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Article

Fabrication and property analysis of treated and untreated bagasse powder-reinforced epoxy resin composites

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Abstract: Bagasse fiber from sugarcane waste is used with epoxy resin to make natural composites. The raw fibers are treated chemically to improve compatibility and adherence with the epoxy polymer. It's anticipated that epoxy resin matrix composites reinforced with bagasse particles would work as a trustworthy replacement for conventional materials utilized in the building and automobile sectors. The amount and distribution of reinforcing particles inside the matrix are two factors that impact the composite's strength. Furthermore, the precise proportion of reinforcing elements—roughly 20–30 weight percent—into the matrix plays a critical role in providing a noticeable boost in improving the properties of the composites. This research investigates the impact of reinforcing alkali-treated bagasse and untreated bagasse powder into an epoxy matrix on aspects of mechanical and morphological characteristics. The hand layup technique is used to create alkali-treated bagasse and untreated bagasse powder-reinforced epoxy composites. Composites are designed with six levels of reinforcement weight percentages (5%, 10%, 15%, 20%, 25%, and 30%). Microstructural analysis was performed using SEM and optical microscopes to assess the cohesion and dispersion of the reinforcing particles throughout the hybrid composites' matrix phase. With reinforcement loading up to 20 wt%, the tensile strength, impact strength, and toughness of epoxy-alkali-treated bagasse and untreated bagasse powder-reinforced composites increased. In contrast, treated bagasse epoxy composites were superior to untreated epoxy composites in terms of efficacy. The results indicate that 20 wt% alkali bagasse powder provides better mechanical properties than other combinations.

Keywords: bagasse powder; epoxy; microstructure; mechanical properties; eco-friendly

1. Introduction

The studies on composite materials constitute a significant proportion of the designed materials that promote various applications ranging from everyday products to advanced technologies. Composites consist of a continuous phase combined with one or more discontinuous phases. The discontinuous phase is typically more rigid and durable than the continuous phase, and it is referred to as the "reinforcement or reinforcing material" whereas the continuous phase is referred to as the 'matrix'. Composites can be categorized as reinforced composites with natural fibers (bamboo, jute, flax, sisal, hemp, etc.) or synthetic fibers (graphite, Kevlar, carbon, boron, glass, etc.). The characteristics of the constituent materials, their distribution, and their interactions with one another all have a significant influence on the properties of composites. Although composites have already demonstrated their value as materials that reduce weight, the current challenge is to make them cheaper and more sustainable [1,2].

Several scholars have been researching the benefits of employing natural powders as load-bearing elements in composite materials in recent years. The usage of such materials in composites is increasing over synthetic powders due to their relatively low cost, ability to recycle, and ability to compete well in terms of strength to weight of material [3,4]. Natural powders come in a variety of forms, including bagasse powder, coir powder, banana powder, jute powder, and hemp powder. Bagasse powders are utilized as a reinforcing material in the manufacture of new forms of composites because of their low fabrication costs and high-quality green final material. Bagasse, a by-product of sugarcane, is used in paper, electricity, and factories as raw materials. However, its low heating value makes burning it as fuel inefficient. Currently, 85% of bagasse is burned, leaving excess waste. Ethanol production uses only 9% of bagasse, but its efficiency is low [5]. Boosting bagasse's economic value is crucial. Sugarcane is widely available due to its cultivation in Bangladesh and around the world. As a result, the supply of bagasse remains constant and stable day after day. Bagasse-based composites are applicable for building and construction materials. Bagasse is also sustainable because it is biodegradable, recyclable, and reused [6,7].

This research is being conducted in order to make a large volume of waste bagasse powders usable as reinforcement in polymer matrixes such as epoxy. Epoxy resin is a well-known thermoset polymer matrix due to its great mechanical strength [8], strong erosion and corrosion resistance, high thermal stability, minimal shrinkage, excellent adherence to a variety of surfaces, and ease of workability [9,10]. It is amorphous and extensively cross-linked, resulting in high tensile strength and modulus, high hardness, simple manufacturing, good thermal and chemical resistance, and dimensional stability [11]. Bagasse improves mechanical qualities such as tensile strength, flexural strength, hardness, and impact strength when modified and fabricated [12]. It is readily modified with chemicals and mixes effectively with other composite materials.

Bagasse powder is hydrophilic and extremely polar, whereas polymer matrixes are predominantly non-polar and hydrophobic. As a result, both bagasse fiber and epoxy matrix surfaces are intrinsically incompatible, restricting stress transfer at the interface. Because the hydrophilic natural fibers and the hydrophobic polymer matrix are incompatible, there is poor interfacial adhesion, resulting in a composite material with poor physical and mechanical properties [13]. To overcome these drawbacks, many methods for surface modification of natural fibers have been used, including alkaline treatment [14], esterification [15,16], etherification [17,18], graft copolymerization [19,20], permanganate, benzoyl, anhydride treatment, silylation [21], or a combination of these methods [22]. Among these methods, the alkaline treatment method is used in this literature for bagasse fiber. Several formulations of bagasse powder and thermosetting in both virgin and impregnated form are proposed, and the composite samples are made using the hand layup technique. These composites are tested to justify their material performance. For microstructural study, optical microscopes (OM) and scanning electron microscopes (SEM) are utilized, and mechanical properties are analysed with a universal testing machine (UTM) and an impact tester. In consideration of the importance of chemical modification and the development of research on bagasse-polymer composites, this research presents an overall review of the manufacturing, morphological behavior, mechanical performance, and application of alkali-treated bagasse powder-reinforced epoxy resin composites.

