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MECHANICAL AND WEAR CHARACTERISATICS OF GLASS FIBRE REINFORCED ALUMINIUM MATRIX COMPOSITES

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Abstract

Pure aluminums are known with defects such as low strength. This can be mitigated by incorporating dispersed glass fibre to enhance the strength and toughness of the resulting composite. The stir casting method was employed, varying glass fibre particle sizes from 0 to 18 wt.%, with the 0% glass fibre sample serving as a control. Mechanical and wear properties were investigated. Results indicated that 12 wt.% glass fibre demonstrated superior performance compared to the control and other glass fibre-reinforced composites for hardness (105 BHN). Flexural strength increased with additional reinforcements, attributed to reduced ductility and elongation. However, 16 wt.% glass fibre reinforcement displayed lowest and minimal wear loss which was due to increased reinforcement at higher percentage. In conclusion, the Al+12 wt.% glass fibre composite showed notable improvements in mechanical properties, while 16 wt.% glass fibre had minimal wear loss compared to the control and other composite samples.

Keywords: Aluminium matrix composite, mechanical properties, wear characteristics, glass fibre.

1.0 Introduction

Glass fiber-reinforced epoxy composites are becoming more appreciated in diverse engineering applications, including seals and gears. Due to advantages like design flexibility and improved strength, they are widely employed in components such as rollers and bearings, surpassing other metal matrices.(Sahu & Sahu, 2020). Glass fiber is readily available as a reinforcing material, and among its various forms, bi-directional woven glass fiber reinforced polymer composites are gaining acceptance in numerous industrial applications. This is attributed to their lightweight nature, ease of processing, and cost-effectiveness. It provides greater impact resistance than unidirectional composites and demonstrates behavior that closely resembles that of a fully isotropic material(Oyewo, Oluwole, Ajide, Omoniyi, Kim, et al., 2023; Oyewo, Oluwole, Ajide, Omoniyi, & Murid, 2023).

The addition of filler particles to glass epoxy composites can enhance their mechanical properties. This is done to improve specific characteristics and lower the overall cost of the product. Glass fiber reinforced epoxy composites, along with different fillers, are utilized in applications where mechanical properties are critical. Studies on glass fiber reinforced aluminum composites demonstrate that various factors, such as the type of filler and glass fibers, their volume or weight proportion, aspect ratio, strength, and modulus, impact the mechanical properties significantly. Additionally, factors like fiber orientation, matrix type, matrix strength, and the interface bonding between the filler or fiber and matrix play crucial roles in enabling stress transfer at the interface(Chak et al., 2020; Fanani et al., 2021). The type and amount of filler material in a composite are crucial factors affecting its mechanical properties. While various studies have explored the use of ceramic, natural, and other particle types as fillers, there is a need for further exploration of lightweight fillers, especially when weight reduction is a key concern for composites. Experimental studies have shown that as the graphite content increases, the tensile strength and dimensional stability of the glass epoxy composite also increase(Fanani et al., 2021). Composite materials utilizing woven glass fabric and incorporating phenolic hollow microspheres demonstrated enhanced specific flexural strength and specific impact strength, alongside reduced density, in contrast to those incorporating calcium carbonate particles. The addition of particles such as mica to glass epoxy composites enhances the hardness and compressive strength of unidirectional E-glass fiber-reinforced epoxy composites(Akinyemi & Dai, 2020). In a similar manner, the addition of soft particles such as mica, tricalcium phosphate, and glass to epoxy composites improves their mechanical properties by strengthening the bond between the fiber and epoxy resin. Some agricultural byproducts, surprisingly, demonstrate advantageous filler characteristics that enhance the strength properties and increase the micro-hardness of the composite(Akinyemi & Dai, 2020).

Glass fiber is renowned for its light weight, high strength, superb malleability, corrosion resistance, and excellent thermal and electrical conductivity. In contrast, aluminum is highly recyclable. The addition of glass fiber powder to aluminum composites enhances their mechanical properties, including hardness, dimensional accuracy, and thermal conductivity. It is recognized that decreasing the particle size significantly improves mechanical properties, while increasing the size enhances thermal conductivity to a greater degree. Therefore, selecting the appropriate particle size of aluminum powder requires careful consideration. A comprehensive literature review reveals that only a small number of researchers have studied the mechanical behavior of glass fiber epoxy composites, considering a range of process parameters. In a composite consisting of three components: resin, aluminum metal, and particulate fibers, Dhanesh et al. (2021)It was observed that the composite's mechanical and thermal properties surpassed those of its individual components. Additionally, researchers discovered that the mechanical properties of aluminum-kevlar fiber composites were 40% greater than those of composites reinforced with PVC fiber or glass fiber.

Generally, researchers have worked to assess the properties of these composites and the impact of incorporating glass fiber into aluminum matrix composites. While there are numerous studies on aluminum matrix composites, research on the use of glass fiber as reinforcement is limited. This study aims to address this gap by investigating the effects of adding glass fiber on the mechanical and wear properties of glass epoxy composites. The findings of this study will greatly contribute to understanding the role of glass fiber filler in aluminum composites.

