Influence of SiC Particles on Microstructure, Hardness, Tensile and Wear of Al6061

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Abstract:
Aluminium matrix composites (AMCs) have significant opportunities for essential automotive, defense, aerospace, marine, agricultural, and nuclear engineering applications. Over other conventional alloys, particle-reinforced AMCs have higher mechanical characteristics and enhanced wear resistance. The present work presents experimental findings on the tribological and mechanical characteristics of Al6061-SiC composites. Stir casting has utilized to manufacture Al6061 composites with 1,3 and 5 wt.% SiC. The AMCs' homogeneous distribution of SiC particles has shown applying scanning electron micrographs. According to the experiments' results, the composites' density and hardness increase as the percentage of SiC enhances. Composites wear resistance with 5 wt. % SiC was superior compared to the matrix material.
Keywords: AMCs, Hardness, MMCs, SiC, Stir-casting process, Wear resistance
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1. Introduction

Metal-metal composites (MMCs) are made of metals and other metals or non-metals, such as ceramics or organic substances [1], [2]. MMCs were designed to solve the requirement for materials with higher specific wear resistance, stiffness, and strength [3]. Aluminum-based MMCs (AMCs) are very important to developing composites because aluminium is the most used metal in the industry [4], [5]. AMCs are reinforced using a variety of materials. Popular reinforcing materials include SiC, TiB_2, B_4C, Al_2O_3, graphene, and fly ash [6], [7], [8]. Aluminum matrix composites may be fabricated using various of techniques such as stir casting, also called liquid state, powder metallurgy, and semisolid. Stir casting is the most common approach to produce AMCs in a liquid state [9], [10], [11]. Stojanovic *et al.* (2013) have studied tribological properties of hybrid composite with Al matrix, Al2219 reinforced with distinct percentages of SiC and graphite. Graphite's soft particles enhance lubrication and minimize friction and wear, while silicon carbide particles enhance the hardness and wear resistance. A tribometer of pin-on-disc was applied to conduct tribological testing under the ASTM G99-95 standard. The volumetric percentage of SiC in the investigated samples ranged from 5% to 15%, with a particle size of 25 *μm* Graphite was applied with a 3 % volumetric share and 45 *μm* sized particles. Results showed that the tribological and mechanical features of the hybrid composites with aluminum matrix changed by adjusting the amount of reinforcement. According to tribological testing, the friction coefficient of composites of Al/SiC/Gr hybrid declines as graphite content increases. The particle size also affects the wear. The wear of the composite decreases with increasing graphite particle size (Stojanovic *et al.*, 2013). Sathish *et al.* (2020) investigated that Silicon Carbide (SiC) was added to the AA7050 aluminum alloy at different weight percentages, such as 6%, 4%, and 0%. The wear of these composites was investigated using the experiments design (Taguchi technique) to improve the parameters of process. Inside this case, a sliding distance of 1800 meters, 6 % of reinforcement, and a 2 *m/s* sliding velocity provided the best wear rates [13]. Vamsi *et al.* (2014) evaluated the impact of Al6061 with SiC and Al6061/SiC/Gr hybrid composite to compare the difference between the single reinforcement with the hybrid composite. To fabricate the composites they used the stir casting method. The amount of reinforcement can be changed from 5% to 15% in steps 5%. They concluded that the greatest tensile strength at 15% SiC/Gr was 192.45 *MPa*. Hybrid composites with SiC/Gr reinforcement performed better mechanically than those with just one reinforcement [14]. Suresha *et al.* (2012) have noticed that composites' hardness decreases as the reinforcement percentage increases. Slide friction of composites of hybrid aluminum reinforced with 2.5%, 7.5%, and 10% SiC and Gr particles, respectively, in equal weight fractions. The friction coefficient is affected by the load and sliding speed, which has an average value of 0.269. However, the friction coefficient is unaffected by the percentage of reinforcement and the length of the sliding path [15]. Dey *et al.* (2020) investigated the wear properties of Al2024 matrix composites supplemented with and without silicon carbide (SiC) using the manufacturing process of stir casting. The SiC particles weight fraction changed between 0% and 9% in 3% increment. Magnesium was added to the melt at a concentration of 2% to improve wettability. Applied a pin on disc tribometer for determining the composite's wear performance. The findings revealed that a composite reinforced with 9 %SiC shows higher wear resistance. As the sliding distance and velocity increase, the wear rate of Al2024-SiC composites rises. So, for applications of speed and low-distance, SiC reinforced Al2024 alloy composites were used [16]. Al2024, Al7010, and Al7009 are high-strength aluminum alloys that Rao and Das (2010) investigated for their influence on the sliding wear properties of the matrix alloy and the effects of the SiC particle. Considering varied used force and a constant sliding speed of 3.35 m/s, composite materials were tested. As a result, 7010 alloy has the highest hardness while 2024 alloy has the lowest. Due to such findings, the 2024 alloy`s wear rate is the highest, while the wear rate of the 7010 alloys is the lowest. As the percentage of

