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Investigation on Mechanical Properties of LM6 Aluminium Alloy – B_4C – Fly ash Reinforced Composites using Stir Casting Process

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Abstract - Composite materials play an important role in automotive, aerospace, marine, transportation and defence applications because of its high strength to weight ratio, high stiffness to weight ratio, superior mechanical properties with wear resistance. Aluminium alloys have been used because of its light weight and better corrosion resistance. In this present work an attempt has been made to prepare the composites. LM6 aluminium alloy reinforced with boron carbide (B_4C) and fly ash particles compositeshave been prepared using stir casting process. Microstructure, hardness, tensile strength, ductility and dry sliding wear behaviour of composites have been investigated. The results reveal that hardness of composites increased with increasing wt% of reinforcements. Maximum hardness of 124 BHN was observed for the composites had 5wt% of fly ash and 10 wt% of boron carbide particles. This composite can be used in various applications because of its better hardness compared to LM6 aluminium alloy.

Keywords: Aluminium alloy; Stir casting; Microstructure; Mechanical properties

1. INTRODUCTION

Composite material consists of two or more materials when they are in different physical and chemical properties. Continuous phase is termed as matrix and reinforcements are added to the matrix to improve the mechanical and wear resistance of matrix. Composites are classified as metal matrix, ceramic and polymer matrix composites. Aluminium matrix composites are used in various applications because of its high strength to weight ratio, high stiffness to weight ratio, stability at elevated temperature, better resistance to abrasion and wear [1,10,13-15,18]. The reinforcements such as aluminium oxide, silicon carbide, boron carbide, boron nitride, aluminium nitride, titanium carbide, zirconium carbide, titanium nitride, carbon, steel, graphite, fly ash are added in aluminium matrix to improve the properties of composites. Based on the types of reinforcements, aluminium matrix composites are classified as particle reinforced composites and fiber reinforced composites.

Aluminium matrix composites can be manufactured using solid state processing and liquid metallurgy route. Casting process is used in various industries because of its ease method of manufacture, viability and low cost [15]. Stir casting process are used to prepare aluminium matrix composites with superior mechanical and wear resistance compared to gravity die casting process [2–9]. In stir casting process, required wt% of reinforcement is added to the molten metal and composite melt is stirred at high speed to produce vortex. Subsequently, the composite melt is poured into the die to produce components with required shape and size

While selecting the reinforcement for particle reinforced composites, particle size and wt% of reinforcement should be considered which significantly influencing the mechanical and wear behaviour of composites. Fiber diameter, length, fiber orientation, bonding between matrix and reinforcement must be considered while preparing fiber reinforced composites.

Particle reinforced composite can be manufactured using stir casting process. In this stir casting process, raw aluminium is charged in crucible and the temperature is raised beyond melting temperature. Reinforcement is preheated in a separate furnace to remove the moisture content and added to the melt after removing the slag. While adding the reinforcements, an electric stirrer is used to stir the melt which produces vortex. This stirring process can help to achieve uniform dispersion of reinforcement throughout the matrix. Subsequently the composite melt is poured into the preheated die to obtain the castings of required shape.

Reinforcements in the form of particles, whiskers and fibers improve the mechanical properties and wear resistance of composites. Several researchers have discussed the effect of reinforcements on mechanical properties of aluminium matrix composites.

Kumar et al [9] investigated the effect of titanium diboride (TiB2) in Al–7Si alloy processed using salt reaction route. Reinforcement of TiB2 particles increased the young's modulus, hardness and ultimate tensile strength of composites. Also wear loss and coefficient of friction of composites decreased with increasing wt% of reinforcement. Worn surface of composites showed adhesion and ploughing at lower loads and delamination was observed at higher loads.

Bharath et al [3] investigated the effect of aluminium oxide (Al_2O_3) particles in 6061 aluminium alloy. Microstructure of samples showed uniform distribution of reinforcement in matrix. Also hardness, tensile strength and wear resistance of composites increased with increasing wt% of reinforcement. However, ductility of composites decreased by reinforcing hard reinforcements in soft matrix.

Mandal et al [11] discussed the effect of steel fiber reinforcement in Al – Mg alloy processed using stir casting technique. The results show that amount of porosity increased with increasing wt% of reinforcement from 2.5 to 10. Hardness and density of composites increased with increasing wt% of steel fiber reinforcement in soft matrix. Tensile strength of composites increased with increasing wt% of reinforcement from 2.5 to 5. Further addition of reinforcements decreased the tensile strength. Regression equation is developed to predict the ultimate tensile strength of composites. Fracture surface of matrix showed dimple formation and composites showed steel wire pulled out from matrix.

