Iranica Journal of Energy & Environment
Journal Homepage: www.ijee.net
IJEE an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

Investigation on Physicochemical Properties of Sugarcane Bagasse Fibre - Reinforced Polyester Composite

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P A P E R I N F O

Paper history:
Received 31 October 2023
Accepted in revised form 21 March 2024

Keywords:
Natural fibre
Physicochemical properties
Polyester resin
Sugarcane bagasse

A B S T R A C T

The experimental study of the physicochemical properties of biodegradable composite of sugarcane bagasse-polyester have been investigated. Natural composite materials having biodegradable property which makes them a material with limited lifespan, thereby there is a need to research on these materials beyond their normal scope before their lifespan for solid material applications as current technological concepts advances. In this research, water absorption, specific gravity, and chemical resistance test were conducted on sugarcane bagasse polyester composite of different specimen, using a laboratory beaker filled with distilled water, HCl, NaOH, H_2O_2, NaOCl and detergent solution, at a particular time observing a suitable ASTM. From the result obtained, specimen with 25 weights % increase in Sugarcane bagasse fibre loading, indicated water absorption value of 1.42 %, which could be acceptable for good resistance to water material. The chemical resistance test, severity of the attack and effect on the appearance and weight of the composites followed the order: 10% HCl > 10% NaOH solutions, the deteriorating effect of the composites showed to be unaffected by neither the amount of filler weight nor the presence of any additive incorporated in the SCB-PES composites.

***doi**: 10.5829/ijee.2024.15.04.09*

INTRODUCTION

Experimental study of the physicochemical properties of biodegradability in composite materials is a key area of study, especially in this era of the escalating need for environmentally friendly and sustainable materials. One such composite, comprised of sugarcane bagasse fibre and polyester for adhesion, has garnered significant attention due to its inherent biodegradable nature. As these materials possess a limited lifespan, their application in solid material contexts necessitates a comprehensive understanding of their properties beyond traditional boundaries. The advancement of technological concepts further accentuates the significance of probing these materials to harness their potential for diverse practical applications. Various studies have made remarks on the importance of investigating the biodegradability of composite materials as a process to address environmental challenges due to municipal solid waste and promote sustainable practices. When compared to synthetic fibres, natural fibres have several advantages, including enhanced life-cycle performance features, biodegradability, feather-light weight, low cost, low viscosity, and sound seclusion (1, 2). The use of polymeric composites in agro-waste fibres has just recently gained traction in our research institutions (3, 4). Recent research has tended to blend natural fibres and polymeric materials with natural minerals, to serve as reinforcement (5, 6). More agricultural waste is produced as the world's population grows, and this waste is used as natural fibres (7). According to Perera et al. (8) and Gañán et al. (9), the combination of sugarcane bagasse bonded with polyester resin holds a remarkable combination due to their biodegradable characteristics, agreeing with the escalating demand for eco-friendly alternatives in various industries. One of the advantages of natural composites is

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Please cite this article as: Obiukwu OO, Nwigwe MN, Uchechukwu TO, Azubuike J, Ekpechi DA. Investigation on Physiochemical Properties of Sugarcane Bagasse Fibre - Reinforced Polyester Composite, Iranica Journal of Energy and Environment, 2024, 15(4):421-7. Doi: 10.5829/ijee.2024.15.04.09

their potential to mitigate the persistent environmental issues posed by non-biodegradable materials (10).

Nevertheless, while the biodegradability of these fibre materials for composite applications is an essential aspect, their physicochemical characteristics also requires close check. The combination between sugarcane bagasse and polyester matrix can affect some experimental attributes such as chemical resistance, specific gravity, and water absorption, directly affecting the suitability for various applications (11, 12). Moreover, understanding the reactions of these composites to distinct environmental situations is important for predicting their potential limitations in practical scenarios and behaviours.