SiC increases the coefficient of friction rises, and Al7010 has a higher coefficient of friction. Depending on the alloy system, the seizure pressure varies; Al7010 showed the highest seizure pressure, while regardless of SiC concentration and processing condition, Al2024 showed the lowest seizure pressure. With enhancing applied pressure, the wear coefficient reduces until it reaches a minimum level and then rises again if the utilized force reaches a level close to the seizure of the specimen [5]. Mohanavel *et al.* (2018) assessed the effects of SiC on Al6351. Different weight % of silicon carbide particles were made in a 4-percent stage from 0% to 20% using the stir casting method. Further results showed that the aluminum matrix composites` mechanical characteristics are influenced by the composite's weight percentage of SiC particles. The best mechanical features come from AA6351/20 wt.% SiC AMCs [17]. In their investigation, Rahman and Al Rashed (2014) reported that adding SiC reinforcements to the aluminum (Al) matrix made it harder and better. AMC with 20% SiC reinforcement had the best hardness and tensile strength. They discovered that Al matrix reinforcement using SiC particles made it more resistant to wear [18]. Reihani (2006) investigated the influence of SiC particles on the wear resistance, mechanical characteristics, and aging behavior of 6061 aluminum alloys formed through the squeeze casting process. 6061 aluminum alloy applied as base material. As a reinforcing phase, SiC particles with mean mass particle sizes of 16 and 22 μm were employed. The study obtained increased tensile strength and greater ductility with reduced reinforcing particle size. Overall, these results indicate that through reducing the size of the reinforcing particles better mechanical features are achieved [19]. Every technological advancement requires an enhancement in the mechanical characteristics of composite materials. In 2020, Sabry *et al.* (2020) published a paper describing the impact of applied load and sliding velocity on wear rate in the Al–SiC-Gr hybrids. AMCs made by varying the SiC volume fraction (15 %, 10 %, and 5 %) while the graphite utilized in composites remains the same (10%) and is fabricated by stir casting. The tensile hardness and strength enhanced from 65 HV to 85 HV and 490 MPa to 710 MPa correspondingly when graphite particles and silicon carbide were added. As the applied load enhanced, the wear rate likewise enhanced. Nevertheless, the sliding velocity rises to 1.2 m/s. After that, it rapidly decreases [20]. Rao *et al.* (2011) investigated that sliding speed and SiC concentration affects the wear behavior of composite materials and aluminum alloy. They used a 5000 m sliding distance for these experiments at sliding speeds between 0.52 and 1.72 m/s and SiC particles in 10, 15, and 25 wt. %. The data shows that the wear rate and temperature decrease as the SiC concentration rises. Conversely, the coefficient of friction shows the opposite tendency [21]. Kumar *et al.* (2020) developed, characterized, and tested the effectiveness of aluminum alloy matrix-based hybrid composites containing graphite particles and silicon carbide. Aluminum alloy (Al + 8%Si + 4%Cu + 3%Mg) with silicon carbide additions of 3 wt. % and 6 wt. % and a constant 2 wt. % graphite particle content. Further analysis showed that composite material with the greatest tensile hardness (49.5*HB*) and strength (234.57*MPa*) is reinforced with 6% SiC at constant Gr [22]. In an investigation into AMCs, Moses *et al.* (2014) found that the ultimate tensile strength (UTS) and microhardness of the AMCs significantly increased with the addition of SiC particles. Alloy 6061 reinforced using various proportions of SiC particles (0, 5, 10, and 15 wt.%) were developed. The results indicated that from unreinforced Al6061 tensile strength and microhardness around 45 *HV* and 130 *MPa* but with 15wt. % SiC exhibits higher tensile strength and microhardness around 105 *HV* and 220 *MPa*. These results indicate that the fracture mode altered from ductile to brittle, when SiC concentration enhanced [23]. Similarly, Laxmi and Sunil (2017) found that when Al6061 was reinforced with SiC, increasing SiC from 10% to 15% increased the composites hardness. After a 20% rise in reinforcing, hardness began to decrease [1]. In 2012, Veeresh and co-workers studied about Al6061–SiC composites` dry and mechanical sliding wear. Liquid metallurgy was used to make Al6061 composites with 2–6 wt. % SiC of size particle 150*μm*. It has been demonstrated that the hardness of composite is greater than its matrix of cast alloy. The composites with more filler have a harder surface. The hardness of the composite material of Al6061–SiC increases by 67% as the SiC concentration rises from 0% to 6%. In summary of the experimental work of ultimate tensile strength, the results show that from 0 to 6 wt.% silicon carbide particles, the final tensile strength of the composite material improves by 86%. Another important finding was that composites' wear resistance is superior to base alloys. A rise in the applied sliding distances and load led to a rise in volumetric wear losses. Overall, the tribological and mechanical performances of Al6061–6 wt. % SiC composites are superior to composites of Al6061–4 wt. %SiC, Al6061–2 wt. % SiC, and Al6061[5].

