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Property Assessment of Locally Developed Bio-Based Feather Fibre Reinforced Epoxy Composite for Automotive Application

Isiaka Oluwole Oladele [a, b], Samuel Olumide Falana[a], Ayodele Olawumi Adedeke [c], Bayode Benson Adeyanju [c], Opeyemi Victoria Oyedokun [c], Linus Nnabuike Onuh[a, d], Isaac Oloruntobi Adebiyi [a]

[a] Department of Metallurgical and Materials Engineering, Federal University of Technology, Akure, Ondo State, Nigeria

[b] Centre for Nanomechanics and Tribocorrosion, School of Metallurgy, Chemical and Mining Engineering, University of Johannesburg, Johannesburg, South Africa

[c] Engineering Materials Development Institute, NASENI, Akure, Nigeria

[d] Department of Materials Engineering, Faculty of Materials and Chemical Engineering, University of Miskolc, Hungary.

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Abstract: **The automotive industry is increasingly exploring sustainable and innovative materials to meet the evolving demands for lightweight, durable, and eco-friendly solutions. This study investigate the development and characterization of epoxy-based composite reinforced with chicken feather fiber for potential applications in automotive components. Chicken feather fiber, a natural and renewable resource, is incorporated into the epoxy matrix through the open mold hand layup technique for the possibility of enhancing the mechanical and physical properties of the composite. Hence, tensile, flexural, hardness, impact, wear, thermal conductivity, and density measurements, were evaluated in order to access the performance of the composite across various parameters. The results demonstrate significant improvements in these properties with the addition of chicken feather fiber (CFF), where CFF between 12 and 15 wt% exhibited optima properties in the tensile, flexural, impact, hardness, and wear properties. Furthermore, the composite exhibits favorable thermal insulation properties and reduced density, offering potential advantages for light weighting and thermal management in automotive applications. The findings of this study highlight the promising potential of chicken feather fiber-reinforced composites as sustainable alternatives to conventional materials in the automotive industry, paving the way for the development of environmentally friendly and high-performance automotive components such as door panels, dashboard components, trim pieces, side skirts, body panels, engine compartment insulation, wear-resistant bushings, and bearings.**

Keywords: **automobile, bio-based fiber, bio-composite, epoxy, feather, lightweight, sustainable material.**

I. INTRODUCTION

The use of natural fibers as reinforcements in polymer matrix composites has attracted increasing attention compared to their synthetic counterparts in the recent times due to their various properties as presented in Table I and their wide range of applications in automobile, aerospace, building and construction as well as biomedical industries. This change in focus has enabled researchers to extensively investigate these materials, acknowledging their ability to provide optimal properties while also supporting sustainability. Referred to as 'bio-composites,' these materials represent a combination of environmental awareness and technological progress. By utilizing the inherent qualities of natural fibers, these composites not only offer improved performance but also demonstrate a tangible dedication to promoting environmental responsibility in the field of composite materials (Bansal et al., 2017).

Table I: Comparison a natural fibers with synthetic fibers (Prakash et al., 2022)

Properties	Natural fibers	Synthetic fibers
Density	Low	Double of natural Fibers
Origin	Natural	Man-made
Fiber structure	Cannot be changed	Changed
Nature	Hydrophilic	Hydrophobic
Durability	Low	High
Cost	Low	High
Use	Low	High
Recyclability	Yes	No
Renewability	Yes	No
Distribution	Wide	Restricted
Energy Consumption	Low	High
Health risk	No	Yes
Co_2 neutral	Yes	No
Specific strength and modulus	High	Low
Strength and modulus	Low	High

In the realm of natural fibers, categorization is typically based on their respective origins, namely vegetable, animal, or mineral sources. Vegetable fibers encompass a diverse range of materials, including wood flour derived from both softwood and hardwood species, as well as plant fibers like hemp, kenaf, curaua, coir, jute, sisal, and bamboo. Animal fibers consist of wool, feathers, and leather while mineral fibers, on the other hand, include glass, boron, and asbestos (Ali et al., 2021; Pickering et al., 2016). Singh, (2021) also categorizes the origins of fibers as flora fibers, fauna fibers, and mineral fibers. From a chemical perspective, plant fibers are identified as cellulose-based (comprising carbon, hydrogen, and oxygen) while animal fibers are referred to as protein-based (specifically keratin) (Basak et al., 2021). Various industries, especially the automotive sector, have been observed to integrate natural fibers into a variety of applications. Major automotive companies such as BMW, Mercedes, Toyota, Daimler, Audi, and Ford have shown interest in utilizing natural fiber composites. These companies have utilized natural fiber-reinforced composites (NFRCs) for various automotive components, such as door linings and panels in car interiors (Neto et al., 2022). Daimler-Benz has been actively working since 1991 to replace glass fiber-reinforced composites with NFRCs. For instance, BMW 7 Series vehicles utilize noise-reducing foam composites (NFRCs) for soundproofing in interior door linings, panels, upholstery, and seatback cushions. Ford has also incorporated components made from soy, rice, and wood composites in many parts of their vehicles. Notably, Motive Industries of Calgary has introduced an electric car featuring components crafted from hemp fiber. This car is acclaimed as the most environmentally friendly globally and is capable of reaching a top speed of 90 km/h (Patel et al., 2023; Vigneshwaran et al., 2021). Also, numerous studies have been carried out in Europe with the aim of promoting the utilization of NFRCs within the automotive industry, specifically focusing on applications such as seat-backs, parcel shelves, boot linings, front and rear door linings, truck linings, and door-trim panels (Shaker et al., 2020; Zhang et al., 2022).

Among these natural fibers, plant fibers such as kenaf, flax, hemp, ramie, jute, bamboo, and sisal are commonly used as reinforcements in polymer composites for automotive applications such as door panels, seat backs, dashboards, car roofs, door handles, and various other parts as well as some structural parts (Ramesh, 2018; Fogorasi and Barbu, 2017). Gavade et al. (2022) conducted a study on optimizing the characteristics of jute/epoxy composites for automotive applications through gray relation analysis. The research revealed that the fiber volume and composite thickness significantly impacted jute fiber-reinforced epoxy composites. The findings demonstrated the successful utilization of these composites in manufacturing motorcycle and three-wheeler mudguards and mirror pockets. The study suggests the potential applications of the composites in automotive components. Uzoma et al. (2023) conducted a study focusing on the utilization of kenaf fiber-reinforced composite materials for both interior and exterior automotive plastic components. The research involved the application of injection molding for the production of the control sample, while the Resin Transfer Molding (RTM) technique was employed for the development of the reinforced composites. The findings indicated that the composite containing 40% fiber exhibited the optimal tensile strength of 55 MPa. Moreover, fiber contents ranging from 10% to 40% were found to be compatible with the epoxy matrix, showing superior mechanical properties compared to the control sample. This investigation highlights the potential of sustainable textile fibers as efficient reinforcements for plastics in manufacturing composite materials for the automotive industry. While plant fibers undeniably dominate automotive applications due to their abundant supply, sustainability, high strength-to-weight ratio, low density, renew-ability, biodegradability, and favorable mechanical properties. Researchers are now exploring the potentials of animal fibers as reinforcements in polymer matrix composites for various reasons. Among these, the distinctive properties of animal fibers, exemplified by materials such as wool and silk, including elasticity, thermal insulation, and flame resistance, hold promise for specific automotive applications. Additionally, the biodegradability of certain animal fibers mirrors the eco-friendly attributes of plant fibers, aligning with the automotive industry's increasing focus on sustainability. However, the utilization of animal byproducts such as chicken feathers or animal hair, which represent significant waste streams, provides an opportunity to develop more sustainable solutions through composite integration, thereby, addressing waste reduction goals. While it is evident that plant fibers currently stand as the pragmatic choice for most automotive applications, ongoing research into animal fibers for specialized niches signifies a pursuit of innovation, diversification, and sustainability in composite materials. This exploration not only aims to unlock the full potential of animal fibers but also underscores their role in shaping the future landscape of sustainable composites within the automotive industry. Given these considerations, our objective is to pioneer the development of a novel chicken fiber-reinforced epoxy composite tailored specifically for automotive applications. This endeavor not only builds upon existing research that uses chicken feathers as reinforcement in polymer matrix composites (Oladele et al., 2014) but also emphasizes our dedication to sustainability. By re-purposing chicken feathers, typically considered as waste and contributors to environmental pollution, as a reinforcement material, this will mitigate waste generation while simultaneously advancing the eco-friendly of automotive composite materials. Through this research, we aim to contribute to the expanding knowledge base on sustainable composite materials and promote a more environmentally friendly future for the automotive industry.

