Romanian Journal of Ecology & Environmental Chemistry, 7(1), 2025

https://doi.org/10.21698/rjeec.2025.105

Communication

Effect of flexural strength and density properties of sugarcane bagasse reinforced unsaturated polyester composite

RUSLAN SHAMSUDDEEN[1], AMINU SANUSI HARUNA[2], ZIYAULHAQ AUWAL ABDULKADIR[3], HUSSAINI FARUQ[4], ANSAR BILYAMINU ADAM[1]*, MUSA YAHAYA ABUBAKAR[1], MOHAMMED ALHAJI USMAN[5]

[1]*Department of Chemical Science, Federal University Wukari, ruslanshamsuddeen@gmail.com, yahayaabubakarmusa2015@gmail.com, Nigeria*
[2]*Department of Science and Technology, Centre for Strategic Research and Studies, National Defense College Abuja, alameensanusi@yahoo.com, Nigeria*
[3]*Department of Pure and Industria Chemistry, Bayero University, kano.zaabdulkadir.chm@buk.edu.ng, Nigeria*
[4]*College of Agriculture Mokwa, Niger State, faruqhussaini44@gmail.com, Nigeria*
[5]*Department of Integrated Science, Umar Suleiman College of Education Gashua, Yobe State, mausman0555@gmail.com, Nigeria*
**Corresponding author: ansarbilyamin@gmail.com*

Received:	Accepted:	Published:
13.11.2024	04.06.2025	15.07.2025

Abstract
As a byproduct of sugarcane processing, bagasse offers a sustainable alternative to conventional synthetic fibers in composite materials. Due to its abundance, low weight, and favorable mechanical properties, sugarcane bagasse has recently attracted increased scientific interest as a reinforcement in plastic composites. This study investigated the effects of sugarcane bagasse (SCB) weight fraction, particle size variation, and chemical treatments on the flexural strength and density of unsaturated polyester resin (UPR) composites. To enhance the adhesion between the bagasse fibers and the polymer matrix, chemical treatments with 5% hydrogen peroxide and 10% sodium hydroxide were applied. The SCB-reinforced UPR composites were fabricated using compression molding, followed by a 5-minute curing process at 130°C and a pressure of 2.5 MPa. Flexural strength and density were then evaluated. Results showed that flexural strength increased with higher bagasse loading, attributed to improved fiber–matrix intermixing. In contrast, density decreased as fiber content increased; for instance, at 100% UPR and 25% weight of 710 µm particles, the density dropped from 1.37 g/cm³ to 0.55 g/cm³. The composite's low weight, combined with its favorable flexural strength and density characteristics, suggests its suitability for structural applications.

Keywords: *sugarcane bagasse, unsaturated polyester resin, flexural strength, composite materials, density reduction*

INTRODUCTION

A material called composite features at least two different substances that combine structurally at the microscopic size. Two constituents form a composite structure where the reinforcing element exists inside the matrix structure. Each component in the mixture cannot dissolve the other substance [1]. The combination of at least two different materials into one substance creates composite materials which demonstrate improved attributes beyond the separate capabilities of their base components. In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. The industrial technology of composite materials involves a combination of two essential components which fundamentally consist of reinforcement elements connected within matrix structures. The distinct compound of composite materials produces enhanced functionality regarding mechanical properties alongside thermal and chemical attributes beyond standard bulk materials.

Functional applications in aerospace along with automotive and construction and biomedical engineering depend on composites because they have exceptional strength without excessive weight. Composite materials make their primary load-bearing component out of the reinforcement phase. The reinforcement material works to improve both the durability and strength alongside stiffness in composite materials. All reinforcement materials maintain superior mechanical performance at different loading points because they exhibit greater strength and stiffness and hardness than the matrix composites [2].

