Chapter 5
Investigation of Wear and Mechanical Properties of Aluminium Hybrid Composites: Effect of Addition of SiC/B_4C Through Casting Process

S. Sunil Kumar Reddy, C. Sreedhar, and S. Suresh

Abstract Aluminium is a binary alloy has a larger importance to engineering industries with excellent wear resistance and stiffness that have been designed for lightweight and higher strength applications in the automobile sectors. To synthesis the hybrid metal matrix composite, silicon carbide is chosen as primary reinforcement varied at different weight fraction (1, 2, 3, 4 wt%) with a constant boron carbide of 3 wt% used in the present study was carried through liquid metallurgy technique. The composites were then subjected to mechanical and wear properties study. The effect of reinforcement particles by increasing various weight fractions have been investigated and characterized mechanical and wear properties. The 4 wt% of SiC/B_4C reinforced composites tends to increases hardness and tensile strength to 29.7% and 20% as compared to the base alloy.

5.1 Introduction

Aluminium is used in a variety of industries because it is the essential aspect in a wide range of products encompassing of most industrial goods and structural components. However, due to their low wear resistance, their applications are minimal. A metal matrix is made up of two parts such as metal and secondary as reinforcement. Metal matrix composites with at least three constituents are known as hybrid composites. Aluminium metal matrix composites (AMMC) alloys are corrosion-resistant and suitable for industrial applications. AMMCs are commonly used for low-cost parts with high-material efficiency. In structural and functional high applications, aluminium composites are often used in the army, sports and manufacturing industry. High-silica content in boron, widespread incidentally with the same strength as SiC, is present in the boron carbide. The glasses are made of ceramic solid clay at elevated temperatures. Baradeswaran and Perumal [1] studied

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the effect of B_4C on Al 7075 composites, both mechanically and tribologically. Mechanical properties and wear behaviour were tested on T6 heat treated samples. Hardness value improved with increasing B_4C particles due to increased strain energy. Increasing reinforcing particles to enhance increased tensile toughness. Improvement in flexural strength indicates that composites possess enough ductility. The wear rate decreased with increase in reinforcing particles because the contact of matrix area with reinforcement was reduced. The presence of iron and oxygen in the EDAX analysis confirmed that the transfer of ferrous from counter faces and oxidation reaction, respectively. However, the mechanical and wear behaviour of as casted composites are not reported. Ramanathan et al. [2] evaluate the effect of aluminium matrix hybrid composites at different weight percentage of silica particles and keeping fly ash particles contents as constant. Addition of reinforcing particles offers more resistance to particle deformation due to which the micro and macro hardness increases. The tensile strength of the composites increases owing to strengthening mechanism on the other hand presence of hard ceramic particles reduces ductility. Gomez et al. [3] revealed lightweight aluminium (6061) alloys with SiC and B4C as reinforcements were many factors to take the residential or commercial properties of the MMC into consideration. Significant as hard steel, SiC and Al_2O_3 are equivalent to 3.20 as well as 3.96 g/cm^3 reinforcement will improves the material strength. The conclusion is that 10% of B_4C is the endorsed amount of support content in order to achieve optimal strength and stability. It also has excessive mechanical reigns and better weathering. Naher et al. [4] deliberated the fabrication and heat treatment process in a crucible up to 800 °C. The reinforcement was then added to the Al matrix with SiC particles treated upto 400 °C. Once the mixed composite has been finished, around 700–800 °C have been plastered into a metal mould. The prepared compound is machined to the necessary form and size after design. Umanath et al. [5] conducted the wear behaviour of T6 heated on the AA6061 alloy improved with silica lubricant and particles of aluminium oxide produced by casting dispersion. The effect of volume fraction, applied load, rotational speed and counter-face hardness on wear behaviour of the composites was analysed through pareto chart, normal probability chart optical and scanning electron micrograph. The limits of the factors were decided by the trial experiments. The results revealed that all the above-mentioned factors were contributed towards the wear rate. In the interface reaction layer, the XRD spectrum unveiled aspects such as Al, Si, C and O. The porosity of the composites increases with a volume fraction increase but it resists delamination process hence wear rate reduces. The worn surfaces of hybrid composites were rougher than unreinforced aluminium alloy which indicated abrasive wear mechanism. The hypothesis of this research is as follows:

- Fabrication was performed through a liquid metallurgy route.
- To identify mechanical properties of Al7075-SiC-B_4C hybrid composites.
- To determine and understand the tribological characteristics for both Al alloy and aluminium hybrid composites.
- To identify surface morphology was carried out through SEM analysis.