The current study aimed to ascertain the impact of adding a small amount of SiC on the hardness, porosity, tensile, and wear of Al6061 because of the difficulties associated with the production of aluminium metal composites (such as cost, weight, porosity, wettability, etc.).

2. Experimental Procedure

The experimental procedure involves materials, casting process, microstructure analysis, tensile, hardness, and wear test.

Materials

Alloy 6061 was chosen as the base material in the research. Table 1 displays the chemical composition of Al6061. As shown in Fig. 1, SiC is used as the reinforcing particle, and the particle size ranges from 1 to 13 μm. The Al6061 matrix and the SiC particles have the physical properties listed in Table 2. A scanning electron micrograph (SEM) of Al6061 and SiC particles is illustrated in Fig. 2. In this research, magnesium (Mg) was utilized to increase the wettability of SiC particles in Al6061 melt.

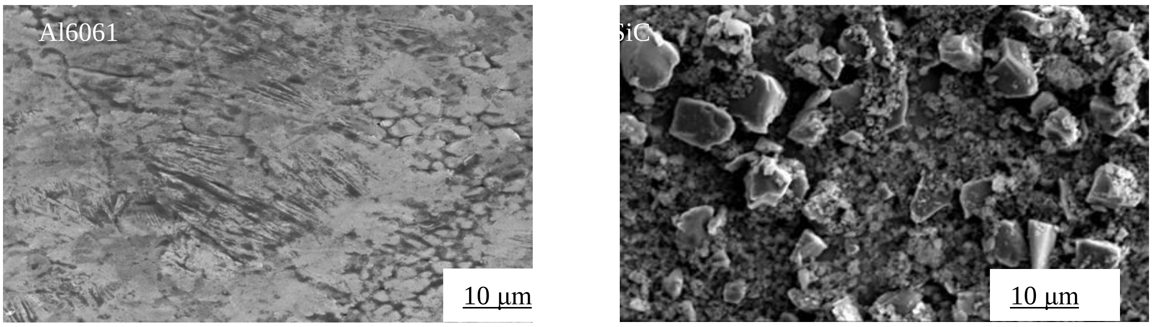
Table 1 Al6061 CHEMICAL COMPOSITION.