2. Materials and methods

2.1. Materials

The matrix used was Araldite AW 106, a thermoset epoxy resin, and the hardener used was HV 953 IN. Those were collected from Nasim Plastic, Dhaka, Bangladesh. The molecular weight of epoxy resin was 393 Da, the viscosity was 9–14 Pas, the density was 1160 kg/m^{-3} and the flash point was > 150 ℃. The molecular weight of hardener was 305 Da, its viscosity was 0.45 Pas, its density was 900 kg/m^{-3} and its flash point was 129 ℃. The reinforcing material, sugarcane bagasse fibers, was brought from Rajshahi Sugar Mills Ltd., Bangladesh. Sodium hydroxide pellets (NaOH) were collected from MERCK, Mumbai, India. The purity was 97.16%.

2.2. Chemical treatment

The bagasse fibers were washed with distilled water. The bagasse fiber was then treated with a 5% NaOH solution at room temperature for 60 minutes while maintaining a liquid to fiber ratio of 15:1. After alkali treatment, the fibers were thoroughly rinsed with distilled water until a neutral pH was achieved. A hot air oven set to 105 ℃ is used to remove moisture from treated fibers. After alkaline treatment, bagasse fibers were taken to a mixer grinder (model-MX-AC400) to be ground into powder. The powders were subjected to pass into screens with sieves no.70 and openings 210 microns. The untreated bagasse fibers were washed with distilled water and dried in a hot air oven at 105 ℃.

The untreated fibers were ground into powder using a mixer grinder (model-MX-AC400) and then passed through screens with sieve no, 70 and 210 micron openings.

2.3. Composite preparation method

Epoxy resin creates a three-dimensional structure when it combines with the hardener or curing agent. The characteristics of epoxy resin can be changed by utilizing various epoxy oligomers and curing processes. Epoxy resin is mixed with hardener in a ratio of 10:1 by weight. Then alkali-treated bagasse powder with different weight percentages (5, 10, 15, 20, 25, and 30) was mixed by hand mixer for uniform distribution of epoxy resin, hardener, and reinforcement. To prepare one type of composite, a 200-gram mixture of matrix and reinforcement was used. A mold of dimension $(3 \times 10 \times 80)$ mm^3 was used for casting the composite sheet. A coat of oil was applied to the inner side of the mold because of the quick and easy removal of the composite. The usual hand lay-up technique was used to manufacture the composite of 6 mm thickness at room temperature for 24 hours (**Figure 1**).

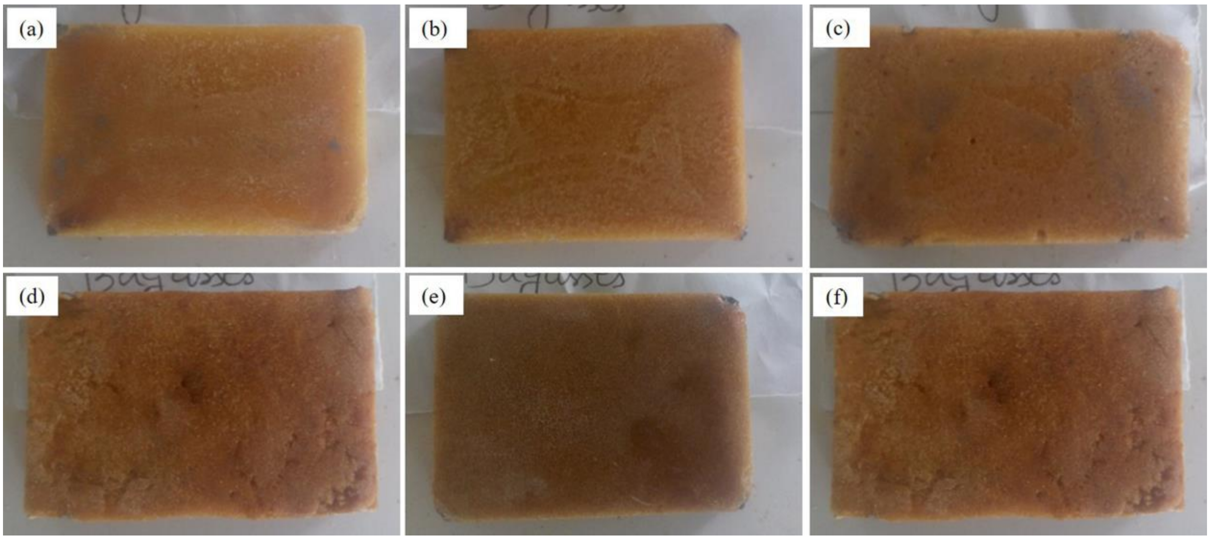

Figure 1. Images of composites having: **(a)** 95–5 wt% epoxy-alkali treated bagasse powder; **(b)** 90–10 wt% epoxy-alkali treated bagasse powder; **(c)** 85–15 wt% epoxy-alkali treated bagasse powder; **(d)** 80–20 wt% epoxy-alkali treated bagasse powder; **(e)** 75–25 wt% epoxy-alkali treated bagasse powder; **(f)** 70–30 wt% epoxy-alkali treated bagasse powder.