5.2 Materials and Methods

5.2.1 Materials

The matrix used in the research work is Aluminium (7075) as base alloy and chemical composition is represented in Table 5.1. In the present investigation, silicon carbide (SiC) is taken as primary reinforcement, and boron carbide is chosen as secondary reinforcement obtained from Indian scientific business (India) Pvt. Ltd., Tirupati at a fragment size of 50 nm. The chemical composition of reinforcement particles is labelled in Tables 5.2 and 5.3.

5.2.2 Fabrication of Aluminium Hybrid Composites

5.2.2.1 Heat Treatment of Aluminium Matrix

Aluminium 7075 bars were sliced into pieces and immersed in 10% sodium hydroxide (NaOH) solution at a 100 °C temperature for 15 min and then cleaned with methanol solution. The alloy was then dried and melted in the furnace.

5.2.2.2 Preparation of Strengthening Particulates

The reinforcements (SiC and B_4C) are pre-heated to 800 °C and maintained at that temperature for about one hour using a muffle furnace to remove the volatile surface impurities, moisture, gases related to powder agglomeration and to improve the wettability between the matrix.

Table 5.1 Chemical composition of Al 7075 matrix

Al 7075	Ti	Si	Mn	Zn	Cr	Fe	Others	Al
% composition	0.045	0.049	0.06	5.7	0.18	0.3	0.030	Reminder

Table 5.2 Chemical composition of nano-SiC

Al 7075	SiC	Si	B	C	SiO_2	Fe
% composition	98.79	0.34	80.1	0.2	0.5	0.07

Table 5.3 Chemical composition of B_4C

Al 7075	Si	Fe	C	Ca	F
% composition	0.5	0.1	18.1	0.3	0.025

5.2.2.3 Casting and Melting of Fabricated Samples

Table 5.4 represents the different compositions of aluminium hybrid composites as follows:

5.2.3 Preparation of Aluminium Hybrid Composites

Al 7075 alloy is incorporating with silicon carbide as primary reinforcement varied at different weight fraction (1, 2, 3, 4 wt%) with a constant boron carbide as 3 wt% were utilized. A stir casting approach was used to create enhanced hybrid composite pieces, which are also illustrated in Fig. 5.1. Whilst an electric oven was used. SiC/ B_4C powders were pre-heated to 800 °C in a separate muffle furnace for 2 h to remove the hydroxide and other gases. The Al 7075 has been heated in a sink. For 10 min, they were melted extensively in the heat oven at roughly 700 °C to melt. The heating SiC then and the B_4C powder contributed slowly to the Al 7075. During mixing, an additional 1% of the magnesium is employed to increase the weight of the aluminium and to create a more reliable liquid metal bath. The lightweight aluminium-coated stainless-steel strainer approximately 10 min and at 400 rpm, respectively [6]. After placing the solution, it kept a substantial blend of slurry. The fluid steel is then placed into the moulds to produce it both the correct

Table 5.4 Volume fraction of aluminium hybrid composites

S. No.	Al 7075 (%)	SiC (%)	B_4C (%)
1	100	0	0
2	96	1	3
3	95	2	3
4	94	3	3
5	93	4	3

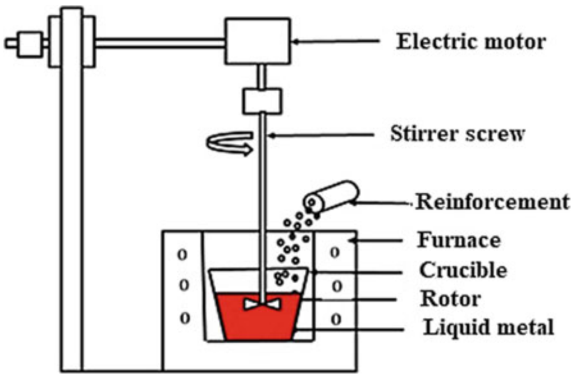

Fig. 5.1 Stir casting setup

shape and the size. The slurry has been placed in pre-heated steel moulds. The specimen was allowed to warm up at 530 °C two hours, then cool down for 4 h (at room temperature) and later heat again is prepared by insertion of 175 °C temperature at 8 h drain under environmentally friendly settings. The composite material sampling was developed on the basis of ASTM samples and all are polished using 200, 400 and 600 grit emery paper for microstructural analysis.