2.0 Methodology

2.1 Materials and melting of scraps metals to form ingots

The glass fibre mats are shown Figure 1were sourced in a chemical store in Lagos. into a pit and left to form an ingot.

Aluminium scraps were obtained in various in Calabar, Cross Rivers States. Preparation of the composites and testings of the samples were performed in Calabar as well as another places Lagos, Nigeria. The aluminium scrap was obtained from a local store. The processes involved in forming the ingots and removal of impurities involves the transfer of aluminium scraps to the foundry where they were heated at 660^{0}C to form a molten compound. In order to get the aluminum, the impurities (caused by paints and other materials) were separated after melting it. Ultimately, the aluminum in its molten form was poured out of the crucible

Figure 1: Glass fibre mats

2.2 Aluminum metal matrix composite formation

The Al-glass fiber metal matrix composites (MMCs) were manufactured through the stir casting process. Initially, the aluminum matrix was heated to a semi-solid state. At the same time, glass fiber particles underwent a two-hour preheating in an electric arc furnace. These preheated glass fiber particles were subsequently introduced into the crucible containing molten aluminum. A motor-driven stirrer was then used to mix the molten metal and glass fiber thoroughly, ensuring an even distribution of the reinforcing particles. The liquid metal is heated to a temperature above its melting point and then cast into a sand mold of the size of 270x32.24mm. The aluminium in its molten state was used for the matrix composite formation by carrying it ou tin four different steps. The aluminium is the matrix while glass fibre was the reinforcement. The first process was to allow the molten aluminium alloy to cool and solidifies through a mold given. Then, the mixing of 4wt% glass fibre to the molten compound and stirred it together as done by Chak et al. (2020) to mix together and evenly circulate with this molten compound. Same process was used for 8wt%, 12wt% and 16wt% glass fibre to the molten compound and stirred it together as done by Chak et al. (2020)to mix together and evenly circulate with this molten compound.

2.3 Tests on Aluminium matrix composite

After casting, tensile strength, impact strength, hardness test and the microstructure examination were conducted for the specimens produced.

2.4 Brinell Hardness Tests

Sample was provided and it was cut in order to get a specific length, after that the sample being cut was filed using hand file in order to harden the surface of the sample. After which the sample was fixed into the extensometer where which was subjected to compression of load of 250kg for about 15 seconds after which the indented diameter was measured by eye scope. And finally, the conversion table was used to know the Brinell or hardness number of the material.

2.5 Tensile test

The tensile test was performed on four samples using UTM machines, adhering to the ASTM E8 standard. Each sample had three identical test specimens for each section thickness, all tested at room temperature. The tests were conducted at a strain/loading rate of 5 mm/min using a computerized Instron Testing Machine (model 3369)..

22.6 Flexural test

The flexural test was performed on rectangular specimens measuring 120 mm in total length, 10 mm in thickness, and 6 mm in width. These specimens were positioned horizontally on two supports spaced 60 mm apart and were loaded perpendicularly at the center using a Universal Testing Machine (UTM) until they fractured. The analysis was conducted at a room temperature of 18°C and 50% humidity, in accordance with the ASTM D 790-03 standard.

2.7 Wear resistance

The wear resistance of aluminum samples, measuring 50 x 10 x 6 mm^3, was assessed using a central circular disc wear testing machine equipped with P 60 Sic coarse emery paper. The initial mass (m_0) of each sample was determined using a Pioneer weighing scale. A sample surface measuring 10 x 6 mm² was securely affixed to the wear rig and positioned on the emery paper at a distance of 50 mm from the disc's center. The disc, along with the emery paper, rotated against the sample surface at speeds of 2 and 4 ms^{-1} for 20 seconds, with an applied load of 10 N. This procedure was repeated, increasing the disc's rotation period from 30 seconds to 3 minutes at 30-second intervals, while maintaining a constant load and increasing the applied load to 20 N and then 30 N. The new mass (m_1) of the sample was measured after each run. After each test, wear debris was cleared from the emery paper surface using a stiff brush. Mass loss due to friction, volume, and wear rate were calculated using Equations 1-2.:

$$Volume\ loss\ = \frac{Mass\ loss}{density\ of\ the\ sample} \qquad 1$$

$$Wear\ rate\ = \frac{Total\ volume\ loss}{total\ wear\ duration} \qquad 2$$

3.0 Results and discussion

3.1 Mechanical properties

3.1.1 Tensile strength

The result of Ultimate Tensile Strength (UTS) of the composite at various mass fractions of glass fibre reinforced in aluminum composite is shown in Figure 2. The result indicates a higher value of UTS as the mass fractions of glass fibre increased up to 18 wt.% composites, but the control (the unreinforced control sample) was the lowest. The tensile strength follow the same trend as that of Kenned et al. (2020), i.e., increased in tensile strength with increase in mass fraction of glass fibre in the matrix. The maximum value of the tensile strength was obtained at 12wt% of glass fibre addition. However, there was a decrease at 18wt.% composite. The improved tensile properties of the composites can be attributed to effective bonding between the particles and the matrix, good wettability, the small size of the reinforcement particles, and the strengthening effect of the glass fiber in the aluminum matrix.(Yaghoobi & Fereidoon, 2019)