Element	*Mg*	*Si*	*Ti*	*Cr*	*Mn*	*Fe*	*Ni*	*Cu*	*Zn*	*Sn*	*Pb*	*Al*
Weight %	*1.45*	*0.93*	*0.02*	*0.04*	*0.51*	*0.70*	*0.02*	*0.83*	*0.21*	*0.02*	*0.06*	*95.23*

Table 2 PHYSICAL PROPERTIES OF AL6061 AND SiC [24].

Properties	*Density, g/cm³*	*Tensile strength, MPa*	*Yield strength, MPa*	*Elastic modulus, GPa*	*Elongation, %*	*Hardness, HV*
Al6061	*2.7*	*310*	*276*	*68.9*	*12-17*	*100*
SiC	*3.30*	*588*		*345*		*3000*

Fig. 1. SiC powder.



(a) (b)

Fig. 2. SEM image for Al6061 and SiC [25].

Casting Process

The current research utilized the stir casting method for the fabricating of Al6061-SiC composites. For removing the moisture from the reinforced particles, first, an electric furnace was used to preheat the reinforced particles to a temperature of 250 ℃. Then, Al6061 alloy in the form of rods was put in a graphite crucible and heated in an electric furnace between 800 and 850 °C for 30 minutes until the alloy was melted entirely (See Fig. 3a). Wettability is essential for particle dispersion in matrix materials, and 1% of magnesium is used for this purpose. The drilling machine was used to stir the mixture at a rate of 600 rpm for around 10 minutes (See Fig. 3b). In the final step, the mixture was poured into the heated mould cavity, allowing it to cool by keeping the mould at room temperature (See Fig. 3c and d).

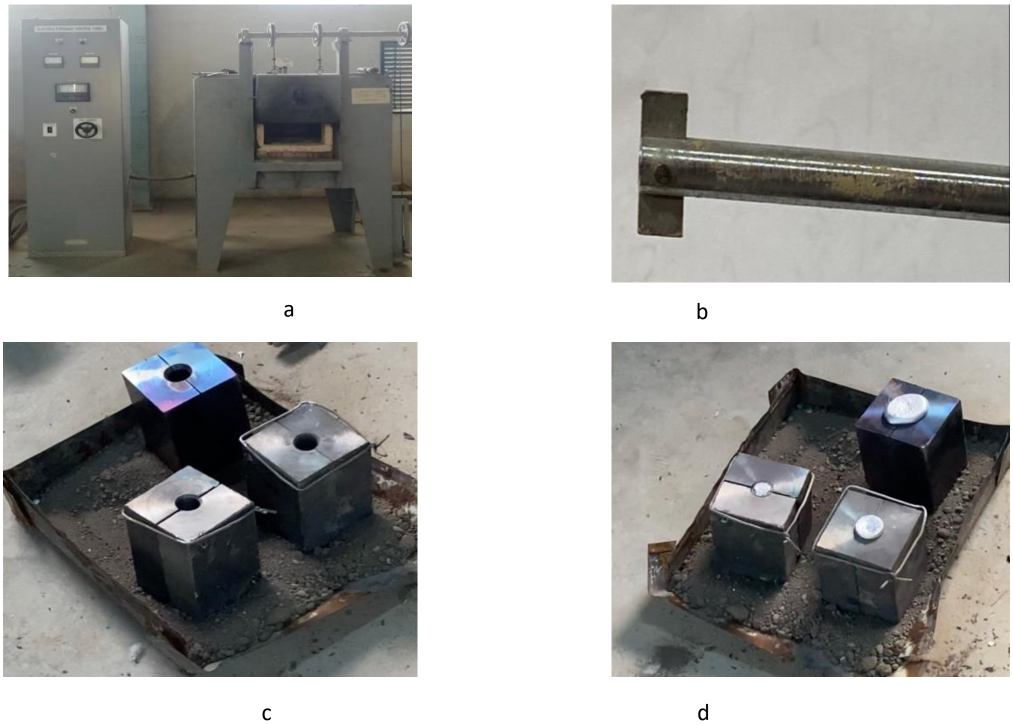


Fig. 3 a) Electrical furnace, b) Stir rod, c and d) Cast iron molds.

