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TRIBOLOGICAL BEHAVIOR OF AL-MG ALLOY REINFORCED WITH MICRO TITANIUM AND BORON CARBIDE PARTICULATE HYBRID METAL MATRIX COMPOSITES

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ABSTRACT

In the present investigation on tribological behavior of Al-Mg alloy reinforced with micro Ti and B4C particulates hybrid metal matrix. The composites were fabricated by using the stir casting technics by varying weight percentage of reinforcements i.e. [for sample 1 (A-Mg 100%), sample 2 (Al-Mg 94%+Ti 5%+B4C 1%), sample 3 (Al-Mg 93% + Ti 5%+B4C 2%), Sample 4 (Al-Mg 92%+Ti 5%+B4C 3%)] the dry sliding wear test carried out of pin on disc wear testing machine. Aluminium matrix composites are widely used in Engineering applications due to their good physical and mechanical properties such as high strength to weight ratio, good ductility, corrosion resistance, availability and low cost. The application of aluminium alloys have been restricted because of soft and for their poor wear resistance. This problem is overcome by addition of reinforcements into the metallic matrix. After reinforcement metal matrix composites have the enhanced properties such as stiffness, specific strength, wear, creep and fatigue properties compared to unreinforced alloys. Aluminium matrix composites are used in engineering applications such as aircraft, aerospace, automobiles and various other fields. In the automobile sector aluminium based metal matrix composites are used for making of automotive Engine components such as

vehicles bodies, cylinder blocks, pistons, pistons rings, cylinder blocks, cylinder liners and brake drum. Wear is one of the serious problems which need further scrupulous solutions.

KEYWORDS: Al-Mg, B4C, Ti, stir casting, tribological, dry sliding wear, pin on disc machine.

INTRODUCTION

Discontinuous reinforced aluminium metal matrix composites (DRAMMC's) are a class of composite materials which are having desirable properties, which include low density, high specific stiffness, high specific strength, controlled co-efficient of thermal expansion, increased fatigue resistance and superior dimensional stability at elevated temperatures etc.[1,2,3] Aluminium matrix composites are fast emerging as engineering materials and exhibits better mechanical and physical properties than common metals and alloys. They are gaining significant acceptance because of higher specific strength, specific modulus and good wear resistance as compared to ordinary unreinforced alloy. Lightweight aluminium metal matrix composite materials hold potential requisite for modern tribological applications due to its inherent and better wear resistant properties over monolithic metallic materials. Metal matrix composites are advanced materials, which combine metallic matrix with a hard ceramic reinforcement such as SiC, B4C, TiC, Al2O3 or soft reinforcement to produce composite materials.[4] Aluminium alloy and its alloy elements such as Magnesium, Copper etc. reinforced with ceramics due to their exponential combination properties. These are used in ship and submarine building, transportation, heavy vehicles, pressure vessels, bridges, buildings, automobile and aircraft parts and braking systems.[5] The aluminium-magnesium-silicon carbide composites reduces the fuel consumption and improves the efficiency due their light weight. The desire in the engineering community to develop a new material with greater wear resistance and better mechanical properties, without much compromising on the strength to weight ratio led to the development of metal matrix composites.[6-10] Aluminium is one of the most commonly used metal matrixes for production of Metal matrix composites. Metal matrix composites exhibits superior wear resistance owing tribological applications. These include pistons and cylinder liners in automotive engines, brake discs/drums in railway vehicles and in automobiles.[11-14] However, cost still remains a major barrier in designing aluminium composite components for wider applications in automotive industries along with the wear problems.[15]

MATERIALS AND EXPERIMENTEL DETAILS

Material

The material used in this study is Aluminium- Magnesium alloy, having the chemical composition as shown in Table-

Component	Weight%
Silicon	0.4
Iron	0.4
Copper	0.1
Manganese	0.4-1.0
Magnesium	4.0-4.9
Zinc	0.25
Titanium	0.15
Chromium	0.05-0.25
Aluminium	Balance

Boron Carbide (B4C)

Boron carbide, (B4C), crystalline compound of boron and carbon. It is an extremely hard, synthetically produced material that is used in abrasive and wear-resistant products, in lightweight composite materials, and in control rods for nuclear power generation. Boron Carbide (B4C) particle of size 250 micron was used as the reinforcing material.