Chicken feathers, traditionally discarded as waste within the poultry industry, are currently being investigated by various researchers for their potential application as reinforcement in polymer matrix composites. Annually, a significant amount of these feathers, totaling billions of kilograms, is discarded by poultry processing facilities. They are often disposed of through incineration or land filling, which worsens environmental pollution. Such disposal methods exacerbate the emission of greenhouse gases, posing significant environmental risks (Oladele et al., 2022). Against the backdrop of heightened concerns regarding sustainability, scholarly attention has increasingly shifted towards research endeavors aimed at integrating recyclable and environmentally friendly materials, with a particular focus on natural and animal-derived fibers. Within this domain, chicken feather fiber (CFF) has emerged as a pivotal subject of inquiry, offering a promising avenue for sustainable utilization and addressing environmental challenges (Farhad Ali et al., 2021; Bessa et al., 2017; Oladele et al., 2014). Recent investigations have revealed that CFF, characterized by its fibrous structure, boasts a composition comprising 91% protein (keratin), 1% lipids, and 8% water, thereby positioning it as the most abundant source of keratin in nature and classifying it as a protein-based natural bio-polymer (Kumar et al., 2020; Vijayan et al., 2020; Guillame et al., 2017). CFF categorize as keratin fibers, being composed of amino acids, exhibit a natural ability to cross-link with polymer matrices by forming sulfide or hydrogen bonds. This enhances the interaction between the fiber and matrix, resulting in desirable properties like stiffness, strength, and lightweight characteristics (Jaya et al., 2018). Moreover, CFF is economically viable and boasts the lowest density among all-natural and synthetic fibers, providing composites with numerous advantages, such as a superior strength-to-weight ratio, excellent thermal insulation, remarkable acoustic properties, biodegradable and exceptional hydrophobic characteristics (Venkata et al., 2023; Hashim et al., 2019).

Furthermore, CFF exhibits thermal stability up to 190-205 °C, attributed to the hydrogen bonds, S-S cross-linking, Van der Waals forces, and electrostatic interactions inherent in its chemical structure (Casadesús et al., 2018). Given the favorable properties exhibited by this fiber, researchers have identified it as a promising reinforcement for polymer matrix composites. These composites demonstrate enhanced mechanical, thermal, and physical properties, as evidenced by various tests conducted on the developed materials. Such attributes position them as viable candidates for applications in the automotive industry, where materials with superior performance characteristics are in high demand. Hashim et al. (2019) conducted a study that focused on developing, designing, and evaluating composite materials made from waste chicken feathers for use in automotive interiors. The research introduced a new environmentally friendly composite alternative for automotive interiors, contrasting with traditional polypropylene, by incorporating waste chicken feather fibers with epoxy resin. Various concentrations of the reinforcement phase, ranging from 2% to 8% by weight, were investigated. The composites were fabricated using a hand lay-up technique, and their tensile and flexural properties were assessed. The findings revealed that adding 2-wt% of chicken feather fibers to epoxy did not significantly impact the tensile strength. As the weight fraction of chicken feather fibers increased, the tensile strength of the composites reached a peak value of 25.9 MPa at a 4% weight fraction. Similarly, the flexural strength of the composites significantly increased with the addition of chicken feather fibers, reaching a maximum value of 98.2 MPa at a 4% weight fraction. In a study conducted by Oladele in 2014, an investigation was carried out to evaluate the potential of thermo-mechanically treated chicken feather fiber-reinforced epoxy composites for use in automobile applications. The research aimed to assess the impact of chemical modification on the mechanical and abrasion characteristics of treated chicken feather fibers when used as reinforcement in epoxy resin to create composites suitable for automotive applications. The findings indicated that the developed composites exhibited promising qualities for automotive applications. The mechanical and abrasion properties were significantly improved by incorporating these chemically modified chicken feather fibers into the epoxy matrix. Optimal improvements in these properties were observed with the addition of 2-8 wt% reinforcements. Among these, the 2-wt% reinforcement showed the best overall performance in terms of mechanical properties, while 4-6 wt% reinforcement resulted in the most favorable abrasion resistance. The utilization of chicken feather fiber (CFF) as reinforcement in various polymer matrices has consistently demonstrated improvements in composite properties, including mechanical, physical, and thermal characteristics. Building upon this premise, our study aims to develop a polymer matrix composite using CFF reinforcement in different proportions (3-18wt %) along with epoxy resin as the matrix. While previous research has explored the incorporation of CFF from babbles into epoxy matrices, the novelty of this work lies in the application of the stuck fibers. This deliberate approach aims to reveal the possible contributions of CFF from stuck and barbs in enhancing composite properties, thereby enriching the understanding of sustainable composite materials.

II. MATERIALS AND METHODS

The sourcing and procurement of all the materials utilized for this research were done in Nigeria. The chicken feathers was locally sourced from a poultry farm in the metropolis area of Federal University of Technology Akure, Ondo State while the commercially available Bisphenol A diglycidyl ether epoxy resin and diethylene triamine curative, commonly known as hardener were acquired from a local vendor in Akure, Ondo State, Nigeria.

PREPARATION OF CHICKEN FEATHER FIBER (CFF)

The processing of chicken feather fibers involves sorting to isolate the parts to be used followed by washing to eliminate various stains like blood and mud residues. The washed feathers were sun-dried at ambient conditions for 5 days to allow the retained moisture to drain. However, to further reduce the moisture content and ensure uniform drying throughout the feathers, subsequent oven drying was carried out at a temperature of 105°C for 2 hours. The chosen drying temperature was adequate to eliminate moisture from the structural walls of the quill without causing harm to the fragile and flammable barbs. After the drying process was completed, the feathers were allow to cooled within the oven to prevent moisture retention caused by condensation. Subsequently, feathers that met the desired moisture content criteria (65% to 70% dryness) were for further processed by focusing on tall (Vaned or Contour) and flight (Down) feathers. The feathers were cut into 10 mm sizes as shown in Figure 1, including both the quill and barbs, to create the desired chicken feather fiber (CFF) for use.

