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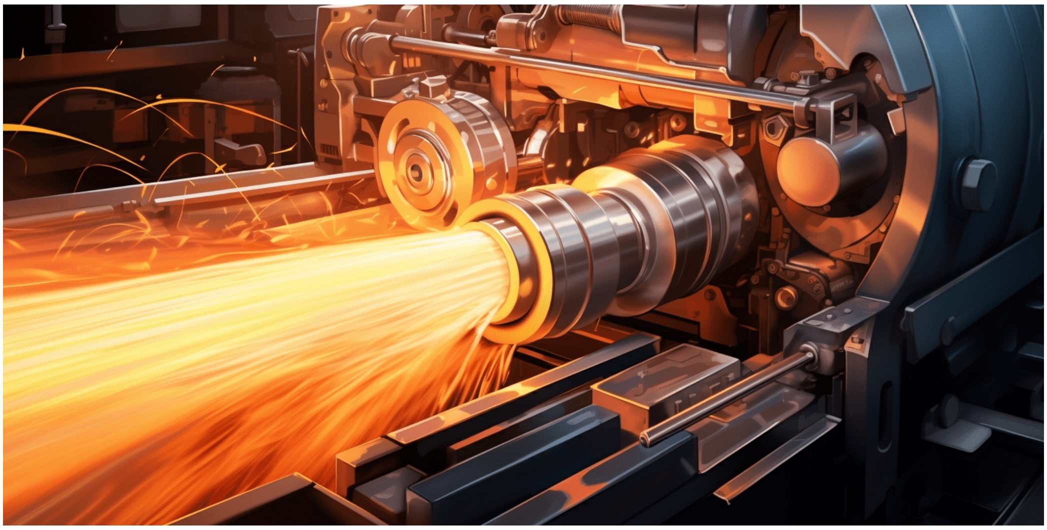

The Influence of Hot Extrusion on The Mechanical and Wear Properties of an Al6063 Metal Matrix Composite Reinforced With Silicon Carbide Particulates

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Abstract

Lightweight composite materials have gained extensive importance over other categories of materials and alloys in industrial and structural applications due to their tailorability to design and engineering for specific requirements. This article addresses the mechanical and wear behaviour study of aluminium 6063 alloy reinforced with different weight fractions of silicon carbide for 'as-cast' and 'hot extruded' conditions. The composite systems were developed using the stir casting technique, and a set of samples was further subjected to hot extrusion at 500 degrees Celsius with an extrusion ratio of 9.0. Both cast and hot extruded samples were investigated for mechanical and adhesive wear studies. The addition of reinforcement improved the mechanical properties and wear resistance, and a significant improvement in mechanical and wear resistance was observed when the samples were subjected to secondary processing through hot extrusion.

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1. Introduction

The alloys are the main constituents for the development of metal matrix composites. Aluminium is the most efficient and commonly used alloy due to its high strength-to-weight ratio, high corrosion resistance, and ease of availability. Aluminium alloys have become popular in the automobile, aerospace, recreational, and construction industries. Base aluminium alloys provide good mechanical, physical, and chemical properties, but reinforcing aluminium alloy with ceramic particles will improve its mechanical as well as tribological properties [1]. Composites can be fabricated by liquid metallurgy or solid metallurgy; many researchers prefer liquid metallurgy over solid metallurgy because it is inexpensive and more cost-effective for mass production. Stir casting is the simplest and least expensive method of processing [2]. Non-uniform dispersion of particulates due to poor wettability and gravity-regulated segregation is a common problem with the stir casting technique. It is critical to avoid the reinforced material forming an intermetallic compound with the matrix element [3][4]. To improve their physical and mechanical properties, aluminium alloys are reinforced with ceramic particles such as SiC, CeO_2, TiO_2, and others. Several aluminium alloy series have been used in industries; the most popular are the Al 6000 and Al 7000 series due to their ease of fabrication, low cost, and machinability. A.M. Xavior et. al [5] developed composites considering aluminium alloys from the 2xxx series as the matrix and SiC and Al_2O_3 as reinforcements by the powder metallurgy route. The composite had 1.5 times the compressive strength of the peak-aged aluminium alloy 6061. The molten metal and ceramic foam only slightly reacted. Microwave sintering was used to process the aluminium reinforced with silicon carbide at 5 vol% at a sintering temperature of 770 °C and a pressure of 250 MPa [6]. Many researchers have attempted to develop metal matrix composites with widely available reinforcements such as graphite, silicon carbide, titanium carbide, tungsten, boron, Al_2O_3, Al-Mg, ZA27, and TiB2[7][8][9][10].

The wear coefficient is a more precise measure of material wear behavior. Kalyan et al.[11] investigated the effects of composite wear life under various normal loads and sliding speeds. When a composite is composed of a base aluminium matrix alloy in a dry lubricated condition, the coefficient of friction was significantly reduced. In dry sliding wear conditions, titanium di-boride (TiB_2) demonstrated improved wear performance and a decrease in the coefficient of friction[12]. The challenge with primary processed metal matrix composites is the non-uniform reinforcement distribution caused by poor wettability, which leads to porosity. To address this issue, researchers are exploring secondary processing techniques such as forging, rolling, and extrusion. In light of the foregoing, the current study aims to characterise aluminium 6063 matrix composites reinforced with silicon carbide in powder form of lab grade with weight fractions ranging from 0 to 8wt%. For developing composites, the liquid metallurgy route stir casting technique was employed. The developed composites were further subjected to post-cast, secondary processing (hot extrusion) to investigate the effect of extrusion on their mechanical and wear properties.