Sivananthan et al [17] studied the effect of multiwall carbon nanotubes (CNT) in aluminium on mechanical properties of composites. The results showed that relative density and hardness of composites increased with increasing wt% of CNT reinforcement in aluminium. Also electrical and thermal conductivity of composites decreased with increasing wt% of reinforcement from 0.5 to 3.

Dhinakaran and Moorthy [5] studied the reinforcement of boron carbide (B4C) in aluminium alloy processed using stir casting technique. Microstructure of sample showed uniform distribution of particles in matrix. Reinforcement of B_4C increased the hardness and tensile strength of composites and higher mechanical properties were obtained for 9wt% of reinforcement in aluminium alloy.

Anilkumar et al [2] discussed the effect of fly ash reinforcement in Al 6061 alloy processed using liquid metallurgy route. The micrographs of samples showed uniform distribution of fly ash without any micro pores at the interface of reinforcement and matrix. Reinforcement of fly ash in matrix improves the mechanical properties of composites. Hardness, tensile strength and compressive strength of composites increased with increasing wt% of reinforcement and reduction in particle size. 15wt% of reinforced composites offered better ultimate tensile strength compared to other wt% reinforced composites and aluminium alloy. Also percentage of elongation decreased with increasing wt% of reinforcement.

Shyu and Ho [16] investigated the influence of titanium carbide (TiC) particles reinforcement in Al–5.1Cu–6.2Ti alloy. Micrograph of composites showed uniform distribution of TiC in matrix. The results showed that hardness, tensile strength and wear resistance of composites increased by reinforcing 6wt% of reinforcement. Hardness of composites increased by 20%, tensile strength and yield strength increased up to 18% by reinforcing TiC in matrix. However wear rate of composites increased with increasing load from 0 to 1 kg.

Karthikeyan and Jinu [8] discussed the effect of zirconia (ZrO2) in LM25 aluminium alloy processed using stir casting technique. The results reveal that weight loss of composites decreased with increasing wt% of reinforcement and increased with increasing normal load and sliding distance. Also wt% of reinforcement in aluminium alloy decreased the surface roughness. Composite containing 15wt% of ZrO_2 offered better wear resistance compared to other wt% of reinforced composites.

Muruganandhan et al [12] investigated the effect of fly ash and titanium carbide reinforcement in Al7075 alloy using stir casting process. The authors reported that addition of fly ash and titanium carbide increased the hardness and tensile strength of composites.

Zhang et al [20] discussed the effect of aluminium nitride (AlN) particles in aluminium processed by casting. Micrograph of composite reveals homogeneous distribution of particles throughout the matrix without particle cluster. Composite showed higher tensile strength over matrix. Also tensile strength of composites decreased with increasing temperature. Coefficient of thermal expansion decreased with increasing wt% of reinforcement.

Chelladurai et al [4,6,7] investigated the reinforcement of steel fibers, wires and mesh reinforcement in aluminium alloy using casting process. The results show that reinforcement of steel fibers, wires and mesh increases the hardness, tensile strength and wear resistance of aluminium alloy. However, the ductility of composites decreased with increasing wt% of reinforcement.

In this present work, LM6 aluminium alloy used as matrix and boron carbide and fly ash were used as reinforcement. A constant amount of 5wt% fly ash is considered and boron carbide wt% varied from 0 to 10. Stir casting process is used for producing composites and microstructure, hardness, tensile strength and wear resistance of composites were investigated and reported.

2. EXPERIMENTAL PROCEDURE

Commercially available boron carbide (B_4C) in the market and fly ash were collected from foundry industries and used as reinforcement. LM6 aluminium is given in Table 1 is used as matrix.

Table 1 Chemical composition of LM6 aluminium alloy (Wt%)

Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
11.8	0.4	0.02	0.02	0.03	0.1	0.08	Bal

Stir casting set up as shown in Fig.1 was used for conducting the experiments. 1kg of LM6 aluminium alloy was melted in an electric furnace and the temperature was raised to 750 ºC. Reinforcements are preheated to 200 ºC and slowly added to the melt when the stainless steelstirrer stirredat 750rpm.

Fig.1 Stir Casting Setup

The die was made up of H_{11} die steel and the composite melt was poured using a ladle arrangement. Cylindrical castings of 30mm diameter and 180mm height were produced and shown in Fig.2.