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Fig. 1. Dried Chicken Feather Fiber

COMPOSITE FABRICATION

The composite was fabricated using the open mould hand lay-up technique where chicken feather fibers (CFF) were integrated into the epoxy matrix at varying weight percentages ranging from 3-18%. The specific weight proportions were presented in Table 2 where the epoxy resin and hardener were combined in ration 2:1 and mixed thoroughly for 7 minutes to ensure the uniform distribution of the reinforcements within the epoxy matrix. To ensure a uniform blend of the epoxy resin, hardener, and CFF for each test specimen, the components were manually mixed using a glass rod stirrer in a polymeric container. Subsequently, the homogeneous mixtures were poured into designated molds tailored for each property under investigation and allowed to cure before remove from mold. The samples were then subjected to post-curing at ambient temperature (24±2°C). The cured samples were then tested in accordance with ASTM standards. Figure 2 showed part of the representative fabricated samples.

Table II: Design of Composite Samples

Sample (%)	Epoxy resin (wt%)	Chicken feather fiber (wt%)
Control	100	-
3	97	3
6	96	6
9	91	9
12	88	12
15	85	15
18	82	18

Fig. 2. Representative samples of de-molded fabricated composite samples before trimming

PROPERTIES EVALUATION

FLEXURAL TEST

The flexural test was carried out on the specimen using a universal testing machine (UTM FS 300–1023, USA) following the ASTM D-790-15 standard guidelines. As per the standard protocol, three samples were tested per batch. The test specimen, measuring 150 × 50 x 3 mm, was firmly attached to the machine's grip. The test was conducted at a rate of 5 mm/min over a 65 mm span, and the collected data was subsequently analyzed. To ensure precision, three duplicates of each flexural sample were prepared for testing, and the mean value was computed to aid in the generation of the flexure graphs.

TENSILE TEST

Tensile testing was conducted on the specimens using a universal testing machine (UTM) with the model number FS 300–1023, USA, at a cross head speed of 5 mm/min. The test was performed in accordance with the ASTM D-638-14 standard at an ambient temperature of 24 ± 2°C. The samples were prepared to meet the specifications outlined in Type IV, with dimensions of 115 mm in total length and 3 mm in thickness.

HARDNESS TEST

A Shore D Hardness Tester was employed to assess the hardness of various substances, with the results recorded as HS values. Six indentations were made on each test specimen at different points, and the average hardness value was calculated for each material. A 15 kg load was applied for 15 seconds during the indentation process, which was conducted at five different locations on the specimens to derive average values for graph construction.

IMPACT TEST

The experiment was conducted utilizing a Hounsfield balanced impact testing machine, specifically identified by serial number 3915 and model number h10-3. Test samples for impact assessment were prepared with dimensions of 64 × 11 x 3 mm and were centrally notched. These samples were positioned horizontally on the machine, maintaining a 60 mm distance between lines of support. Placing the samples in a cantilever position, they were clamped upright with a V-notch aligned with the top of the clamp. The machine's pendulum was then released to strike the test piece and fall freely to a predetermined height. Furthermore, three replicates of each impact sample were manufactured for the test, enabling the calculation of average values to facilitate graph plotting.

WEAR TEST

The investigation into the resistance to wear of the specimens was performed utilizing a Taber abrasion tester, specifically the TABER Rotary Platform Abrasion Tester – Model 5135 manufactured in the United States, in compliance with the ASTM D4060-10 standard. To secure the test piece onto the apparatus, a central orifice with a diameter of 10 mm was fashioned on the specimen. The specimen was firmly positioned on the machine platform, which is propelled by a motor at a velocity of 500 revolutions per minute (rpm). Each sample was a flat circular disk with an approximate diameter of 100 mm and a standard thickness of about 6.35 mm. The wear resistance was determined by assessing the weight loss after a specified number of abrasion cycles (500), following the guidelines outlined in the ASTM D4060-10 standard. The test specimens were exposed to a contact load of 1000 grams, as two rotating abrasive wheels with a thickness of 12.6 mm and a diameter of 50 mm were applied against them. The procedure was executed at a rotational speed of 500 rpm for roughly 1000 cycles. The wear indices were ascertained by computing the weight reduction of the sample using Equation (1) where Wi, Wf, and C represent the initial weight, final weight, and number of test cycles, respectively.

$$\text{Wear Index} = (W_i - W_f)/C*1000 \quad (1)$$

THERMAL CONDUCTIVITY

The thermal conductivity of the newly created composite material was assessed utilizing the Lee's disk apparatus in accordance with the guidelines outlined in ASTM E1530-19. The thermal characteristics of both the developed composites and the control sample were evaluated using the Lee's disk apparatus. The methodology involved placing the sample between the disks while maintaining a specified temperature (t) on the temperature controller. Heat transfer occurred from the initial disk to the subsequent disk through the sample. Alterations in temperature within the metal disks were monitored by two sensors attached to the disks. Changes in temperature within the second disk were observed and documented at regular intervals until thermal equilibrium was reached. Equation 2 was employed to determine the thermal conductivity of the material. Where, M - mass of the disk, 0.0078 Kg , Cp - specific heat capacity of the disk, 0.91 kJ/ KgK, Ø1, Ø2 - initial and final temperature of disk A and B, D - diameter of the sample, 0.04 m, x - thickness of the sample, 0.003 m, T_1, T_2 - temperature of disk A and B in Kelvin, t - final time taken to reach a steady temperature.

$$K = MCp\,(\emptyset 1 - \emptyset 2)\, 4x \,/\, \pi D2\,(T1 - T2)t \quad (2)$$

III. RESULTS AND DISCUSSION

TENSILE PROPERTIES

The tensile characteristics, such as ultimate tensile strength, tensile modulus, and elongation at break were measured and are illustrated in Figures 3-5, respectively. Fig. 3. illustrates the ultimate tensile strength (UTS) of both reinforced and not reinforced (control) composites. It is evident that there is a significant improvement in the ultimate tensile strength (UTS) with an increase in chicken feather fiber content from 0 wt% (pure epoxy) to 15 wt%. This enhancement demonstrates the successful reinforcement of the epoxy matrix with chicken feather fibers, increasing its ability to withstand tensile forces before failure. The peak ultimate tensile strength (UTS) is attained at 15 wt%, reaching a value of 49.8 MPa, which represents an approximately 84% increase compared to the not reinforced epoxy. The decrease in ultimate tensile strength (UTS) observed at 6 wt% compared to 3 wt% can be attributed to inadequate fiber distribution or incomplete fiber wetting by the epoxy. This could potentially result in weak inter facial regions between the fibers and the matrix, leading to premature failure and reduced ultimate tensile strength (UTS). Moreover, a significant decrease in ultimate tensile strength (UTS) was observed at 18 wt%. This could be attributed to fiber-matrix partial bonding, as the adhesion between the fiber and epoxy may be compromised at higher fiber contents, leading to premature failure. Despite the reductions observed at 6 wt% and 18 wt%, the ultimate tensile strength (UTS) data indicates that all reinforced composites exhibited higher UTS values when compared to the pure epoxy matrix. This highlights that the inclusion of chicken feather fibers enhances the ultimate tensile strength (UTS) of the composite material as this trend was also observed in Kumar et al. (2020) and Hashim et al. (2019).

