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TENSILE PROPERTIES AND MICROSTRUCTURES OF HYBRID UNIDIRECTIONAL COIR/CARBON FIBRE-REINFORCED EPOXY COMPOSITES

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ABSTRACT

Bio-fibres from plants as well as fibres from other natural materials have been immensely exploited for use as reinforcements in composites. The aim of this work is to determine the tensile properties of hybrid unidirectional coir/carbon fibre reinforced epoxy composites manufactured via hand layup. Coconut from which coir (coconut fibre) is obtained is abundant in Nigeria. Coir is a lignocellulosic fibre known for its relatively low density and thus savings in energy hence recommendable for light weight applications. Being a natural fibre, it is also eco-friendly. Carbon fibre (T700 Carbon) is a synthetic fibre notable for its high strength. The study seeks to harness the potential of hybridizing coir with carbon as reinforcements to improve the tensile properties of the epoxy composites. This work also advances beyond existing studies on similar composites via the unique stacking sequences. The average tensile strength, Young's modulus and elongation at break were obtained from three different stacking sequences: Carbon-Carbon-Coir-Coir-Carbon-Carbon, Coir-Carbon-Coir and Carbon Coir Carbon. The stacking sequence that exerted the highest influence on the tensile properties of the manufactured composites was found to be Carbon-Carbon-Coir-Coir-Carbon-Carbon with the tensile strength 63 and 34% higher than those of Coir-Carbon-Coir and Carbon-Coir-Carbon respectively. However the stiffness of Coir-Carbon–Coir was 26% higher than that of Carbon-Coir-Carbon. Therefore, improved mechanical properties of hybrid coir/carbon composites can be achieved using stacking sequence: carbon-carbon-coir-coir-carbon-carbon. The morphology of the coir and carbon and the failure modes of the composites were also carefully investigated.

Keywords: Coir, Carbon, Composite, Tensile properties, Microstructure

INTRODUCTION

The durability of a material and its applications is dependent on its mechanical and physical properties, such properties include; strength, stiffness, density and others. Natural fibres such as Kenaf (Balakrishnan et al., 2024) , hemp (Anand et al., 2023) , coir (Madueke et al., 2023) , jute (Maharana, Pandit and Pradhan, 2022), flax (Maharana, Pandit and Pradhan, 2022) and ramie (Rajesh et al., 2022) have been used as reinforcements in polymer matrix for composites production. Newer natural fibres that have been investigated by researchers for use as reinforcements include; datepalm (Shariff et al., 2023) and desert Plant (Yadav and Singh, 2023) Synthetic fibres such as E-Glass (Balakrishnan et al., 2024) and Kevlar (Maharana, Pandit and Pradhan, 2022) have been reported for improved mechanical properties in composites. Carbon is peculiar for its high strength. Carbon being a synthetic fibre possesses certain advantages such as high strength (Bahrami et al., 2023) , uniform diameter, besides, their properties can be tailored to meet specific applications however they are not environmentally friendly and are of higher density than natural fibres. Natural fibres are environmentally friendly, non-abrasive, reduced wear, sustainable: weight reduction, cost reduction, availability, non-abrasive, reduced friction, lower energy requirement in the course of processing. Coir is a natural lignocellulosic fibre and of much lower density than synthetic fibres. Composites in which natural fibres are used as its reinforcement possess tendency to reduce friction thereby reducing surface wear of the developed composites. Coir, obtained from coconut is chemically composed mainly of cellulose, hemicellulose and lignin (Costa et al., 2023) , however, their limitations as natural fibre, include poor moisture resistance (Elfaleh et al., 2023) and high porosity (Madueke, 2021). Coir can be reinforced with several polymeric materials (Babatunde, 2025).On the other hand, synthetic fibre such as Carbon obtained from crude oil is quite expensive and encourages increase in carbon foot print. The use of natural fibre increases waste utilization and recycling. As natural fibre reinforcement is increased, synthetic polymer matrix is reduced leading to savings in the depletion of crude oil, therefore, effective hybridization can minimize these problems. It is obvious that the overall performance of natural fibre reinforced composites may not be good enough to meet the demands especially where advanced structural materials with high strength, high stiffness are required, hence, it becomes imperative to hybridize these natural fibres with a certain percentage of synthetic fibres to manufacture composites. Composite materials are formed from two or more constituent materials that act in synergy to form a material with improved mechanical properties. Hybrid composites are composites with more than one constituent reinforcement or matrix.