Boron carbide properties

Density 2.52gcc

Melting point 2445^{0}C

Young's Modulus 450-470GPa

Figure: Boron Carbide powder.

Titanium Powder

Titanium powders vary in terms of size and purity and can alloyed with several other kinds of other metal additives producing powders such as titanium iron alloy and titanium aluminium alloy. Titanium is also a key material in powder metallurgy and used extensively in filters, machinery, and components are used extensively in the medical industry, being used in heart pacemakers and cranial shells. More recently it has seen a rise in demand due to the rise in popularity of 3D printing and the ideal properties of the material.

Properties of Titanium

Density- 4.506gcc

Melting point -1668^{0}C

Young's Modulus -116GPa

Color – Gray

Fabrications of Composites

Furnace and heated up to 650^{o} .The metal was stirred with the help of mechanical stirrer to form a fine vortex. The boron carbide powder (250 micron) along with Ti powder is preheated at about 250^{0}C and it is added with the molten metal. The molten mixture is then stirred continuously at 320rev/min. The molten liquid metal is poured into the permanent mould which has preheated at 250^{o}C. By varying the weight percentage of the boron carbide (1%, 2%, 3%,) the material has been fabricated.

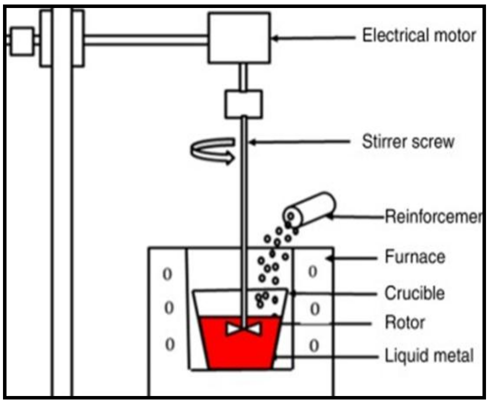

Figure 3.1: Line diagram of stir casting.

Steps Involved in casting process

- First of all, 1200gm of commercially available aluminium-magnesium was melted in a resistance heated muffle furnace and casted in a clay graphite crucible. For this the melt temperature was raised to 7500C.
- Before mixing Titanium and B4C particulate preheating at 500^{0}c temperature
- Titanium and Boron carbide powders were mixed in the red hot liquid Al-Mg kept in the crucible in the required composition. By stir casting method all the composites are well

stirred such all the constituent material get mixed properly with the base metal that is Al-Mg.

- Later the red hot liquid mixture is poured in to ASTM casting dies and allowed it for solidification for ½hour.

Figure a: The Electric furnace.

Figure b: The Graphite Crucible.

Figure c: The Al-Mg alloy ingots.

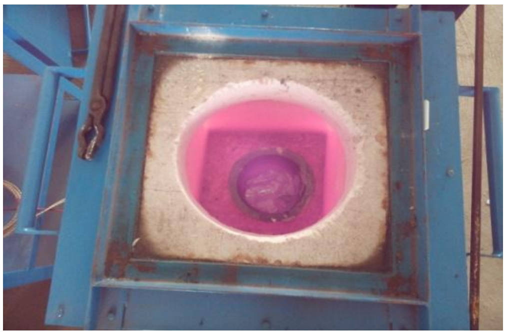

Figure d: The crucible inside metal.

Figure e: The crucible temperature sets.

Figure f: The pre heat die.

Figure g: The degassing tablet.

Figure h: Pouring of molten metal into mould box.

Figure i: opening die Removal of composite from mould box.

Figure 6.2: steps involved casting process.