Fig. 4. illustrates the tensile modulus of composites reinforced with chicken feather fibers (CFF) compared to not reinforced composites. The findings reveal a similar pattern to the ultimate tensile strength (UTS), with the tensile modulus steadily increasing from the not reinforced epoxy (0 wt%) to a fiber content of 15 wt%. This trend indicates that incorporating chicken feather fibers into the epoxy matrix increases stiffness, thereby enhancing its resistance to elastic deformation under tensile stress. The highest modulus value is achieved at 15 wt% (489.80 MPa), representing a substantial 74% increase compared to the pure epoxy. Conversely, a significant decrease in tensile modulus is observed at 18 wt% fiber content, similar to the ultimate tensile strength (UTS) results. This decline may be attributed to challenges related to fiber distribution, adhesion, or the presence of defects at higher fiber concentrations, as previously discussed in relation to ultimate tensile strength (UTS). Overall, it is observed that all carbon fiber fabric (CFF)-reinforced composites exhibit higher tensile modulus values compared to the pure epoxy composite, except for the 18 wt% CFF composite. These results suggest that adding chicken feather fiber reinforcement effectively enhances the stiffness of the composite material.

The findings presented in Figure 5 demonstrate a consistent reduction in elongation at the break of the composite material as the chicken feather fiber content increases. This trend indicates a decrease in ductility, which is defined as the capacity to undergo plastic deformation before fracture, with higher fiber content. The observed phenomenon can be attributed to the inherent stiffness of chicken feather fibers compared to the epoxy matrix. Consequently, as the fiber content increases, the overall stiffness of the composite also increases, limiting its ability to elongate before failure. Moreover, the limited matrix deformation during tensile testing may also contribute to this effect, as the fibers impede the flow and deformation of the epoxy matrix. Consequently, an increase in fiber content results in reduced space for epoxy flow and deformation, leading to diminished elongation at break. In essence, the incorporation of chicken feather fibers as reinforcement seems to hinder the composite material's ability to deform before failure, leading to a decrease in elongation at break. The fibers likely act as obstacles that impede the movement of the epoxy matrix, thereby reducing its ductility. Remarkably, the findings in the tensile properties of the composite exhibited a notable consistency with prior research conducted in this field as seen in Patrick et al., (2020), Farhad et al., (2021) bolstering the reliability and validity of the results.

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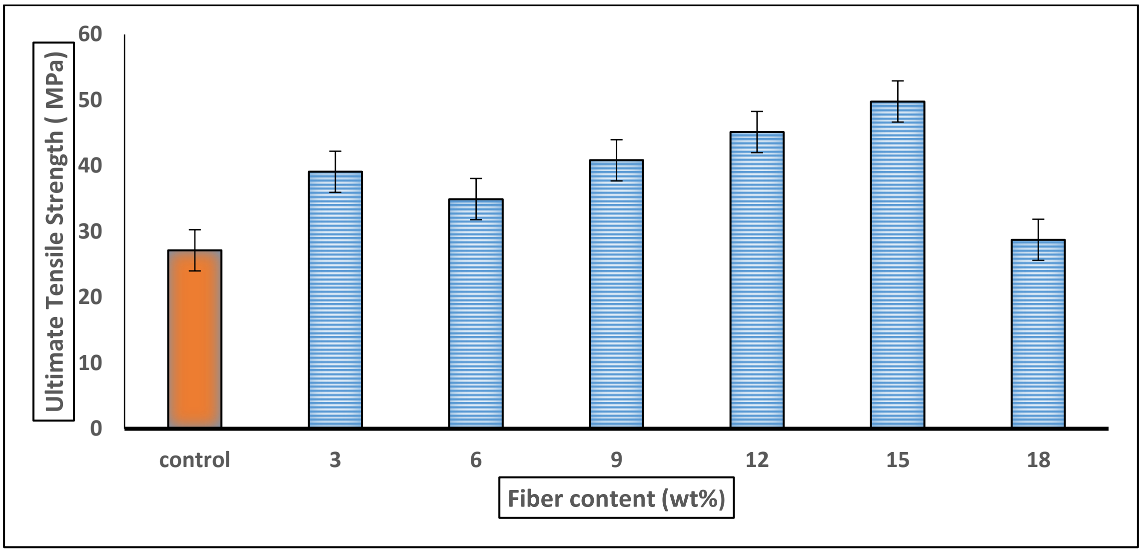