The same hand-lay procedure was used to create composites from untreated bagasse powder (**Figure 2**). Untreated bagasse powder with different weight percentages (5, 10, 15, 20, 25, and 30) was mixed with epoxy by hand mixer.

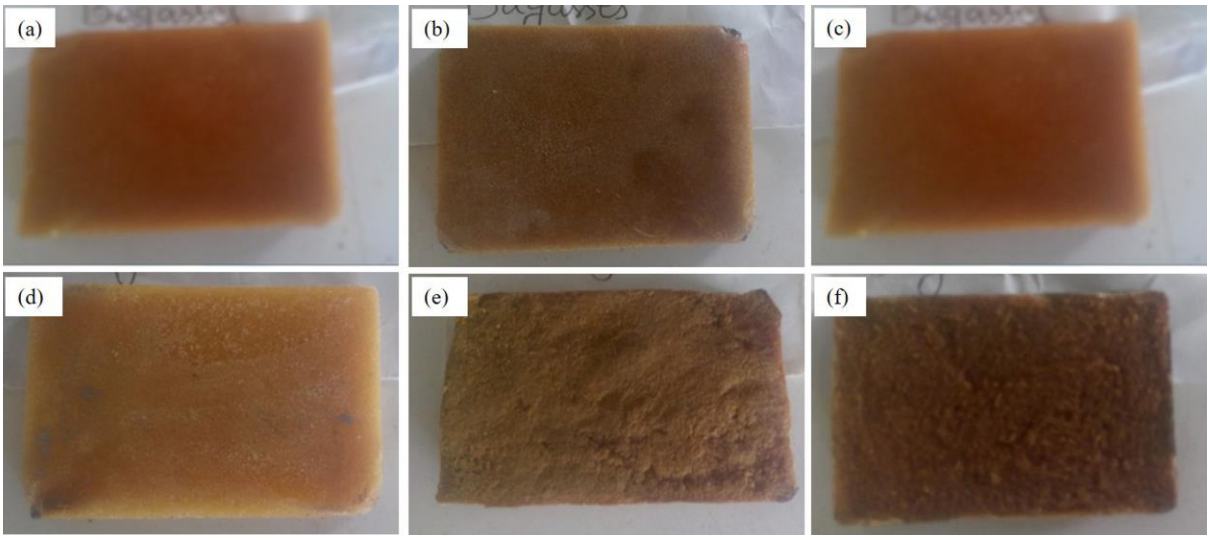

Figure 2. Images of composites having **(a)** 95–5 wt% epoxy-untreated bagasse powder; **(b)** 90–10 wt% epoxy-untreated bagasse powder; **(c)** 85–15 wt% epoxy-untreated bagasse powder; **(d)** 80–20 wt% epoxy-untreated bagasse powder; **(e)** 75–25 wt% epoxy-untreated bagasse powder; **(f)** 70–30 wt% epoxy-untreated bagasse powder.

2.4. Microstructural analysis

Optical microscopy (OM) (ML-803, Taiwan) and a scanning electron microscope (SEM) (JSM-7600 F) provided by JEOL Company Limited, Japan, were used to investigate the interfacial bonding between the reinforcement and epoxy matrix in the produced composites. Prior to morphological investigation under a scanning electron microscope, composite samples were coated with gold.

2.5. Mechanical testing

The materials underwent tensile, Charpy impact, and toughness testing. For every test and composite type, five species were examined, and the average values were recorded. Following ASTM D 638-01, tensile tests were performed at a crosshead speed of 10 mm·min^{-1} using a Universal Testing Machine (UTM) (Model: MSC-5/500, Agawn Seiki Company Limited, Japan). Using a Universal Impact Testing Machine (Model: 7408, Hung Ta, Taiwan), dynamic Charpy impact tests and toughness tests were conducted on notched composite specimens in accordance with ASTM D 6110–9724 and ASTM E23.

3. Results and discussion

3.1. Morphological observation

The microstructure of the prepared composite samples was observed using an optical microscope (OM) at various magnifications (10 X, 40 X, and 60 X) to find out the presence or absence of clusters, cracks, voids, particle distribution, particle aggregation, and morphology of the composites [23,24].

In **Figure 3**, uniform dispersion of bagasse powder is clearly seen throughout the matrix phase. Each particle is also surrounded by a matrix phase, which prevents bagasse powder aggregation in the composite. In other words, the uniformity of reinforcement in the matrix phase is nearly reached, increasing the load-bearing capability of composites. The interfaces are sharp, with no big voids or reaction substances, and the integrities are intact [25].