The glass fibre served as reinforcement because the major share of load has been taken up by the crystalline fibrils resulting in extension of the helically wound fibrils along with the matrix. Although the tensile properties increase was proportional to fibre loading in the composite, there was a sharp decline in sample 18 wt.% fibre composite. This could be attributed to defect that arises from human error during fabrication. There was too much of reinforcements which the matrix aluminium could not sufficiently hold, thus creating stress concentration area which lowered the stiffness of composite as reported by Zhang et al. (2016). In addition, above 12 wt. % glass fibre loading, i.e., 18wt.% glass fibre composite, the developed composite sample was not well formed, non-homogenous, hard and thus brittle. This is because at higher volume fraction of fibre, there is a practical limit percent of volume reinforcement that can be added to form a composite. At higher percentage of fibres, there was too little matrix to support the fibres effectively (Barrios-Muriel et al., 2018; Mohan & Kanny, 2019; Rajesh et al., 2020).

Previous studies have demonstrated similar increases in tensile strength when glass, carbon, or kenaf fibers were incorporated into composites(Saba et al., 2016; Safri et al., 2018). Notably, the highest tensile strength displayed by 12 wt.%, 155.42 MPa, as compared to the other samples can be attributed to the absence of pore agglomeration and voids in the reinforcing carbon fibers. Kohli et al. (2021); Venkatasudhahar et al. (2020) observed a correlation between the increase in carbon fiber content and the improvement in tensile strength of hybrid composites (kenaf/carbon aluminium composite).

3.1.2 Flexural strength

Figure 3 depicts the bending characteristics of aluminum composites with varying levels of glass fiber additions. The flexural strength shows an increase from 48 MPa (control sample) to 56 MPa (6 wt. %), 62 MPa (12 wt. %), and 58 MPa (18 wt. %) in the presence of glass fiber reinforcement. Error bars on the curves represent the standard deviations of four aluminium/glass fiber composite samples tested at each reinforcement level. The small standard deviation values (ranging from 4 to 9) compared to the flexural strength at each point indicates the close proximity of flexural strength values, suggesting isotropic behavior of the composite

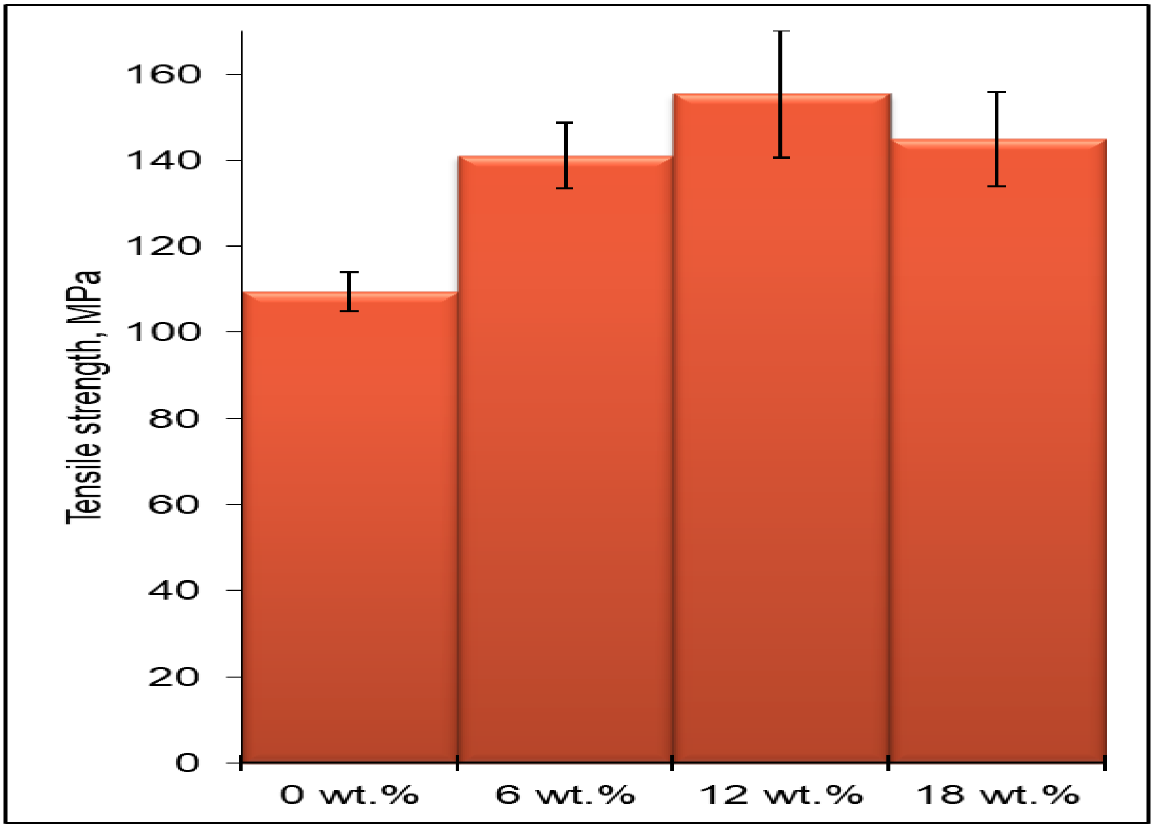

Figure 2: Tensile properties of 0 –18 wt.% glass/aluminium composites.