In composite engineering workplace, reinforcement materials can be traditionally classified into two classes which include fibrous and particulate. Among the fiber group, the carbon fibers, glass fibers, and Kevlar(R) fibers are the commonest, due to their better mechanical properties. Carbon fibers in specific are exceptionally stiff, with high thermal resistivity and with an outstanding strength-to-weight ratio thus making them invaluable in the structure of aircraft, and high-performance sports equipment. Carbon and Kevlar reinforced composites have therefore been widely used in engineering circles, where thermo stability and mechanical efficiency are what counts [3]. Glass fibers represent a favorable economic choice along with high performance characteristics that enable their extensive use for automotive and buildings [4]. The incorporation of silicon carbide (SiC) and graphene nanoparticles as particulate reinforcements has been shown to significantly improve composite wear resistance, hardness, and dimensional stability [5] reported that alumina–SiC whisker ceramics with added graphene exhibited nearly twice the wear resistance of their unreinforced counterparts, largely due to the formation of a protective graphene-based tribolayer on the surface. This synergy of hard ceramic particles and two-dimensional graphene yields composites that are both hard and dimensionally resilient under abrasive and high-load conditions.

Reinforcement orientation together with mechanical behavior determination remains essential for composite materials. The reinforcement method exists in three types: continuous aligned fibers, random chopped fibers, and woven interlocked fibers which bring separate mechanical advantages [6]. The matrix function as the binding element to maintain the reinforcement relationship and transmit loads effectively between fibers or particles. The matrix material establishes protection for the reinforcement systems by giving the material resistance to impacts and environmental degradation while improving its toughness [7].

Materials used for matrices include polymeric and metallic and ceramic structures that provide different benefits. Polymer matrices dominate the materials market because they offer light weight combined with processing ability and excellent resistance to corrosion. Engineering thermosetting polymers including epoxy and polyester maintain robust chemical immunity and outstanding thermal resilience that makes them apt for marine and aerospace sector uses [8]. Thermoplastic polymers such as polypropylene (PP) and polyether ether ketone (PEEK) are increasingly utilized in applications requiring recyclability, high impact resistance, and weight reduction. According to [9], PP offers advantages like low density, chemical resistance, and recyclability, making it suitable for automotive and packaging industries. Meanwhile, PEEK is valued for its thermal stability, chemical resistance, and mechanical strength, which make it ideal for high-performance biomedical and aerospace applications.

In contrast, demanding environments involving high temperatures and mechanical wear necessitate the use of metal matrix composites (MMCs) and ceramic matrix composites (CMCs). As reported by [10], MMCs—comprising matrices such as aluminum, titanium, or magnesium—enhance mechanical strength and thermal conductivity, supporting their use in engine components and military-grade protection systems. CMCs, as explained by Rashid et al. [11], exhibit exceptional oxidation resistance and high-temperature stability, making them indispensable in turbine blades, space shuttle tiles, and other aerospace components.

Using composite materials creates various advantages compared to the usage of standard bulk materials. These materials provide exceptional weight-related performance that makes them excellent for aircraft structures and automotive body panel applications [12]. Composite materials maintain an exceptional performance in fatigue resistance and they possess high levels of both impact tolerance and fracture toughness thus prolonging their operational lifespan in critical applications [13].

Polymer and ceramic matrix composites are highly valued for their outstanding resistance to oxidation and chemical degradation—properties that make them especially durable in harsh industrial and marine settings. In their review of marine applications, Rubino et al. note that polymer matrix composites, including carbon- and glass-fiber-reinforced polymers, are frequently utilized in ship hulls, offshore platforms, and underwater pipelines precisely for their exceptional corrosion resistance and long-term durability in saline environments [14]. Engineers can create material properties of composites through adjustments of reinforcements types combined with their volume fractions and orientation patterns to achieve industry versatility [15].

The fabrication difficulties along with brittleness cause particulate composites to hold a lower cost structure while featuring limited reinforcement contents that reach 40 to 50 volume percent [16]. Natural fiber-reinforced polymer composites receive intense research interest from both academic institutions and industrial sectors since the last ten years. The usage of natural fibers rose to standard practice during recent times especially within automotive applications. Successful uses of thermoplastic and natural fiber-thermoset composites include interior applications including door panels together with trim pieces and chairs and parcel shelves. The mechanical qualities coupled with ease of access make flax, hemp, banana and kenaf together with sisal among the most broadly used natural fiber types in composite materials [17].

