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Impact of Nano Silicon Carbide Particles on Mechanical and Wear Properties of Pure Aluminum/Hemp Fiber Composites

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Abstract

Hybrid composites made of aluminum (Al) are a relatively novel type of metal matrix composites that show promise for meeting the needs of cutting-edge technologies. Therefore, pure Al alloy reinforced with nano silicon carbide (SiC) particles is employed to meet the demanding requirements of cutting-edge applications. Pure Al/nano-SiC composites under varied nano-SiC volume fractions have been stir cast with 14 wt.% hemp fiber to improve the mechanical and wear properties of Al hybridized composites. Composites comprising nano-SiC particles reinforced with pure Al and 14 wt.% hemp fiber has been examined for its impact on physical characteristics, mechanical properties, and wear rates (WR). Improvements in mechanical characteristics and wear behavior are evaluated quantitatively. Analyses showed that the Al/14% nano-SiC/14 wt.% hemp fiber composite had a hardness (BHN) of 20.1%, an ultimate tensile strength (UTS) of 49.56%, a yield strength (YS) of 49.24%, an elongation percentage (EL) of just 3.75%, a compressive strength (CS) of 13.5%, and a WR of 48%.

Keywords

Mechanical properties, Wear properties, Physical properties, Hemp fiber, Nano silicon carbide, Pure aluminum

Introduction

The potential features of Al-based fiber-metal composites make them useful in various industries, like aviation, automotive, and defense. The Al-based fiber-metal composites are a viable substitute for fiber metal laminates. Fiber composites have gained popularity recently because of their many applications over more conventional building materials. These advantages include lower overall weight, greater strength and durability, lower production costs, and less tool wear. Many scientists are drawn to it since it is cheap, readily available, non-toxic, and produces no waste during manufacture [1]. Improvements in mechanical characteristics and eliminating structural flaws have been at the forefront of natural composites research and development over the past two decades [2]. Initially, fibers were mostly added to composites to increase quantity and minimize cost rather than to improve mechanical qualities. However, the environmental concerns associated with the production and use of manufactured fibers have altered the situation, prompting experts to enhance the mechanical qualities of natural fibers for use in fields such as aerospace, automotive, biomedical, and prosthetics. Authors [3] assess the effectiveness of jute yarns as a reinforcement for rammed-earth buildings. The effects of reinforcing a polypropylene matrix with abaca strands vs epoxy fiber glass were studied [4]. Researchers found that while abaca strands initially adhered poorly to the polypropylene matrix, things improved once malleated polypropylene was introduced as a compatibilizer. Using a hybrid fiber composed of abaca, jute, and two layers of glass fiber, authors [5] created several orientations with more rigidity than epoxy fiber-reinforced matrices. They tried out different fiber combinations, too, to see what effects they had. Sugarcane bagasse fiber was tested by authors [6] after being subjected to sodium hydroxide and hydrochloric acid. Researchers discovered that sugarcane fiber treated with sodium hydroxide exhibited improved tensile and impact properties, while sugarcane fiber treated with hydrochloric acid decayed at the surface by collecting electrons. Authors [7] showed that the impact resistance of epoxy matrix fibers was significantly improved by employing constant and modified jute fibers, with an increase of up to 30% in the amount of impact energy absorbed. The needle punching procedure created a jute/glass hybrid composite, with the jute mat positioned on top of the glass mat [8]. The flexural strength (59.7 MPa) of the jute/glass hybridized composite was significantly greater than that of the jute-mat fiber composite. Mechanical characteristics of E-glass/jute epoxy composites with different fiber ratios were investigated and assessed [9]. The composite with 25% E-glass by weight performed better than the 30% E-glass composite.