2. Experimental work

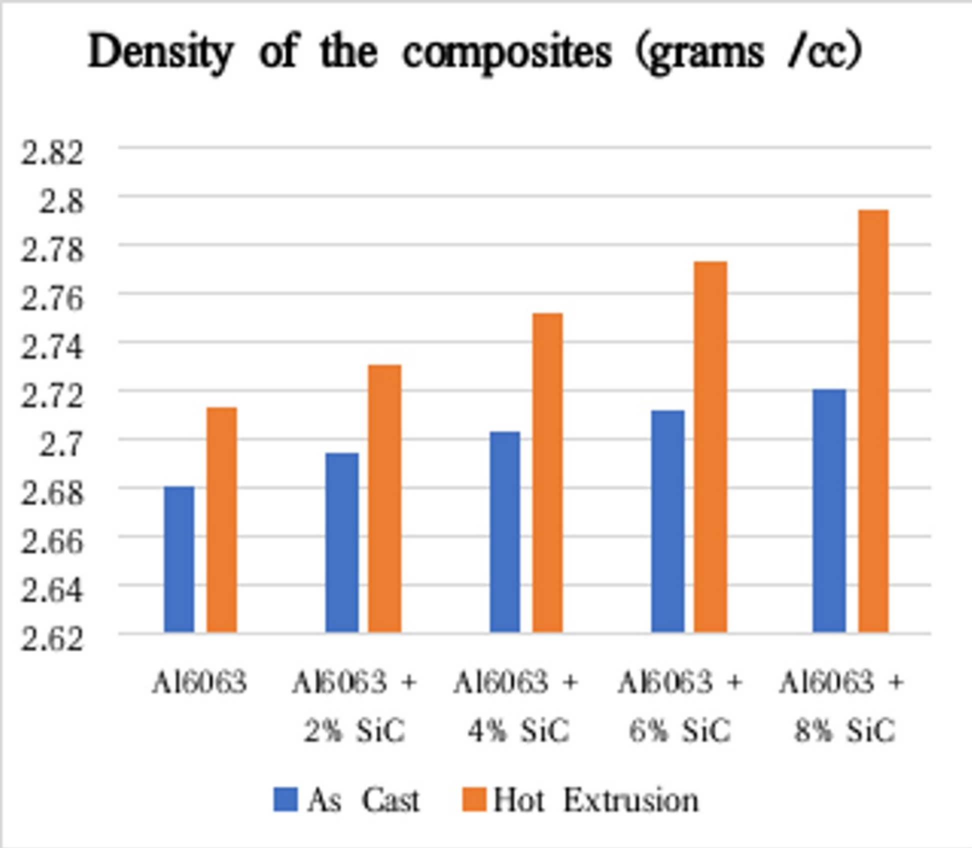
2.1. Fabrication of the composite

Al6063-SiC composites were fabricated using a liquid metallurgy route (stir-casting). The aluminium ingots were procured locally and melted in an electric resistance furnace to molten liquid form. The reinforcement, silicon carbide, is preheated to 400°C to remove moisture and trapped gases. The pre-heated silicon carbide was introduced into the molten aluminium at a predefined weight percentage. A continuous stirring process was carried out using a mechanical stirrer to ensure the reinforcement and matrix alloy are assorted. The molten melt temperature was maintained at 720°C, and the stirring process was continued for 10 minutes at a speed range of 300-400 rpm. The developed molten melt was then poured into permanent moulds that were pre-heated to 200°C to drive out moisture. The stirring speed, duration, and temperature, which are crucial parameters, were meticulously considered [13]. Subsequent hot extrusion processing was executed for the cast composite. The hot extrusion operation was carried out on a 500-ton extrusion press at an extrusion temperature of 550°C, an extrusion ratio of 9.0, and a ram speed of 2 millimeters per second. For mechanical and wear testing, all the developed composite specimens were machined in accordance with ASTM and IS standards. Tensile and compression tests were conducted as per ASTM B557M and ASTM E-9 standards. Al6063 and its developed composite systems were subjected to a tensile test on an FIE (Fluid Instruments and Engines) machine with a 400 kN capacity. Vickers microhardness tests were performed on all samples as per ISO 6507. The polished samples were subjected to microhardness tests on a Shimadzu Microhardness tester. The microhardness was determined by applying a 10 N load for 20 seconds. The specimens were prepared as per the IS1757 standard for the charpy impact test. The notch is located at the bottom, opposite to the hammer. An adhesive wear test was performed on a standard pin on a disc wear test rig as per the ASTM G99 standard. Wear test samples for various loads ranging from 10 N to 60 N in steps of 10 N at a constant speed of 100 rpm and a constant track radius of 0.2 m were used to study the wear rate of both the matrix alloy and its composite system.

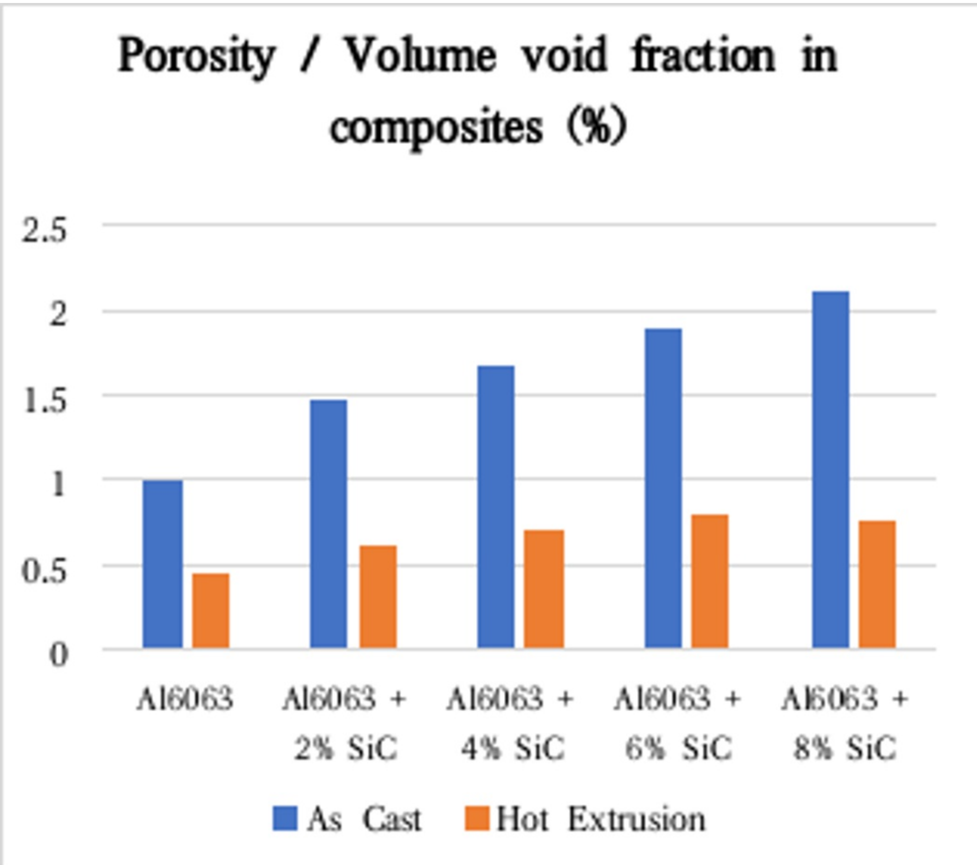
3. Results and Discussion

3.1. Density and porosity

The density test was conducted on all prepared composite systems, for both the as-cast and hot extruded conditions,



Graph 1. Density of composites with different reinforcement percentages in as-cast and hot extruded conditions.



Graph 2. Porosity of composites with different reinforcement percentages in as-cast and hot extruded conditions.

Graphs 1 and 2 show the density and porosity of the developed composite systems with varying weight percentages in the as-cast and hot extruded conditions.

The results reveal that the density continued to increase with increasing weight fractions of reinforcement in composites. Due to differences in the density and mechanical structure of crystals and the atomic arrangement in ceramic reinforcements, density exhibits a relative enhancement with the increasing weight fraction of reinforcement. This is consistent with the findings of other researchers such as Hima et al[14]. Density improves further in postcast processing by 1.2%. This is due to strain hardening and the atomic compacting of composites, which results in optimal interstitialcy and atomic substitutions at elevated temperatures (generally in a higher state of temperature), a similar observation found with other researchers [15][16].

It was noticed that the porosity of the composite is mainly influenced by the particle size of ceramic reinforcements; thus, as the volume fraction of reinforcement is increased, porosity is also increased due to the inhomogeneity of the alloy and the reinforcing element at the atomic level and the particulate nature of reinforcements. Mohanakumar et al. [17] reported that the porosity percentage was significantly reduced in the secondary processing extrusion when compared with the cast composite.

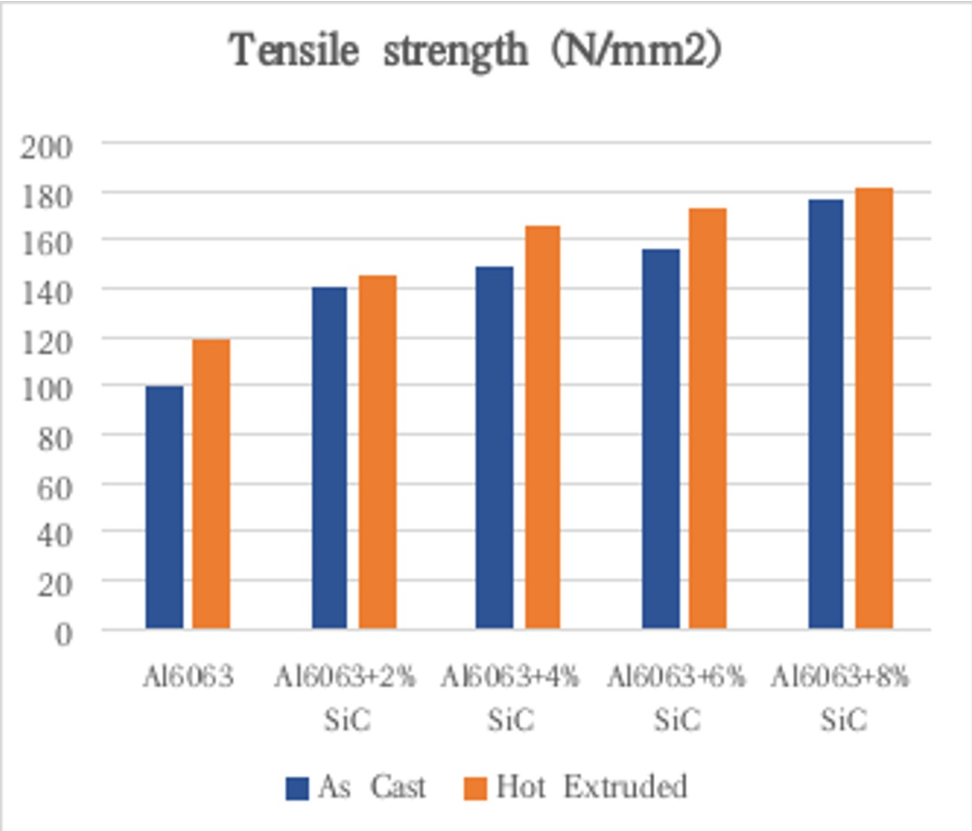
3.2. Tensile test results

Tensile tests were performed under controlled conditions on composites containing varying weight fractions of SiC reinforcements of 2%, 4%, 6%, and 8%, as shown in Fig. 1.

