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Mechanical and Sliding Wear Characterization of LM14 Aluminium Metal Matrix Hybrid Composites

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Abstract: Generally, Aluminium alloys are used as the construction material for the engine pistons. This paper discusses the use of hybrid aluminum matrix composites to enhance the mechanical properties of the piston. The major components of the matrix are LM14, silicon carbide (SiC), boron carbide (B_4C) and graphite (Gr). Addition of SiC improves the strength and thermal properties of the piston. Gr addition leads to better lubrication properties, which eventually reduce the wear rate of the piston. Tensile test, hardness test, wear rate, and thermal properties are analyzed in the fabricated samples. Thus, the novel hybrid composite material was proven to withstand high temperature applications, especially for pistons. Further, the durability of the piston can be enhanced with the introduction of these matrix components.

Keywords: Hybrid Aluminium Composites, Piston Part, Durable Materials, Mechanical Characterization, Structural Analysis

1. Introduction

Metal Matrix Composites (MMC) are the mixture of additional elements in the existing alloys to replace and improve the mechanical properties of the conventional material. Its advantages over monolithic alloys provide greater demand in the market at an affordable price. Aluminum based composites show enhanced mechanical properties when reinforced, especially with ceramic particles than unreinforced Aluminum Alloys (AA). The tribological wear in the parts can be reduced, and the product can withstand for years because of its inherent properties such as high strength/density ratio and improved wear resistance. AA reinforces particles to create a composite material that significantly enhances tribological properties. Particulate MMC is commonly used for tribological applications over coated materials because of its advantages, such as lesser weight, higher load bearing capacity, and better sliding wear resistance. There are some proven results. that indicate that these composites can be used for high-abrasive wear applications [1]. In the case of AA reinforced with ceramic particles, there is a greater probability of increasing the wear resistance. The introduction of SiC and solid particles in this AA can make this composite material suitable for engine parts applications such as pistons, connecting rods, etc., where the tribology study plays a vital role in enhancing the life of the product. The B_4C and solid lubricant particles are reinforced with AA in order to enhance the wear resistance. Prabhakar *et al.* (2014) conducted wear test on aluminium/boron carbide matrix composite by varying the loads [2], velocities, and loads using a Taguchi L_{27} orthogonal array. Optimum conditions are obtained using smaller the better condition for wear rate and coefficient of friction. Birari U P *et al.* (2017) [3] investigated the tribological properties of AA 7068 plus boron carbide and graphite hybrid composite for defense. The authors have used the same stir casting method, and friction wear is analyzed using pin-on-disc wear test. Sam *et al.* (2019) developed a novel functionally graded LM14Al/12Si_3N_4/3Gr composite using centrifugal casting [4].

The authors found the minimum wear rate in the composite for an optimum parametric influence of load, velocity, and slide distance. In addition, Surappa (2003) reviewed the importance of short and long fibers in the AA based composites [5]. Kumar *et al.* (2016) also reviewed the importance of Al-B_4C for various applications of this particular composites [6]. However, the method of processing the composite also greatly influences the wear behaviour of the composites. From the literature analysis, the introduction of boron carbide and graphite combination in the LM14 cast alloys is not studied. The main aim of this work is to develop hybrid AA composites using silicon carbide, boron carbide, and graphite. The wear resistance of the aluminum matrix composites [7] is to be studied, which depends on the nature, shape, size, hardness of particles, volume fraction and distribution of particles, properties of matrix alloys, bonding between matrix and particles.

2. Materials and Methods

Experimental conditions include reinforcement type, nature of load, sliding wear distance, and sliding wear speed. The samples are prepared using the stir casting process. Materials are selected based on the properties, cost, and application. Table 1. Shows the chemical composition of LM14 cast aluminium alloy considered in this study.

The addition of reinforcement materials such as SiC and Gr solid lubricant particles (graphite and molybdenum disulphide) with aluminium LM 14 cast alloy will improve the tribological behavior of the composite materials. Table 2 shows properties of LM14 cast alloys.