Experimental Procedure

Wear Test Procedure

- Immediately prior to testing, and prior to measuring or weighing, clean and dry the specimens. Take care to remove all dirt and foreign matter from the specimens. Use non-chlorinated, non-film-forming cleaning agents and solvents. Dry materials with open grains to remove all traces of the cleaning fluids that may be entrapped in the material. Steel (ferromagnetic) specimens having residual magnetism should be demagnetized. Report the methods used for cleaning.[16]

- Measure appropriate specimen dimensions to the nearest 2.5µm or weigh the specimens to the nearest 0.001g
- Insert the disk securely in the holding device so that the disk is fixed perpendicular (+/-1°) to the axis of the resolution.
- Insert the pin specimen securely in its holder and, if necessary, adjust so that the specimen is perpendicular (+/-1°) to the disk surface when in contact, in order to maintain the necessary contact conditions.
- Add the proper mass to the system lever or bale to develop the selected force pressing the pin against the disk.[17]
- Start the motor and adjust the speed to the desired value while holding the pin specimen out of contact with the disk. Stop the motor.
- Set the revolution counter (or equivalent) to the desired number of revolutions.
- Begin the test with the specimens in contact under load. The test is stopped when the desired number of revolutions is achieved. Tests should not be interrupted or restarted.
- Remove the specimens and clean off any loose wear debris. Note the existence of features on or near the wear scar such as: protrusions, displaced metal, discoloration, micro cracking, or spotting.[18]
- Remeasure the specimen dimensions to the nearest 2.5µm or reweigh the specimens to the nearest 0.001g, as appropriate, spotting.
- Repeat the test with additional specimens to obtain sufficient data for statistically significant results.

The data of pin height loss was used to calculate the wear rates of the cast hybrid composites given by the formula:

$$\text{Wear Rate (mm3/m)} = \frac{\text{volume of wear}}{\text{sliding distance}}$$

$$\text{Volume of wear(mm3)} = \frac{\text{mass loss}}{\text{density}}$$

$$sliding\ distance\ (m) = \frac{2\pi\ \text{RNT}}{60}$$

Where

R= crack radius of disc in m.

N= speed of disc plate in rev/min.

T= time of sliding in sec.

Figure 4.1: Wear Testing Equipment.

Figure 4.2: Wear Test Specimen.

RESULTS AND DISCUSSIONS

The wear test was conducted using a pin on disc test machine in accordance with ASTM standard G99-05.The following wear results are obtained for

- Four different applied loads of 20N, 30N, 40N & 50N for a total sliding distance of 3000m at a constant sliding speed of 0.84 m/s.
- Four different sliding velocities of 0.42 m/sec, 0.84 m/sec, 1.26 m/sec & 1.6 m/sec, against normal loads of 20 N for constant 3000m sliding distance.
- Four different sliding of 1000m, 2000m, 3000m & 4000m at constant sliding velocity 0.84 m/sec & 20 N load.

Co-efficient of Friction

Effect of Load

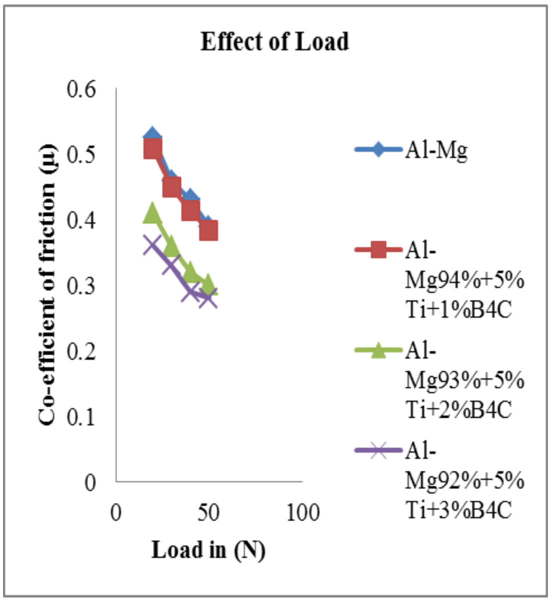

Figure 5.1: Indicate Coefficient of Friction of Both A1-Mg alloy and its Composites Decreases with Increased Loads.

Friction coefficient is the ratio between the force developed and the applied force. Friction values for matrix and composite material were in expected range for light metals in dry sliding conditions, with remark that composite material, for the applied load range, showed slightly higher values comparing to the matrix material.[21] Wear resistance of the composites increases with increase in percentage of fly ash.[22] The friction coefficient of composites with coarse fly ash particles is higher compared to those of fine particles. The friction coefficient of fly ash particles exhibits increasing trend with increase in particle size. Higher coefficients of friction in the case of composites containing hard particles may be due to the formation of tribofilm at the interface between pin and disk. Composites decreases with increase in fly ash.