The improved resistance of aluminium/glass fiber composites to stress-induced deflection during bending tests is attributed to the rigidity of the glass fiber second-phase particles, ductility of the aluminium matrix, and a robust interfacial bond between the ceramic second-phase particles and the aluminium matrix. While flexural strength increased with higher reinforcement levels, there was a slight decrease with the 16 wt. % composite. According to the conventional strength increase-elongation reduction theory, the flexural strength of aluminium/glass fiber composites is expected to surpass that of aluminium/aluminum composites at each point.

At 12 wt. %, the flexural strength of aluminium/glass fiber composites surpassed that of the control and other reinforced composite samples, suggesting that these composites are suitable for applications requiring higher strength. Achieving an optimal combination of flexural strength is a crucial factor in material selection for high-strength applications, as noted Tay et al. (2021).

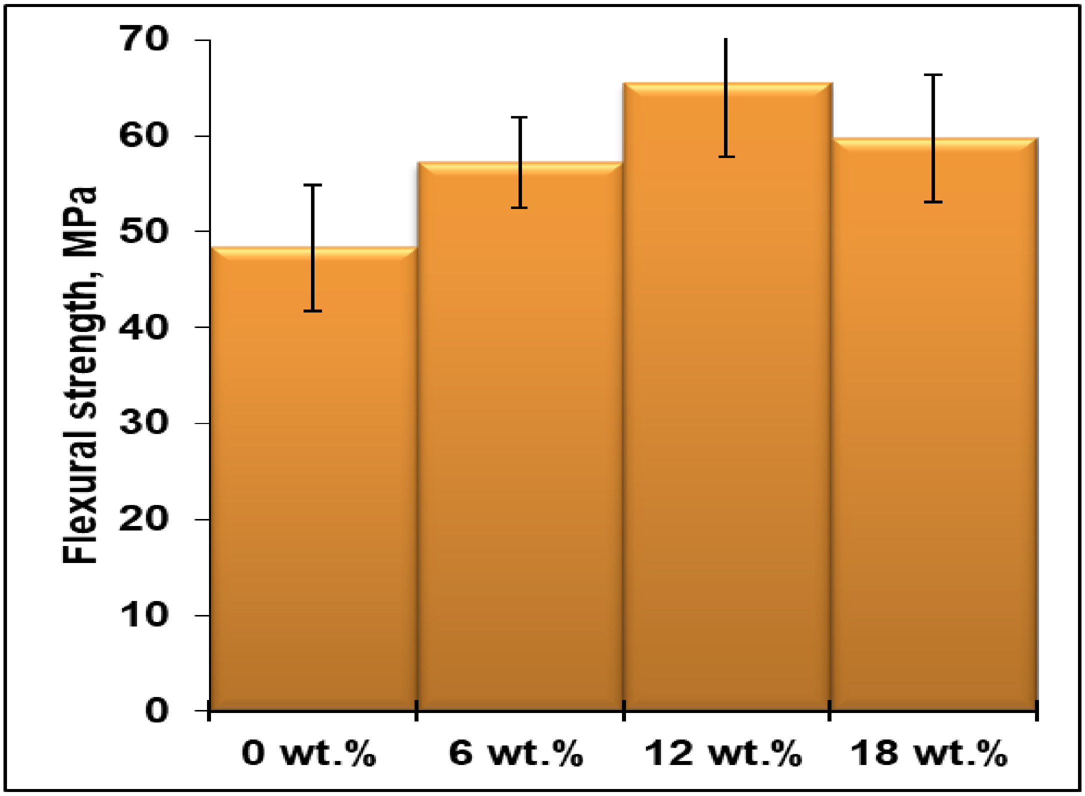

Figure 3: Flexural strength of 0 –18 wt.% glass/aluminium composites

3.1.3 Hardness test

Figure 4 illustrates the outcomes of the Brinell Hardness Test conducted on the composite with varying reinforcement reinforcements. The control sample exhibited a hardness value of 78 BHN, the lowest among all the samples investigated. There was an increase in hardness at 6 wt% glass fiber, reaching 86 BHN, the lowest hardness value among the glass fiber composites. Subsequently, there was a rise to 105 BHN for 12 wt% glass fiber reinforcement, followed by a decrease to 91 BHN for 18 wt% glass fiber reinforcement.

In summary, the samples achieved maximum hardness with 12 wt% glass fiber reinforcement. It was noted that the hardness of the composites increased with the rise in glass fiber up to 12 wt%. Hardness values progressed from 78 BHN at 0% glass fiber to 105 BHN at 12 wt% glass fiber particles. These increments are attributed to the higher weight percentage of the hard and brittle phase of glass fiber in the aluminium matrix, influenced by the chemical composition of the fiber. Additionally, the presence of glass fiber in the aluminium increased the dislocation density at the particle-matrix interfaces due to differences in the Coefficient of Thermal Expansion (CTE) between the hard and brittle reinforced particles and the soft and ductile polymer matrix, resulting in elastic and plastic incompatibility between the matrix and the reinforcement, as noted by Khare et al. (2021). This pattern of increasing hardness property due to reinforcement addition was also reported by Alaneme and Sanusi (2015); Devireddy and Biswas (2017). The enhancement in hardness of the composites is reported to be influenced by interfacial bonding, uniform dispersion, and robust bonding strength between filler and matrix components in composites. Hence, this study aligns with the notion that an increase in hardness is a function of filler content, and hardness is directly proportional to the reinforcement loading, as reported by Kerni et al. (2020).

