength is slightly diminishing, as Gr. being a soft material introduced as reinforcement. The tensile strength has increased by 12% in comparison with the base alloy. Literature citation.

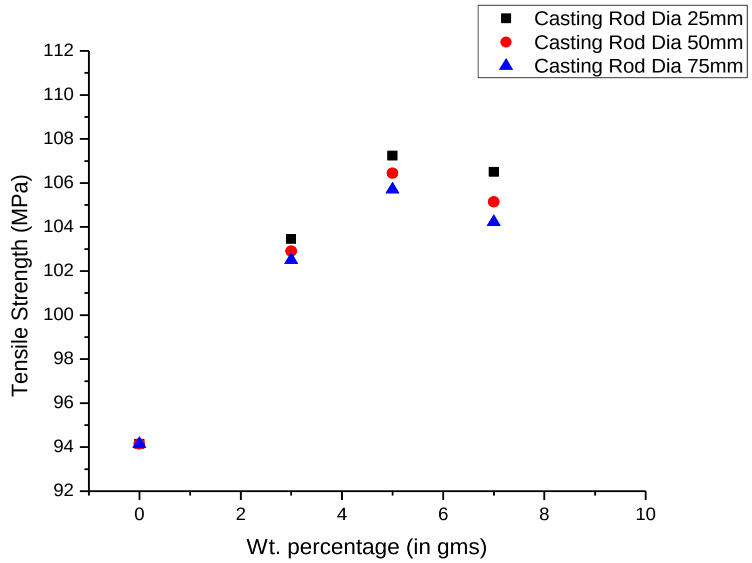

Fig-5: Tensile strength of the Al-3Mg reinforced with 3, 5, & 7 wt.% of Gr. For three different as-cast diameter

3.3 Hardness test

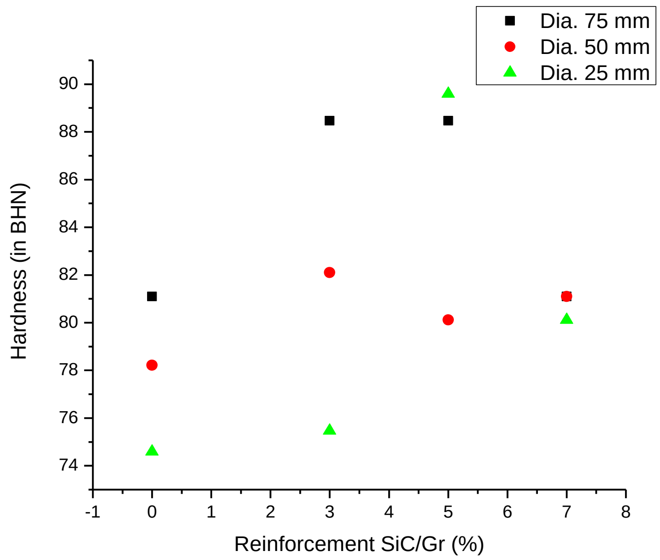

Fig-6: Hardness of the Al-3Mg reinforced with 3, 5, & 7 wt.% of Gr. For three different as-cast diameter

The hardness of the Al-3Mg hybrid metal matrix composite is shown in the fig No. 6. The hardness of the three different diameters of the as-cast rod was compared with the increase in the weight percentage of graphite and keeping SiC constant by 5 wt. % as reinforcement. It can be observed that the hardness of the composite is increased with the decrease in the density of the composite as observed in fig No. 4. the hardness has increased with the increase in weight percentage of reinforcement. The increased spikes of the hardness values identify the proper diffusion of hard SiC constituents in Al-3Mg matrix material. Further addition of Gr. can be seen as a slight reduction in the hardness values of the Al-3Mg composite. Hardness of Al-7Si/Gr. hybrid metal matrix composite seems to be diminishing, due to the addition of soft graphite solid lubricator into Al metal matrix. The Soft Graphite content contributes to a decrease in the hardness of the Al-Si matrix [9]. SiC up to 25% weight fraction. Beyond this weight fraction, the hardness trend started decreasing as SiC particles interact with each other leading to clustering of particles and consequently settling down. Eventually, the density of SiC particles in the melt started decreasing thereby lowering the hardness [4].

3.4 Compression Test

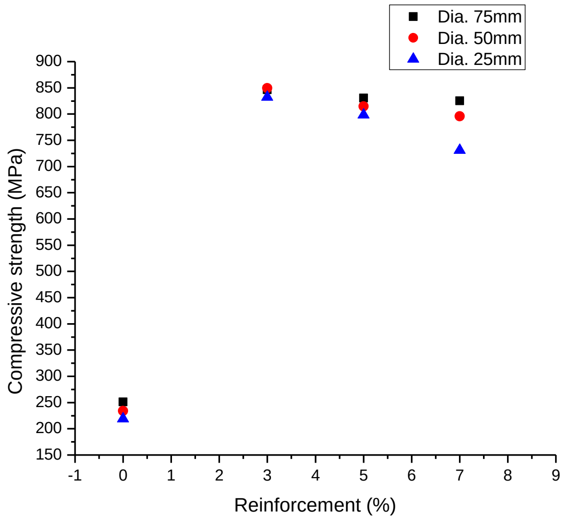

Fig-7: Compression Tests results of Al-3Mg / 5SiC/ Varying wt.% of Gr.