Some researches have been carried out on hybrid composites such as: coir/glass (Wasti et al., 2024) , ramie/glass (Prasad et al., 2023) , Carbon/flax (Bahrami et al., 2023) and jute/aramid/graphene nanoplatelets (Costa et al., 2023) . They all reported an improvement in the mechanical properties. This work therefore focuses on the mechanical properties of hybrid unidirectional Coir/Carbon fibre reinforced epoxy composites, the effects of surface layering on the tensile properties of coir/carbon composites for low-medium strength applications subject to bending stresses. This study addresses underexplored stacking configuration using coir and carbon fibres.

MATERIALS AND METHODS

Materials

The reinforcements are T700 Carbon and coir fibre. The resin used was epoxy resin (Araldite LY3505) and hardener XB3403 supplied by Huntsman, UK. The mixing ratio of the epoxy to hardener was 100:35 parts by weight respectively.

Manufacture of coir- carbon composites

The method used for the manufacture of the composites was hand lay-up. The coir fibres used were carefully washed using luke-warm water to remove inherent debris and dust particles. The washing was carried out for four times until all the dust remains were completely washed out. The fibres were sun-dried for three days. The fibres were then manually and unidirectionally-aligned on a coated rectangular metal plate with dimensions of 25 x 120 mm which served as the mould. Fibre orientation (De Albuquerque et al., 2000) and fibre stacking (Madueke, Umunakwe and Mbah, 2022) exert enormous role on its mechanical properties hence the unidirectional arrangement. The coir and carbon fibres were then placed as shown in Table 1.

Table 1: Composites' Identification and Stacking Sequence

Composite	Stacking sequence	Code
A	Carbon-Carbon-Coir-Coir-Carbon-Carbon	2C2Co2C
B	Carbon-Coir-Carbon	CCoC
C	Coir-Carbon-Coir	CoCCo

The samples were impregnated using a mixture of epoxy resin (Araldite) and hardener (amine) prepared in a stoichiometric ratio as specified by the manufacturer, then left for 24 hours at room temperature to cure. Post-curing was carried out in a labouratory oven at 80 ^oC for eight hours. Subsequent work will address the fibre volume fraction and the void content analysis.

Tensile tests

The samples for tensile testing were end-tabbed with aluminium end tabs using Scotch-weld. The tensile test was conducted on Instron 5507 with cross-head speed of 1mm/minute at room temperature in accordance with EN ISO 527-5:1997.The gauge length was 100 mm with a load cell of 10KN and a cross-head speed of 1mm/minute.

Sample Preparation for Optical Microscopy

The composite samples were mounted and ground with rotating discs of silicon carbide paper after which polishing was carried out using polishing cloth and a diamond polishing suspension of low viscosity.The samples were washed with water and placed in the ultrasonic bath for optimal cleaning for three minutes. The samples were removed and dried in the vacuum oven at 80^{o}C for 6 hours and kept ready for morphological characterization.

RESULTS AND DISCUSSION

Thickness and Tensile Properties of the Developed Composites

The tensile strengths of the developed composites are shown in Figure 1 while the thickness, Young's modulus and elongation at break of the composites are displayed in Figure 2. From Figure 1, average tensile strengths of 181.42, 119.03 and 76.69 MPa were achieved by composite A, B and C respectively. This shows an improved tensile properties when compared with the tensile strength of coir non-hybridized composites (Rait, 2014) . Composite A shows about 16% increase in tensile strength when compared with hybrid Glass-Glass-Coir-Coir-Glass-Glass (Madueke, 2021). Composites A show the highest tensile strength, this could be attributed to the two double layers of carbon present since carbon fibre has much higher strength than coir. The composite with two layers of coir (Composite C) displayed the lowest tensile strength; this is as expected since single coir fibre possesses much lower tensile strength than carbon fibre. From Figure 2, the thickness of composite A is higher than those of composites B and C. This could have contributed to the variations in the tensile properties of the composites. The Young's modulus for the developed composites A, B and C are; 3.96, 2.23 and 3.26 GPa respectively, this shows that composite C with single layer of coir as the faces are stiffer than when the faces are swapped with single layer of carbon with coir as the core. The highest elongation at break was achieved when coir was used as the core as displayed in Figure 2. Also the number of layers of coir and carbon in the composites may result in the resin being insufficient to wet the fibers entirely and lead to poor fibre matrix interfacial bonding and thus lowering the tensile properties of the composites. The stress strain graphs of the composites are shown in Figures 3-5.Tensile failure of composites is strongly dependent on the composite structure, configuration, alignment and packing of constituent fibres. For composites with loosely-bonded fibres, the failure mechanism could be as a result of fibre slippage or breakage reducing the load bearing capacity and the strength of the composites.