Fig. 3. Ultimate tensile strength of developed composites and control sample

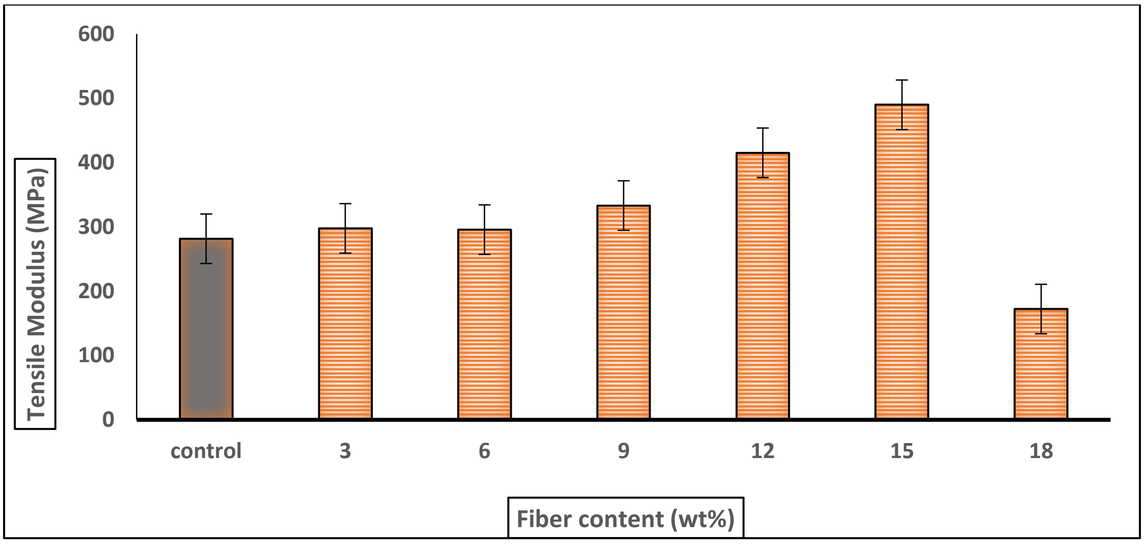

Fig. 4. Tensile modulus of developed composites and control sample

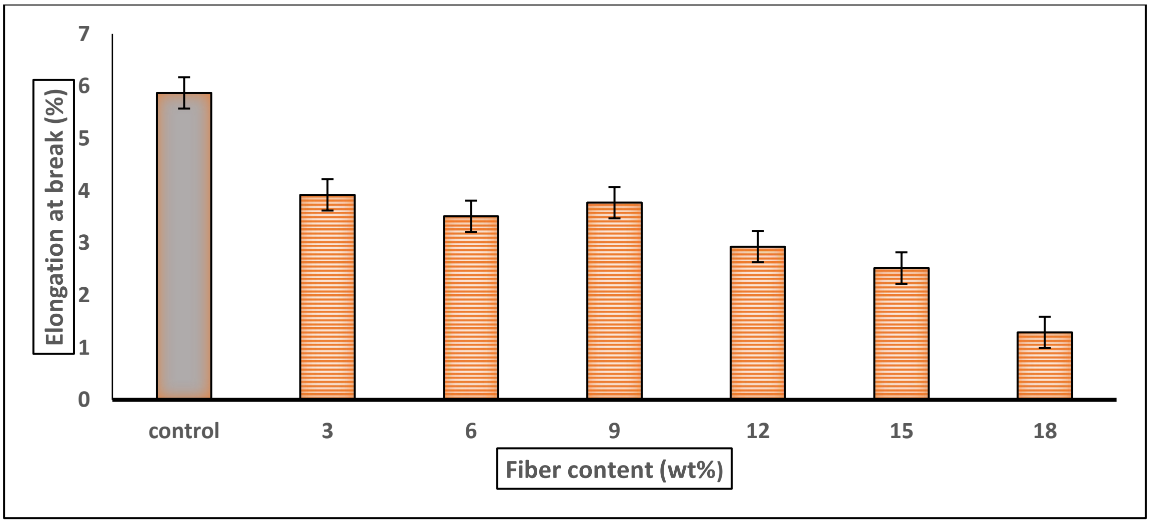

Fig. 5. Elongation at break of developed composite and control sample

FLEXURAL PROPERTIES

The flexural properties, also known as bending properties, involve applying a load to a specimen in a manner that causes bending or flexural deformation. The flexural strength and flexural modulus were measured for each composite, and their results are illustrated in Figures 6 and 7, respectively. Figure 6 illustrates a gradual enhancement in flexural strength as the chicken feather fiber content increases up to 12 wt%. This progression indicates the successful reinforcement of the epoxy matrix by the fibers, thereby enhancing its resistance to bending forces. The peak flexural strength is attained at 12 wt% (26.35 MPa), representing a nearly 73% increase compared to the not reinforced epoxy. This finding suggests that this specific composition may offer an optimal balance between fiber reinforcement and epoxy matrix characteristics. Moreover, at this fiber content level, the composite demonstrates a significant improvement in flexural strength without compromising other favorable material properties, such as process ability or cost-effectiveness. In contrast to the sharp decline observed in tensile properties, the flexural strength shows only a modest reduction at higher fiber contents (15% and 18% by weight). This phenomenon could be attributed to partial fiber bonding, which, while potentially detrimental in tensile tests, may slightly diminish the overall flexural strength at elevated fiber contents due to partial bonding in certain regions during bending. In general, this trend indicates that incorporating chicken feather fibers up to a specific threshold enhances the flexural strength of the composite by utilizing the fibers as load-bearing components within the epoxy matrix. This mechanism effectively disperses and transfers the applied load, thereby strengthening the composite's resistance to bending forces and enhancing its overall strength. Beyond this threshold, further increases in fiber content may not result in significant additional improvements or could potentially lead to a decrease in strength.

Figure 7 illustrates the flexural modulus, also known as the bending modulus, of a material, which signifies its resistance to bending. The analysis revealed a similar trend in flexural modulus as observed in flexural strength, indicating a general increase with the rise in weight percentage of chicken feather fiber up to a certain threshold (12 wt%). Subsequently, there was a plateau or a slight decline at higher fiber concentrations. This behavior suggests that incorporating chicken feather fibers into the epoxy matrix enhances its ability to withstand elastic deformation when subjected to bending, thereby stiffening the composite. The peak modulus recorded at 12 wt% (1.79 GPa) was approximately 320% higher than that of the not reinforced epoxy, indicating an optimal balance between fiber reinforcement and matrix characteristics for maximizing stiffness. The observed plateau or slight decrease in flexural modulus at 15wt% and 18wt% fiber contents may be attributed to factors such as fiber clustering or agglomeration, which can lead to uneven stress distribution and reduced overall stiffness. It is recognized that beyond a certain fiber content, an excess of fibers may reach a saturation point where further additions do not significantly enhance stiffness and may even result in diminishing returns. The results of the flexural modulus analysis highlight the positive impact of reinforcing epoxy-based composites with chicken feather fibers on stiffness. The trends observed in both flexural strength and flexural modulus of the epoxy-based composite reinforced with chicken feather fibers align with previous findings reported in Ali et al. (2021) and also in Venkata et al. (2023). These results not only contribute to the expanding knowledge base on natural fiber-reinforced composites but also affirm the viability of chicken feather fiber as a sustainable and efficient reinforcement material for automotive applications.

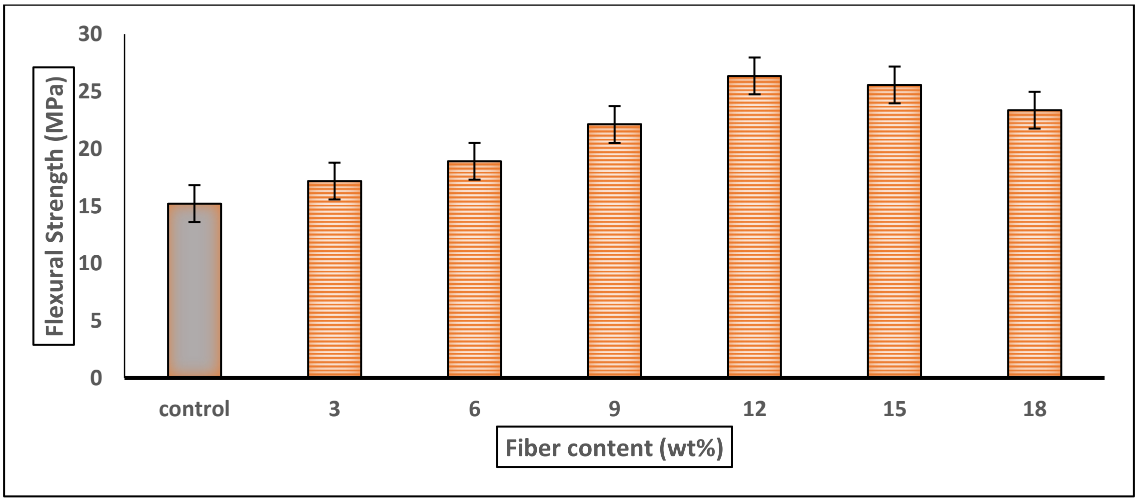

Fig. 6. Flexural strength of developed composites and control sample

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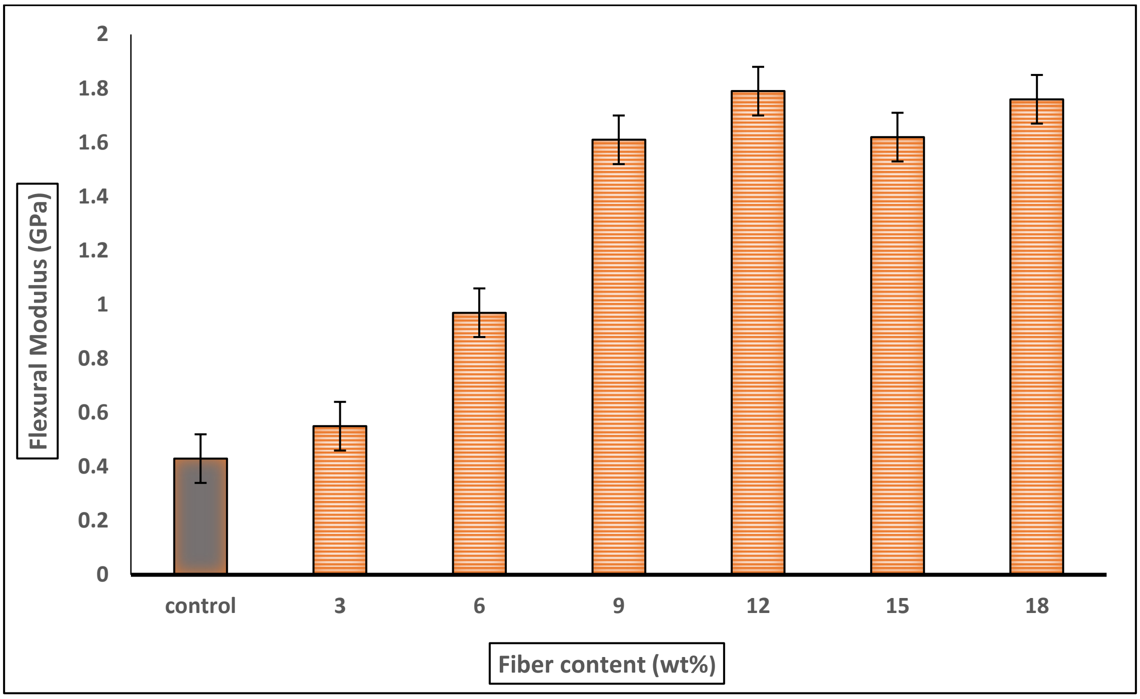