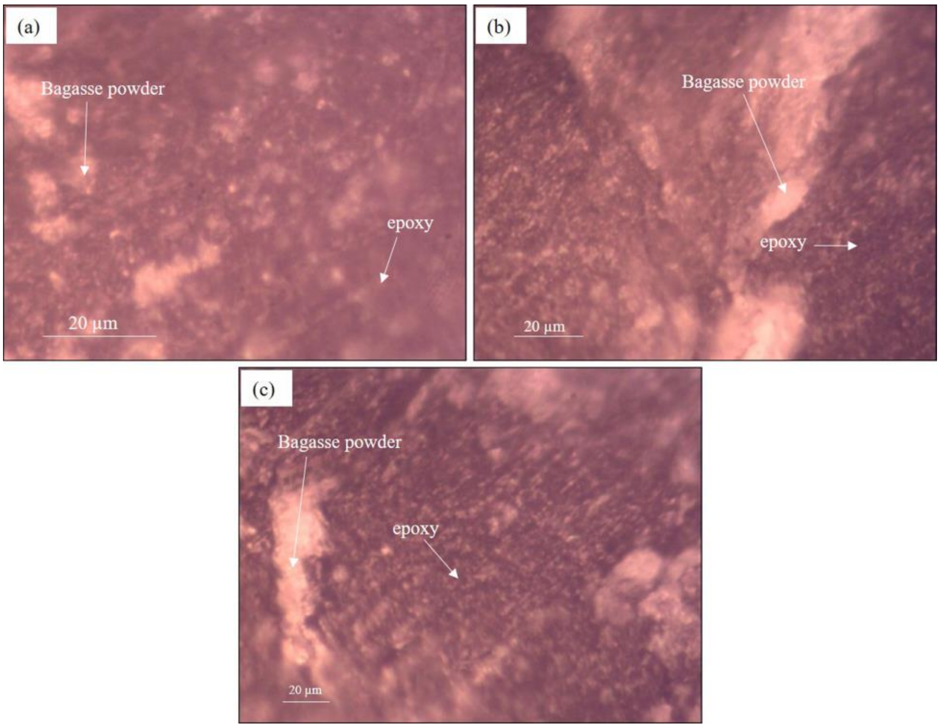

Figure 3. Optical micrograph of cross-section of composites at **(a)** 10 X; **(b)** 40 X; **(c)** 60 X; magnification for 20 wt% of epoxy-alkali-treated bagasse powder composite.

SEM (scanning electron microscope) observation of the cross-section of the composites can reveal information about the sample, such as the exterior morphology (texture), chemical composition, interfacial adhesion, crystalline structure, and orientation of the materials that make up the sample. In this research, SEM (scanning electron microscope) was used to observe the uniformity of reinforcement at micro level [26].

Figure 4 shows the morphology of a 20 wt% epoxy-alkali-treated bagasse powder composite. A uniform distribution of reinforcement throughout the matrix phase is observed, which is evidence of good interfacial bonding [27]. Here, a very good mixing of alkali-treated bagasse powder and epoxy is noticed. The lack of pores, cavities, or voids is also observed in this SEM micrograph. The findings reveal that in a composite, the intermediate load-bearing components are the major working factor of the matrix. Although the primary function of reinforcement is to retain the load and thereby maximize the strength of composites, since there are no voids or cracks present in the composites, they should display better mechanical properties.