Fig.2 Castings Produced by Stir Casting Process

Microstructure of castings was examined using image analysis system to study the distribution of particles in matrix. Samples were prepared to investigate thehardness and tensile strength. Hardness was measured using Brinell hardness testing machine with a load of 500kgf, dwell time of 15 s with 5 mm ball indenter. Tensile specimens of 25 mm x 6 mm x 6mm were machinedusing wire-cut electrical discharge machine. Extensometer was used to perform the tensile tests. Wear test was performed using pin – on – disc apparatus to study the wear resistance of composites. Specimens of 10mm diameter and 35mm height were prepared as per ASTM G99 standard for a sliding distance of 3000m and 10N load. Electronic weigh balance was used to measure the weight of the pin before and after wear test.

3. RESULTS AND DISCUSSION

3.1. Microstructure:

Microstructure of LM6 aluminium alloy – boron carbide – fly ash reinforced composites is shown in Fig.3. It is observed that boron carbide and fly ash particles are uniformly dispersed in LM6 matrix. This may be attributed due to high stirring speed during the manufacturing of composites. Similar results are reported by other researchers [7,11] that high stirring speed produced vortex during stir casting process which results in uniform dispersion of reinforcements in matrix.

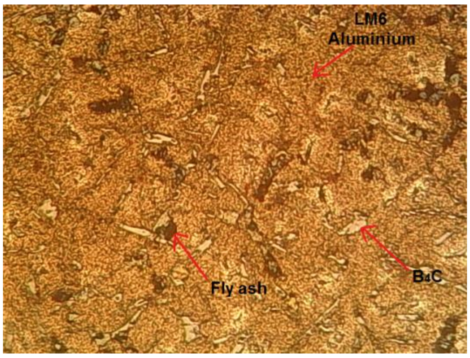

Fig.3 Microstructure of LM6 – B_4C – Fly ash reinforced composites

3.2. Hardness:

Hardness of LM6 aluminium alloy and boron carbide and fly ash reinforced composite is used in Table 2. Cylindrical samples were prepared as shown in Fig.4and the hardness values were observed at three locations in a sample and average three hardness values are presented. Hardness of composites against particle wt% is plotted in Fig.5.

Fig.4. Samples prepared for Hardness

From Fig.5, it is observed that there is a major improvement in hardness with the reinforcement of hard particles in LM6 aluminium alloy. Addition of hard particles increased the hardness of composites and maximum hardness of 124BHN was observed for 10 wt% of boron carbide particles with 5wt% of fly ash reinforced composites. Addition of hard particles in soft matrix resist plastic deformation while indentation.

Many investigator[12,19] reported that the lower density, high hardness and thermalstability of boron carbide and fly ash might be possible reasons for the increased hardness of composites.

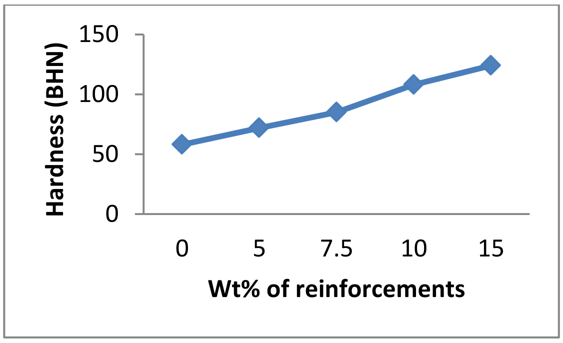

Fig.5 Variation of hardness with wt% of reinforcements

Table 2 Hardness and Tensile strength of composites and LM6 aluminium alloy

Wt% of Aluminium alloy	Wt% of Boron Carbide (B_4C)	Wt% of fly ash	Hardness (BHN)	Ultimate Tensile Strength (MPa)
100	-	-	58	109
95	-	5	72	111
92.5	2.5	5	85	114
90	5	5	108	141
85	10	5	124	145

3.3. Tensile Strength:

Tensile strength of composites is reported in Table 2. It is seen that tensile strength of composites offers better tensile strength compared to LM6 aluminium alloy. Variation of tensile strength with wt% of reinforcement is shown in Fig.6. It is observed that tensile strength of composites increased with increasing wt% of reinforcements. It is due to addition of hard particles in LM6 aluminium alloy which absorbs load during the tensile test. Earlier researchers [4.7] also reported that increase in wt% of reinforcements increased the tensile strength of composites.