Nikhade et al. (13) conducted a research on composite material, focus on creating a strong and sustainable composite material using glass fibre, ash form of sugarcane bagasse, cement and blast furnace slag. The composite's compressive and flexural strength, density, and other properties were tested, showing varying results based on mix ratios. The composite's strengths reached up to 1055.5 kPa (compressive) and 217 kPa (flexural) at different mix ratios. The lightweight material could potentially reinforce weak soils for better load-bearing capacity. Velmurugan et al. (14), used sugarcane bagasse fibre, wood powder, and rice husk composite materials to investigate the mechanical and physical characteristic. Two cases were compared, both using epoxy (50%) with varying fibre and filler ratios. Mechanical tests were conducted to determine the optimal fibre volume fraction. SEM analysis examined surface cracks, bonding, and pullout. X-Ray Diffraction (XRD) and Thermo-Gravimetric Analysis (TGA) were performed for material characterization. SBF combined with epoxy showed strength of 14-18 MPa. When combined with RH and WP, strength increased to 16-20 MPa. This study investigates the sugarcane bagasse-polyester composite's water absorption, specific gravity, and chemical resistance. It's possible that the analysis did not cover all possible set of environmental circumstances that these materials may run across in real-world applications. Furthermore, the concentration on specific chemical solutions—distilled water, HCl, NaOH, H_2O_2, NaOCl, and detergent solution—may not accurately represent the variety of chemicals to which the composite may be exposed in practical settings.

MATERIALS AND METHODS

Selected materials and its characteristics

The main material selected for this research includes: polyester resin (PES), starch/Poly lactide, ketonox (catalyst), napholite (accelerator) sodium hydroxide (NaOH), distilled water (H_2O), aluminium foil, cellophane bag, and masking tape and processing oil were purchased from Rovet Chemicals, Lagos, Nigeria, while the sugarcane bagasse fibre was obtained from sugar cane stem sellers at Ama Awusa, Owerri southern part of Nigeria. Table 1 summarized some properties of polyester resin and sugarcane bagasse (13, 15).

Experimental method and instrument used

For easier understanding of the processes, Figure 1 represents the process flow chart of the study.

Preparation procedure of the composites

Sugarcane bagasse (SCB) was soaked, cleaned, sun-dried, and shredded to < 4cm size after mastication and squeezing. Alkali treatment with 5% NaOH was applied to the SCB to make it suitable for compounding. The treated SCB was ground to a fine powder and stored for later use. Compounding of SCB, polyester (PES) resin, and additives, afterward, mixing SCB, starch, Poly lactide (PLA), PES resin, catalyst, and accelerator followed. The mixture was stirred manually until homogeneous and poured into a mold, compressed at 150-170°C, and left to cure for 5-20 minutes based on composition. After cooling, SCB-PES composites were removed from the mold, wrapped, and stored for testing. Table 2 states the specimen composition of the various specimens.

Specific gravity test procedure

The determination of the specific gravity of the developed SCB-PES composites was carried out according to ASTM D 792-08 method reported by Głogowska et al. (16). In this process, small test pieces

Table 1. The Characteristics of Sugarcane Bagasse and PES

Sugarcane Bagasse		Polyester Resin	
Properties {Units}	**Value**	**Properties {Units}**	**Value**
Tensile Strength {MPa}	10 – 30	Tensile Strength {MPa}	50 – 80
Flexural Strength {MPa}	30 – 60	Flexural Strength {MPa}	60 – 100
Compressive Strength {MPa}	15 – 35	Water Absorption {%}	0.2 - 0.5
Hardness {GPa}	0.5 – 2	Hardness {Shore D}	70 – 90
Density {kg/m³}	100 – 200	Density {kg/m³}	1.1 - 1.4
Moisture Content {%}	5 – 15	Elastic Modulus {GPa}	2.0 - 4.0
Calorific Value {MJ/kg}	14 – 18	Thermal Conductivity {W/(m·K)}	0.15 - 0.30
Thermal Conductivity {W/(m·K)}	0.05 - 0.20	Specific Heat Capacity {J/(g·K)}	1.0 - 1.2
Specific Heat Capacity {J/(g·K)}	1.2 - 1.6	Coefficient of Thermal Expansion	50-70 x 10^{-6} /°C