Microstructure Analysis

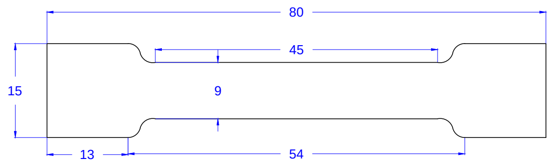
The particle distribution was studied by observing the microstructures of the samples. The composite specimen was mechanically polished to remove surface debris using emery paper of grades 800-2500. Before using Keller's reagent for etching, velvet and diamond polishing were performed to achieve a fine finish. After that, the samples were etched using Keller's reagent (ASTM E407 standard), a solution composed of 1% hydrofluoric acid (HF), 1.5% hydrochloric acid

(HCl), 2.5% nitric acid (HNO_3), and 95% distilled water for about 10 seconds before their microstructural examination [26].

Tensile and Hardness test

During the tensile test the ASTM-E8 standard was followed (the diameter of the specimen was 9 *mm* and 45 *mm* of the gauge length and 100 *mm* length). At room temperature the experiments were done. A photograph and a schematic of the tensile samples are shown in Fig. 4. The tensile strength values presented are an average of three for each weight percentage of SiC particles.

a



b) dimensions are in mm

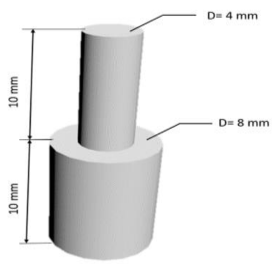
Fig. 4 A photograph and a schematic of the tensile specimen.

The Brinell hardness machine is applied for measuring the hardness of the Al 6061 alloy and the composites. The polished sample was subjected to 5 *kg* for 15 seconds. Then, five readings of each sample were obtained in order to minimize the effects of reinforcement matrix segregation. Finally, the hardness value was converted into a Vickers hardness number using the hardness conversion table.

Wear test

Pin-on-disc equipment was utilized to perform the wear test at room temperature. The tests were conducted using the TQ-Plint TE91/1 equipment type for various specimen numbers. The specimen was made according to ASTM G-99 standards. Fig. 5 and Fig. 6 show the wear specimen's dimensions and the pin on disc machine. The counterpart disc was created from stainless steel of Duplex (SAF 2205), with an outer diameter of 50 *mm* and a thickness of 2 *mm*. The hardness of SAF2205 is 291 *HV*, which is greater than the Al6061.

a



b

Fig. 5 A photograph and a schematic of the wear specimen.

Fig. 6 pin on disc machine.

Experiments were carried out with a 0.240855 *m/s* sliding velocity, a fixed normal load of 20 *N*, a time of 15 *minutes*, and a fixed sliding distance. The wear amount of fabricated composite material was estimated as the distinction between the specimen's weight before testing and the measured weight after every test by utilizing a microbalance (with maximum accuracy of 0.0001 *g*).

The wear rate may be calculated using Equation (1):

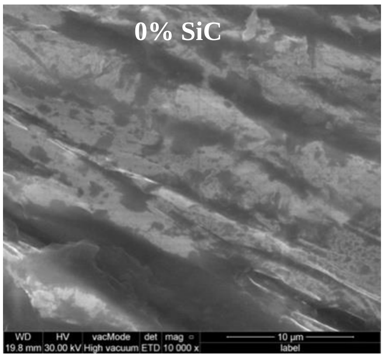
$$W_r = \frac{\Delta W}{\rho} (mm^3) \qquad 1$$

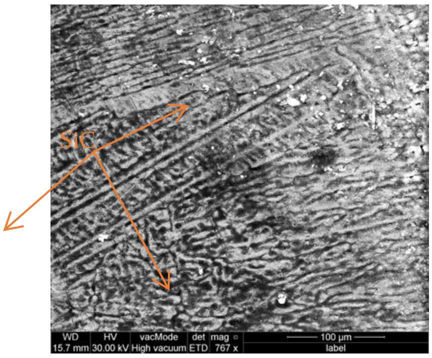
Where W_r is wear rate and ρ is the density of Al6061.