Mechanical properties of stir-cast composites of Al/SiC matrices with SiC concentrations between 4% and 20% by weight of Al were studied [10]. Mechanical parameters, including hardness and tensile strength, were evaluated for various reinforcing compositions. The mechanical properties of stir-casting Al hybridized matrix composites [11]. Adding 10 wt.% SiC particles and alumina (Al_2O_3) to the parent AA7075 alloy increases the strength of the resulting Al matrix composites, as shown by the graphs and hardness values. Using the stir-casting technique, authors [12] analyzed the characteristics and microstructural of an AA7075 matrix strengthened with SiC particles (SiC_p). The friction coefficient increases with increased applied stress, yet the WR decreases as the weight percent of SiC_p increases.

Al7075/SiC composites were discussed by authors [13]. The stir-casting technique was chosen to produce AA7075/SiC composites with a filler percentage of up to 6 wt.%. The impact of Al metal matrix composites' composition on wear and mechanical properties by including boron carbide and SiC. Taguchi analysis revealed that operating at 7% SiC, 300 rpm rate, 10 N loads, and 250 m range resulted in the least wear. Increases in the reinforcing material content, then, significantly boost wear resistance.

The effects of incorporating red mud, SiC, and fly ash into an Al alloy 7075 base alloy to increase UTS and WR. Using a pin-on-disc device, authors [14] studied the impact of load on the dry sliding speed, friction coefficient, and wear behavior of an Al alloy 7075/fly ash composite. Wear resistance was improved by 1800 to 350 when particulate graphite was added to Al/SiC composites [15]. Therefore, raising the graphite particle size enhances Al/SiC/Graphite composites' wear resistance.

Authors [16] propose that using a zirconia sand composite in the stir-casting process can alter the wear characteristics of Al6063 alloy. Composites of the A356 matrix alloy were developed by authors [17], with nano-Al_2O_3 particles added for reinforcement. They demonstrated that increasing the nanoparticle volume fraction improved the as-cast composites' ductility, UTS, and YS. In addition, the as-cast composites had higher microhardness than the base alloy. Authors [18] investigated the wear produced by 10 wt.% SiC_p composites made by ultrasonic probe stir-casting on Al5083 during dry sliding operations. Wear loss properties of Al6061/Al_2O_3 and Al7075/SiC composites were investigated [19]. Results showed that wear might be reduced by raising the percentage of reinforcing weight in the particles. The experimental results demonstrated that as the Al_2O_3 and SiC_p concentrations were raised, the microhardness of the composites increased while the toughness decreased. As authors [20] found, microhardness and wear resistance can be enhanced by increasing the cerium volume in Al/12Si4Mg alloy from 0 to 2 wt.%. However, when more than 2 wt.% of cerium is added to a matrix alloy, the microhardness values drop, resulting in decreased wear resistance.

According to additional research, the microstructural and mechanical characteristics of pure Al/nano-SiC composites have been refined and enhanced. But for better mechanical qualities and wear behavior, nobody has looked into hybrid composites made of pure Al, mano-SiC, or hemp fiber. To create a wide range of hybrid composites, this effort involved combining pure Al with x nano-SiC (where x ranges from 0 to 14% by weight) at a percentage volume of 14%. Researching the mechanical characteristics and WR of a hybridized composite comprising pure Al, nano-SiC, and hemp fiber is a new contribution of this work. These are the goals of my research: (i) Various tests, including BHN, UTS, YS, and CS, measure hybrid composites' toughness, (ii) Use stir-casting to make composites with different amounts of nano-SiC, Al, and hemp fiber, and (iii) Evaluation of hybrid composites' wear resistance.