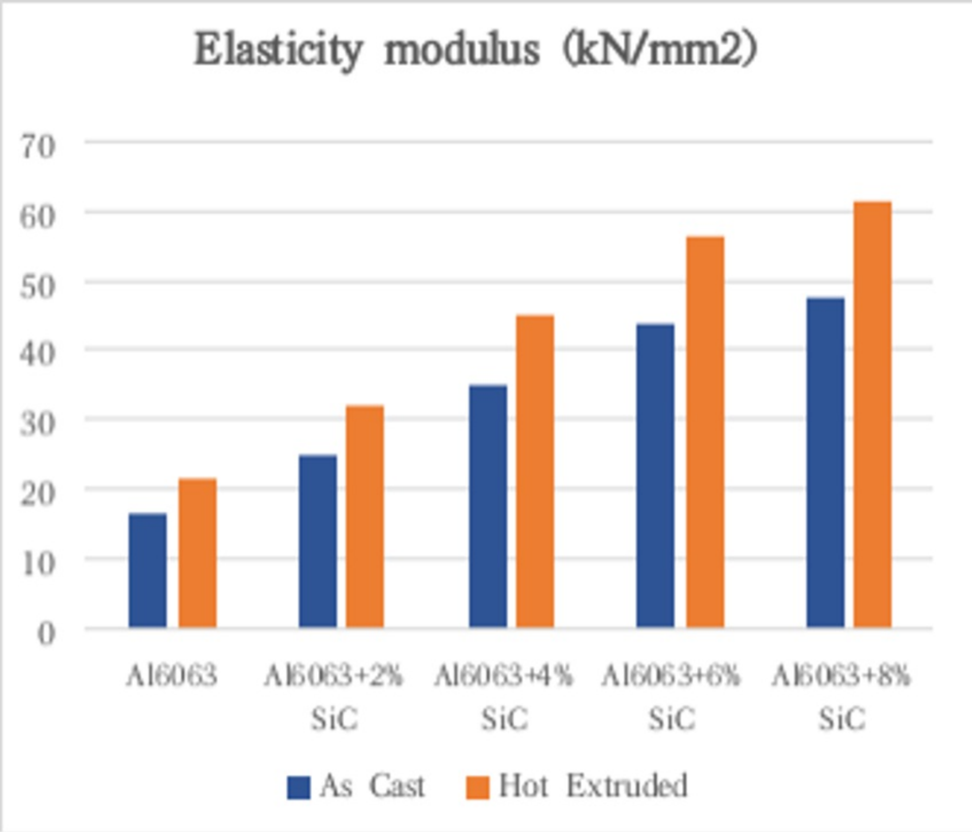
Fig. 1. Tensile tested specimen

The test results were compared to those of the unreinforced Al6063 alloy. The ASTM E-8 standard was followed in the test, and testing standards were carefully studied. Three specimens were tested for each sample to statistically optimise the test data. The mechanical testing data were used to calculate the tensile properties and the strength of the composites, resulting in tensile strength and elasticity modulus. The elongation of the material is observed to decrease with the incorporation of ceramic reinforcements. A similar observation was made by another researcher [18]

The elasticity modulus of composites with SiC reinforcement had a significant effect on tensile strength. Tensile strength was improved by 78% with an increased reinforcement quantity in composites. Furthermore, with post-cast conditions of hot extrusion, tensile strength was improved as observed in graph 3. The Young's modulus of the composites was improved at a maximum reinforcement of 8%, as seen in graph 4.



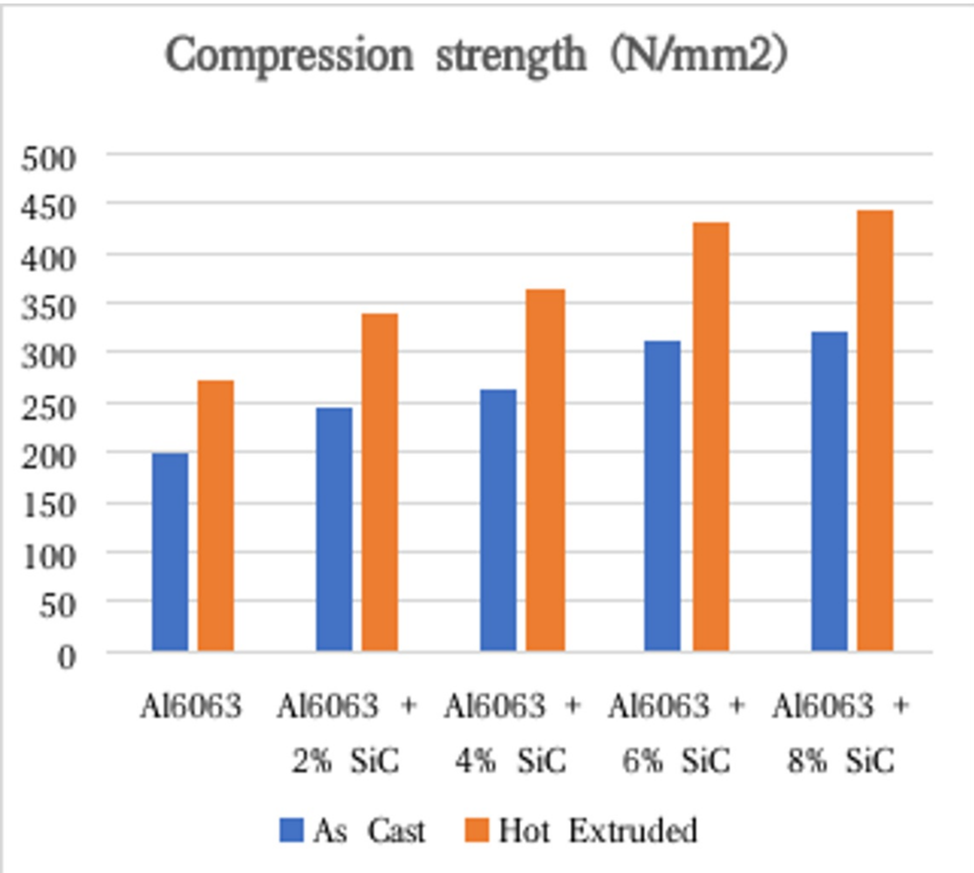
Graph 3. Tensile strength effect on the progressive integration of SiC reinforcement from 0% to 8% in as-cast and hot extruded conditions.



Graph 4. Young's modulus effect on the progressive integration of SiC reinforcement from 0% to 8% in as-cast and hot extruded conditions.

3.3. Compression test

Fig. 2. Samples of the compression test specimen



Graph 5. Compression strength for the effect of the progressive integration of reinforcement under cast and hot extruded conditions.

The crushing of SiC-reinforced composites was observed to be steady due to the optimal mixture of SiC into the aluminium alloy. Compression strength was increased by 62% for a maximum SiC reinforcement of 8%, as seen in graph 5. The fracture behaviour of silicon carbide-reinforced composites was found to be identical to that of the as-cast condition, with progressive integration of SiC reinforcement resulting in a harder and stronger material under compression.