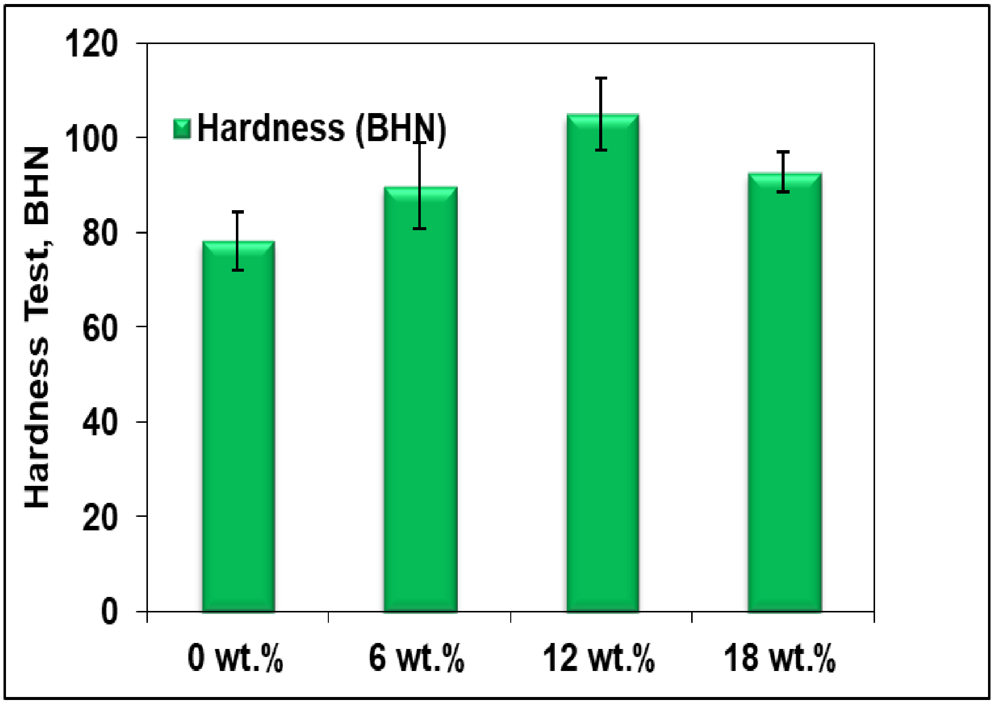

Figure 4: Hardness test of 0 –18 wt.% glass/aluminium composites

3. 2 Wear test

3.2.1 . Specific wear rate

Figure 5 and Figure 6depict the specific wear rates at velocities of 2 m/s and 4 m/s, respectively. The extent of wear a material undergoes is influenced by factors such as applied load, sliding velocity, and distance. The samples were prepared following ASTM D1242 guidelines, with varying conditions including load (10, 20, 30 N), sliding speed (2 and 4 m/s), and a constant distance of 1000 m as per Biradar et al. (2020). The unreinforced control sample (0 wt.% glass fiber) exhibited the highest wear rates, measuring 0.215, 0.32, and 0.341 g for 10, 20, and 30 N, respectively. However, wear rates decreased with the incorporation of glass fiber reinforcements in the 6, 12, and 18 wt.% glass fiber composite samples. Consequently, the 6 wt.% sample demonstrated the lowest wear among all load applications, followed by the 12 wt.% and 18 wt.% glass fiber aluminium composites. These results clearly indicate that reinforcement significantly mitigated the wear process. Moreover, an increase in sliding speed correlated with an elevated wear rate, aligning Biradar et al. (2020)'s findings that both load and sliding speed play substantial roles in the wear process. The addition of 18 wt.% glass fiber reinforcement resulted in a harder sample. Kumar et al. (2017) reported that as a composite material becomes harder, its wear rate decreases.