Materials and Method

The hybrid composites of pure Al, nano-SiC, and hemp fiber were made using a stir-casting technique. In this technique, the components in table 1 were considered embedded in a pure Al matrix. The percentage of SiC ranged from 0% to 14%, with a weighted average of 7%. Reinforcement came from a powdered form of S-hemp fiber. Table 2 displays the physical characteristics of pure Al, hemp fiber, and nano-SiC. Three different types of hybrid composites were produced using the stir-casting technique: Al/0% nano-SiC/14% hemp fiber, Al/7% nano-SiC/14% hemp fiber, and Al/14% nano-SiC/14% hemp fiber are shown in table 3. According to preliminary experiments, mechanical and wear properties were not improved by adding hemp fiber to an Al/14% nano-SiC composite. Therefore, Al/nano-SiC composite was permanently fastened with hemp fiber at 14 wt.% as a consistent reinforcement. Nano-SiC and hemp fiber were warmed in separate furnaces before injection into molten

Table 1: Chemical composition of pure AI.

Element	Wt.%
Si	0.25
Fe	0.40
Cu	0.05
Mn	0.05
Mg	0.05
Zn	0.05
Ti	0.03
V	0.05
Al (Balance)	99.50

Table 2: Physical characteristics of materials.

Properties	Materials
Pure AI	
Melting point (°C)	660.2
Modulus of elasticity (GPa)	68.3
Thermal conductivity (cal/cms.°C)	0.57
Elastic resistivity at 20 °C (Ω.cm)	2.69
Boiling point (°C)	2480
Density (g/cm^3)	2.6898
Co-efficient of linear expansion (0 - 100 °C) (x 10^{-6}/°C)	23.5
Poisson's ratio	0.34
Hemp fiber	
Cellulose (wt.%)	68-81
Hemicellulose (wt.%)	10.66-22.4
Lignin (wt.%)	3.7-13
Pectin (wt.%)	0.9
Density (kg/m^3)	1450-1520
Nano-SiC	
Density (g/cm^3)	3.21
Molecular weight (g/mol)	40.11
Melting point (°C)	2730

Table 3: Composition of samples.

Composites	Code	Composition
Composite 1	C1	Al + 0% nano-SiC + 14% hemp fiber
Composite 2	C2	Al + 7% nano-SiC + 14% hemp fiber
Composite 3	C3	Al + 14% nano-SiC + 14% hemp fiber

Al alloy during hybrid composite production. A steady stirring speed of 1000 rpm was set to ensure that the nano-SiC and hemp fiber were thoroughly combined with pure Al.

The brinell hardness test on hybrid composite was performed by ASTM E10-07 standards, with a 10 mm ball indenter diameter and 500 kg load applied for 30 sec. Brinell macro-hardness test line diagram is shown in figure 1. The UTS, YS, and EL were evaluated using the Universal Testing Machine (UTM) by ASTM E08-8 (EL).

Tensile samples undergoing testing are seen in figure 2. At room temperature, ASTM E9-09 compliant ultimate compression strength measurements were taken using automated

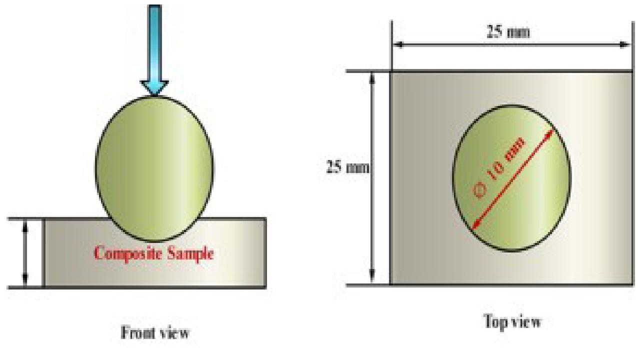

Figure 1: An outline of the brinell hardness testing machine.

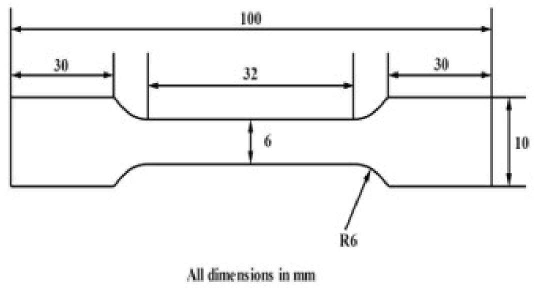

Figure 2: An outline of the tensile test sample.