3.4. Vickers hardness test

The investigation revealed that reinforcement has a significant impact on hardness. The hardness of the material increased as the quantity of reinforcement increased, and it demonstrated linear improvement with systematic doping of particulate reinforcement. For a maximum weight fraction of 8%, silicon carbide has the highest hardness. Hot-extruded aluminum-based composites have influenced hardness because the pressurized and hot work of the material has evidently resulted in the compacting of crystals under mechanical and thermal loads, resulting in a greater atomic packing factor in the material and thus increased atomic density, which has improved hardness. This is coherent with the observations of other researchers. [19][20]

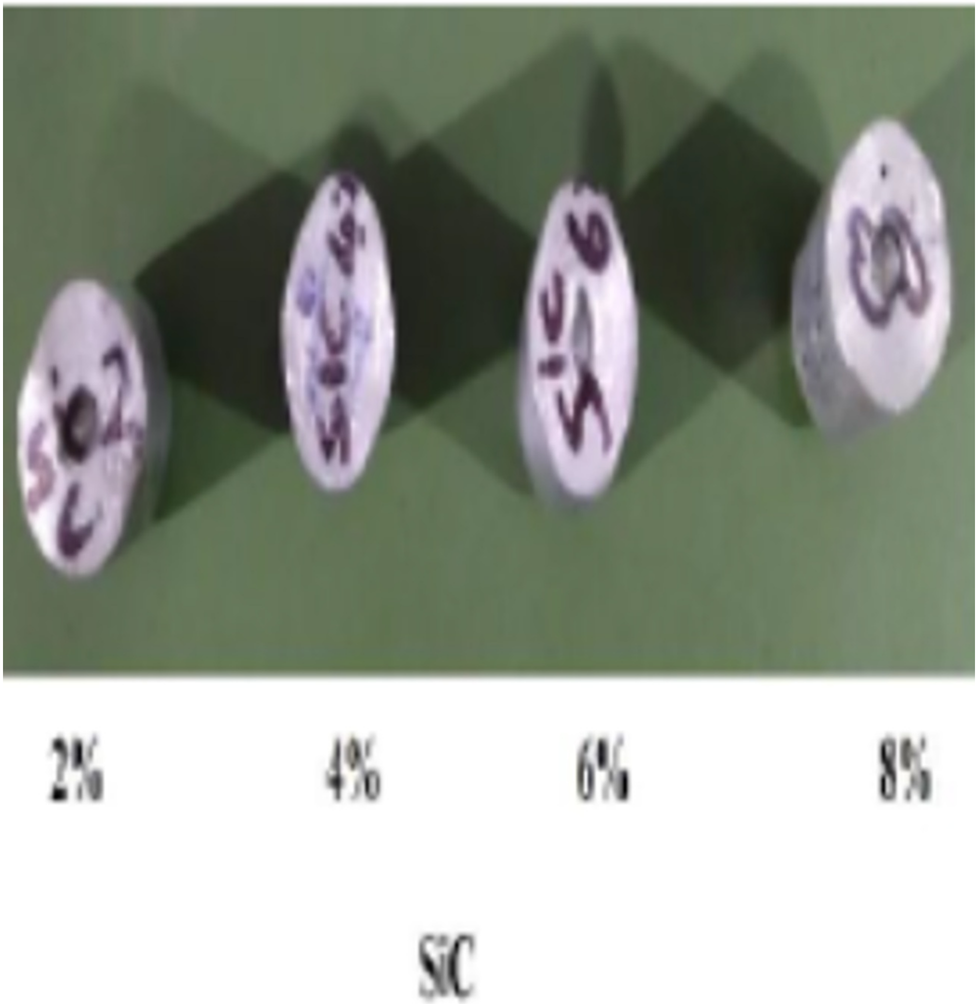
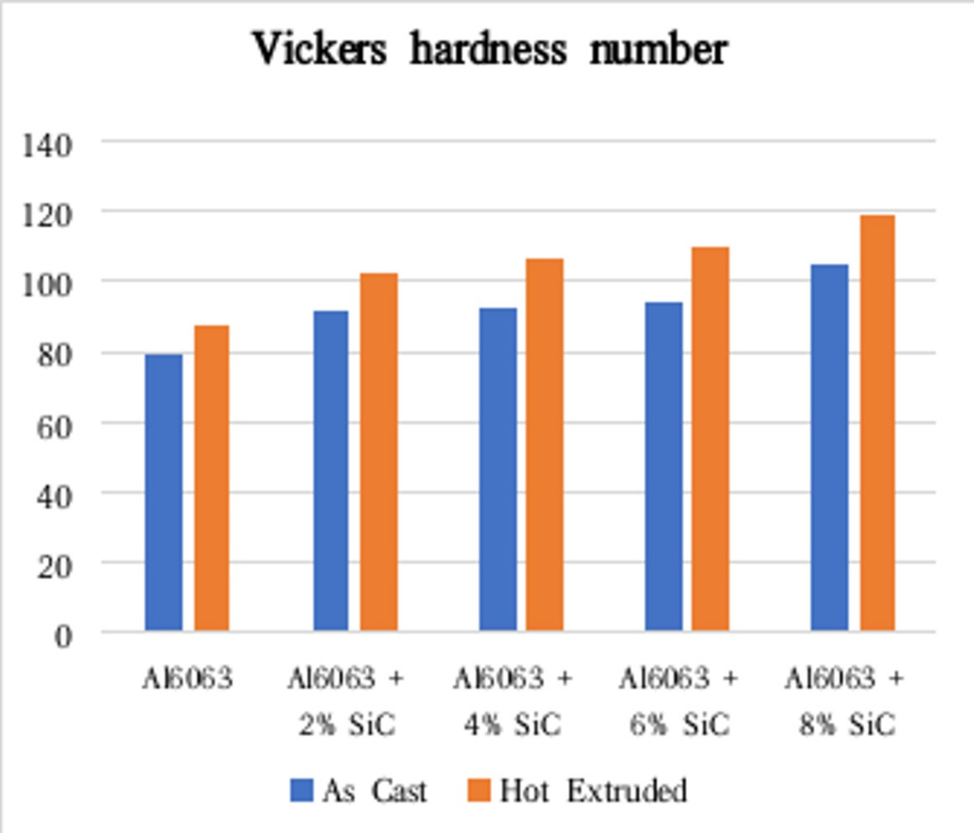


Fig. 3. Specimens tested for hardness using a Vickers hardness tester



Graph 6. Hardness of composites by varying the percentage of reinforcement in the as-cast and hot extruded conditions

3.5. Impact test

Graph 7 shows that the impact strength of the material has an adverse effect on composition and showed depleting impact strength as the reinforcement quantity increased. This is due to the fact that densification of the material increased hardness, which increased brittleness and thus resulted in crack propagation by intergranular augmentation, and thus the material failed due to embrittlement of the material due to the intense doping of ceramic reinforcements causing over-interstitialcy and a reduction in the ductile nature of the material, as observed in other research findings[21][22]. Due to its high-temperature working environment, the hot extrusion process has significantly reduced the distortion of impact strength, and recrystallization of the material has aided in the effective doping and arrangement of atoms in their orientation, which has resulted in atomic bonding, allowing it to withstand impact loads, in agreement with similar findings from other researchers [23]