Natural fiber reinforcement of polymer composites has become popular because of their environmental advantages combined with their low cost and large availability [18, 19]. Sugarcane bagasse demonstrates exceptional potential for composite development because it offers renewability alongside low density and acceptable mechanical properties as per research [20]. The use of this material supports worldwide initiatives for eco-friendly material development together with efforts to decrease environmental damage from non-biodegradable synthetic fibers

Several techniques exist for polymer composite fabrication including injection molding along with compression molding and hand lay-up and vacuum bag molding and spray-up and filament winding and pultrusion and vacuum-assisted resin transfer and its alternative name vacuum infusion molding and resin transfer molding (RTM). Manufacturers face both advantages and disadvantages when utilizing the methods mentioned in [1] for producing composites.

Reinforced polymer composites represent a preferred type of structural material because fibers present superior mechanical properties and affordable production opportunities and cost-effectiveness when compared to polymer resins. The automotive industry now selects plastics and composite materials instead of steels because weight reduction is essential for reaching better fuel efficiency and following strict safety and emission regulations instituted by governments [20].

The demand for sustainable materials during recent times has led researchers to undertake extensive studies regarding natural fiber-reinforced composites. The materials serve as a sustainable option against standard synthetic composites since they support excellent mechanical properties alongside lower environmental footprint. Sugarcane bagasse obtained from the sugarcane industry demonstrates promise as a reinforcement material because it offers abundant availability, low cost, lightweight density and excellent mechanical properties. Sugarcane bagasse which used to be disposed as agricultural waste can now be utilized as a reinforced material for polymer composites to serve different industry applications.

The use of Unsaturated Polyester resin as a composite material matrix stands as the preferred choice due to its solid mechanical capabilities together with chemical resistance properties and reasonable costs as well as straightforward processing requirements [21]. Unsaturated polyester (UP) resin matrices gain sustainability as well as mechanical performance benefits by integrating natural sugarcane bagasse fibers. Scientific studies show that composites containing natural fibers such as sugarcane bagasse achieve excellent flexural strength with lower mass and high impact resistance which makes them appropriate for automotive and construction and packaging industries [22, 23].

Fiber-reinforced composite materials depend completely on their flexural strength and density to determine their structural ability and practical uses. The resistance against bending forces under load can be measured with flexural strength along with density that determines material weight and handling properties [24]. These properties need enhancement because they determine lightweight

requirements along with load capacity needs for automotive systems aerospace elements together with construction requirements.
Scientists have conducted research to determine how incorporating sugarcane bagasse into unsaturated polyester composites affects their flexural strength and density for developing sustainable modern materials for industrial use. The utilization of sugarcane bagasse renewability and mechanical properties within this research complies with global initiatives to develop sustainable and efficient materials.

MATERIALS AND METHODS

For the experimental tests were used: The study utilized high-purity reagents including UPR, MEKP, and cobalt naphthenate (≥98÷99%) sourced from Nycil Nigeria Ltd., Lagos. Additional chemicals such as NaOH, acetic acid, benzene, and KOH (≥85÷99.8%) were obtained from Sigma-Aldrich, USA, while $KMnO_4$ and H_2O_2 (≥99%) were supplied by BDH Chemicals Ltd., UK. All reagents were used without further purification; distilled water.

Sample collection

Sugarcane sourced from a farm near Gabasawa, Kano State, was used as the raw material for this study. The stalks were manually processed to extract the juice, and the remaining fibrous residue—bagasse—was collected for subsequent fiber preparation. Unsaturated polyester resin (UPR) was used as the polymer matrix. Cobalt naphthenate was used as the accelerator, while MEKP, obtained from NYCIL Nigeria Ltd., Ikeja, Lagos State, was employed as the catalyst.