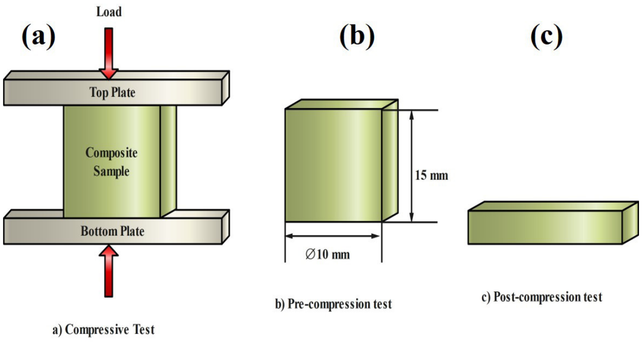

Figure 3: An overview of **(a)** Compressive test, **(b)** Pre-testing, and **(c)** Post-testing.

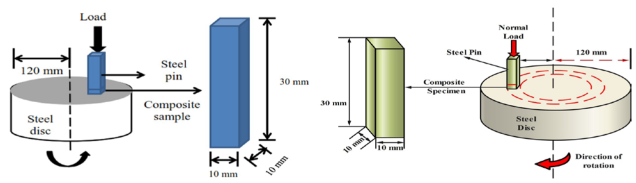

Figure 4: An outline of the pin-on-disc wear testing machine.

UTM equipment. The accuracy of the final CS measurement can be attributed to the fact that it is automated. The crosshead speediness for the test was 1 mm/min.

Figure 3 is a graph depicting a compression test's before and after results. The manufactured composite was polished with 1200 grit to remove scratches and surface flaws. WRs were determined using the pin-on-disc technique as specified by ASTM G-99. The mechanism is depicted diagrammatically in figure 4. Wear test composite samples that were pre-cut and mounted on steel pins that were 10 mm x 10 mm x 30 mm in length. The hybrid composite was subjected to a wear test, during which weights of 40 N and 80 N were applied in increments of 40 N, and sliding speeds of 0.3, 0.6 and 0.9 m/s were applied. Previous studies served as the basis for selecting the wear test's parameters [21].

Results and Discussion

Mechanical properties

Hardness

A brinell hardness machine was used to deliver a constant force over a set period to evaluate the hardness of hybrid composites. Figure 5 indicates the variation in hardness across many hybridized composites. The hardness of hybridized composites made from Al and 14 wt.% nano-SiC and 14 wt.% hemp fiber was found to be better than that of Al and 0 wt.% nano-SiC and 14 wt.% hemp fiber. The lack of nano-SiC in the hybrid composite allowed for high hardness. The hardness of the hybridized composite was superior to that of the matrix, while ductility decreased. Hemp fiber and nano-SiC contributed to the high hardness of the hybrid composite. With a constant density of hemp fiber, the hardness was increased by adding nano-SiC. The density was compared to that of other reinforcing materials. The Al/nano-SiC reinforcement combined with the 4.29 g/cc titanium dioxide densities and the 7.24 g/cc chromium density resulted in a very hard material. Compared to earlier efforts [22], the current result demonstrated increased hardness after varying the nano-SiC concentration. After extensive testing, the Al/boron carbide/rice husk ash combination was superior to the Al/zirconia/graphite/fly ash particle.

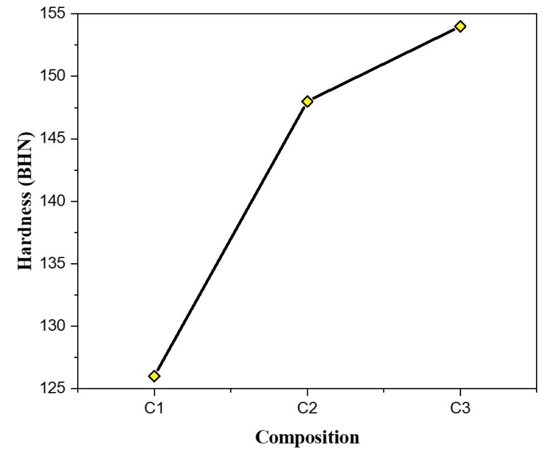

Figure 5: Comparison of hardness for various samples.