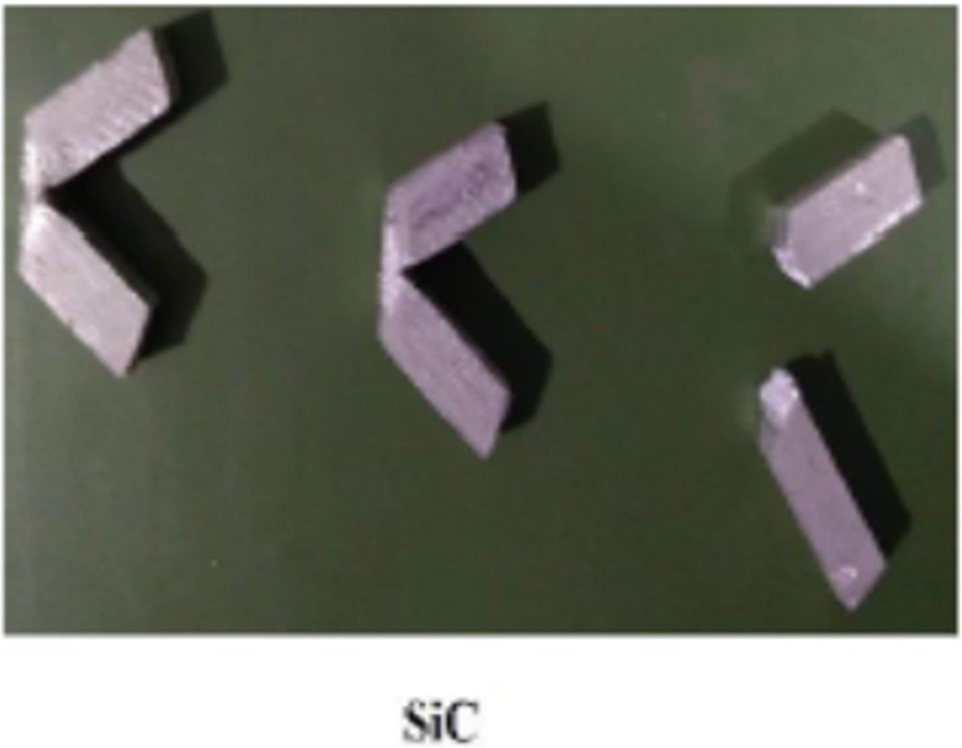
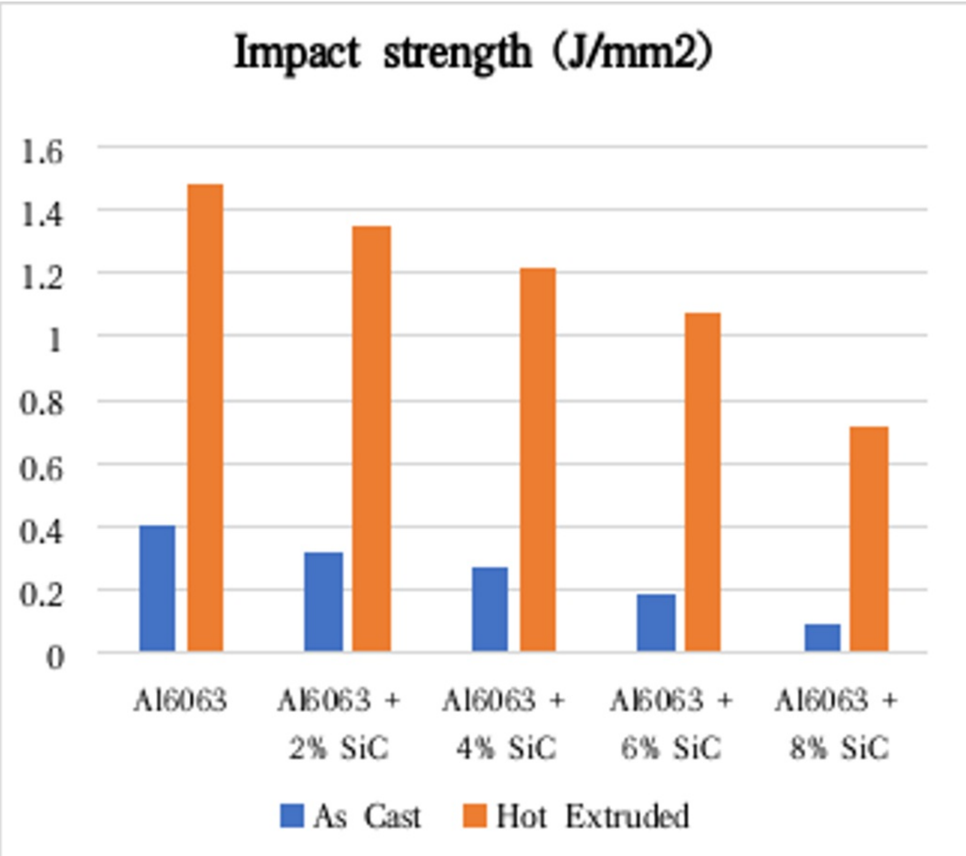
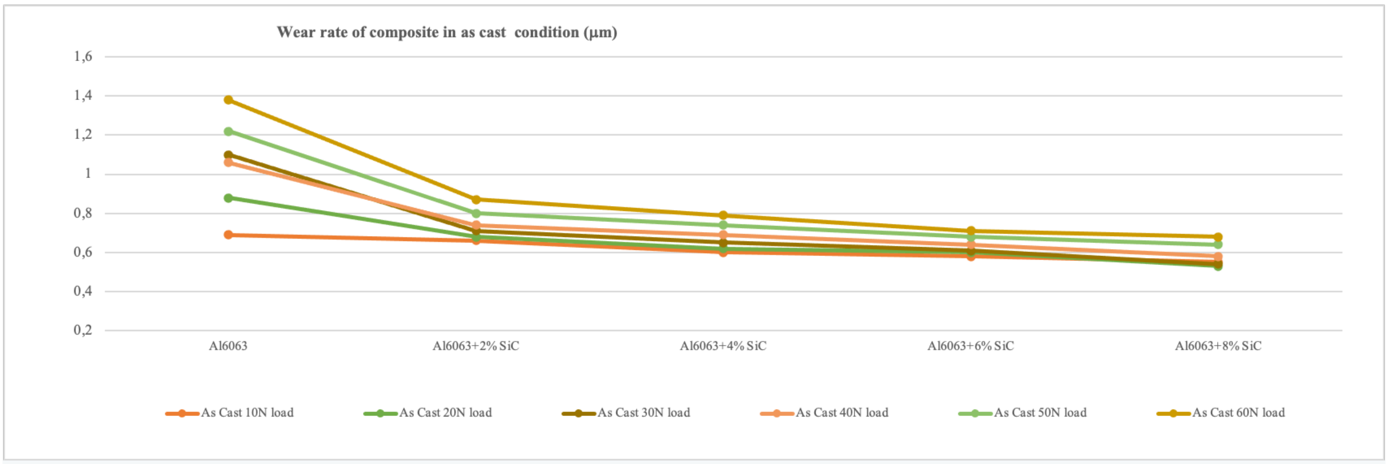


Fig. 4. Specimens tested under Charpy impact

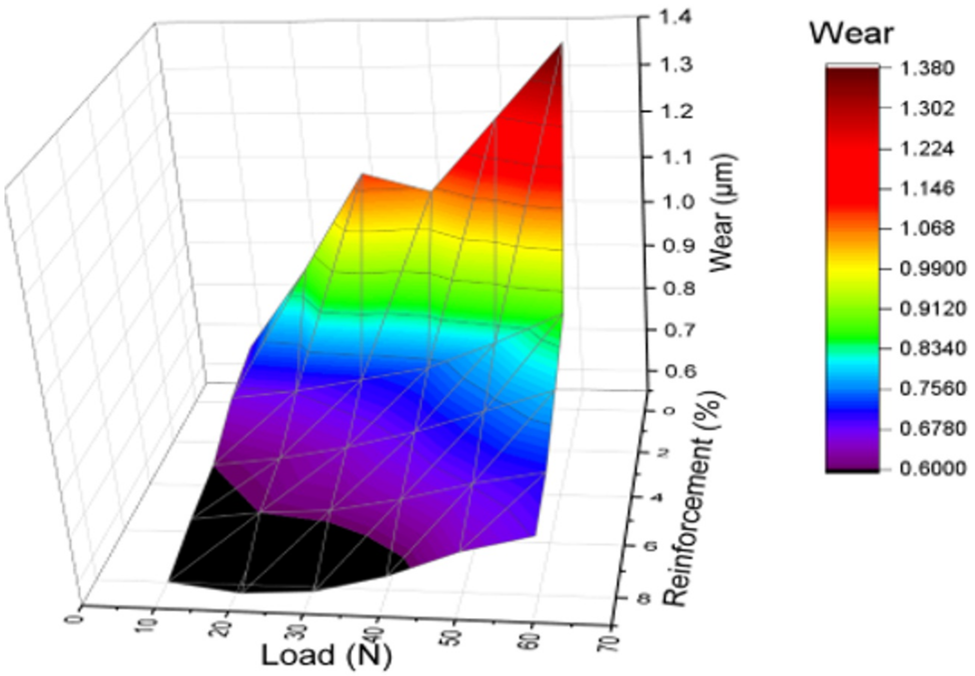


Graph 7. Impact strength of composites with varying percentages of reinforcement in the as-cast and hot extruded conditions