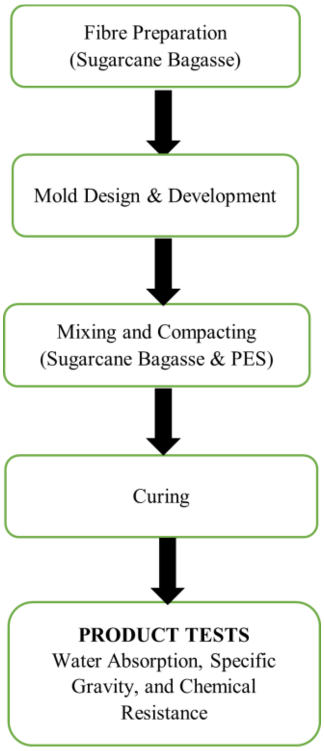

Figure 1. The Process Flow Chart of the Experimental Methodology

measuring 50 × 30 × 3.0 mm and previously weighed with precision to four decimal places, were initially hung in the air and then placed in water within a container. The samples were then taken out of the water, dried with tissue paper, and weighed once more. The specific gravity/density (ℓ) was calculated using the following formulas:

$$\text{Specific gravity} = \frac{soaked\ weight - dry\ weght}{soaked\ weight - suspended\ weght}\ x\ 100 \quad (1)$$

$$\text{Density} = \frac{dry\ weigth}{soaked\ weigth - suspended\ weigth} \quad (2)$$

Water absorption test procedure

Water absorption by the various SCB-PES composites and control was determined by the mass change reported by Głogowska et al. (16). After subjecting individual test specimens measuring 50 mm X 15 mm X 10 mm to a 50 °C oven for 24 hours, they were extracted and allowed to cool in a desiccator for an additional 24 hours. They were then precisely weighed (W0) using a scale accurate to four decimal places. Following this, the samples were immediately submerged in distilled water held in separate plastic containers at room temperature. The arrangement was left undisturbed for a 56-day period, during which the individual samples were removed and weighed at seven-day intervals. Before each weighing to determine the weight of the samples after immersion (W1), any water clinging to the sample surface was gently removed using tissue paper. At the conclusion of each weighing cycle, the sample was returned to the water for the subsequent measurement. The quantity of water absorbed by each sample was then calculated and expressed as a percentage (%) using the given model:

$$\%\ W.A.(s) = \left[\frac{(WI - W0)}{W0}\right] X\ 100 \quad (3)$$

where WI = weight of sample after immersion in water and $W0$ = its weight after conditioning and drying. Finally, the average water absorption by each composite for the entire period was calculated.

RESULTS AND DISCUSSION

Specific gravity of SCB-PES composites

Figure 2 shows the specific gravity result. Specific gravity is the ratio of a substance's density to the density of a reference standard, usually water. The specific gravity of the SCB-PES composites was found to increase with increasing SCB content; the composites were hard to the touch and had a dull brown coloration. The reason for the increase in specific gravity with increasing filler weight is that SCB filler migrates to and builds up in the

Table 2. Formulation of Polyester (PES) Resin/ Poly Lactide (PLA)/ Sugarcane Bagasse (SCB), Catalyst/ Accelerator/ Starch Composites

Filler (Wt. %)	Starch (Wt. %)	PLA (Wt. %)	PES Resin (Wt %)	Napholite (Accelerator) (ml)	Ketonox (Catalyst) (ml)
00.00	0.00	0.00	125.00	2.00	2.00
9.37	1.00	1.00	113.63	2.00	2.00
18.74	2.00	2.00	102.26	2.00	2.00
28.11	3.00	3.00	90.89	2.00	2.00
37.49	4.00	4.00	79.51	2.00	2.00
46.80	5.00	5.00	68.20	2.00	2.00
56.88	5.50	5.50	57.12	2.00	2.00