5.3 Results and Discussions

5.3.1 Tensile Strength

The test results are shown in Fig. 5.2, which indicates a difference in the strength of the traction with the increase in weight of SiC and B_4C particles according to ASTM E 08-8 standards. The tensile strength increases from 267 to 300 MPa when reinforced using SiC/B_4C reinforcement fragments, according to the experimental results. In a lightweight aluminium matrix, the accessibility of interbreed support pieces increases resistance to fracture initiations resulting in an improved tensile strength [7]. The highest composite tensile resistance increased by 12.35%, whilst the supports increased dramatically to 4%.

5.3.2 Microhardness

The microhardness of the Al alloy and aluminium hybrid composites at different weight fractions were observed in Fig. 5.3. As the number of strengthening particles increases, the toughness of the composites often increases. A larger number of

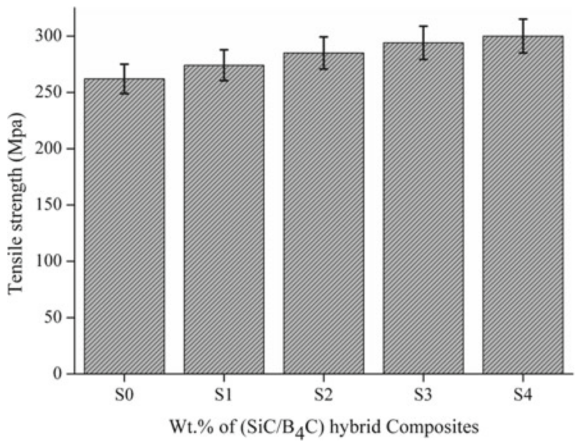

Fig. 5.2 Graphical representation of tensile strength versus wt% of (SiC/B_4C) hybrid composites

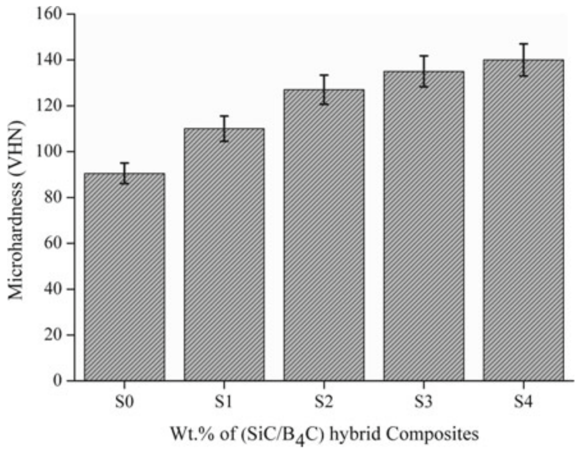

Fig. 5.3 Microhardness versus wt% of (SiC/B_4C) composites

strengthening bits can contribute to strengthening the composite. However, the microhardness enhanced from VHN 90.6 to VHN 140 by increasing the support fraction from SiC/B_4C particles strengthening to 0% to 4% [8]. In comparison with the unreinforced Al7075 aluminium alloy, an increase in 54.52% in Vickers microhardeness is seen in compounds.

5.3.3 *Wear Behaviour*

Dry sliding wear was calculated based using pin-on-disc methods that were determined by the ASTM G-99 process. Each sample's dimensions were taken as 30 mm diameter, and the length of 6 mm was cut out by turning with a lathe tool. A pin positioned a set centre vertically on a rotating metallic piece and revolving on EN 31 steel disc [9].

5.3.3.1 Effect of Load on the Wear Rate

The influences of load on wear rate with a variation of the sliding velocity are shown in Fig. 5.4a, b. The graphs showing the wear rates of the hybrid composites at various load applied such as 20 N, 30 N and 40 N with two sliding speeds such as 2 m/s and 4 m/s, respectively. Every composite used for this investigation exhibit wear rate as a function of its loading rates at two sliding speeds. The pin gets extremely hot as the load is higher there is a significant amount of deformation occurring with the aluminium on the countertop [10]. Through assessment of 40 N loads, the hard surface is going to start wearing the aluminium

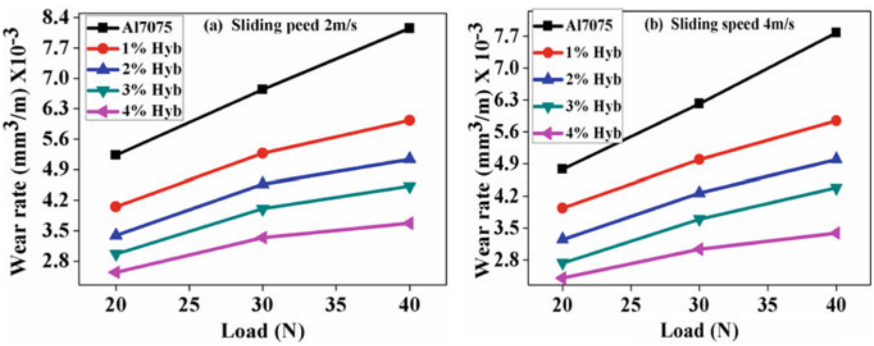

Fig. 5.4 Wear rate versus load

matrix. Then, the new SiC crystals are exposed to the worn iron surface. Such ultra-fine particles are responsible for regular inter-region interaction between the interfaces.