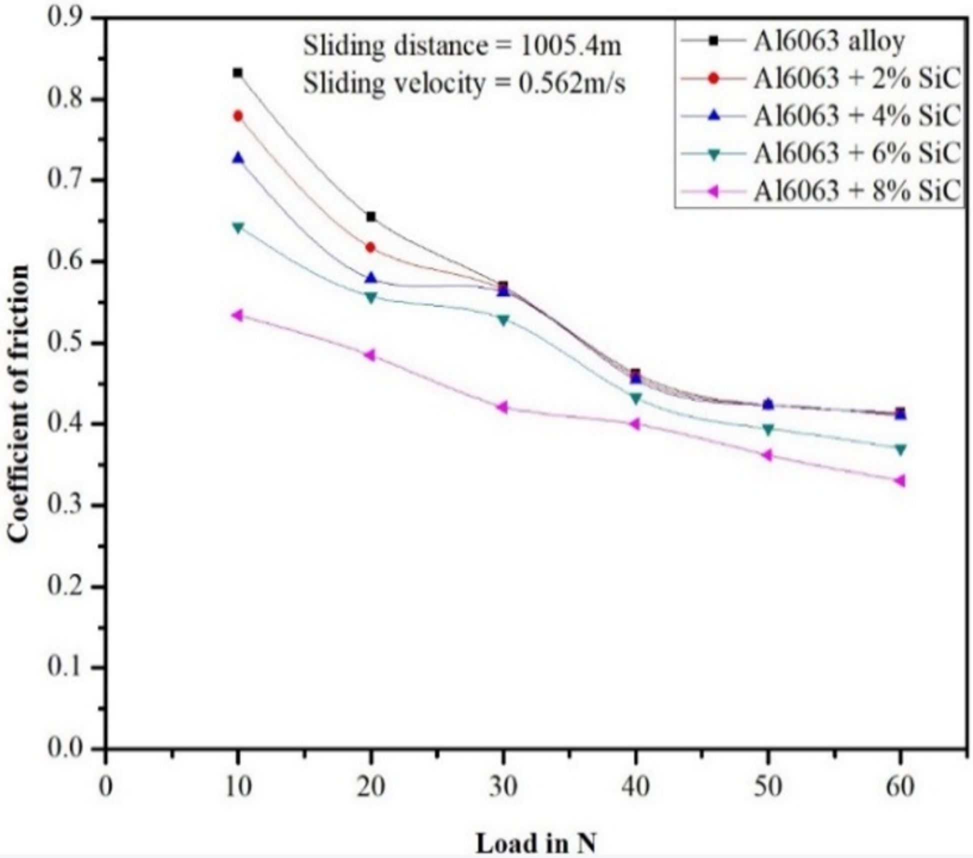
3.6. Adhesive wear test



Graph 8. Wear rate of composites in the as-cast condition under different loads, reinforced with a silicon carbide reinforcement.

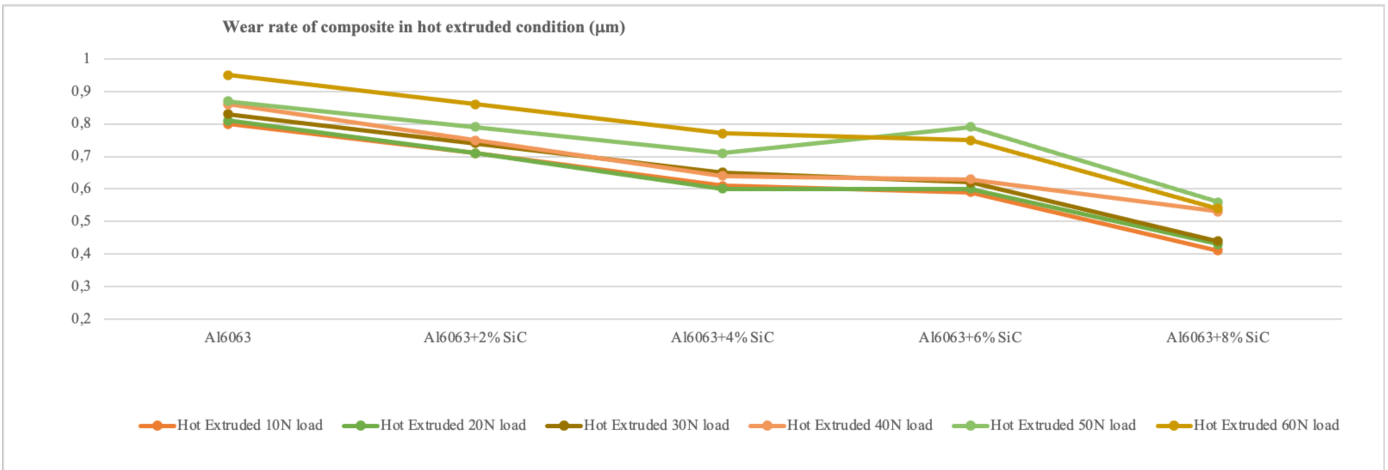


Graph 9. Effect of load and reinforcement on the wear rate of SiC-reinforced composites in the as-cast condition.

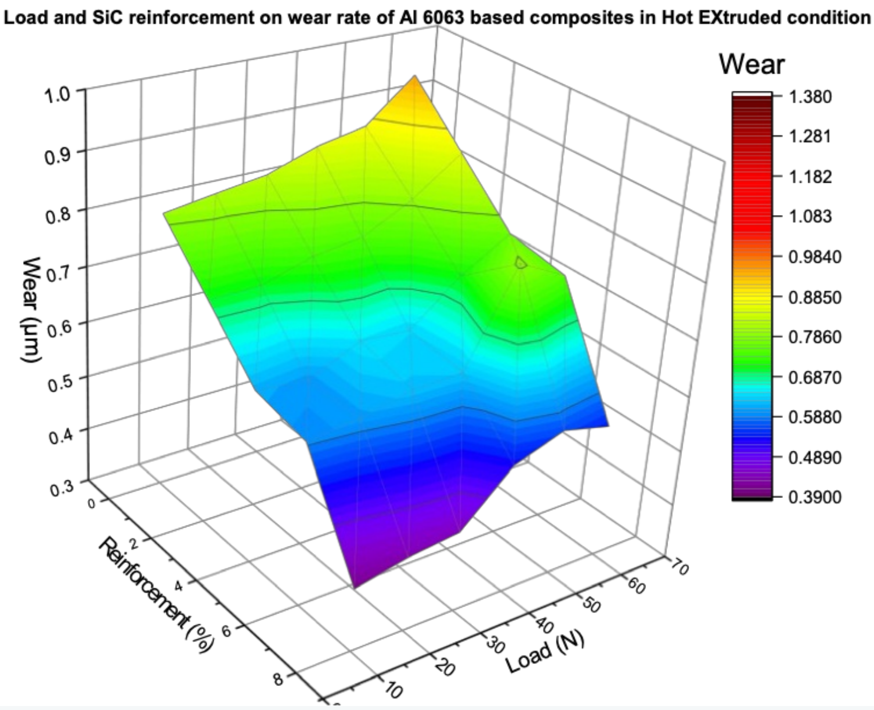


Graph 10. Coefficient of friction of composites by varying the weight of SiC reinforcement at different loads in 'as cast' condition.