3. Results and Discussion

SEM Analysis

Optical micrographs of Al6061 alloy and Al6061-SiC composites are illustrated in Fig. 7. SEM image demonstrating the relatively uniform dispersion of SiC particles all over the aluminium matrix. Moreover, the micrographs reveal a strong bond between the reinforcement particles and matrix, resulting in a more efficient load transferring from the matrix to reinforcing material.





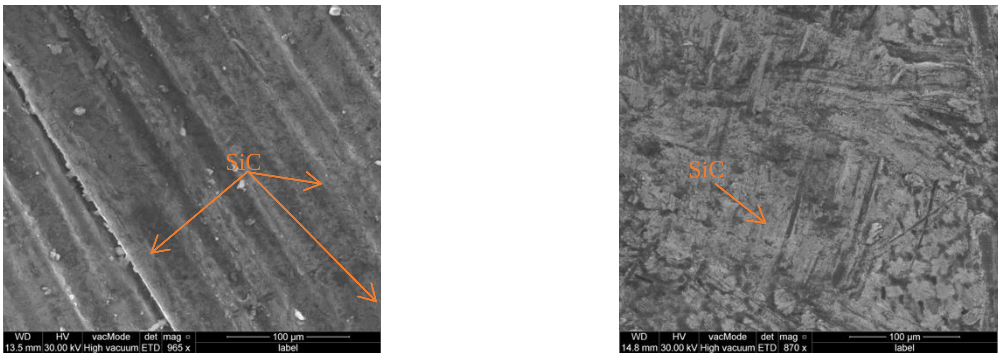


Fig. 7 SEM photomicrographs of Al6061–SiC composites.

Density

Fig. 8 shows a distinction between the the composite material`s actual density value and the theoretical density value, and the results may be from poor ingredient mixing, casting shrinkage, etc. Fig. 9 shows the results of porosity for the composites. The findings indicate that adding the particles to the matrix increases porosity and voids within the composite due to the poor casting process that causes porosity and voids within the composite.

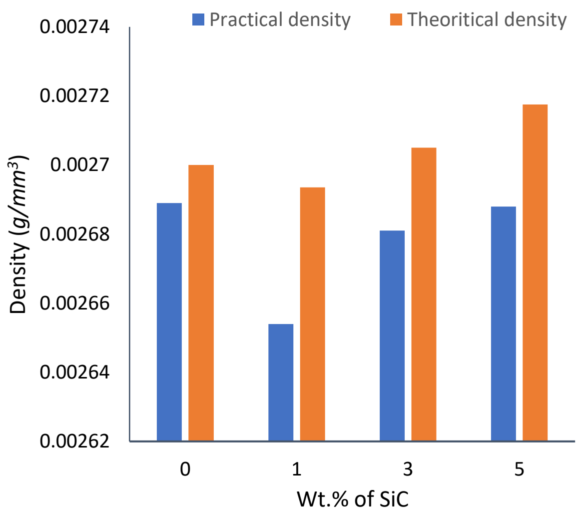


Fig. 8 Density of Al6061-SiC composites.

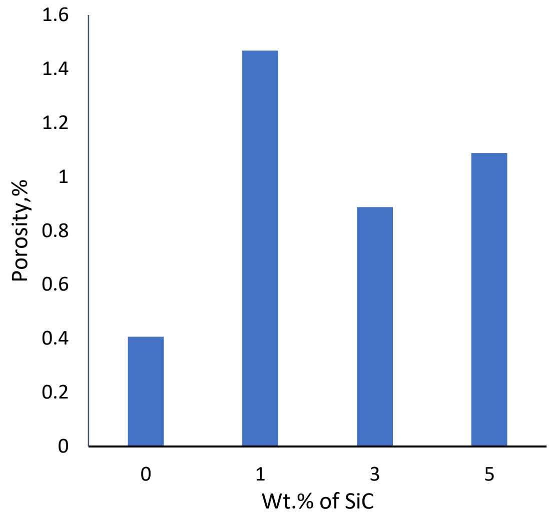


Fig. 9 porosity of various wt.% of SiC.