Tensile properties

Using the UTM, tensile tests were to be conducted at room temperature on hybridized composites, as specified by the ASTM standard. The YS and UTS of a hybrid composite formed by mixing nano-SiC particles with alloy at different crosshead speeds are shown in figure 6 of the study above. EL was measured and is displayed in figure 7. In these evaluations, it was shown that increasing the amount of nano-SiC reinforcement in Al hybrid composites enhanced both the UTS and YS. Stronger UTS and YS were measured after combining nano-SiC and hemp fiber with an Al matrix. Since nano-SiC particles are dislocation-resistant, adding more led to a stronger hybrid composite.

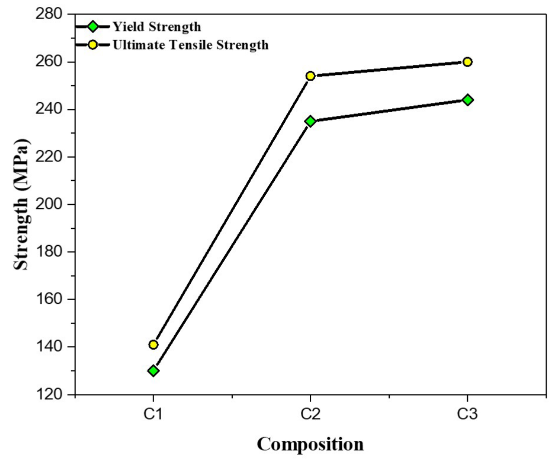

Figure 6: Comparison of tensile properties for various composites.

Adding 2 wt.% of nano-SiC and Al_2O_3 to the matrix increased the tensile strength to 148 MPa, which is somewhat higher than the current value. Different reinforcing materials and water quenching provided varying UTS in hybrid composites. Similar results were seen when combining nano-SiC particles with AA7075/hemp fiber enhanced the dislocation resistance of hybrid composites. UTS and YS were improved, leading to less particle-containing EL. Comparatively, the Al/8% rice husk ash + nano-SiC hybridized composite had an EL of 8%, which was greater than the EL of the present results (4%) [23]. Different particle characteristics with alloy led to this end outcome. Several ideas and techniques characterized the fortification of the hybrid composite.

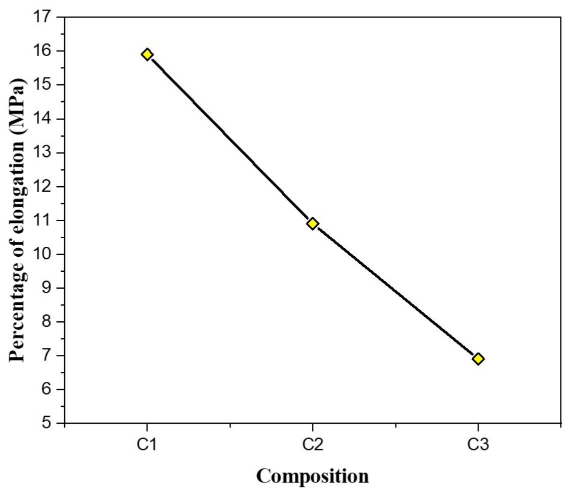

Figure 7: Evaluation of EL for various composites.

Further, a unique mechanism was not linked to the superior strength of hybrid composites. Several mechanisms operate in tandem with one another. Here, a thermal mismatch between the strengthening and the matrix led to a rise in dislocation density, which strengthened the material. Therefore, the EL of the hybrid composite was shown to be most affected by the coefficient of thermal expansion.