The compression test results show an increase in the trends with the increase in the wt. % of Gr. with the higher as-cast rod diameter in comparison with others. The compression test results show the Al-3Mg hybrid metal matrix composite undergoes strain hardening to achieve desired properties through forming process as the material posses quality of ductile by nature.

3.5. Wear Test

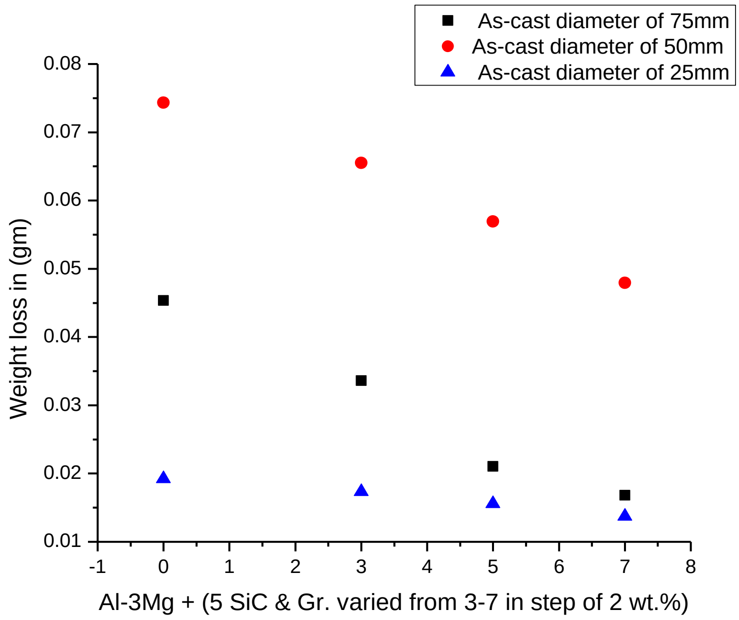

Fig-8: Wear rate of Al-3Mg / 5SiC/ Varying wt.% of Gr.

The wear test results as observed from the fig No.8 depicts that wear resistance is increased with an increase in the weight percentage of the graphite reinforcement in composite in comparison with the base alloy. The soft graphite particulates also act as a solid lubricator might have control on the wear rate, It has also been noticed in some cases that an increase in the temperature has also resulted in the wear rate even with the increase in the Gr. as reinforcement. As the load increases the wear rate also increases and base alloy shows the maximum wear[5].

3.6 Microstructural analysis

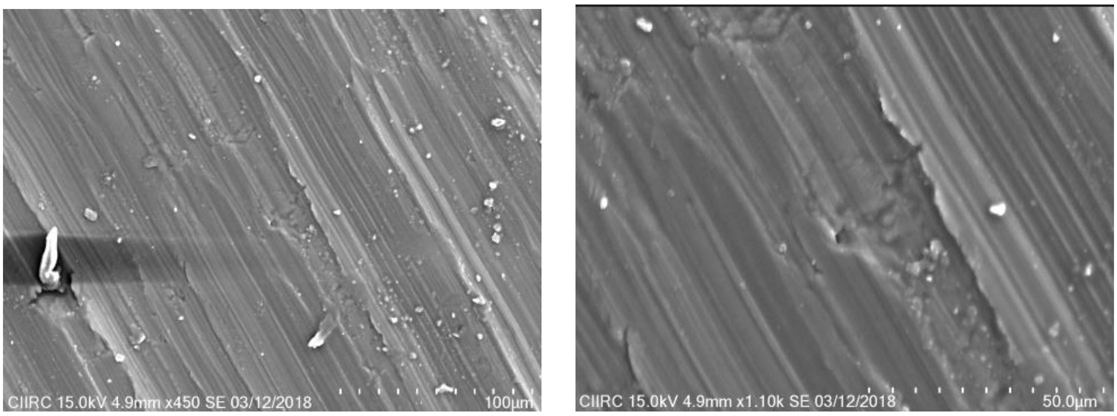

Fig-9: SEM images of wear specimen of Al-3Mg / 5SiC/ Varying wt.% of Gr.

The demostrations of Fig No. 9 shows the SEM analysis results of the worn-out surface of the pin which has undergone a dry wear test of graphite between 3-7 in step of 2 wt.% of Gr. and 5wt. % of SiC. With the increase in the Gr. particulates, it is observed that uniform dispersion of Gr. and SiC in Al-3Mg matrix material. The SEM images show that not much of the material is removed as a result of the quantum of the reinforcement particulates present to strengthen the matrix material.

4. CONCLUSION

- The vortex method was successfully adopted in the production of Al-3Mg composite reinforced with 5 SiC & 3,5, & 7% of Gr. for three different diameters of the as-cast rod.
- The hardness of the Al-3Mg hybrid metal matrix composite found decreasing with increase in graphite constitutes beyond 7 wt. % as reinforcement in the Al-3Mg
- The SEM microstructural analysis shows that the contribution of graphite in Al-3Mg as reinforcement has improved the wear resistance by minimizing the debris and cracks on the specimens while wear tested.
- The Energy Dispersive (EDS) analysis shows the spikes of a different constituent of composites. The element Gr. is seen in the form of Carbon and SiC percentage along with Mg with Al as a major alloy blending.

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