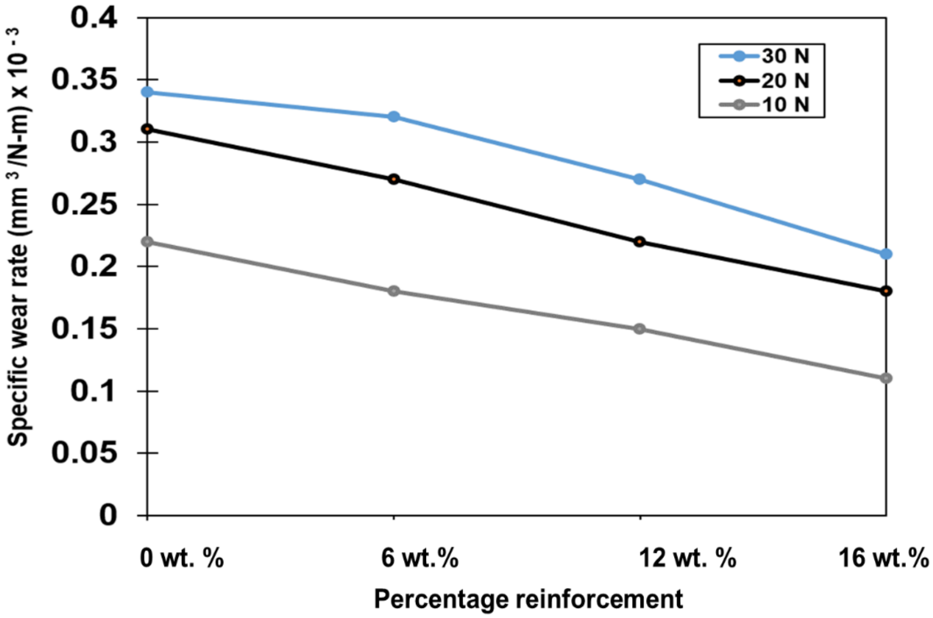

Figure 5: Specific wear resistance of 0 – 18 wt.% glass fibre/aluminium composite at 2 m/s for 10, 20, 30 N.

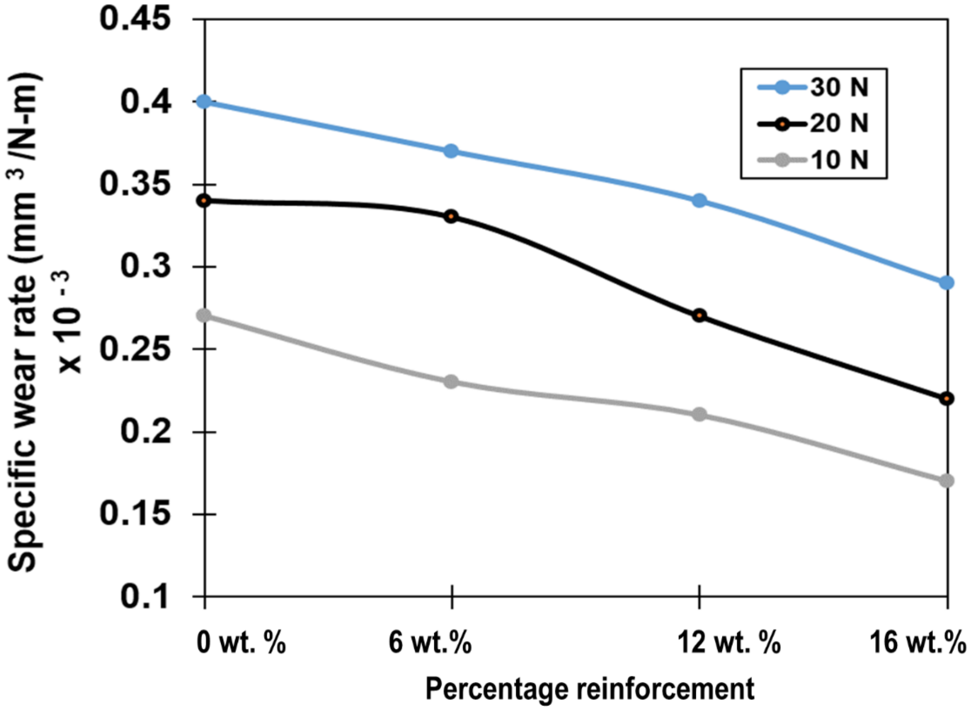

Figure 6: Specific wear resistance of 0 – 18 wt.% glass fibre/aluminium composite at 4 m/s for 10, 20, 30 N.

3.3 Loss of weight

Figure 7illustrates the impact of reinforcement on weight reduction at 2.0 m/s, attributed to the introduction of glass fibre reinforcements. Likewise, Figure 8

displays the weight loss for a sliding speed of 4.0 m/s at 10, 20, and 30N for all samples. Variances in weight loss were observed between glass fiber reinforcement and the unreinforced composite sample (control). The research findings indicate that as the applied loads increased by 10, 20, and 30 N, the weight loss in the composites gradually decreased. Both speed and load exert a significant influence on the extent of wear loss, where higher combinations of load and speed result in increased wear rate and weight loss, as observed in studies Sahu and Sahu (2020).

Overall, the results demonstrate that 16 wt.% of glass fiber, especially when not exceeding this percentage, exhibited the lowest weight loss among the composites. The incorporation of hard reinforcement particles, such as glass fiber, enhanced hardness and reduced weight loss in polymer composites, as noted by Sahu and Sahu (2020).