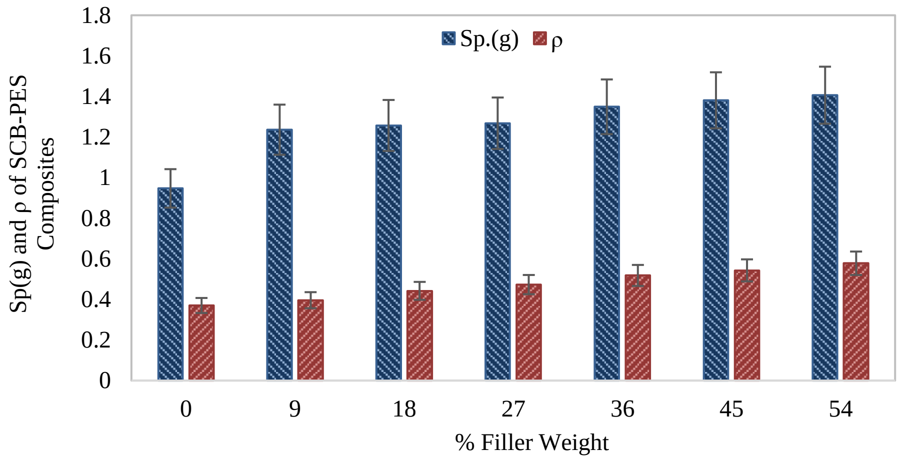

Figure 2. Specific Gravity (sp) / Density (ρ) of the Specimens and Control, against % Filler Weight

intra-molecular spaces in the polymer chains and pendant groups during the mechanical agitation process of the compounding stage (17–19). Numerous studies in the literature have documented increases in polymer composites' specific gravity (g)/ρ when natural fibre is added. The inferior specific gravity (g) characteristic shown by lignocellulose-based composites relative to their mineral fibre-filled equivalents was reported by Brito et al. (20).

Water Absorption (WA) of SCB-PES Composites

Figures 3 and 4 depict the results of the water absorption by the SCB-PES composites. When molecules of water are drawn to solid surfaces by forces of attraction, this process is known as water absorption. The pure SCB exhibited better water absorption than the SCB-PES composites, which in turn absorbed more water than the unmodified PES resin or 0.00% Filler weight (FW). The rationale for the Polymer Composites Reinforced with Vegetable Fibre's absorption of water molecules was disclosed by Brito et al. (20). The observed strong attraction of the latter to the SCB biomass of the composites can be attributed to the chemical affinity of -O-H groups for water molecules. According to Monishita et al. (21), the hydrophilicity of bagasse fibre is responsible for the greater water absorption characteristic of hybrid polypropylene composites supplemented with chicken feathers and bagasse. Ghali et al. (22) state that the abundance of free -OH groups in bagasse-containing cellulose and lignin promotes quick water absorption and assimilation into the fibre cell walls via -H bonding. Additionally, Yunus et al. (23) highlighted that the potential to absorb water was connected proportionally with the presence of high polarity free -OH groups including abundant cellulose and hemicellulose vegetable fibres. The results also revealed that adding 25% more weight of sugarcane bagasse fibre to the composites greatly improved their ability to absorb water. The remarkable water absorption tendency shown by the high filler weight SCB-PES composites under research was attributed to imperfect adhesion/compatibility between Sugarcane bagasse particles and the polyester matrix. Further increases in the natural fibre content made it more difficult to process the composite at the micro level, which led to the fibre layering out of the SCB-PES composites and the formation of micro-voids and fractures. Thus, the PES-SCB composite in this study can, like other materials of a similar kind, deteriorate through water absorption over time due to persistent exposure to a humid environment. While this may compromise the composite's mechanical properties, it is still desirable as it ensures the composites' biodegradation. The hydrophilic property of fibres, according to Tufan et al. (24), leads them to expand in water and degrade due to ultraviolet destruction of the high temperature that breaks down cellulose and hemicelluloses, which in turn triggers microbial assault. Okikiola et al. (25) indicated that the SCB-PES composites' lowest Water Absorption value of 1.42% in this investigation is a suitable marker of strong water resistance.