Fiber preparation

The sugarcane bagasse (SGB) fibers were first soaked in water for three days to remove impurities, then air-dried for seven days. Following drying, the fibers were ground and treated with 10% NaOH, 5% $KMnO_4$, and 5% H_2O_2. To obtain different particle sizes, the treated fibers were sieved using standard sieves, resulting in three distinct size fractions: 180 μm, 400 μm, and 710 μm.

Sugarcane Bagasse/unsaturated polyester resin composite

To fabricate the bagasse-reinforced composites, the appropriate volumes of UPR, cobalt naphthenate (accelerator), and MEKP (catalyst) were accurately measured. Table 1 present the proportional amount of bagasse.

Table 1. Formulations of particulate bagasse/ unsaturated polyester composite

Specimen size (μ)	Composition (g)			
	Particulate Bagasse Filler	UPR	MEKP (catalyst)	Cobalt naphthenate (accelerator)
180	10.0	90.0	1.0	0.5
180	15.0	85.0	1.0	0.5
180	20.0	80.0	1.0	0.5
180	25.0	75.0	1.0	0.5
400	10.0	90.0	1.0	0.5
400	15.0	85.0	1.0	0.5
400	20.0	80.0	1.0	0.5
400	25.0	75.0	1.0	0.5
710	10.0	90.0	1.0	0.5
710	15.0	85.0	1.0	0.5
710	20.0	80.0	1.0	0.5
710	25.0	75.0	1.0	0.5

Preparation of the unsaturated polyester/bagasse composite

An electronic weighing balance was used to determine the weight of the necessary materials. It was possible to create unsaturated polyester matrix composites using different weight fractions of particle bagasse filler. Tables 1 display the weight percentages of the ingredients. The mass of the unsaturated polyester was adjusted in relation to the reinforcement to yield a total of 100g for creating the reinforced polyester composites. After adding the sugarcane bagasse to the polyester resin, it was continually swirled for about two minutes with a glass rod until the mixture became homogenous. Subsequently, 0.5g of accelerator was added and mixed for approximately two minutes, followed by the addition of 1g of catalyst using a disposable syringe. Poured into a mold that had been prepared with paper tape and hydraulic oil (a mold release agent), the mixture was left to cure for two hours. The process was carried out again for the other specimen, which is indicated in Table 1, but with different particulate filler weight percentages. A control sample was also generated [25]. The mold was subjected to a curing process using a compression molding machine for three minutes at 130ºC and 2.5 millipascals of pressure (Mpa). After that, the mold was allowed to cool for approximately ten minutes at room temperature. The samples were cut into dog-bone and rectangular shapes after a day for additional characterization.

Characterization of the composites

The characterization was carried out according to ASTM standards for testing materials [26].

Flexural Strength Test

The unsaturated-bagasse composite's flexural test was carried out on rectangular specimens in order to ascertain the flexural strengths in accordance with ASTM-D792 standard. Additionally, a Shimadzu (MODEL AG-1) universal testing machine (UTM) was used, which used a three-point test method at a speed of 10 mm/min.

The flexural strength and modulus were also calculated using the formula below:

$$\text{Flexural strength} = 3pl/2bt^2 \quad (1)$$

where: p = applied load; l = span length of sample; b = sample width; t = sample thickness

Density test

A Mettler Toledo (Model XP603S) precision balance with ± 0.001 was used to determine the mass of the composite, and a vernier caliper was used to determine the sample dimensions and composite volume. Using the following expression (2), the density of the composites was calculated for three distinct samples each, and the average was assessed:

$$\text{Density} = \text{mass} / \text{volume} \quad (2)$$

where, M = mass of the composite, g; V = volume of the composite, cm^3.