Tensile Strength Results

Each Tensile strength changes for SiC reinforced composites, and aluminium 6061 alloys are shown in Fig. 10. With the percentage of silicon carbide particles shown in Fig. 11 tensile strength varies. An improvement in tensile strength from 126.26 *MPa* to 165 *MPa* was seen after adding 1 wt.% silicon carbide particles to aluminium 6061 alloy. Tensile strength of 3 wt.% SiC decreased to 115 *MPa*. Because there are pieces that are broken in the structure, this is because the interface between the particulars and the matrix is not strong enough. When 5 wt.% SiC particles added into the alloy, UTS was shown to increase slightly. This finding was also reported by Ozben *et al.* (2008), by adding 15 wt.% of SiC particles, ultimate tensile stress decreased [28].

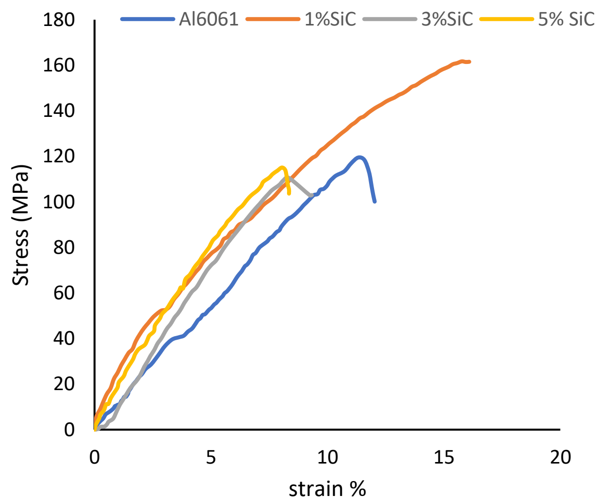


Fig. 10 Stress-Strain curves for all Al6061-SiC composites.

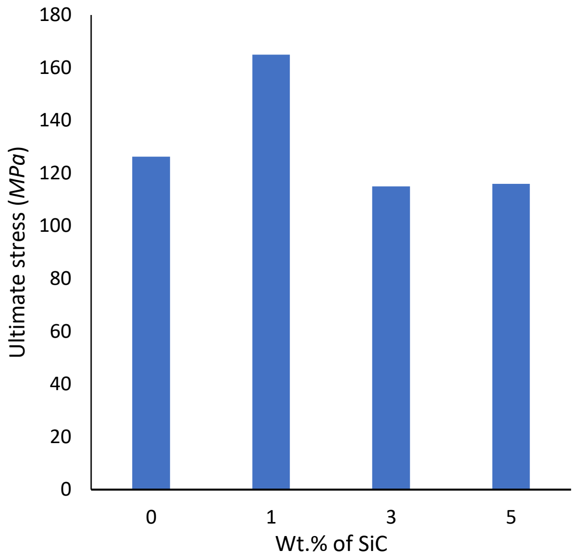


Fig. 11 The ultimate tensile strength varies with the wt.% of B_4C.

Hardness Result

The material's hardness was significantly increased by incorporating SiC particles into the aluminium matrix, as seen from the data in Fig. 12. Adding 1wt.% of SiC particles increased hardness slightly from 81*HV* to 83.175*HV*. Adding 3 wt.% SiC particles to the Al 6061 alloy raised the hardness progressively from 81 to 91.62 *HV*. Al 6061-5% SiC MMC was found to have the hardness with the highest value, 92.74 *HV*. These results reflect those of Vanam *et al.* (2018) who also found that the composite hardness increased through adding the reinforcement [29]. In accordance with this data, we can infer that the current findings have better results according to the findings mentioned below. Sivananthan *et al.`s* (2020) research illustrated that through adding 4 wt.% of SiC particles to Al6061, the hardness increased by 25% comparing with the unreinforced alloy [30]. Furthermore, Veeresh Kumar *et al.* (2012) in their work illustrated that when 6 wt.% of SiC was added to the matrix, the hardness increased by 65% compared to base alloy [31].