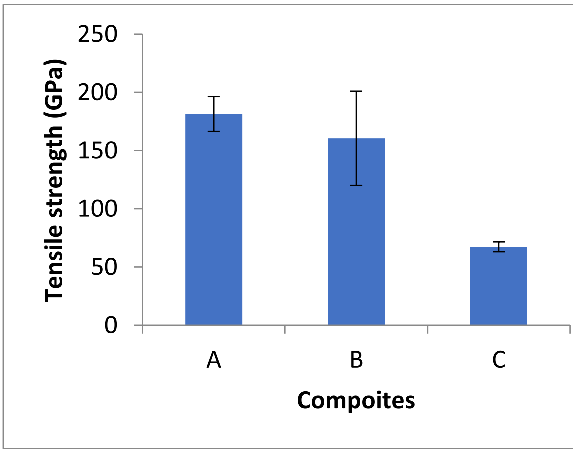

Figure 1: Tensile strength of the developed composites

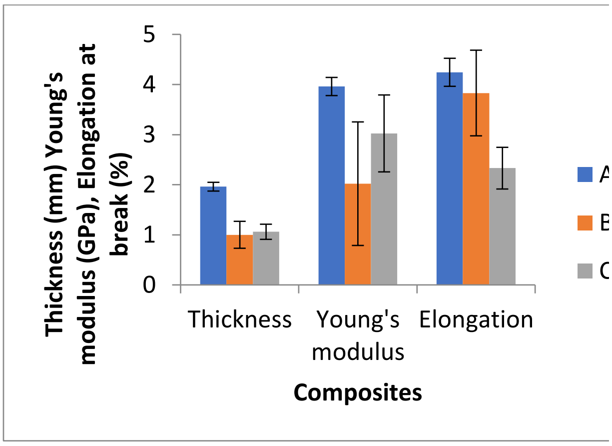

Figure 2: Thickness, Young's modulus and elongation at break of the developed composites