Higher amount of copper and nickel content in the LM14 alloy decreases material ductility and offer greater resistance to corrosion. The iron content presence in this LM14 alloy decreases the material strength and ductility. The addition of SiC particles of size 20 microns as reinforcement increases the strength of this materials. The inherent properties of SiC particles is that it possesses higher hardness, lower specific gravity, better neutron absorption and high elastic modulus properties applicable for cermet and armor applications. Figure 1. shows the Scanning Electron Microscopy (SEM) image of SiC particles considered in this study.

Table 1. Chemical composition of LM14 cast aluminium alloy

Constituent	**Cu**	**Mg**	**Si**	**Fe**	**Mn**	**Ni**	**Zn**	**Pb**	**Al**
Weight %	1.1	1.2	11	1	0.5	0.25	0.5	0.1	Remainder

Table 2. Physical properties of Aluminium LM 14 cast alloy

Property	**Value**
Density	2,680 kg/m^3
Modulus of elasticity	72 GPa
Thermal expansion (20 ºC)	21.4×10^{-6} $^oC^{-1}$
Specific heat capacity	963 J/(kg K)
Thermal conductivity	167 W/(m K)
Electric resistivity	4.0×10^{-8} Ohm m
Heat of fusion	3.89×10^5 J/kg

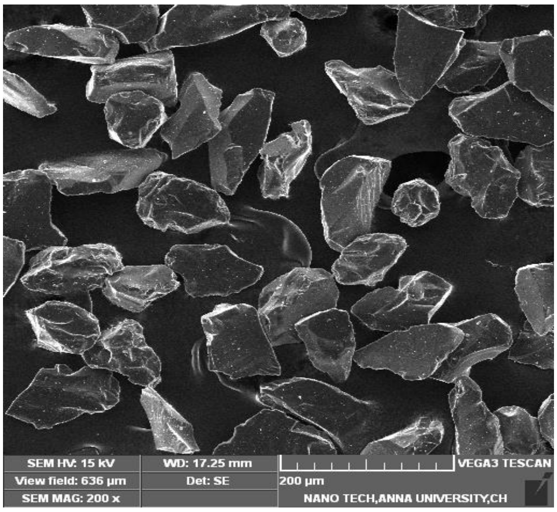


Figure 1. Morphology of SiC particles

2.1 Fabrication of MMC by stir casting

Aluminum matrix composites are usually processed with stir casting set-up as shown in the figure 2, which is the commonly available fabrication methods.

Three composite samples fabricated using stir casting are LM 14 aluminium alloy with 5% SiC particles, LM 14 aluminium alloy with 5% B_4C + 2% Gr and LM 14 aluminium alloy with 5% B_4C + 1% Gr. All the MMC samples in this study are fabricated using the stir casting method. LM 14 aluminum alloy in ingots form was stir-cast by melting at superheating temperature in graphite crucibles above 850 °C.

These processed metals need to be minimized by covering them with flux material. Sample 3 is prepared with 5% B_4C and 2% Gr particles for every 100 grams of aluminum alloy, which are preheated at 900°C. The casting mixture is mixed with a mechanical stirrer for 5 minutes at a 300 rpm impeller speed.

3. Results and Discussion

The fabricated samples are subjected to pin on disc wear tests, Vickers micro-hardness test and tensile tests at specified conditions. The results are presented in the following sub-sections.

3.1 Pin-on-disc wear test

The disc material chosen is the heat-treated EN 31 steel alloy. The raw circular block is machined to a diameter of 55 mm with a thickness of 10 mm. The hardness in the disc is maintained at an average of 58-60 HRC. Cylindrical pin sample specimens of size 8 mm in diameter and length 32 mm are used in this study for analyzing the wear rate of those samples. The test method follows pin-on-disc sliding wear testing apparatus, which follows the standard operating procedures for sliding tests.

