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Full Length Research

Studies on the electrical and mechanical properties of biomass reinforced conductive composite

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ABSTRACT: The production of high-quality conductive composite (CC), using carbon-based material and agricultural waste material, was the major goal of this study. Composite samples were produced from carbon black (CB) and rice husk (RH), in accordance with American Society for Testing and Materials (ASTM) International. Additionally, the tensile strength and electrical conductivity of the CC specimens were duly analysed in harmony with ASTM procedures. Results acquired from the laboratory evaluations depicted that the CB and RH have a significant impact on the CC mechanical and electrical properties. It was noted that the CC tensile strength inclined non-uniformly from 51 to 61 MPa, as the RH volume increased from 0 to 10% (% matrix mass). Likewise, the study outcomes indicated that the CB substantially increased the composite's EC level. Remarkably, the EC increased from 1.3 x10^{-12} to 6.8 x10^{-3}, as 9% CB was incorporated into the pure epoxy matrix. This study's findings will be helpful in the various sectors, primarily in electrical, automobile and aircraft components manufacturing companies.

Keywords: Carbon materials, circuit board, electron mobility, environmental protection, tensile strength.

INTRODUCTION

Composite materials (CMs) are rapidly gaining traction in the industrial sectors, primarily due to their versatility, substantiality, cost-effectiveness, and environmental friendliness. Composites are basically optimised for engineering applications, mainly in the aerospace, electrical, automotive and construction industries. These materials have gained popularity, as they have appreciable mechanical, electrical and other engineering properties; thereby, leading to their utilisation as suitable partial/full replacement material for traditional non-composite material (Parveez *et al*., 2022). Scientifically, it has been verified that CMs are corrosion resistant, lightweight, lower toxicity and have minimal maintenance requirements; thus, increasing their sustainability in the machine's components production, mostly mechanisms exposed to harsh working conditions (Edafeadhe *et al*., 2020; Bairagi *et al*., 2024; Rashid *et al.,* 2024).

Composite is mainly produced through the amalgamation of reinforcement materials (RMs) with matrix material (MM). The reinforcement and matrix materials can be either green (organic) or inorganic (synthetic) materials. Generally, the MM is the binding agent, which binds the reinforcement materials together, to produce an entity with greater structural integrity, stability and durability (Huang *et al.,* 2023). Reinforcement materials used for CMs creation are usually fibres, sheets, fillers (particulates) and fabric, and they provide the required engineering properties. Natural reinforcement materials are widely utilized for CMs production, particularly automotive and electrical/electronic materials, principally due to their lower density, ecologically friendly and biodegradability characteristics (Asyraf *et al.,* 2022; Okieke *et al*., 2022).

There are different types of composites, each designed and produced for specific applications. Conductive composite (CC) is one of these specially formulated CMs,

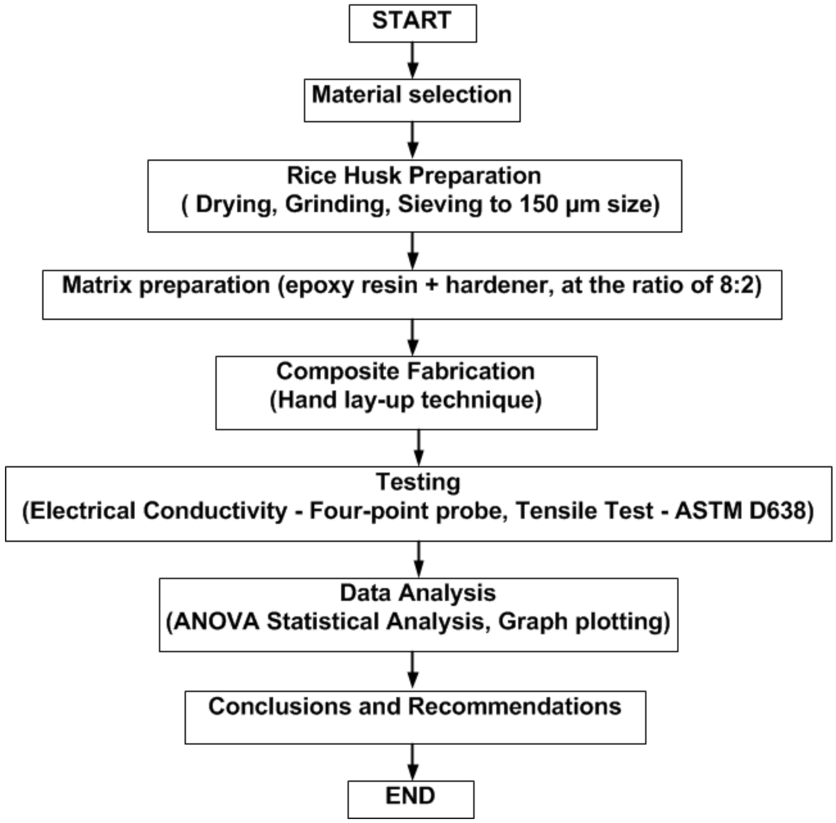

Figure 1. The methodology flow chat.

with enhanced electrical and mechanical properties, typically employed in electronics and automobile components/accessories production (Mohammad *et al.,* 2024). This composite is produced by integrating conductive RMs into the matrix at a specific ratio to obtain CC with ideal and reliable strength and electrical behaviours (Idama *et al*., 2024). In the engineering sector, CCs are used to produce devices for storing energy, mainboards, sensors, heat management units, and lightning protection devices. Therefore, they are promising materials for the production of aircraft fuselages and other electronic fittings (Alemour *et al*., 2019; Rezanezhad *et al*., 2023).