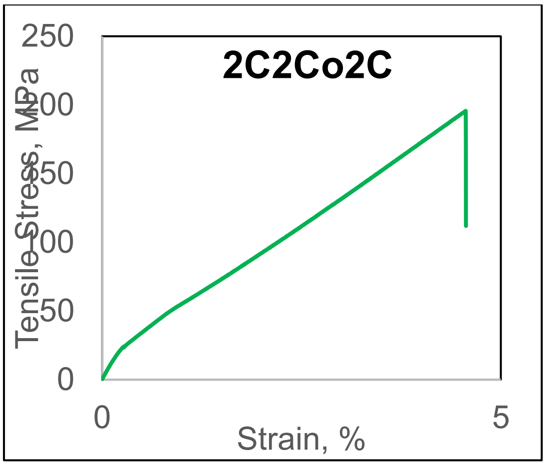

Figure 3: Stress/Strain graph of Composite A

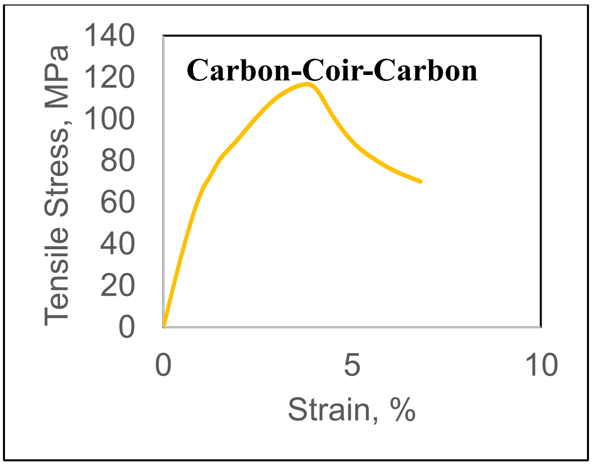

Figure 4: Stress/Strain graph of Composite B

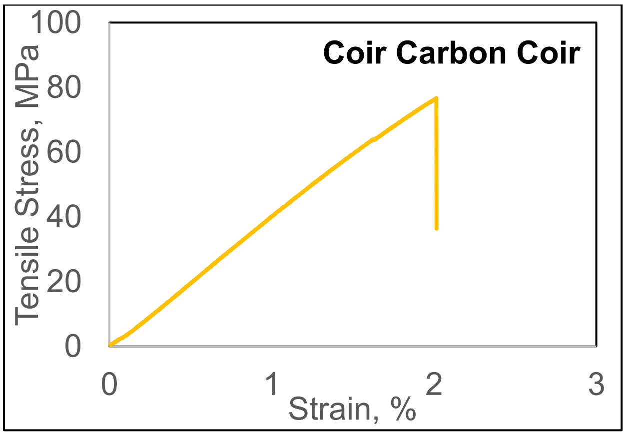

Figure 5: Stress/Strain graph of Composite C

Microstructure

The microstructure of coir fibre, carbon fibre and hybrid coir-carbon composite are shown in Figure 6. It can be seen that coir fibre is highly porous (Madueke, Umunakwe and Mbah, 2022) with a larger lumen about the centre. The microstructure of the coir-carbon epoxy hybrid composite as displayed in Figure 6c shows the layering of the coir fibre and the carbon fibre within the matrix as has been previously observed (Madueke, Umunakwe and Mbah, 2022).

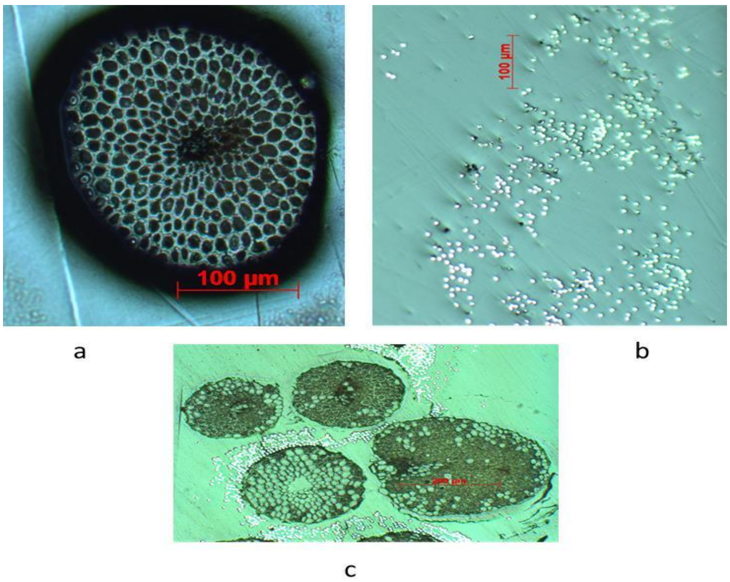

Figure 6: Micrographs of (a) Coir, (b) Carbon (c) coir/carbon fibre epoxy composite

Hence considering the properties of the developed sandwich composites with carbon as the skin and coir as the core, they could be used in the interiors of automobiles such as the trays, door whiners and press bottons.

CONCLUSION

The mechanical properties of hybrid unidirectional coir/carbon fibre reinforced epoxy composites have been determined. The stacking sequence that exerted the highest influence on the tensile properties of the manufactured composites was found to be Carbon-Carbon-Coir-Coir-Carbon-Carbon with the tensile strength 63 and 34% higher than those of Coir-Carbon-Coir and Carbon-Coir-Carbon composites respectively. However the stiffness of Coir-Carbon –Coir was 26% higher than that of Carbon-Coir-Carbon. An improved mechanical properties of the formed composite was recorded even when compared with literature findings on similar researches.

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