Fig. 7. Flexural Modulus of developed composite and control sample

HARDNESS PROPERTY

The hardness analysis of the developed composite material is depicted in Fig. 8, showcasing variations in hardness values corresponding to changes in the weight percentage of chicken feather fiber. Initially, the pure epoxy exhibited a hardness value of 54 HS, serving as a reference point for evaluating the impact of chicken feather fiber reinforcement on composite material hardness. At 3 wt%, the composite's hardness decreased to 47.2 HS. This initial decline in hardness could stem from inadequate bonding between the epoxy matrix and chicken feather fibers at lower concentrations, resulting in less effective load transfer and subsequently reduced hardness. Additionally, the presence of voids within the composite may contribute to decreased hardness. As the weight percentage of chicken feather fibers increased from 6 wt% to 15 wt%, the composite's hardness increased as compared to the control. This rise in hardness across the reinforced composite from 6-15 wt% suggests that reinforcing the epoxy matrix with chicken feather fibers at these concentrations may have improved inter facial adhesion and load transfer between the fibers and the matrix, possibly due to better dispersion of the fibers within the matrix. Furthermore, it was observed that 15 wt% exhibited optimum hardness (61.4 HS) among the reinforced composite. Compared to the control, this represents an 8% increase, indicating an optimal balance between fiber content and dispersion within the matrix, resulting in maximum reinforcement efficiency. At this concentration, chicken feather fibers likely provided significant reinforcement without excessively compromising the integrity of the composite structure. This 8% increase in hardness may be attributed to effective inter facial adhesion between the reinforcing agents and the matrix, enhancing the hardness property. Additionally, this phenomenon could be linked to increased stiffness and interlocking of fibers (Oladele et al., 2023; Dehury et al., 2017). However, beyond this optimal point, as the weight percentage of chicken feather fibers further increased to 18wt%, the hardness value decreased to 50.9 HS (still higher than control). This decline could be attributed to potential fiber agglomeration or clustering within the matrix at higher concentrations, leading to stress concentrations and reduced mechanical properties. Additionally, excessive fiber loading might result in overcrowding within the matrix, hindering effective resin impregnation and leading to incomplete wetting of the fibers, which can adversely affect composite performance.

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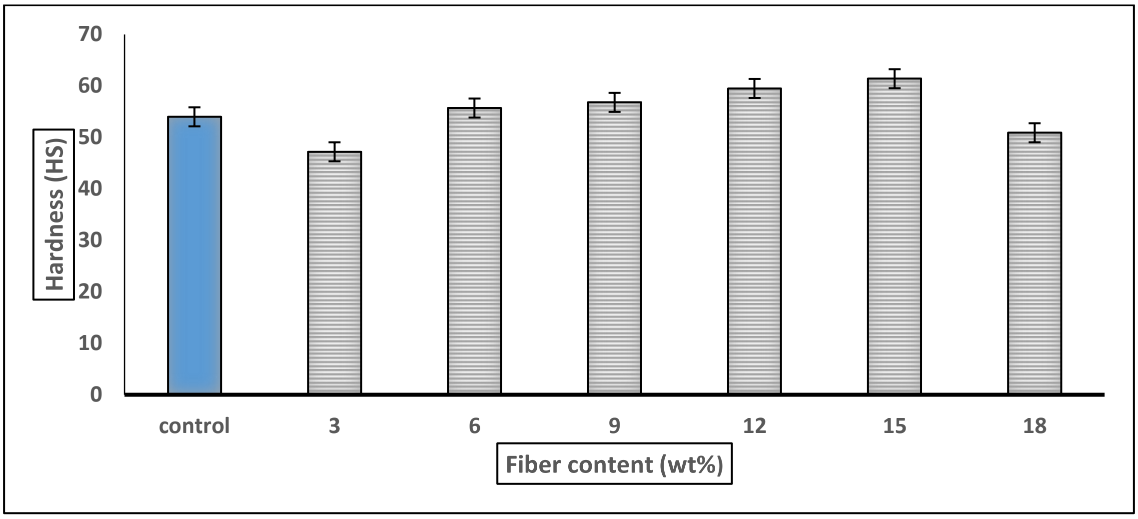

Fig. 8. Hardness of developed composite and control sample

IMPACT STRENGTH

The graph in Fig. 9. illustrates the impact strength findings, showing a decline in impact strength at 3 wt% compared to the not reinforced epoxy, followed by a steady increase up to 15 wt%. This pattern suggests that lower fiber content may create vulnerabilities in the composite, diminishing its ability to withstand impact forces. However, as the fiber content increases, the fibers become more adept at absorbing and dispersing impact energy, resulting in enhanced impact strength. The peak impact strength is achieved at 15 wt% (136.56 J/mm^2), representing a nearly 38% improvement over the not reinforced epoxy. This trend implies that integrating chicken feather fiber enhances the composite's impact resistance, with an optimal fiber content yielding the highest impact strength. Similarly, a marginal decrease in impact strength was noted at the highest fiber content (18 wt%), although it remained above that of the not reinforced epoxy, likely for the same reasons as previously explained. Overall, the rise in impact strength with increasing fiber content can be attributed to the mechanical reinforcement offered by the chicken feather fibers within the epoxy matrix. These fibers function as energy-absorbing components, proficiently managing applied impact forces and reducing the risk of fracture or failure. Consequently, the impact strength outcomes underscore the beneficial influence of chicken feather fiber reinforcement on the impact resistance of the epoxy-based composite. The impact test results corroborate and extend existing knowledge on the impact resistance of CFF reinforced epoxy composites. By aligning closely with findings from Uzun et al. (2011) and Venkata et al. (2023) our study contributes to the cumulative understanding of the mechanical behavior of these novel materials and underscores their potential for diverse engineering applications.