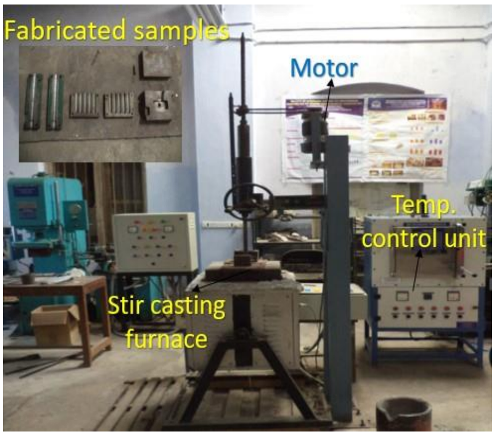


Figure 2. Stir-casting set-up and the fabricated samples

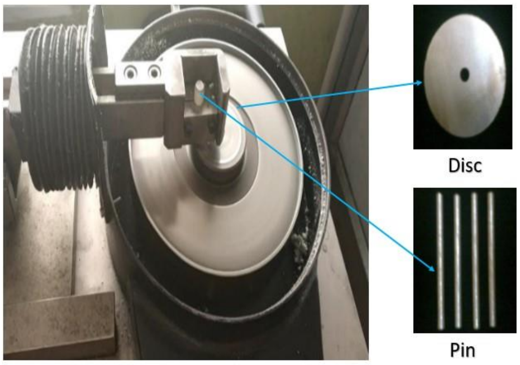


Figure 3. Pin on Disc wear testing machine

Table 3. Test parameters and machine setting for pin-on-disc wear test

Test parameters			Machine setting		
Applied load (N)	**Sliding velocity (m/sec)**	**Sliding distance (m)**	**Sliding diameter (mm)**	**Speed (rpm)**	**Time (sec)**
10	3	2000	50	500	300

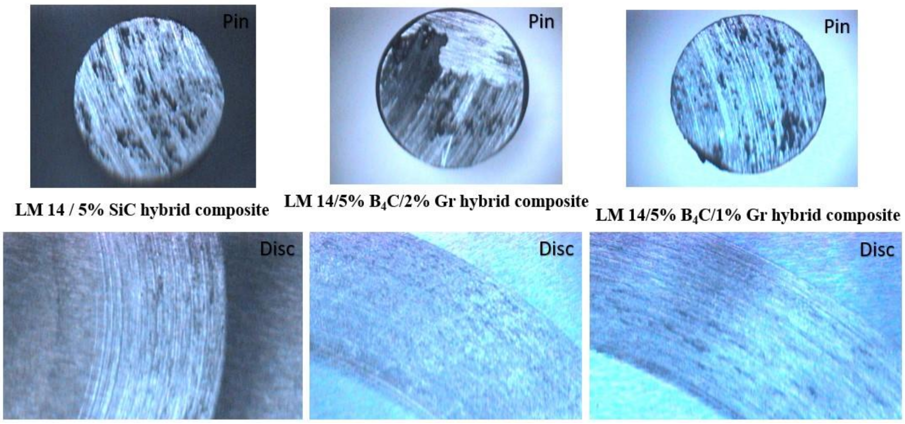


Figure 4. Worn out portions of the pin and disc for three different samples of hybrid composites considered in this study.

Table 4. Wear loss in the samples

Sample	Materials	Density (gm/cm^3)	Initial weight (gm)	Final weight (gm)	Wear loss (gm)
1	LM 14 / 5% SiC	2.78	3.275	3.271	0.12213
2	LM 14 / 5% B_4C / 2% Gr	2.75	3.355	3.353	0.5961
3	LM 14 / 5% B_4C / 1% Gr	2.77	3.461	3.436	0.72233

Materials are tested without the use of any abrasive materials. The wear rate in the samples is found from the weight loss in the samples at various test and machine setting parameters for pin-on disc testing machine as shown in figure 3.