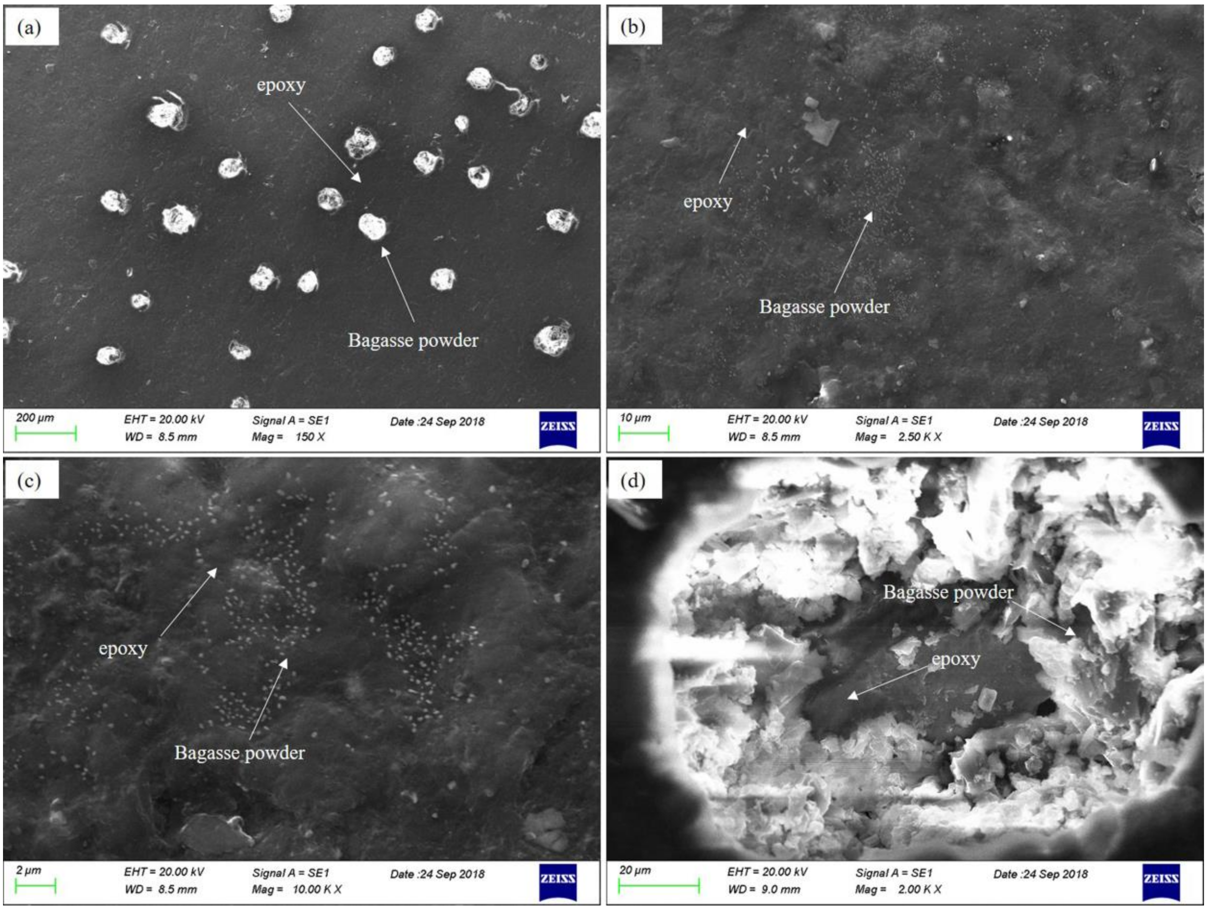

Figure 4. SEM micrograph of cross-section of composites at **(a)** 150 X; **(b)** 2.5 KX; **(c)** 10 KX; **(d)** 2 KX; magnification for 20 wt% of epoxy-alkali-treated bagasse powder composite.

Although the form of the powder remained largely unchanged, it is evident that it underwent a definite separation of its structure following treatment with a 5% NaOH solution (**Figure 4**). This allegedly occurred as a result of some lignin components dissolving upon the addition of the base. Morphological alterations in bagasse after NaOH modification. Intermolecular hydrogen bonds on the carboxylic group connecting the fibers into a break are thought to be the mechanism separating them from one another. This occurs because adding NaOH causes the Na atom in the carboxylic group to replace the H atom [28].

3.2. Mechanical properties

3.2.1. Tensile properties

Tensile tests are used to measure the strength of polymer composites by applying a constant tensile load along the material's axis. The Universal Testing Machine (UTM) (H5OKS, Hounsfield, USA) is suitable for these tests, measuring tensile properties at a speed of 100 mm·min^{-1}.

Figure 5 shows that the tensile strength is increasing with an increase in the weight percentage of powder up to 20 wt% reinforcement. The maximum value of tensile strength is 14.042 MPa for epoxy-untreated bagasse powder composites and 15.839 MPa for epoxy-alkali-treated bagasse powder composites at a 20 wt% powder-to-matrix ratio. Further increase in powder ratio, decrease in tensile strength. The improved load-carrying capacity of powder over matrix increases the tensile strength of up to 20 wt% powder ratio. Tensile strength decreased as reinforcement was loaded farther because of inadequate interfacial adhesion between powder and matrix. In addition, microspace formation in composites increased [29]. Additionally, as compared to virgin epoxy matrix, the treated and untreated composites show superior tensile strength (**Figures 5a**,**b**).