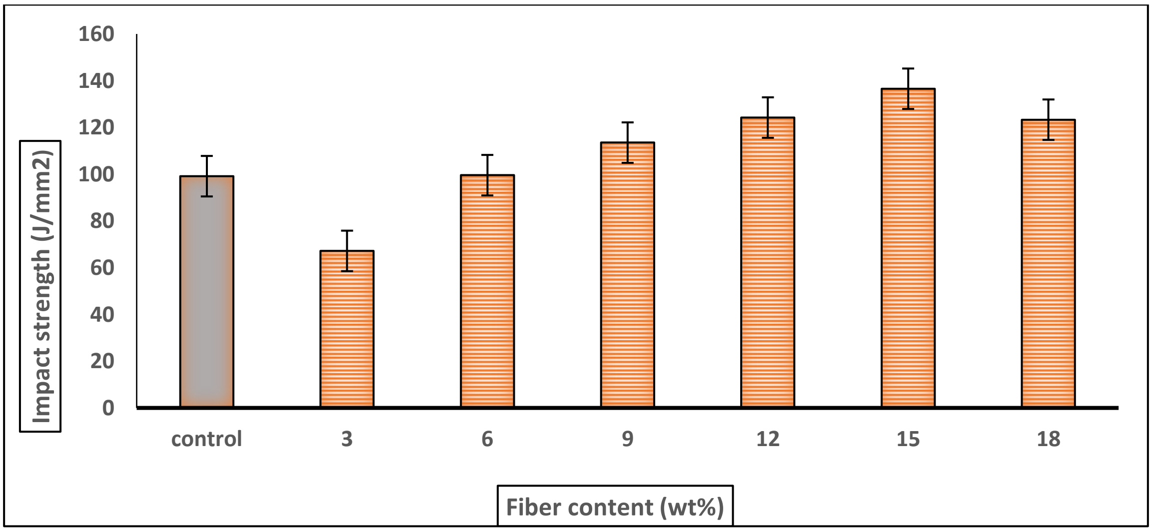

Fig. 9. Impact strength of developed composites and control sample

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WEAR PROPERTY

The findings depicted in Fig. 10. illustrate a favorable trend as the chicken feather fiber content increases, leading to an enhancement in the wear resistance of the composite material. A notable reduction in the wear index was evident with the rise in chicken feather fiber content up to 12 wt%. This phenomenon implies that the fibers serve as lubricating agents and effectively strengthen the epoxy matrix, thereby mitigating wear and abrasion during testing. The lowest wear index value was achieved at 12 wt% (0.059 mg), signifying a substantial 57% advancement in wear resistance compared to the not reinforced epoxy. Nevertheless, a slight rise in the wear index was observed between 15 and 18 wt% CFF content, possibly due to the abrasive nature of certain fibers, despite the general lubricating role of chicken feather fibers. It is plausible that some components within the fibers possess mildly abrasive properties at higher concentrations, contributing to the increased wear index within that range. Moreover, the occurrence of fiber-matrix non bonding at elevated fiber content levels could also be a contributing factor. Weak bonding between the fibers and the matrix at such levels may lead to nonbinding regions that act as particle accumulation sites, consequently accelerating wear during testing. Overall, the incorporation of chicken feather fiber in the composite material enhances its wear resistance by offering additional reinforcement and bolstering its ability to withstand abrasive forces. The well-dispersed and properly aligned fibers within the matrix function as barriers against material loss and diminish surface wear, as evidenced by the consistently lower wear index values across all reinforced composites compared to the not reinforced epoxy. Generally the addition of reinforcements (animal fiber) tend to increase the wear resistance of polymer composite as this trend was also observed when Oladele et al.(2018) conducted research on the effects of fiber fraction on the mechanical and abrasion properties of treated cow hair fiber reinforced polyester composites. Likewise in a research conducted by Ramesh et al. (2014)

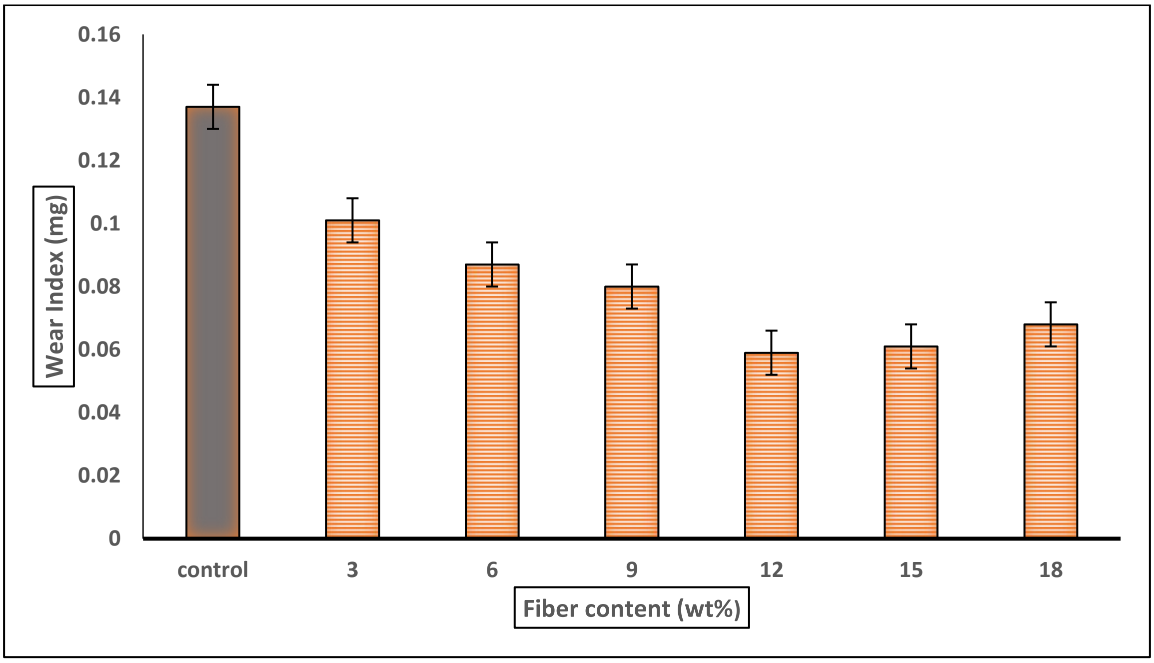

Fig. 10. Wear Index of developed composites and control sample

THERMAL CONDUCTIVITY

The outcomes of the thermal conductivity analysis exhibit a consistent decline with the increase in chicken feather fiber (CFF) content within the composite material. Specifically, the composite containing 18wt CFF demonstrates the least thermal conductivity, with low thermal conductivity indicating a heightened resistance to fluctuations in temperature. This observation suggests that the chicken feather fibers serve as effective thermal insulators, diminishing the capacity for heat transfer in the composite when compared to the not reinforced epoxy matrix. Generally, the introduction of chicken feather fibers (CFF) into the epoxy matrix leads to a reduction in the thermal conductivity of the composite material. This phenomenon can be ascribed to the insulating properties inherent in natural fibers like chicken feather fibers, which typically

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exhibit lower thermal conductivity in contrast to the epoxy matrix. The incorporation of these fibers into the matrix establishes thermal barriers within the material, impeding the flow of heat. Consequently, this yields a composite material with an overall lower thermal conductivity. Furthermore, the incorporation of reinforcement fibers amplifies the quantity of interfaces between the fibers and the matrix, along with the presence of imperfections such as voids and spaces. These interfaces and imperfections serve as thermal resistances, further obstructing the transmission of heat through the material. The arrangement and dispersion of the reinforcement fibers within the epoxy matrix can also influence thermal conductivity, as disordered or misaligned fiber orientations may create convoluted paths for heat transfer, ultimately diminishing the overall thermal conductivity.