Recently, numerous improvements have been made on CC, to manufacture CMs with substantial engineering properties and a friendly environment sustainability (Alemour *et al*., 2019; Obukoeroro and Uguru, 2021; Dong *et al*., 2022; Okieke *et al*., 2022; Idama *et al*., 2024). Research on the utilisation of recycled and green materials, on the production of high-quality CC for industrial applications, is still at an early stage. Therefore, the major objective of this research is the production of high-quality conductive epoxy composite, reinforced with rice husk (biomass) and carbon black (conductive filler). Information obtained from this study will be useful in various manufacturing industries, including the production of cars and aeroplanes.

MATERIALS AND METHODS

To fulfil the purpose of this study, the flow chart of the approach is provided in Figure 1. The epoxy resin (LY556), hardener and carbon black were of the analytical grade, manufactured by Thermo Fisher Scientific Inc., America. Also, the rice husk was obtained from a local rice mill in Benue State of Nigeria.

The RH was sundried, ground and sieved with a 150 µm sieve to achieve fine RH particulates. This fine particle will enhance the binding and adhesion properties of the RH with the matrix; hence, increasing the mechanical properties of the composite created (Okieke *et al*., 2022).

Composite production

The materials mix design used for the CC production is presented in Table 1. The RM quantities chosen in this research were selected to have some significant variations from previous studies (Yim and Park, 2019; Obukoeroro and Uguru, 2021; Okieke *et al*., 2022). Remarkably, the resin and hardener were mixed at a ratio of 8:2 to create the CC matrix. Furthermore, the percentage volume of the RMs presented in Table 1 was based on the mass of the matrix. The components were batched by mass to maintain the consistency of the materials used for the CC

Table 1. Experimental design.

Sample Code	*RH (%)	*Carbon Black "CB" (%)	Matrix (%)
Control	0	0	100
ID 1	12	3	85
ID 2	10	5	85
ID 3	8	7	85
ID 4	6	9	85

*% mass of the matrix.

Figure 2. The mechanical testing of the CC unit.

formation. Additionally, the hand lay-up approach was used for the composite production, with the CC formed subjected to a dead load of 10 kg for 24 hours. The CC specimens were produced and cured under laboratory environmental conditions (30±5°C).

Laboratory testing

The tensile strength of each CC sample was measured following ASTM approved procedure, by using the universal testing machine, as shown in Figure 2 (ASTM D3039, 2017). At each test conclusion, the CC's tensile strength was computed with Equation 1 (Edafeadhe *et al.,* 2020). Additionally, the CC electrical conductivity (EC) was determined in agreement with ASTM D257-14 guidelines, using the precision multimeter (model: Fluke 8845A 6.5, manufactured in America) (ASTM D257, 2021).

$$Tensile\ strength, \sigma = \frac{Force_{Max}}{Area} \quad (1)$$

Data Analysis

The Analysis of Variance (ANOVA) was used to evaluate the impact of the CB and the biomass on the mechanical and electrical properties of the CC. Also, each test was performed five times, and the calculated average was documented.

RESULTS AND DISCUSSION

Mechanical properties

Figure 3 shows the results of the CC units tensile strength pattern. The ANOVA result depicted that the RM had a significant impact on the CC tensile strength (TS). Remarkably, the TS values recorded in the Control unit, ID's 1 – 4 groups were 51, 49, 58, 67 and 61 MPa, respectively. This is an indication that a lower proportion of the RH (≤ 8%) initiated a strength increment in the composite. Despite the fact that integration of RH and CB improves the composite's TS level, the results of the study indicate that the addition of excess RH reduces its TS, which can be linked to poor binding between the matrix and RM (Obukoeroro and Uguru, 2021). This observation was similar to the findings reported by Bera *et al*. (2018) and Idama *et al*. (2024) during their investigations into bio-composites. The authors stated that lower percentages of RMs were able to improve the mechanical qualities of composite panels.

This study's TS outcomes were within the range of results documented by Sadiq *et al*. (2020) for composites produced from periwinkle shells powder. The prevalence of weaker bonding formation, occurring between the matrix and the excessive RMs, can be linked to the CC's mechanical property deterioration as the RH content rises above 8%. Though the CB content was lower in samples ID 1 and ID2, RH has significantly lower density than CB; hence, the volume of RH in the composite will still be much higher. Therefore, this will result in a decline in the cohesiveness and adherence of the RMs with the binder, eventually leading to poorer mechanical properties of the product produced (Okieke *et al*., 2022).