CS

At room temperature, a UTM calibrated to ASTM standards was used to conduct compression testing on hybrid composites. Figure 8 shows that as the number of nano-SiC particles in the alloy increased, so did the material's CS during these tests. In part, increased CS was attributed to the hybrid composite's decreased ductility. As the particle percentage was raised, it was also found that the hybrid composite's tensile and CS increased steadily. Hemp fiber and nano-SiC with Al alloy interfaced well enough to get the desired effect. Particles were also evenly dispersed throughout the matrix alloy. This nano-SiC reinforced with pure Al had a CS inversely related to its elongation, just like the Al alloy/nano-SiC foam/nano-SiC hybrid composite now in use. Due to the poor ductility and extremely limited mobility, unusual behavior was observed. Nano-reduced SiC's ductility relative to unreinforced alloy was caused by dislocation movement, and it was achieved at a weight percentage of 14%. The plastic deformation of the material exposed the lack of ductility. However, hybrid composites outperformed pure Al in terms of CS. This result was obtained because the reinforcing particles delayed the dislocation movement. The CS of nano-SiC reinforced with pure Al at 14 wt.% was 305 MPa, whereas that of nano-SiC reinforced with 8 wt.% Al_2O_3 and 5 wt.% graphite was 305 MPa [24]. The CS of the Al-Li/18 vol.% nano-SiC composite was 623 MPa, which was greater than the CS of nano-SiC reinforced with pure Al at 14 wt.%. The strength-enhancing characteristics are credited with the high value. AA6061/6 wt.% has a CS of 265.47 MPa. Nano-SiC (3% by weight) zirconia was less than the 14 wt.% reinforcement of AA6061. Nano-SiC (pure Al) [25]. According to the results of a CS investigation, the reinforcing particle contributes more to the hybrid composite's qualities than pure Al.

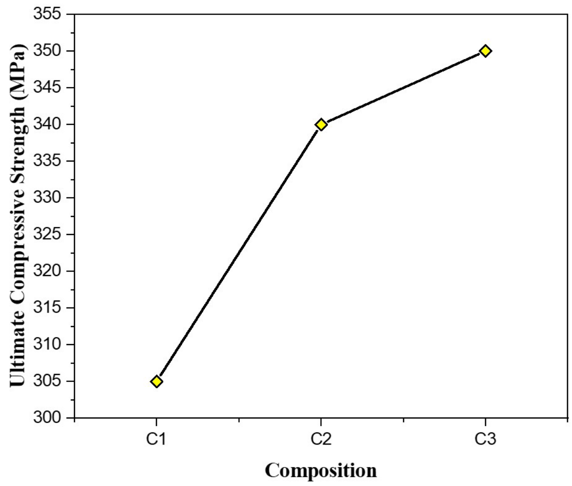

Figure 8: Evaluation of CS for various composites.

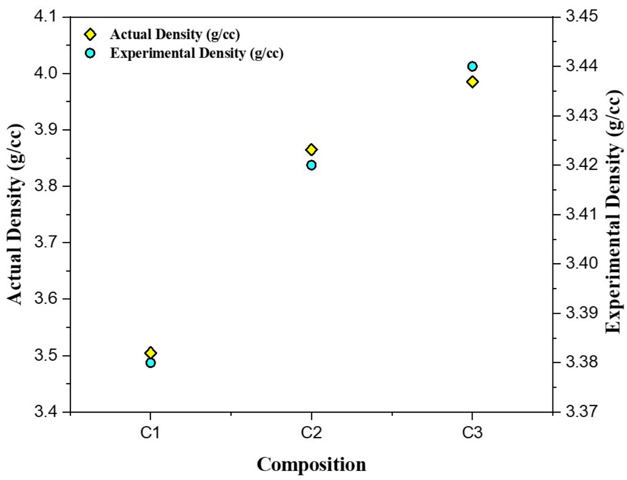

Figure 9: Density for hybrid composite.