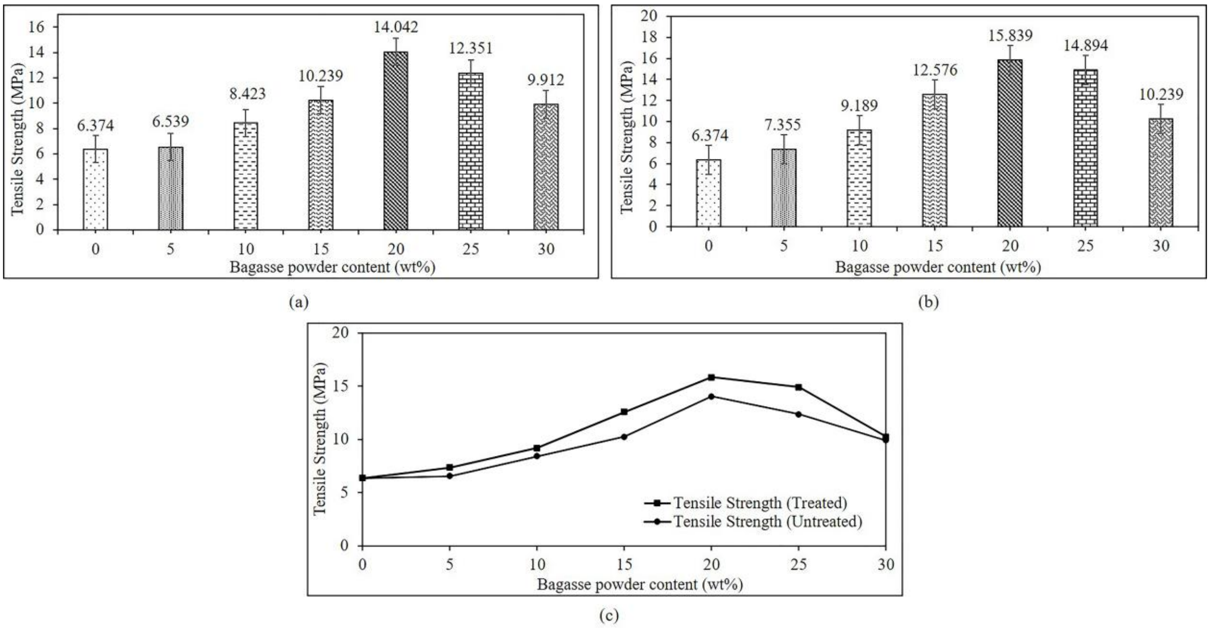

Figure 5. Tensile strength of **(a)** epoxy-untreated bagasse powder composites; **(b)** epoxy-alkali-treated bagasse powder composites; **(c)** a comparison graph of tensile strength between treated and untreated powder composites.

The tensile strength curve of the epoxy-alkali-treated bagasse powder composite is slightly higher than that of the epoxy-untreated bagasse powder composite, as shown in **Figure 5c**. Alkaline treatment of bagasse powders increases the powder's load-bearing capability by eliminating a smaller fraction of lignin, pectin, waxes, and contaminants. Furthermore, alkali treatment increases particle strength, giving the powder relatively excellent mechanical qualities. In addition, this resulted in a rough powder surface, which tends to provide better adherence to the matrix. The alkaline treatment method also resulted in a swollen structure due to changes in structure, morphological, mechanical, and dimension properties [30]. Alkaline treatment breaks the alkaline-sensitive hydroxyl groups (–O–H bond structure) found in natural powder molecules. It then reacted with water, phenols, or alcohol molecule groups (H–O–H bond structure) and migrated in or out of the powder structure depending on the powder's characteristics toward the alkaline reaction. Thus, the remaining reactive molecules indirectly produced the powder cell of the –O–Na bond structure between the cellulose molecular chain [31,32].

3.2.2. Impact strength and toughness

Figure 6 depicts the impact characteristics increasing with powder loading of the epoxy-untreated bagasse powder composite and the epoxy-alkali-treated bagasse powder composite. They indicate a distinct trend from those for tensile strength. Furthermore, **Figure 6a**,**b** show that both the treated and untreated composites have better impact energy-absorbing capacity than virgin epoxy matrix. This is because powder absorbs more energy than matrix [33]. **Figure 6c** further shown that treated composites have superior impact properties compared to untreated composites.

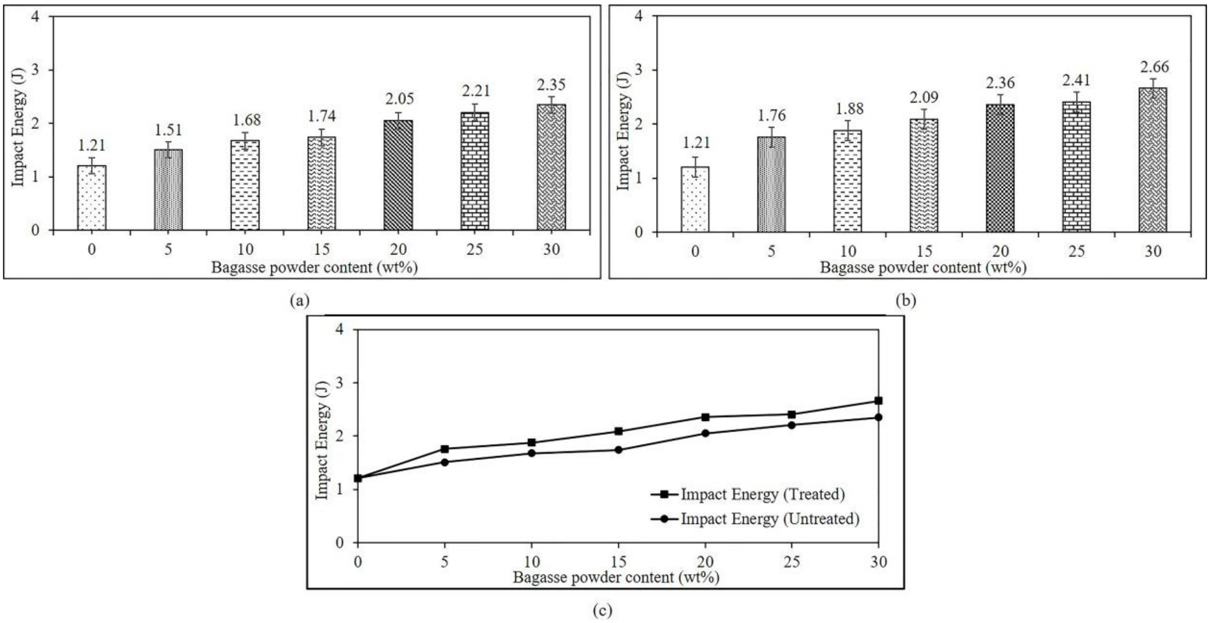

Figure 6. Impact energy of **(a)** epoxy-untreated bagasse powder composites; **(b)** epoxy-alkali-treated bagasse powder composites; **(c)** comparison graph of impact energy between treated and untreated powder composites.