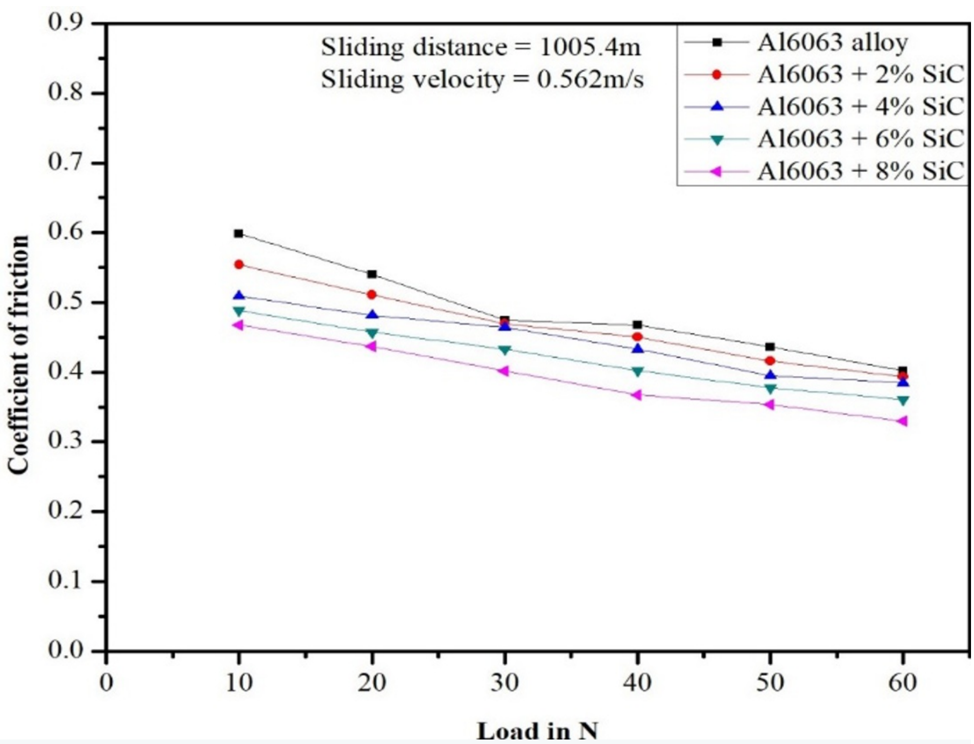
Graphs 8-10 show the wear rate and coefficient of friction for various loads for a composite reinforced with SiC with various weight fractions under 'as cast' conditions.. Similar observations have been made by other studies [24][25]



Graph 11. Wear rate of composites in the hot extruded condition under different loads, reinforced with Silicon carbide.



Graph 12. Effect of load and reinforcement on the wear rate of SiC reinforced composites in the hot extruded condition.



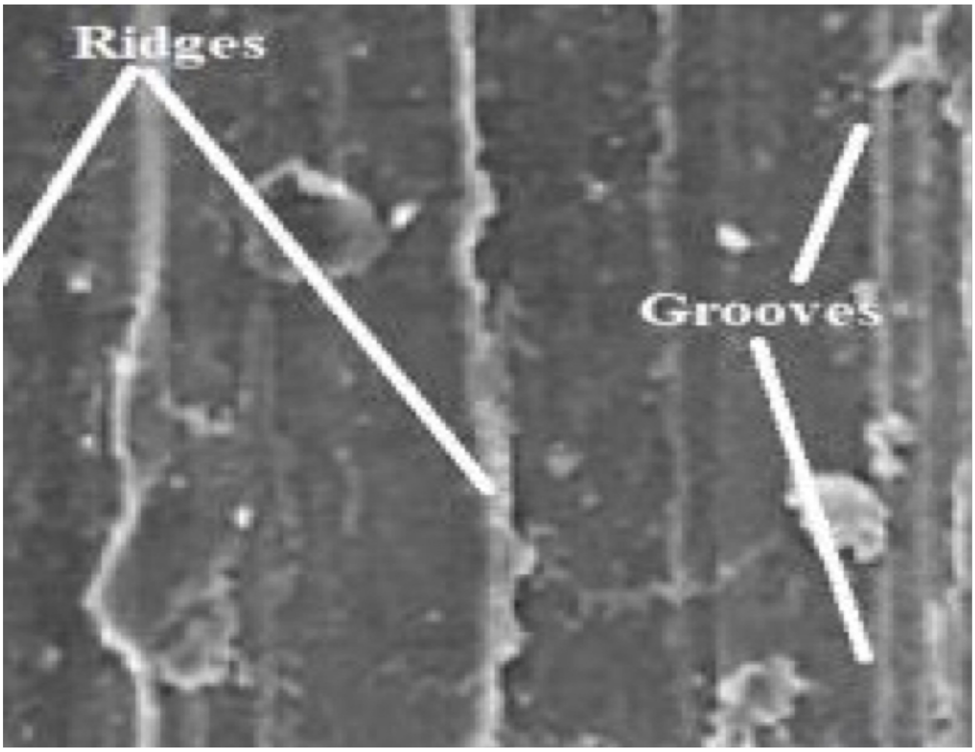
Graph 13. Coefficient of friction of composites by varying the weight of SiC reinforcement at different loads in the hot extruded condition.

Graphs 11-13 show the wear rate and coefficient of friction for various loads for a composite reinforced with SiC with various weight fractions under 'as cast' conditions.

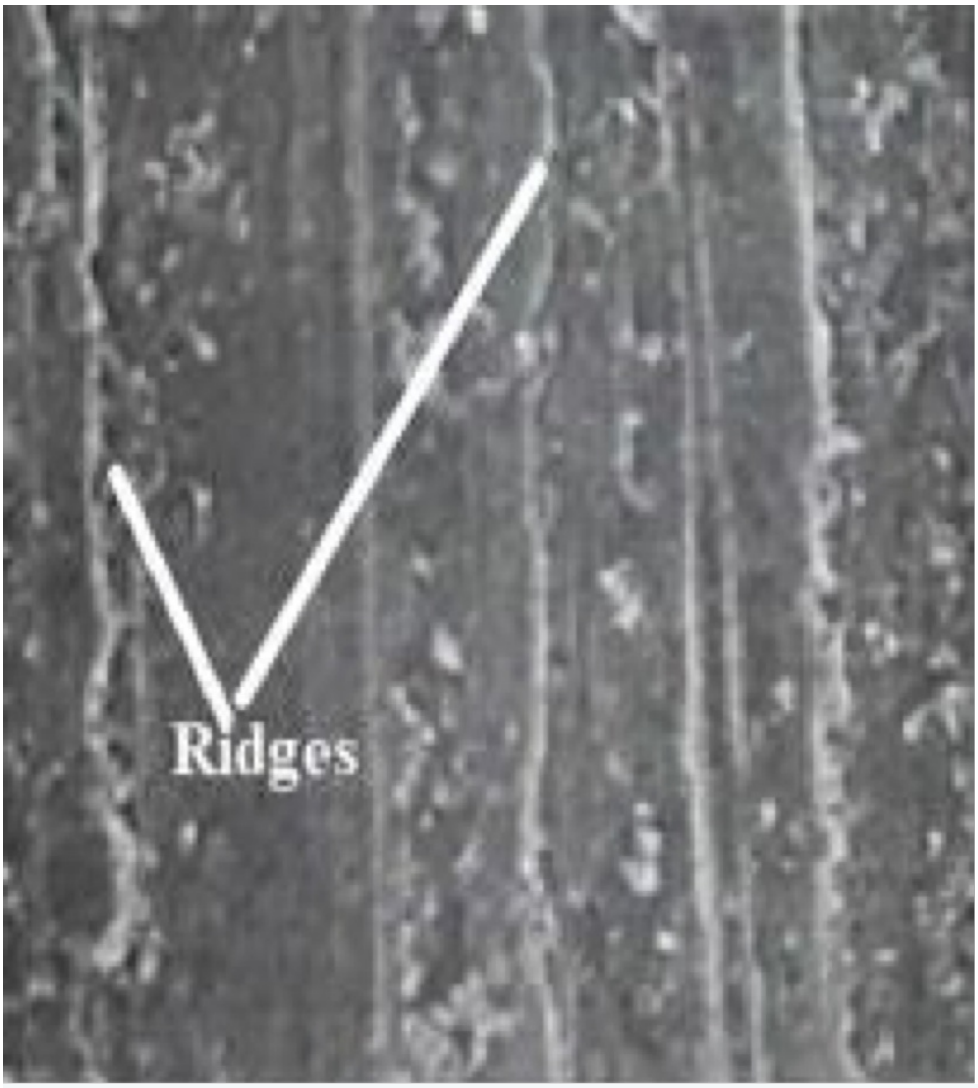
From the above graph, 8-13 wear rates for the developed composite system under as-cast and hot extruded conditions, the graph reveals that as the load increases, the wear rate of the composite also increases due to higher contact pressures and increased adhesive forces. The wear rate is almost linear as the applied load is still considered as a lighter load. The wear rate is linearly reduced with an increase in reinforcement percentage; also, the hot extruded composite shows a significant impact on improving the wear rate of the developed composite. It is observed that material transfer between the composite and the counterpart material in the as-cast condition is reduced in the hot extruded condition. The coefficient of friction was high in the as-cast condition, whereas in hot extruded composites, it is found to be relatively low, reflecting the prevalence of adhesive wear and less abrasive interaction due to the high compactness of composites developed under high pressure and temperature in the hot extrusion process. This results in smooth wear tracks with some material transfer and plowing. Wear track morphologies change with varying loads, and it is observed that different wear mechanisms are dominating at different loads, as seen in graph 14-17... A similar observation was made by other studies [24][25][26][27][28]