5.3.3.2 Effect of Applied Load on C.O.F

The various loading types of aluminium-based alloys on the pure aluminium alloys are seen in Fig. 5.5a, b. From Figure, friction coefficient would reduce the addition of reinforcement percentage composition increases. The coefficient of friction value decreases with growing the moving speed and reduces as the loads start to rise. This graph shows that the friction coefficient decreases as the linear velocity increases from 2 to 4 m/s. It observes a substantial decrease in the coefficient of friction as sliding speed is enhanced. Due to the weak particle reinforcements in the composite materials, they have cracked on the mating surface areas. The COF is decreased as the metal contact gets smaller and more constraints are used, resulting in less metal interaction between the reinforcements and the matrix [11].

5.3.4 Worn Surface Analysis

An SEM investigation was conducted to validate the wear test results. SEM studies were also utilized to identify the major wear mechanisms under a particular loading condition as well as the transition from one wear mechanism to another due to the change in test conditions. The scanning electron micrography (SEM) studies show visual evidence of particle pull-out and wear debris formation. When the sample and counter are available, regular and tangential loads pass through the contact points. The lower surface's asperities are subjected to relative motion resulting from the force applied to the lower surface. Initially, the pin and disc are rougher than the

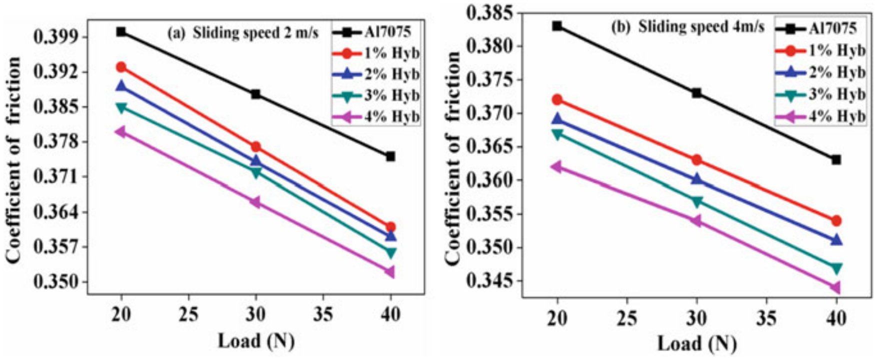

Fig. 5.5 Coefficient of friction versus load

smooth surface. The points of contact between the two surfaces are primarily at these locations. The drawback of plastic distortion on the soft surface effectively exists because of repeated loading activity, which aspects wear debris in Fig. 5.6d. Whilst alloys are softer than other metals used in impact wrenches, the wear debris can reach the smoother metal surface more quickly, forcing the weaker material on the surface to expand and break [12]. A small amount of projected particle fragments acts as debris, ploughing the softer surface on the specimen (Fig. 5.6b). In the case of hybrid composites, the broken reinforcements and the sharp asperities on the disc surface readily abrade the soft matrix surface of the composite specimen, causing it to wear faster. The grooves were positioned parallel to the countertop's counter surface, so the applied load was uniform across the surface un-fractured reinforcement particulates present in debris form also plough the specimen and disc surface, thus developing wear tracks along the surface of the hybrid composites (Fig. 5.6c). This worn-out debris acts as third-party abrasive particulates leading to crack formation. As a result of crack formation in the pin, small flakes of material are removed by delamination. An increase in wear rate with an increase in the reinforcement content is validated by the SEM micrograph of the composite pins. Scanning electron microscopy images of the base alloy ligaments show severe delamination, which results in the large removal of metal from the pin surface. The loss of ceramics in the Al 7075 alloy leads to an effortless removal of steel from the surface, and thus, the wear price is more significant. To conclude, it can be inferred that delamination was the leading wear mechanism in the Al 7075 alloy. The delamination and adhesion wear were minimized by using reinforcements from 1 to 4% (Fig. 5.6b, d). There is ample evidence that in the case of particulate reinforced composites, the alumina and silicon carbide particulates were strongly bonded with the Al 7075 core, protecting the bottom layer against delamination, which in turn minimized the wear rate. Also, the addition of 1–4% silicon carbide to the matrix resulted in a change in wear mechanism from delamination wear to abrasive wear type and the formation of mild wear tracks with the addition of reinforcements (Fig. 5.6a–e). Therefore, experimental values can be confirmed that the Al7075/4%