Similarly, the toughness of composites improves as the powder content increases. Toughness is the capacity of a material to tolerate stress and deformation without rupturing, as measured by the amount of energy absorbed per unit volume before fracture. Ductility is a measurement of the plastic deformation of a material before rupture. High ductility does not ensure high toughness; it can be obtained by combining strength and ductility. Brittle materials with poor ductility, such as ceramics, are not tough, whereas ductile materials with low strength do not have high toughness ratings. A small specimen was used to measure toughness [34].

Figure 7 reveals the toughness parameters of epoxy-alkali-untreated and epoxy-alkali-treated bagasse powder-reinforced polymer composites. Toughness steadily rises as the powder content increases. In addition, **Figure 7c** demonstrated that treated composites had better toughness characteristics than untreated composites. Because lignin, pectin, oil, wax, and other impurities are removed from the cell wall surfaces of the fibers, the alkaline treatment increases the bonding between natural fiber and polymers, strengthening the structure of natural fiber with composites. This increases the surface roughness of the fiber, exposing short-length crystallites and improving its mechanical properties [35].

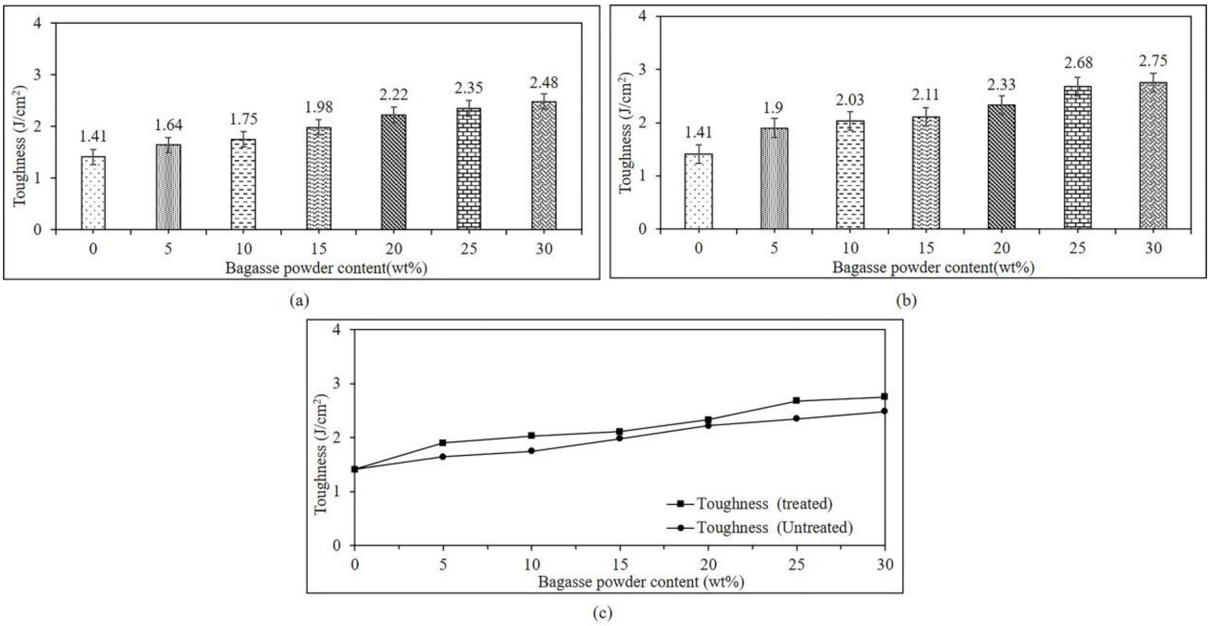

Figure 7. Toughness properties of **(a)** epoxy-untreated bagasse powder composites; **(b)** epoxy-alkali-treated bagasse powder composites; **(c)** a comparison graph of toughness between treated and untreated powder composites.

The reinforcement particles act as an adhesive by filling up pores in the polymer matrix, resulting in a stronger link between the matrix and the reinforcement. As a result, when the matrix and particles develop a stronger link, the mechanical characteristics of the composites are improved.