RESULTS AND DISCUSSION

Figure 1 displays the outcome of the flexural test for the materials under investigation. Using the compression molding method, the modulus of elasticity of bagasse unsaturated polyester demonstrated a minimum of 19.7 Mpa at 10% filler loading of 180µm and a maximum of 78.6 Mpa at 25% filler loading of 400µm. It was determined that as the SCB fiber content increased by up to 25% filler loading of all three particle sizes, the modulus of elasticity increased as well. The improved stiffness and rigidity brought about by the fillers' even dispersion and distribution throughout the polymer matrix may be responsible for the increase in flexural strength, which effectively prevents chain movement during deformation. Hossain et al. found similar outcomes in his investigation of some mechanical characteristics of UPR loaded with water melon and sunflower seed shells [27].

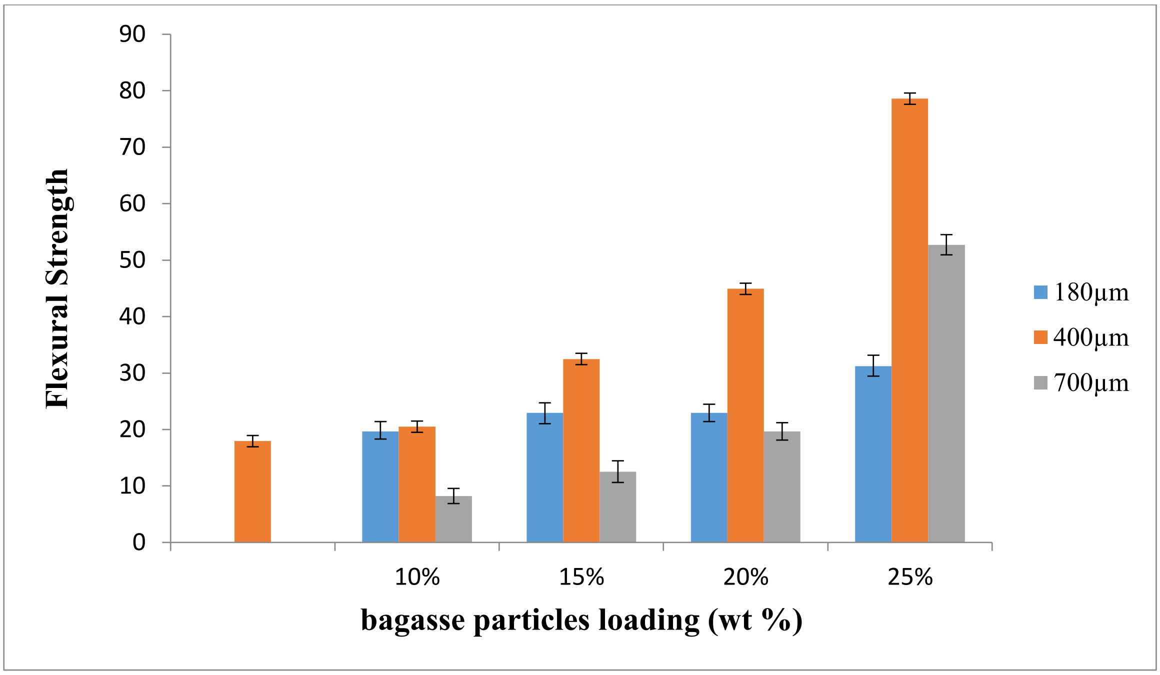

Fig. 1. Effect of particle size and filler loading on flexural strength

The densities of unsaturated polyester and bagasse are displayed in Figure 2, The density of the samples decreases slightly from 10% to 25% filler loading, respectively, when compared to the control sample, which has the highest density value of 1.37g/cm^3 as reported by [28].