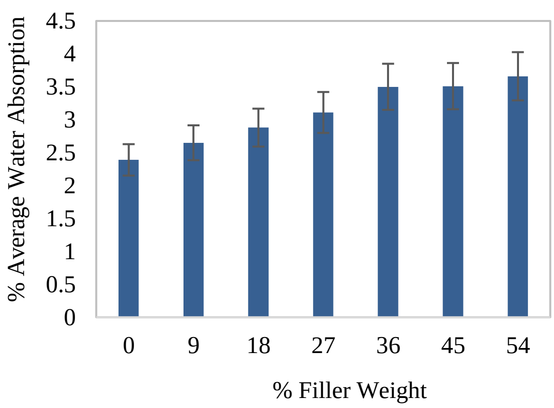

Figure 3. Water Absorption Rate of the Specimens after 7 Days

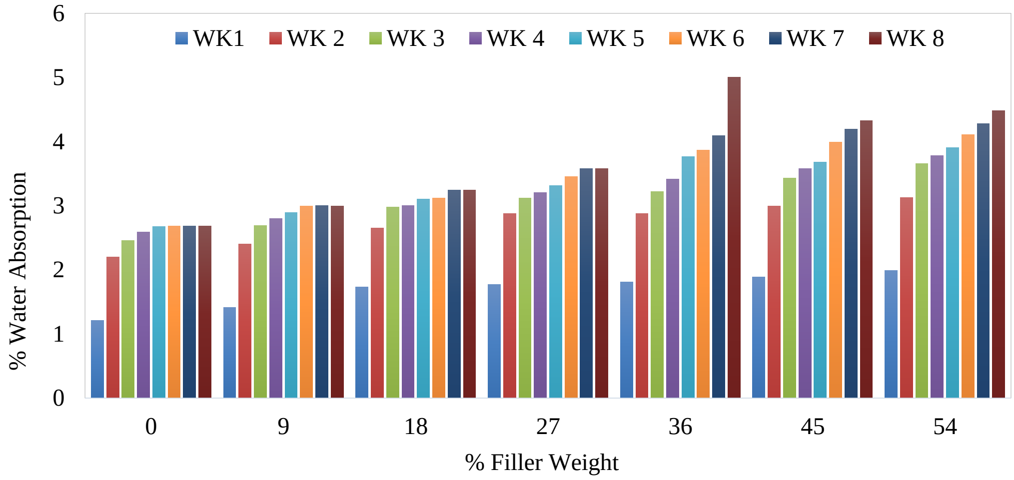

Figure 4. Merged Water Absorption Rate of SCB-PES Specimens at the end of 56 Days

Chemical resistance of sugarcane bagasse-polyester (SCB-PES) composite

Figure 5 shows the chemical resistance of the sugarcane bagasse-polyester (SCB-PES) Composites. The results of the investigation of the effect of HCl, NaOH, H_2O_2, NaOCl and a detergent solution on the hardness of the developed SCB-PES composites showed significant decreases in weight of the composites after interacting with the chemical and detergent solutions. The graphical illustration showed that the severity of the attack and effect on the appearance and weight of the composites followed the order: 10% HCl > 10% NaOH solutions. The deteriorating effect of the composites showed to be unaffected by neither the amount of filler weight nor the presence of any additive incorporated in the SCB-PES composites. Numerous studies have looked into surface modification and physicochemical aspects as ways to improve the natural fibre quality for intended uses (19, 26–28).

CONCLUSION

The study explored specific gravity, and chemical resistance of sugarcane bagasse-polyester composites. The investigation demonstrated that increasing sugarcane bagasse loading led to higher specific gravity, suggesting better material density. Water absorption tests revealed that SCB-PES composites resisted water well, with a 25% increase in bagasse loading yielding a water absorption value of 1.42%. Chemical resistance testing highlighted vulnerability to chemicals, with 10% HCl and 10% NaOH causing the most damage. The deteriorating effect was unaffected by filler weight or additives. The study's approach involved treating sugarcane bagasse, compounding with polyester resin and additives, and curing the mixture. The obtained results contribute to understanding the properties and potential applications of these composites. It's important to duplicate these procedures using alternative methods and additives to