Electrical properties

The results of the CC electrical conductivity (EC) are

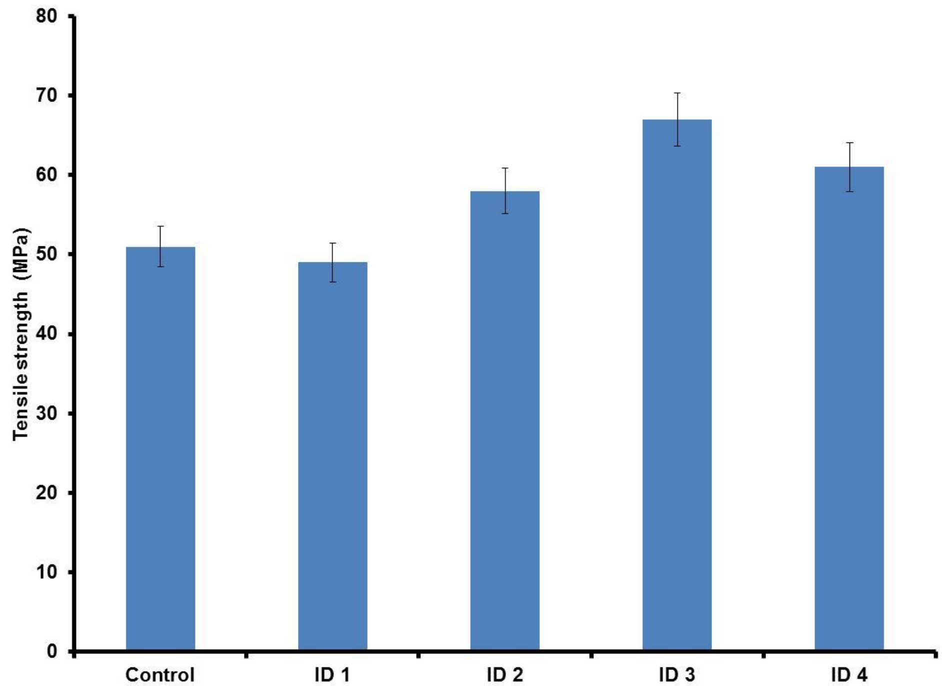

Figure 3. The composite TS.

Table 2. The composites EC values.

Sample Code	EC (S/m)
Control	1.3E-12[e]±1.9E-12
ID 1	2.6E-07[d]±4.1E-07
ID 2	2.1E-05[c]±3.4E-05
ID 3	1.4E-04[b]±1.8E-04
ID 4	6.8E-03[a]±3.6E-03

n = 5; rows sharing the same superscript letter, portrays no significant differences at $p \leq 0.05$ according to DMRT.

presented in Table 2. It was noted that the RM significantly affected the composite's EC values, according to the ANOVA result. Interestingly, the composite's conductivity inclined non-linearly, as the CB quantity increases. The lower EC values recorded in samples with codes ID 1 and ID 2 can be partially attributed to the larger volume of RH in the composite. Typically, rice husk is a non- conductive biomaterial; hence, it has the ability of retarding elections mobility in the composite (Kordi *et al*., 2024). Insufficient bonding between the RM and the matrix can lead to lower electrical conductivity values, thus inhibiting free movement of electric charges (Oxfall *et al.,* 2015; Okieke *et al*., 2022).

This study's findings are consistent with those of Ma and Liu (2012) and Okieke *et al*. (2022), who found that carbon-based RMs significantly increase electron mobility in composite boards. In a similar vein, Bahaa (2011) found that adding more carbonized materials to the composite during the manufacturing process tends to the creation of a product with improved electrical conductivity. Although CB improves the EC of polymer composites, the CB content should be above the percolation threshold to produce CC with superior effects (Obukoeroro and Uguru, 2021; Kordi *et al*., 2024). The study's findings have highlighted that CB and discarded agricultural waste (rice husk) can be utilised in the formulation of conductive composites with notable electrical conductivity. These composites have the potential to be used in various industrial sectors – automobile and aircraft manufacturing.

Conclusion

Public safety is one of the major criteria to be considered during engineering design and development. The foremost purpose of this study is to investigate the potential for producing conductive composites (CC) by utilising environmentally friendly ingredients. The tensile strength and electrical conductivity (EC) of composite samples, made from rice husk and carbon black, were tested in accordance with established ASTM methods. Results obtained revealed an upsurge in the EC values after the CB addition to the matrix. Likewise, an improvement in the CC tensile strength was detected after the incorporation of lower RH quantities. Remarkably, this study's findings highlighted the higher prospect of achieving high quality composites, with appreciable mechanical and electrical parameters, through the incorporation of biomass (RH) and carbon black.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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