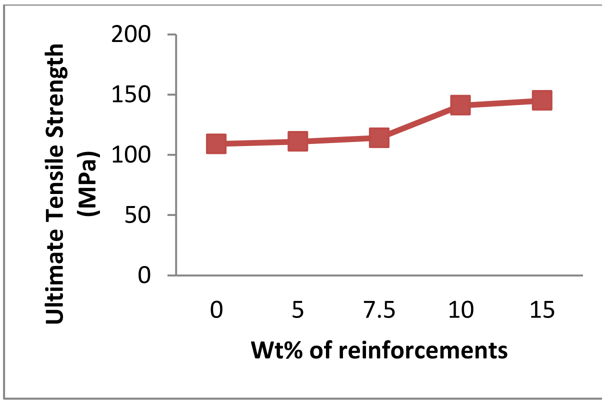

Fig.6 Variation of tensile strength with wt% of reinforcements

3.4. Wear behaviour of composites**:**

Wear behaviour of LM6 aluminium alloy and LM6 aluminium alloy – B_4C – fly ash reinforced composites are tested using wear testing apparatus as shown in Fig.7. Samples of 10mm diameter and 40 mm height are produced and tested using a load of 10 N with sliding distance of 2000m. An electronic weigh balance as shown in Fig.8 is used to measure the weight of samples. Coefficient of friction is calculated using frictional force and normal force. Weight loss of samples is calculated by measuring initial weight and final weight of pin.

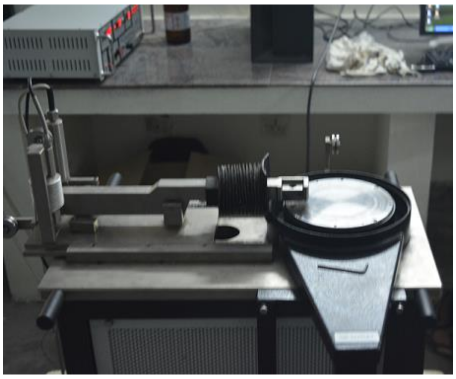

Fig.7. Pin – on – disc apparatus

Fig.8. Electronic weigh balance

Variation of weight loss against sliding distance is depicted in Fig.9. It is observed that weight loss of composites increases with increasing sliding distance from 0 to 2000m. However, weight loss of composites decreases with increasing wt% of reinforced particles viz., boron carbide and fly ash. This may be attributed to the hard ceramic particles (B_4C) in soft matrix which increases the bulk hardness of composites and reduces the amount of material removal from the pin during the sliding wear. Similar results are observed in other studies that weight loss of composites increases with increasing sliding distance and decreased with increasing the amount of reinforcement.

During the wear test, coefficient of friction is observed by measuring frictional force and normal force. Coefficient of friction for LM6 aluminium alloy is found to be 0.32 and 0.28 respectively. It is evident that composites offerlower coefficient of friction compared to LM6 aluminium alloy.

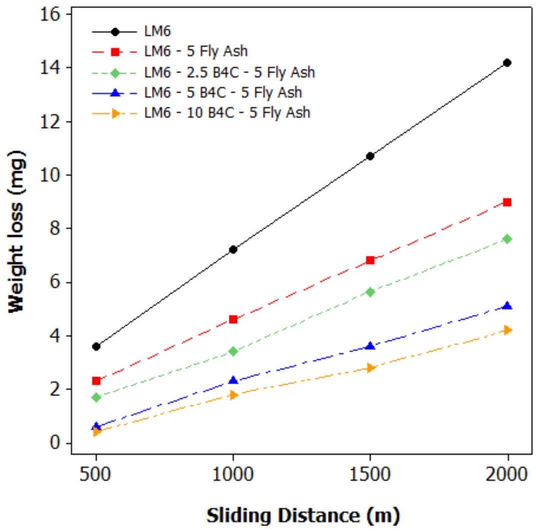

Fig.9 Variation of weight loss against sliding distance

4. CONCLUSION

Boron carbide (B_4C) and fly ash particles were successfully reinforced in LM6 aluminium alloy and the composites have been prepared using stir casting process. Microstructure of composite shows uniform dispersion of reinforcements in LM6 aluminium alloy. Hardness of composites increased with increasing wt% of reinforcements. Maximum hardness of 124 BHN was observed for the composites had 5wt% of fly ash and 10 wt% of boron carbide particles. Ultimate tensile strength of composites increased with increasing wt% of reinforcements. Wear weight loss of composites increased with increasing sliding distance and decreased with increasing wt% of reinforcements. This composite can be suggested as alternate material to LM6 aluminium alloy for various applications because of its excellent hardness compared to LM6 aluminium alloy.

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