This wear measurement system consists of a driven spindle, chuck, revolving disc, lever-arm device to hold the pin, and attachments with pin specimens to be kept against the disc at a specified load. Prior to testing, the samples are cleaned and dried by measuring their weights. Table 3. Shows the test parameter values and machine setting information of the wear tester. The wear rate has an inverse relationship with the sliding speed. But it has a direct relationship with the sliding distance and load.

Proper mass to the system lever or bale is added by calculating the appropriate force for pressing pin against disc. Three samples are tested for a sliding wear time of 5 minutes against the work piece. The samples are tested under same specified load at same time. In this study, wear loss is minimum in the sample with 5% boron carbide and 2% graphite. Figure 4. depicts the worn out surfaces of the pin-on disc with the developed samples.

Presence of Gr in these samples control the impact of wear loss rate in this study. Density is the most important factor of composite materials, which decides the weight of the composite materials. These density values are calculated using the weight of the pin and the volume of the pin**.** Table 4. shows the wear loss in different samples of the aluminum matrix alloy composites.

Wear loss is generally the amount of weight lost by the specimen during the pin-on-disc wear testing machine. The impact of wear rate in the samples can be analysed from the presence of craters, debris, or hollow surfaces present in the tested samples after study. The density of the samples is based on the amount of ingredient material, which is measured at specific time intervals. Hardness and tensile test results are discussed in the subsequent sub-sections.

3.2 Hardness test

The increased brittle nature of the LM14/5% SiC solid lubricant composites with an increase in reinforcement particles is responsible for this effect. The hardness is tested by the micro hardness testing machine. This is also connected to the digital value. This machine load is applied by the pyramid shape hardness indenter. Figure 5. Shows the Vickers micro hardness tester used in this study.

The hardness of the composite materials with varying reinforcement content is shown in Table 5. It is observed that the hardness increases with an increase in reinforcement content. This phenomenon of an increase in the mechanical properties with the addition of reinforcement particles are the key characteristics [8], which are quantitatively measured in this study.From the tabulated results, it is found that sample 1 (LM 14+SiC) combination provide higher hardness samples.

But the presence of 2% graphite in the LM14 alloy increases the hardness and the hardness values are on par with the hardness values of LM14+SiC composite combination.

3.3 Tensile Test Results

In addition, a tensile test is carried out to understand the inherent mechanical property of the composite samples. The tensile strength is higher in the samples containing graphite particles. Figure 6. shows the tensile testing machine used in this study, which has the capability up to 10 tons. The samples are prepared for tensile testing as per ASTM D3552 standards [9].

The results of the tensile testing are provided in the table 6. From the results, the third sample composite has the highest value which is LM 14, 5%Sic and 1%Gr.

Figure 5. Hardness tester used in this study

Table 5. Various roughness values of measured surface roughness in various samples

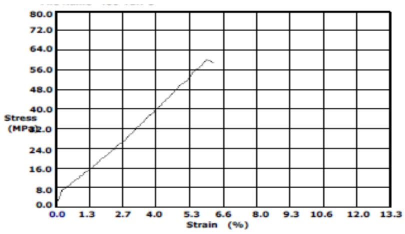
Sample	Reading 1(HV)	Reading 2 (HV)	Reading 3 (HV)	Avg. value (HV)
1	141.0	143.2	145.0	143.06
2	131.5	130.0	128.9	130.13
3	131.8	142.1	138.6	139.3

Figure 6. Tensile testing machine

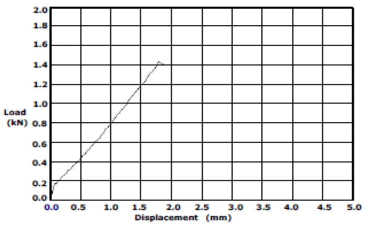
Table 6. Tensile test results

Sample	Max. tensile stress (MPa)	% Elongation	Max. displacement (mm)
1	60.16	1.43	2.4
2	83.3	1.98	3.42
3	103.49	2.55	4.03