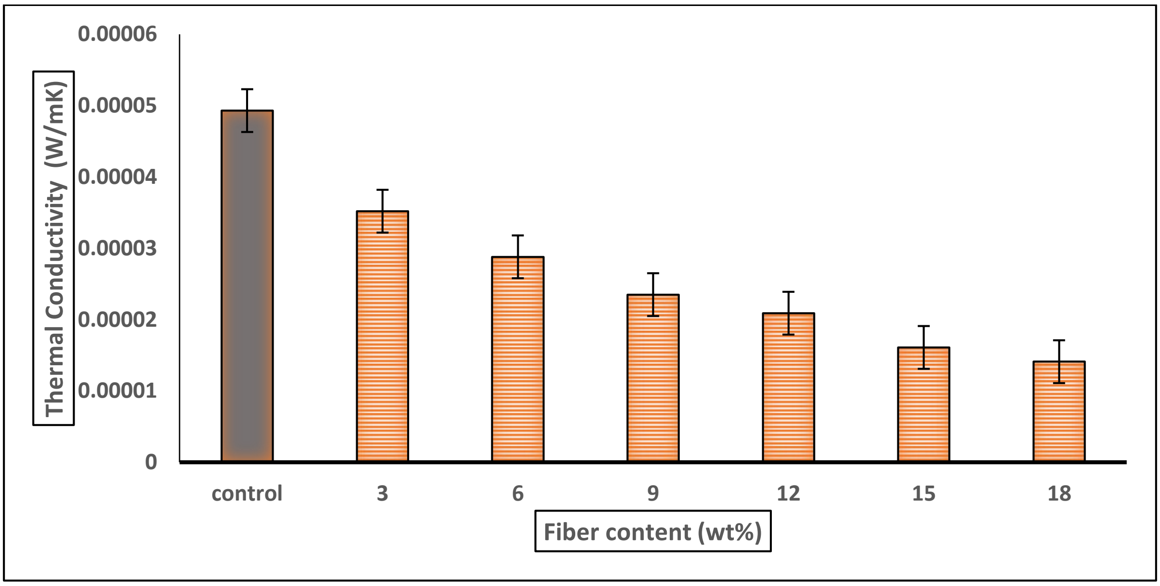

Fig. 11. Thermal conductivity of developed composite and control sample

DENSITY

Fig. 12. illustrates the response exhibited by an epoxy composite reinforced with CFF in relation to density. A comparable trend was noted in Figure 8 concerning the hardness of the composite, indicating a direct relationship between density and hardness. According to Oladele et al. (2020), higher density contributes to increased material hardness. The examination in Figure 12 revealed that density initially decreases at 3wt% reinforcement, indicating a reduction compared to the pure epoxy. This decrease could be attributed to the incorporation of chicken feather fibers, which have a lower density than the epoxy matrix. However, as the fiber content increases from 3 wt% to 15 wt%, density gradually increases. This rise suggests that the addition of chicken feather fibers contributes to an increase in composite material density, possibly due to better fiber dispersion. At lower concentrations (3-6 wt%), the fibers may not be uniformly dispersed within the epoxy matrix, leading to lower overall density due to void spaces. However, as the fiber content increases, better dispersion may occur, resulting in a denser composite. Additionally, with increasing fiber content, the volume fraction of reinforcing fibers within the composite increases, further contributing to higher density. Conversely, at higher concentrations (18 wt%), there was a decrease in composite density, possibly due to the agglomeration of chicken feather fibers within the matrix, leading to localized areas of higher density. This agglomeration could result in irregular fiber distribution and fluctuations in composite density. Furthermore, at these higher fiber loading, the epoxy matrix may reach saturation, limiting its ability to fully impregnate the fibers and resulting in incomplete wetting, which could create void spaces within the composite and contribute to density variations. As reported by Asokan et al. (2019), who noted a natural fiber density range of 1.2 – 1.6 g/cm^3, the outcomes depicted in Figure 12 indicate that all reinforced composites fell below this density range. This discovery is significant as it implies that employing such low-density composites could potentially result in fuel efficiency in automotive applications while also fostering the advancement of fully biodegradable composites for environmentally sustainable growth.

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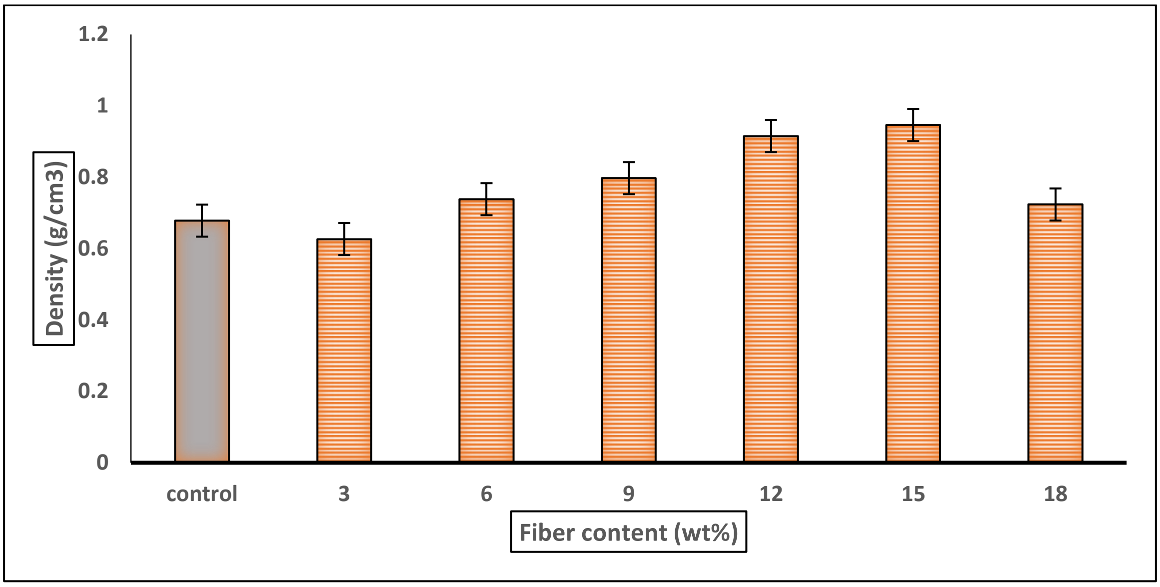

Fig. 12. Density of developed composite and control sample

IV. CONCLUSION

The development and characterization of an epoxy-based composite reinforced with chicken feather fiber present promising opportunities for innovative materials in the automotive industry. From this assessment study our result shows that the peak ultimate tensile strength (UTS) is attained at 15 wt%, reaching a value of 49.8 MPa, which represents an approximately 84% increase compared to the (control sample) not reinforced epoxy. Also, the peak impact strength is achieved at 15 wt% (136.56 J/mm^2), representing a nearly 38% improvement over the not reinforced epoxy (control). This trend implies that integrating chicken feather fiber enhances the composite's impact resistance, with an optimal fiber content yielding the highest impact strength. Hence, chicken feather fibers effectively reinforced the epoxy matrix by improving its tensile and flexural properties. Notably, 12-15 wt% fiber content exhibited optimum properties where 15 wt% and 12 wt% showed optima tensile and flexural properties, respectively. These samples also demonstrated improved resistance to impact loading at 15 wt% as well as hardness property while wear resistance was optimum at 12 wt%. These improvements make the composite well-suited for a wide range of automotive components, including interior, structural, and exterior parts such as door panels, dashboards, armrests, trim panels, side skirts, and body panels. Thermal conductivity and density properties of the composites offer additional advantages, such as enhanced thermal insulation and reduced weight, contributing to improved fuel efficiency and overall vehicle performance. This makes the composite suitable for use in engine compartment components, such as heat shields and insulation panels, protecting sensitive engine components from heat damage and improving overall vehicle performance. Thus, the study revealed chicken feather fibers as sustainable reinforcement material for epoxy composites for automotive applications. However, further research may be carried out to optimize the composite's properties through hybridization, treatment of fiber and the use of alternative manufacturing processes.

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