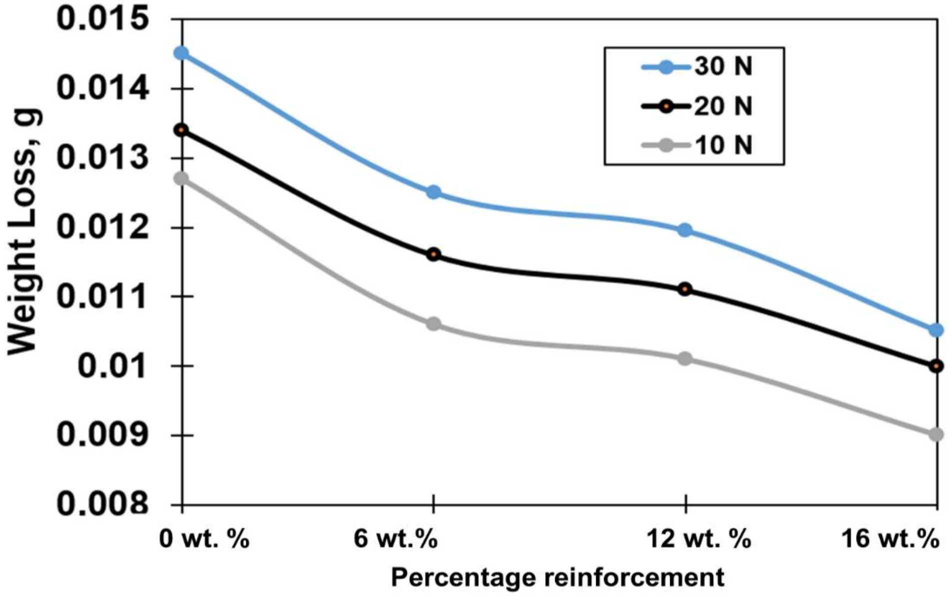

Figure 7: Loss of weight of 0 – 18 wt.% glass fibre/aluminium composite at 2 m/s for 10, 20, 30 N.

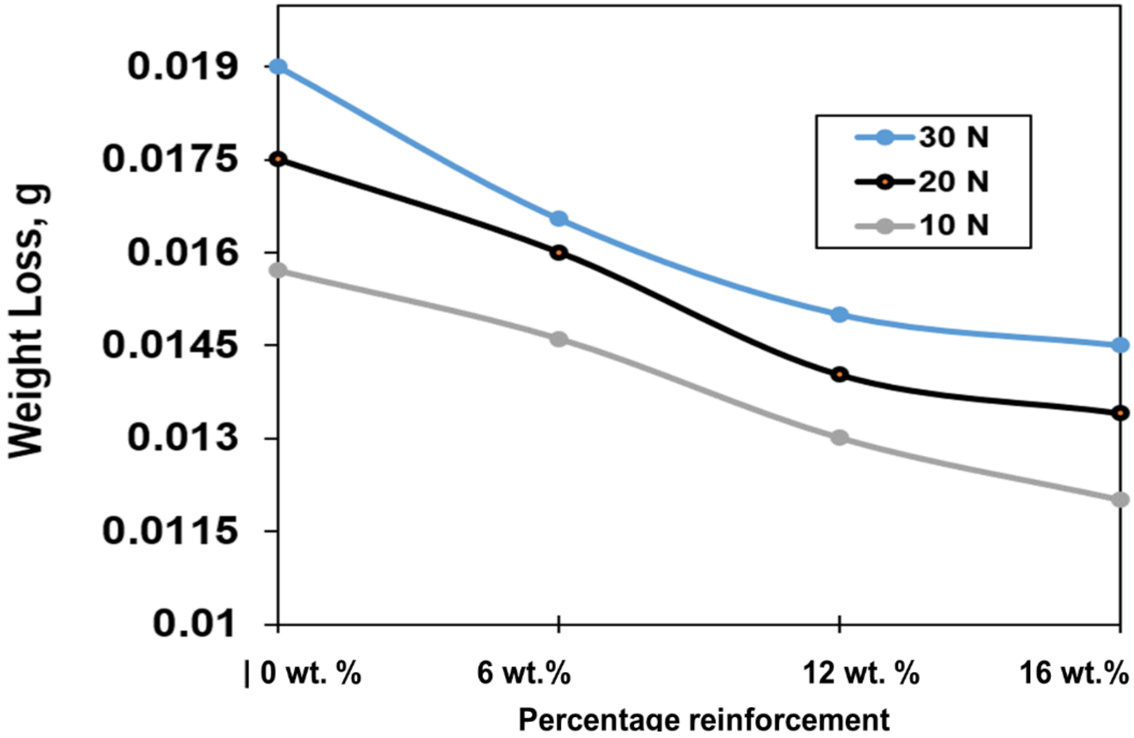

Figure 8: Loss of weight of 0 – 18 wt.% glass fibre/aluminium composite at 4 m/s for 10, 20, 30 N.

3.4 Coefficient of Friction

The coefficient of friction (COF) data for composites consisting of 0, 6, 12, and 18 wt.% glass fiber aluminum composite is presented in Figure 9and Figure 10for 2 and 4 m/s, respectively. The results indicate that the introduction of glass fiber reinforcements leads to a decrease in COF. The control composite (0 wt.%) exhibited the highest

COF, followed by 4 wt.% and 12 wt.%, while the lowest COF was observed with 16 wt.% glass fiber reinforcement. Notably, in contrast to the wear rate analysis, the COF reached its minimum point under a 10N load. As the load increased to 20N and 30N, the COF also increased accordingly. Similarly, an increase in speed resulted in a proportional increase in the COF. It was observed that the incorporation of glass fibers had a diminishing effect on the COF of the composite.