The Coefficient of Friction of unreinforced Al-Mg & reinforced Al-Mg composite were studied for four applied loads 20N, 30N, 40N & 50 N and five different composite specimens with varying weight percentage of particle reinforcement. It is found that the coefficient of friction is maximum at a load of 20 N for both the matrix alloy Al-Mg and its composites. However the boron carbide (3%) weight fraction reinforced composite possesses the lowest coefficient of friction at this load and the friction coefficients are reduced by 30% in the range of 0.3–0.42 it can be noticed in graph. The coefficient of friction of both Al-Mg alloy and its composites decreases with increased loads.

Wear Rate

Effect of Load

Applied load affects the wear rate of alloy and composites significantly and is the most dominating factor controlling the wear behavior at constant speed, the wear rate of the Al-Mg composites and the matrix increases with increase in load. Similar observations were reported in the Influence of Particle Size on Dry Sliding Friction and Wear Behavior of Fly Ash Particle – Reinforced A380 Al Matrix Composites.[23] The results indicate that the volume Content of particulates boron carbide reinforcement has a marked effect on the wear rate. The wear rate of the composite specimens decrease with increasing weight percentage of boron carbide particulate reinforcement.

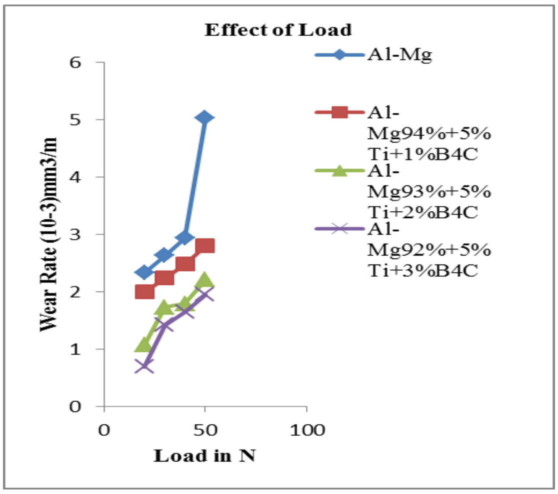

Figure 5.2(a) Indicate That the Wear Rate Increases with Increasing Applied Load for all the Composites.

Similar to the results were observed by Amro and. AI-Qutub et al[23] expected, the wear rate of a Al-Mg Metal matrix composite specimen with a fixed four percentage of reinforcement increases with Increasing applied load as shown in graph. Adhesive wear was a predominant mechanism of wear followed by plastic deformation with increase of specific load.[24]

Effect of Sliding Velocity

The variation of wear rate as a function of load at different sliding velocity is shown in figure-5.2(b) the composites and the base alloy for a constant applied load of 20 N and for a constant sliding distance of 3000 m. The wear rate of Al-Mg alloy remains almost constant 0.42m/s and then increases linearly up to 1.5m/s. At speeds above 1.5m/s, the wear rate rapidly increases. For the composites, as the sliding speed increases the wear rate decreases slightly up to 1.6m/s and then increases. The wear rate is lowest for Al-Mg93%+5%Ti+3%B4C composite.

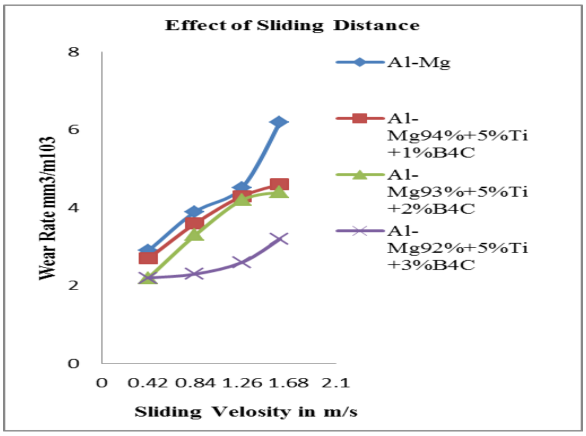

Figure 5.2(b): Indicate That the Wear Rate increases with increasing velocity.