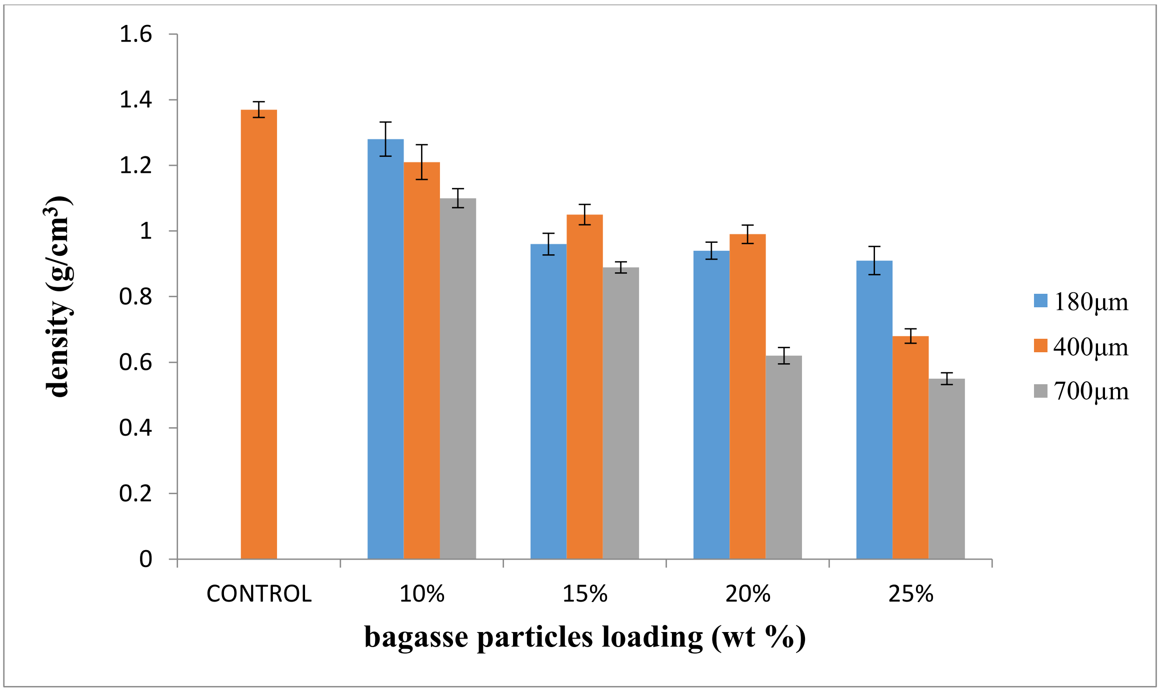

Fig. 2. Effect of particle size and filler loading on the density of UPR/SBG Composite

However, the density of the composite decreases as the fiber content increases. The partial elimination of lignin, cellulose, and hemicelluloses from the fiber treatments may be the cause of the density decrease. Nonetheless, natural fibers have the benefit of being lighter, which explains why the density of the composites decreases as the filler content increases, in accordance with the outcome found by [29]. It should be mentioned that, according to the mixture rule, the density of composites is determined by the product of the matrix's density and the fiber's density, which is added to the matrix's volume and the fibers' density, which equals the density of the composites [30]. However, because volume is inversely proportional to density and filler weight is less than resin weight, density will decrease as filler loading increases. These density results suggest that these composites can replace non-natural filler composites due to their light weights.

CONCLUSIONS

The sugarcane bagasse-reinforced unsaturated polyester composite shows excellent flexural properties along with low weight alongside strong potential for automotive components and building elements whereas the aerospace market and furniture sector also benefit from this composite. Sugarcane bagasse-reinforced unsaturated polyester composite stands as a strong replacement option for conventional synthetic composites because it combines affordable production costs with environmental advantages alongside reduced weight properties toward sustainable industrial material progress. Additional research needs to enhance both the mechanical properties along with biodegradability improvements while establishing large-scale manufacturing techniques to facilitate commercial market integration.

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Citation: Ruslan S., Aminu S.H., Ziyaulhaq A.A., Hussaini F., Ansar B.A., Musa Y.A., Mohammed A.U., Effect of flexural strength and density properties of sugarcane bagasse reinforced unsaturated polyester composites, *Rom. J. Ecol. Environ. Chem*., **2025**, 7, no.1, pp. 53÷60.