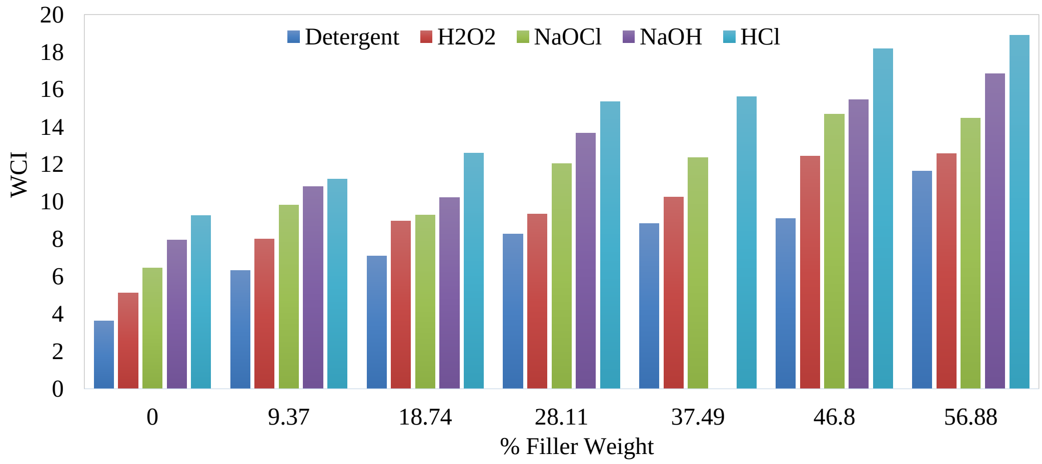

Figure 5. The Chemical Resistance of SCB-PES Composites and Control after Chemical Treatment (WCI - Weight Loss of Composites after Chemical Interaction)

evaluate process efficiency, economic factors, product quality, potential issues, and environmental safety. Professionals in engineering and product development can identify potential uses, and promote their adoption in chemical and related industries.

ACKNOWLEDGMENT

TETFUND is acknowledged for funding support for the NRF Grant -TETF/ES/DR&D-CE/NRF2021/HSS/CDS/0061/VOL.1..

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Persian Abstract

چکیده

مطالعه تجربی خواص فیزیوشیمیایی کامپوزیت زیست‌تخریب‌پذیر نیشکر باگاس-پلی استر مورد بررسی قرار گرفته است. مواد کامپوزیتی طبیعی دارای خاصیت زیست تخریب‌پذیری هستند که آنها را به موادی با طول عمر محدود تبدیل می‌کند، بنابراین نیاز به تحقیق در مورد این مواد فراتر از محدوده طبیعی آنها قبل از طول عمر آنها برای کاربردهای مواد جامد با پیشرفت مفاهیم تکنولوژیکی فعلی وجود دارد. در این تحقیق، آزمون جذب آب، وزن مخصوص و مقاومت شیمیایی بر روی کامپوزیت پلی استر باگاس نیشکر نمونه‌های مختلف، با استفاده از یک بشر آزمایشگاهی پر از آب مقطر، HCl، NaOH، H_2O_2، NaOCl و محلول شوینده، در یک زمان خاص با مشاهده یک ASTM مناسب انجام شد. از نتایج به‌دست‌آمده، نمونه با ۲۵ درصد افزایش وزنی در بارگیری فیبر باگاس نیشکر، ارزش جذب آب را ۱/۴۲ درصد نشان داد که می‌تواند برای مقاومت خوب در برابر مواد آب قابل قبول باشد. آزمایش مقاومت شیمیایی، شدت حمله و تأثیر بر ظاهر و وزن کامپوزیت‌ها به ترتیب انجام شد: محلول‌های ۱۰٪ NaOH 10% > HCl، اثر زوال کامپوزیت‌ها نشان داد که نه از مقدار وزن پرکننده و نه از وجود هر گونه افزودنی موجود در کامپوزیت‌های SCB-PES تأثیر نمی‌گیرد.