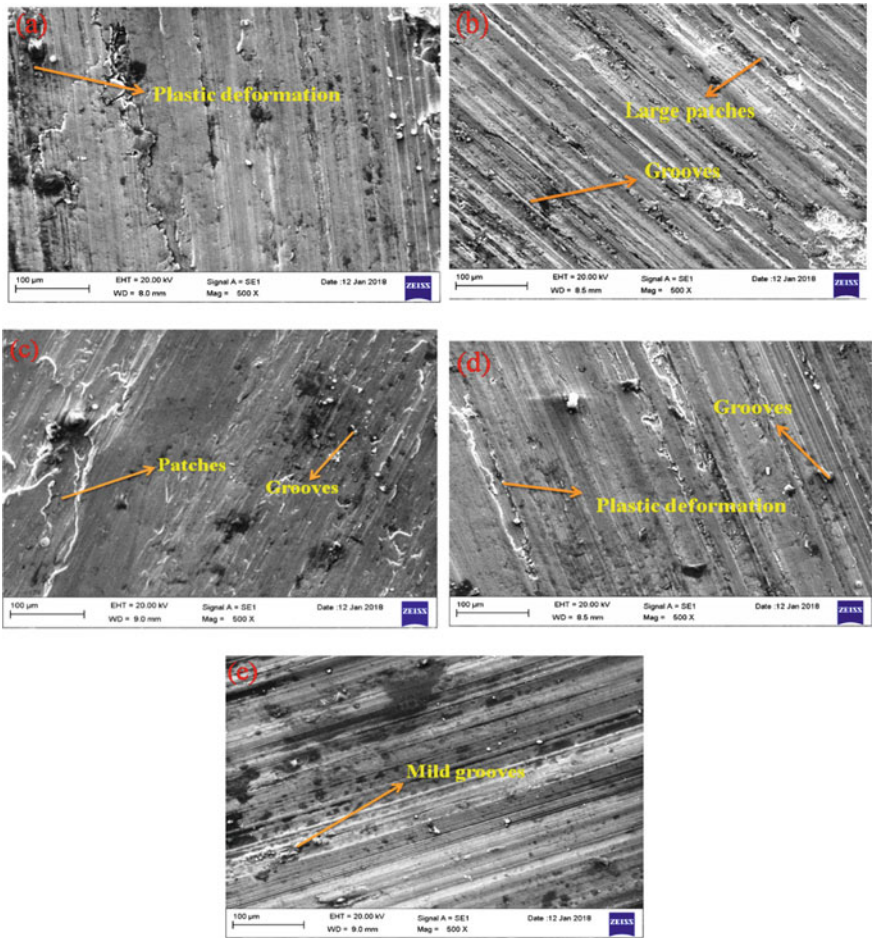

Fig. 5.6 Surface morphology of **a** 7075 Al alloy, **b** 7075/1% (SiC/B_4C), **c** 7075/2% (SiC/B_4C), **d** 7075/3% (SiC/B_4C) and **e** 7075/4% (SiC/B_4C) composite materials

SiC/4% B_4C composite strengths, minimized wear rate at all load and weight percentage of reinforcements.

5.4 Conclusions

The SiC/B_4C nanoparticles were produced utilizing the stir casting process in the form of 0, 1.0, 2.0, 3.0 and 4.0 wt% aluminium 7075 reinforced nanoparticles. Composites were invented and explored with mechanical and wear characteristics. The following conclusions have been reached from the experimental results.

- Aluminium with SiC and B_4C at different compositions were successfully fabricated through stir casting process.
- The enhancement of reinforcement particles substantially influenced the mechanical properties of the composites Al 7075 and reinforcement.
- Tensile strength and microhardness are higher for the addition of 4% (SiC-B_4C) reinforced with Al 7075 alloy in comparison to as-cast alloy. The improvement of tensile strength is attributed to the presence of high silica and boron content.
- Wear loss and coefficient of friction were reduced by the addition of SiC and boron carbide particles. The presence of hard ceramic particularly in hybrid composite was found to have more influence on the wear properties due to the presence of reinforcement particles.
- Enhancement of wear resistance of materials is due to increased hardness. Hence, 7075/4% (SiC/B_4C) composite material is more favourable in automobile sectors.

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