Tensile test results of LM 14 / 5% SiC hybrid composite

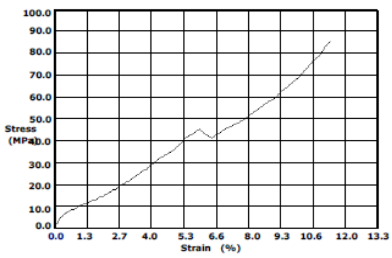


Stress vs. strain graph

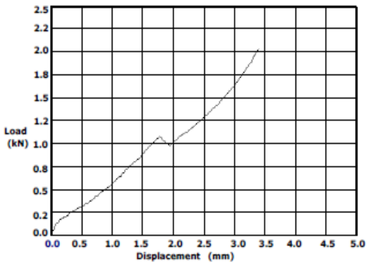


Load vs. displacement graph

Tensile test results of LM 14 / 5% B_4C / 2%Gr hybrid composite

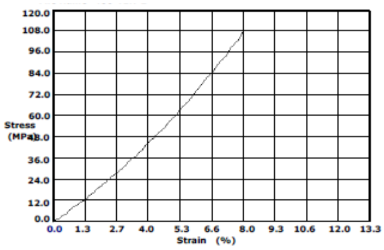


Stress vs. strain graph



Load vs. displacement graph

Tensile test results of LM 14 / 5% B_4C / 1% Gr hybrid composite



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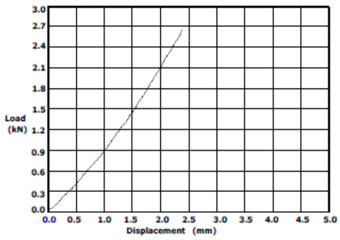

Load vs. displacement graph

Figure 7. Experimental tensile test results of various compositions of composites

The tensile test graphs for the three combinations of composites developed in this study are provided in figure 7. This type of aluminum composite can be used for automotive applications for a longer product life [10]. And the nature of the casting process can also be modified for its applications in the automobile industry. Advanced tribological studies [11] are needed to understand the importance of this hybrid composite for industrial applications.

4. Conclusions and future scope

Three different aluminium matrix composites were fabricated using the stir casting technique, and mechanical characteristics are validated in this study. Some of the conclusions obtained from this study are provided in the following points.

- The percentage of reinforcement is directly proportional to the wear resistance of the composites. An increase in the percentage of solid carbide and graphite lubricant restricts the wear rate of the composites materials.
- The tribological properties of the aluminium LM 14 alloy were considerably improved by the addition of solid lubricant particles. These solid lubricants react with aluminium and silicon

carbide particles. This forms the protective layer, which protects wear and friction.

- Three composite materials were compared for their tribological properties and higher hardness of 143 HV is obtained in the LM 14 alloy plus 5% SiC composites.
- The composite material (LM14+5% B_4C+2% Gr) shows reduced wear of 0.5961 gm by comparing with tribological properties of other composites. Because of the presence of larger amount of graphite material controls the wear rate of the composite materials.
- While composite materials such as LM 14 alloy + 5% B_4C and 1% Gr give a larger load carrying capacity of 103.49 MPa. This result is because of the presence of boron carbide and graphite in the LM14 aluminum alloy matrix composites.
- The hardness, tensile, and wear results for the tested composites provide alternate best results for the considered composites. Hence there should be a tradeoff consideration between the selections of alloying elements.

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Authors Contribution Statement

Perumal Sudalai: Investigation, Methodology, Writing - Original Draft. Madhanagopal Manoharan: Data Collection, Writing - Review & Editing, Supervision. 3. Ajithram Arivendhan: Conceptualization, Formal Analysis, Visualization. C. Rajendra Thilahar: Data analysis, Drafting and report generation, Supervision. All authors have read and agreed to the published version of the manuscript.

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Competing Interests

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Data Availability

The data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

Has this article screened for similarity?

Yes