Physical characteristics

The density of a hybridized composite is a significant factor in determining its physical characteristics. Therefore, increased density improves the functionality of composites. Pure Al, nano-SiC, and hemp fiber have different densities: 2.92 g/cc, 3.36 g/cc, and 2.54 g/cc. The density of the hybridized composite was determined by combining experimental and numerical data on the increased density of pure Al with nano-SiC particles. Numerical density (ρ_n) was determined using equation 1.

$$\rho_n = (\rho_m \text{ x } wt.\% \text{ } matrix) + (\rho_r \text{ x } wt.\% \text{ } nano\text{-}SiC \text{ } reinforcfement) + (\rho_m \text{ x } wt.\% \text{ } hemp \text{ } fiber) \quad (1)$$

Whereas ρ_n is numerical density and ρ_r is density of reinforcement.

Using the Archimedes method [26], the true density of hybridized composites was determined. The density of the experimented hybridized composite was compared to the theoretical composite in figure 9. Increasing the nano-SiC fraction in the hybrid composite was shown to enhance its density. The hybrid material's density grew together with the concentration of nano-SiC particles. Because of the voids, the hybrid composite's mechanical qualities were suffering. Both entrapped air and a poor link between the alloy and reinforcement caused void formation in hybrid composites. The hybrid composite's void formation was traced to particle size and melting point variations. Hemp fiber/nano-SiC had a much lower melting point than pure Al. Therefore, equation 2 must be used to evaluate the void.

$$Void\ content(\%) = \frac{\rho_t - \rho_e}{\rho_t} \quad (2)$$

Nano-SiC particles containing 100% pure Al and 14% hemp fiber were used to create the error bar chart illustrated in figure 10. Pure Al/nano-SiC/hemp fiber hybridized composites were found to have the maximum void content. Nano-SiC particles of pure Al have a small fraction of voids by weight. This hybrid composite's significant void content was brought about by blending entrapped air in hemp fiber (air bubbles in hemp fiber). It wasn't confined before being cured. That's why there were so many voids detected. There was a significant discrepancy between the calculated and measured densities, and voids and pores played a substantial role in this.

WR

The mechanical characteristics of the Al alloy-enhanced reinforcing particles significantly affected the WR. It occurs when one solid exerts enough mechanical pressure on another to remove material from the solid's surface. Mechanical contact between stressed sliding surfaces causes wear, manifesting as a steady material loss over time. As shown in figure 11, WRs reduced with increasing loads while maintaining a constant sliding speed of 0.9 m/s. The lowest WR material was made by combining pure Al, 14% nano-SiC, and 14% hemp fiber. The WR was also shown to rise with both the applied force and the concentration of nano-SiC particles. Previous studies [27] found similar recurring trends. The hybrid composite's improved wear resistance over pure Al hemp results from adding nano-SiC fibers. The most wear resistant hybrid composites comprised 14% nano-SiC and 14% hemp fiber. Figure 12 displays a similar pattern: with a constant load of 80 N, the WRs are reduced with cumulative sliding speed. An anti-wear composite of pure Al, 14% nano-SiC, and 14% hemp fiber was created. Wear was also shown to rise with sliding velocity and nano-SiC particle load. The nano-SiC/hemp fiber reinforcement significantly increased the hybrid composite's wear resistance compared to the zero-reinforcement matrix alloy. The same form of properties has been seen by other studies [28, 29]. The Al + 5% Graphite + 10% SiC produced a WR of 1.2 mm^3/m when evaluated with a sliding distance and an applied force of 50 m and 15 N, respectively, which is relatively low compared to other studies [30]. As a result, the final product is far better than the status quo. The WR of AZ91D/5 wt.% graphite + nano-SiC was found to be 0.0247 mm^3/m when subjected to a tension of 10 N and a sliding distance of 500 m [31]. The WR of AA7050 with 4 wt.% nano-SiC was 0.00339 mm^3/m over 1800 m of sliding distance with 20 N applied [32]. Therefore, the outcome was less desirable than the present work. The variation in outcomes was due to nano-SiCs in the matrix alloy.