3.7. Surface micrograph study of wear

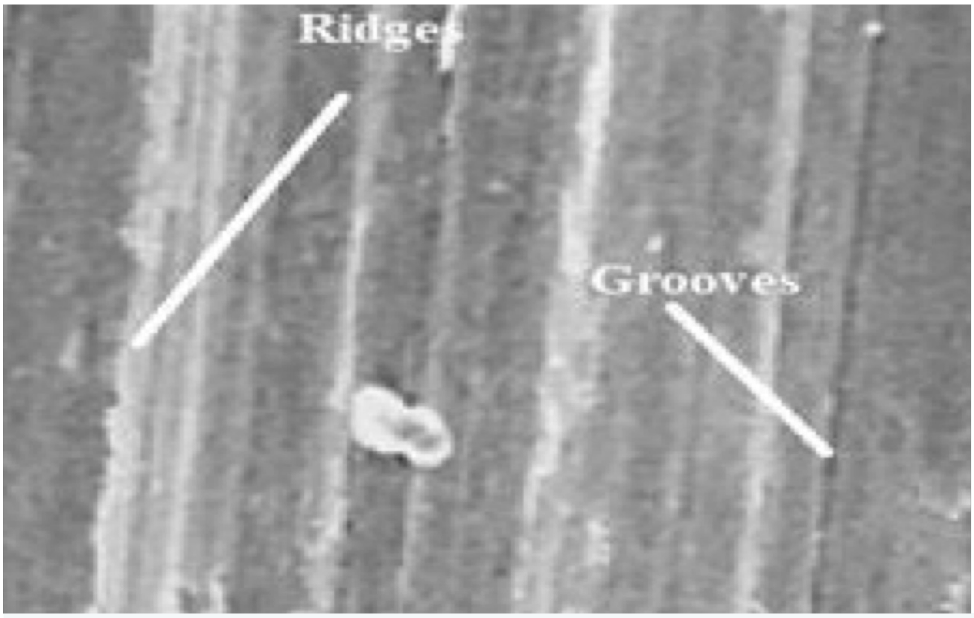
In the micrographs, it is seen that material was removed due to adhesion and abrasion in the sliding wear mechanism. Graph 14 represents the micrograph of the worn surface of the Al 6063 alloy, in which it is seen that the alloy formed ridges, grooves, flash, and wedges due to the soft nature of the material. The SiC-reinforced composite has shown resistance, and hence not much debris or flash is seen, but it formed ridges and grooves due to the residual wear track. This is in accordance with other researchers [29]



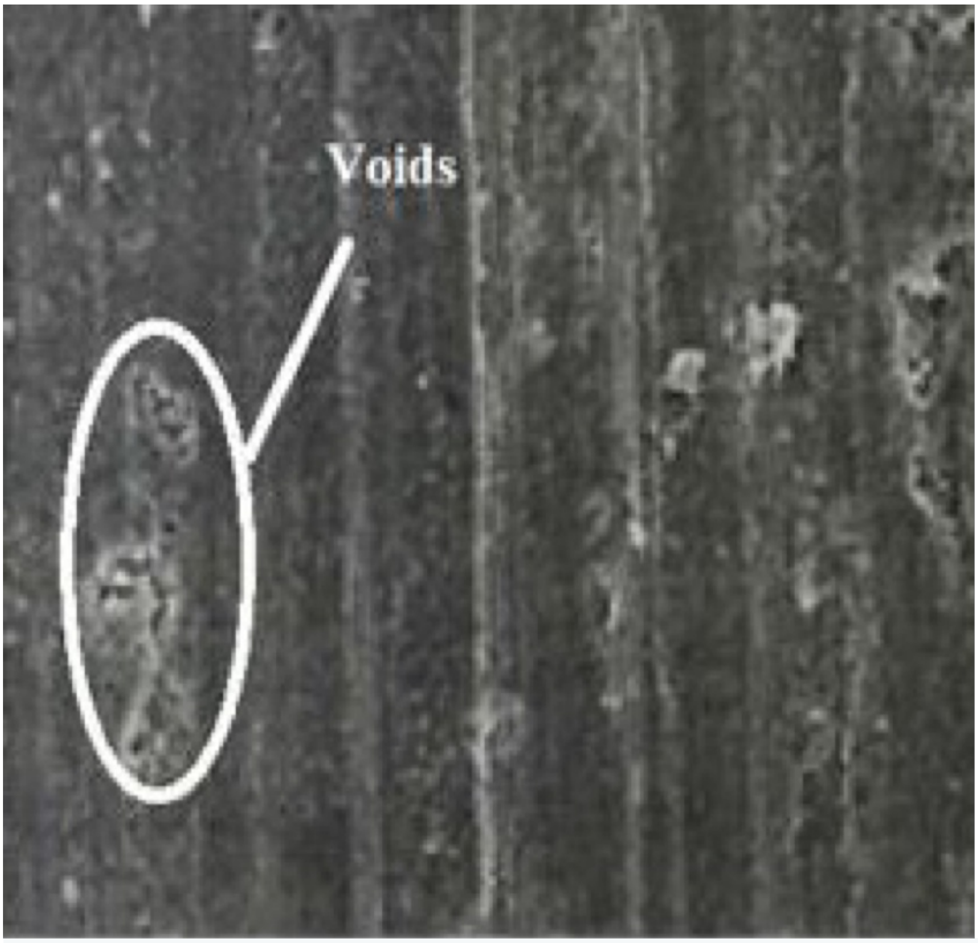
Graph 14. SEM micrographs of the wear surface of reinforced composites in the as-cast condition: Al6063 without reinforcement



Graph 15. SEM micrographs of the wear surface of reinforced composites in the as-cast condition with 8wt.% SiC



Graph 16. SEM micrographs of the wear surface of reinforced composites in the hot extruded condition, Al6063 without reinforcement



Graph 17: SEM micrographs of the wear surface of reinforced composites in the hot extruded condition with 8wt.% SiC

Hot extruded materials have higher material hardness and thus a lower wear rate. The hot extruded alloy Al6063 formed ridges and grooves in graph 17, indicating that the extrusion process reduced the wear rate. Wear debris is primarily composed of fine particles, such as aluminium and SiC, and may show signs of mild deformation and adhesive transfer. It indicates adhesive wear behaviour by showing material transfer from the counterpart material to the composite surface or vice versa.

4. Conclusion

- The density of the composites increased proportionally to the percentage of reinforcement. The highest density was observed with 8% reinforcement. In hot extruded Al 6063, the volume of voids or porosity was found to be reduced by 54%.
- The mechanical properties of the composites improve significantly with the addition of reinforcements before extrusion. The hot extrusion samples showed even more improvement.
- In the hot extruded composite, the grains were noticeably refined, and the reinforcement layers were considerably dissolved, reflecting the effective diffusion and doping of reinforcement atoms into the Al 6063 matrix.
- The wear rate of the composites decreased as the reinforcement quantity increased, as the form and quantity of reinforcement demonstrated the tribological advantage of materials.
- Topographic analysis of the worn surfaces of sliding wear observed under SEM and the optical specimen under sliding wear revealed less wear and tear.

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