Wear Volume

Effect of Sliding Distance

Figure 5.3(a) shows the variation of wear volume loss with sliding distance for both as cast aluminum Magnesium alloy and Al-Mg/Ti/B4C composites with varying percentages of B4C reinforcement. It can be seen that as the sliding distance increases, the wear of the both the composites as well as the unreinforced alloy increases. The wear of the reinforced alloy is more than that of the composite for all sliding distance. Further, as the percentage of reinforcement increases, the wear composite decreases. There is not much change in wear during the initial phase of the sliding distance for composite with different percentages. The incorporation of boron carbide particles into Al-Mg alloy improves the sliding wear resistance as compared to the unreinforced alloys.

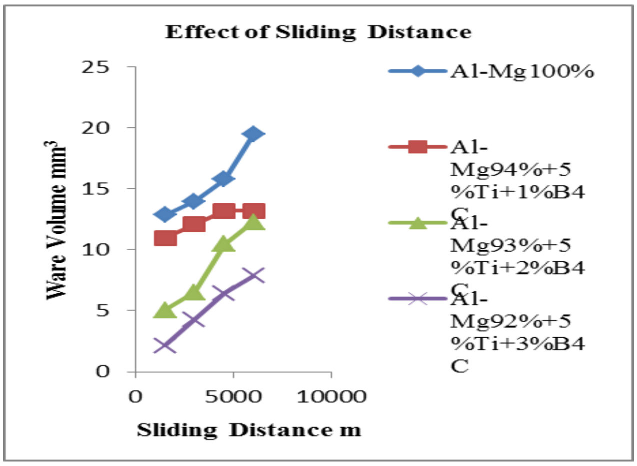

Figure 5.3(a): Variation of Wear Volume of Al-Mg/Ti/B4C at different sliding distance and a constant load.

The variation of sliding wear volume loss with sliding distance at an applied load of 20N and for a sliding speed 0.84m/s. the volume loss the monolithic alloy and composites increases with the increase in sliding distance. The base alloy, the wear volume loss increase linearly with sliding distance For the composites, the rate of increase the sliding distance.

Effect of Reinforcement

Figure5.3 (b) shows the variation in volume loss versus different percentages of boron carbide reinforcement at different sliding distance at a constant sliding speed of 0.84m/s and for a 20N load for a fixed sliding distance of 4000 m. as the reinforcement content increase, the wear resistance of the composite increases. A drastic decrease in wear volume was observed for composites with 3 percent of boron carbide. As the amount of reinforcement increases, the wear resistance increases for all sliding distances.

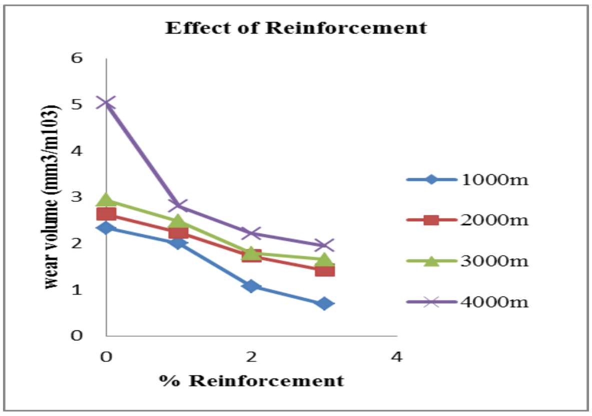

Figure 5.3(b): Variation of Wear Volume loss v/s different Reinforcement of B4C and constant Ti at variation sliding with sliding speed.

CONCLUSION

Stir casting process were used in the preparation of AL-Mg hybrid composites containing varying % of Micro Ti and B4C particulates as reinforcement. And the test specimens were prepared according to ASTM standards. The wear result of Al-Mg hybrid composites increased with the increase in speeds hence wear is maximum for higher speed. The wear rate for a particular speed was reduced as the percentage of the reinforcement was increased. Hence more the reinforcement added better will be the wear rate.

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