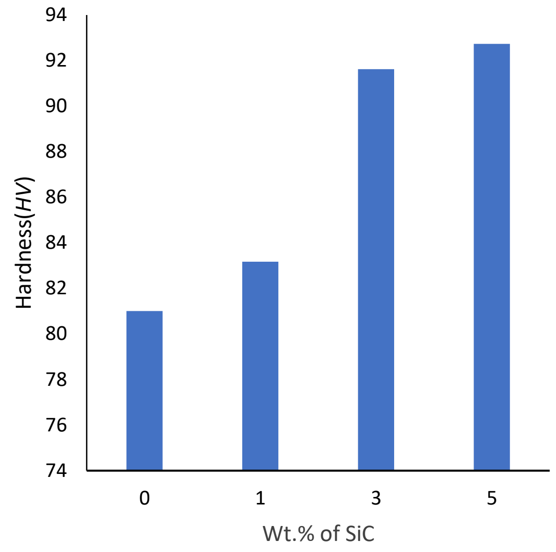


Fig. 12 Hardness variation with weight percentage of SiC.

Wear Results

A pin-on-disc tribometer machine was utilized for performing the dry sliding wear experiments for the Al6061-SiC composites. As shown by the data in Fig. 13 that adding 1% of SiC wear rate increased comparing with base alloy because the wear rate increased by increasing the porosity of the sample. Then by adding 3,5% of SiC wear rate decrease compared to base alloy.

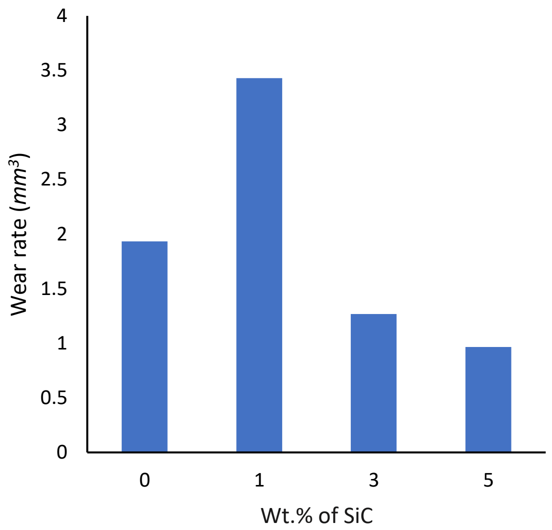


Fig. 13 Wear rate of Al6061- wt.% of SiC.

4. Conclusion

The current research aimed to determine the influence of introducing SiC particles into the Al6061 alloy. SiC was added to Al6061 at different weight percentages, ranging from 1, 3, and 5%. The research's most striking conclusion is that:

The results of adding SiC particles to Al6061 show that theoretical density is more significant than experimental density. The minimum practical density of 0.002654 g/mm^3 was observed for Al6061-1%SiC because of its higher porosity. Adding 5 wt.% of SiC increased practical density to 0.002688 g/mm^3.

Adding 1% of SiC porosity increased from 0.4% to 1.46%. Then, adding 3,5 wt.% of SiC to the matrix porosity decreased compared to adding 1 wt.% of SiC. All of the composite samples were found to have a porosity level of less than 5%, indicating that there were no casting faults in the composites.

This study has shown that adding 5wt% of silicon carbide to the Al6061 improved hardness from 81 *HV* to 92.74 *HV*.

The research has also shown that adding 1 wt.% of SiC to the matrix tensile strength increased by 30.68% compared to the base alloy, but adding 3,5 wt.% ultimate tensile strength decreased by 30%, and 29.6% compared to Al6061-1wt.% SiC.

It was found that by adding 1wt.% of SiC, the wear rate increased due to its porosity. Then by adding SiC wear rate decreased compared to the base alloy.

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