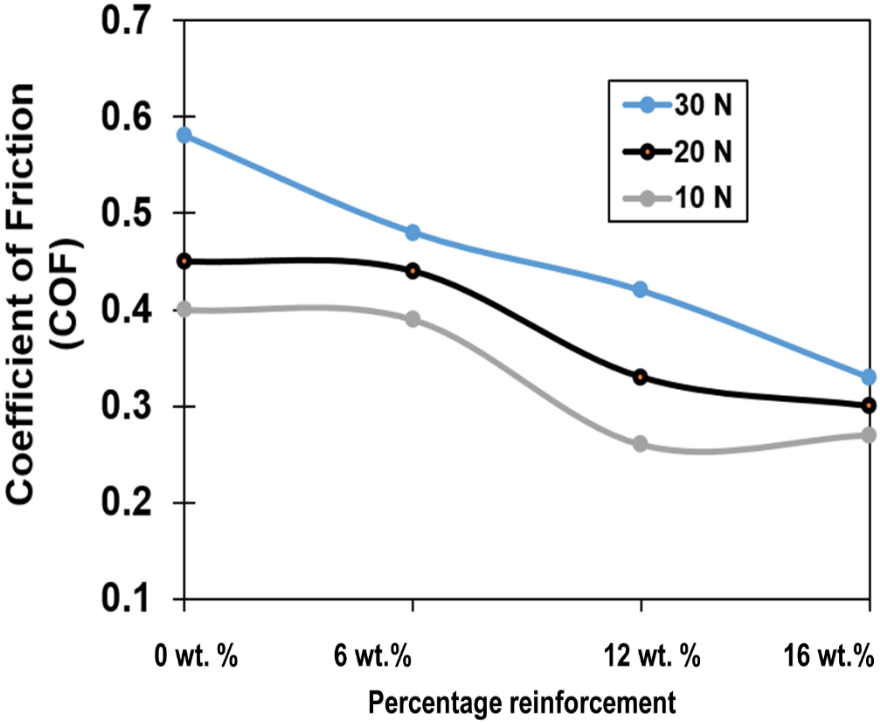

Figure 9: Coefficient of Friction 0 – 18 wt.% glass fibre/aluminium composite at 2 m/s for 10, 20, 30 N.

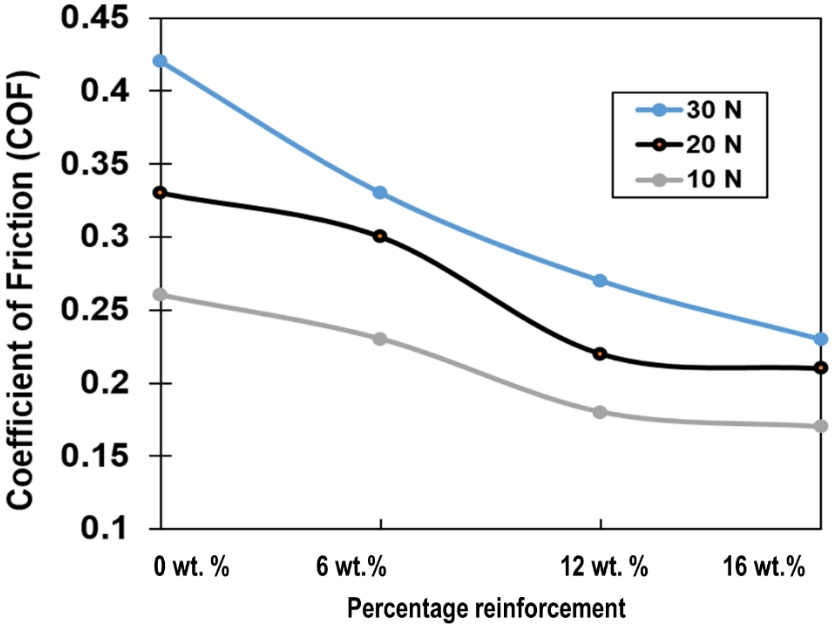

Figure 10: : Coefficient of Friction 0 – 18 wt.% glass fibre/aluminium composite at 4 m/s for 10, 20, 30 N.

4.0 Conclusions

BHN Hardness test shows that the control sample had a hardness value of 78 HB which was the lowest among in all samples. There was a steady increase in hardness with the addition of glass fibre at 6, 12 and 18wt% glass fibre aluminium composites. However, sample 12wt% glass fibre composite gave the highest hardness (105 BHN). The maximum value of the tensile strength was obtained at Al+12wt% mass of glass fibre composite. There was a decline in the strength at 18wt% glass fibre composite due to insufficient matrix to bear the excessive glass fibre load. Flexural strength shows that the control sample had an impact strength value that was above the reinforced 6, 12 and 18 wt.% glass fibre composites. This was due to the glass fibre particle that increases the toughness of the composites. However, sample 12wt% glass fibre compo site gave the highest impact strength (62 MPa). Tribological analysis was used to determine the composites' resistance to wear. The results showed that higher load (30N) and higher velocity (4 m/s) resulted into greater wear loss as compared with lower loads (10 and 20 N) and speed (2 m/s). Also, more reinforcement of glass fibre reinforcement reduces the wear loss because the composite was becoming harder. Therefore, the minimum wear loss was found with 16 wt. % sample.

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