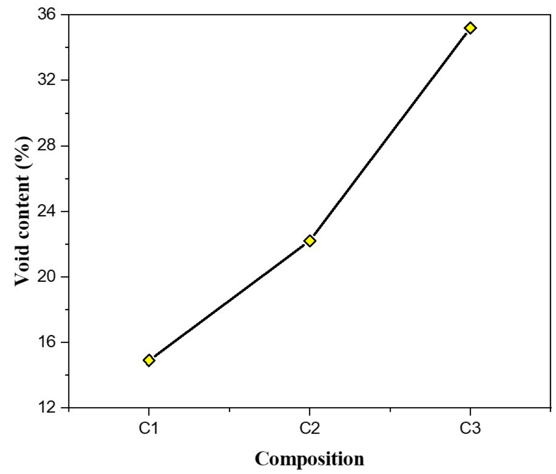

Figure 10: Comparison of void content for hybridized composite.

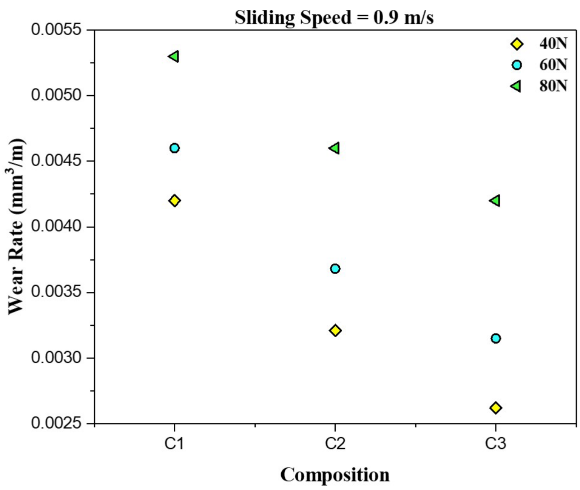

Figure 11: Comparison of WR to load.

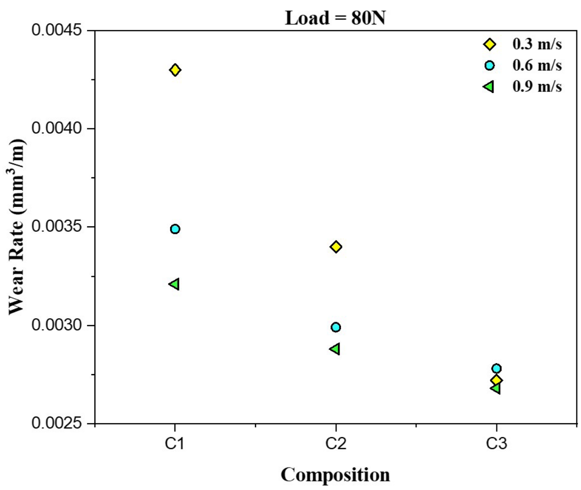

Figure 12: Comparison of WR to sliding speeds.

Conclusions

Mechanical properties, physical characteristics, and WRs were all studied to varying wt.% of nano-SiC with a constant 14 wt.% hemp fiber reinforced with pure Al. The following claims have been made in the course of this research.

- Based on the percentage increase in properties, the Al/14% nano-SiC/14% hemp fiber hybrid composite possesses excellent UTS, YS, CS, and BHN with very little EL.
- The mechanical qualities of hemp fiber have been enhanced thanks largely to nano-SiC.
- The void content has not significantly impacted hybridized composites' mechanical properties and wear behavior.
- The low WR results from pure Al, 14 wt.% nano-SiC, and 14% hemp fiber.

Acknowledgements

None.

Conflict of Interest

None.

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