4. Conclusion

Natural fibers are available in nature and can be easily made into reinforcement materials. In this study, treated and untreated bagasse powder is combined with epoxy resin through a hand-lay process to produce composites with the desired properties. According to the optical microscope (OM) and screening electron microscope (SEM) analyses, no large voids, cavities, or reaction products are found in the composites, and a uniform distribution of reinforcement is also observed. The mechanical characteristics of the composite improve as the weight of bagasse powder increases. Tensile strength is maximum at 20 wt% reinforcement, whereas impact energy and toughness are maximum at 30 wt% reinforcement. Alkaline treatment is significant because it increases the powder's load-bearing capability by eliminating a small percentage of lignin, pectin, waxes, and impurities. Bagasse powder-reinforced epoxy composite has several technical applications due to its environmental acceptability, technological feasibility, and economic viability. One of the major applications of bagasse-based composites is the fabrication of tiles for construction industries [36]; it is also used in the automotive industry, the aerospace industry [37], the building industry, the furniture industry [38], etc.

Author contributions: Conceptualization, ANF; methodology, ANF and MSRT; software, ANF and ADJ; validation, ANF, MSRT, ADJ and MRKS; formal analysis, ANF and MSRT; investigation, ANF and MSRT; resources, ANF, MSRT and MRKS; data curation, ANF, MSRT and ADJ; writing-original draft preparation, ANF, MSRT and ADJ; writing-review and editing, ANF and ADJ; visualization, ANF; supervision, ANF; project administration, ANF and MSRT; funding acquisition, ANF. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest: The authors declare no conflict of interest.

References

1. Devadiga DG, Bhat KS, Mahesha G. Sugarcane bagasse fiber reinforced composites: Recent advances and applications. Cogent Engineering. 2020; 7(1): 1823159. doi: 10.1080/23311916.2020.1823159
2. Gholampour A, Ozbakkaloglu T. A review of natural fiber composites: properties, modification and processing techniques, characterization, applications. Journal of Materials Science. 2019; 55(3): 829–892. doi: 10.1007/s10853-019-03990-y
3. Karimah A, Ridho MR, Munawar SS, et al. A review on natural fibers for development of eco-friendly bio-composite: characteristics, and utilizations. Journal of Materials Research and Technology. 2021; 13: 2442–2458. doi: 10.1016/j.jmrt.2021.06.014
4. Elanchezhian C, Ramnath BV, Ramakrishnan G, et al. Review on mechanical properties of natural fiber composites. Materials Today: Proceedings. 2018; 5(1): 1785–1790. doi: 10.1016/j.matpr.2017.11.276
5. Timung R, Naik Deshavath N, Goud VV, et al. Effect of Subsequent Dilute Acid and Enzymatic Hydrolysis on Reducing Sugar Production from Sugarcane Bagasse and Spent Citronella Biomass. Journal of Energy. 2016; 2016: 1–12. doi: 10.1155/2016/8506214
6. Guna V, Ilangovan M, Hu C, et al. Valorization of sugarcane bagasse by developing completely biodegradable composites for industrial applications. Industrial Crops and Products. 2019; 131: 25–31. doi: 10.1016/j.indcrop.2019.01.011
7. Cao Y, Shibata S, Fukumoto I. Mechanical properties of biodegradable composites reinforced with bagasse fiber before and after alkali treatments. Composites Part A: Applied Science and Manufacturing. 2006; 37(3): 423–429. doi: 10.1016/j.compositesa.2005.05.045
8. Singla M, Chawla V. Mechanical Properties of Epoxy Resin-Fly Ash Composite. Journal of Minerals and Materials Characterization and Engineering. 2010; 09(03): 199-210. doi: 10.4236/jmmce.2010.93017
9. Liu Y, Zhang J, Chen R, et al. Ethylene vinyl acetate copolymer modified epoxy asphalt binders: Phase separation evolution and mechanical properties. Construction and Building Materials. 2017; 137: 55–65. doi: 10.1016/j.conbuildmat.2017.01.081
10. Jiang J, Lu Z, Niu Y, et al. Investigation of the properties of high-porosity cement foams containing epoxy resin. Construction and Building Materials. 2017; 154: 115–122. doi: 10.1016/j.conbuildmat.2017.06.178
11. Balguri PK, Samuel DGH, Thumu U. A review on mechanical properties of epoxy nanocomposites. Materials Today: Proceedings. 2021; 44: 346–355. doi: 10.1016/j.matpr.2020.09.742
12. Mohan PA. Critical Review: The Modification, Properties, and Applications of Epoxy Resins. Polymer-Plastics Technology and Engineering. 2013; 52(2): 107–125. doi: 10.1080/03602559.2012.727057
13. Gwon JG, Lee SY, Chun SJ, et al. Effects of chemical treatments of hybrid fillers on the physical and thermal properties of wood plastic composites. Composites Part A: Applied Science and Manufacturing. 2010; 41(10): 1491–1497. doi:

10.1016/j.compositesa.2010.06.011

14. Setswalo K, Molaletsa N, Oladijo OP, et al. The Influence of Fiber Processing and Alkaline Treatment on the Properties of Natural Fiber-reinforced Composites: A Review. Applied Science and Engineering Progress. 2021; 14(4): 632–650 doi: 10.14416/j.asep.2021.08.005
15. Naik JB, Mishra S. Esterification effect of maleic anhydride on swelling properties of natural fiber/high density polyethylene composites. Journal of Applied Polymer Science. 2007; 106(4): 2571–2574. doi: 10.1002/app.25329
16. Naik JB, Mishra S. Esterification Effect of Maleic Anhydride on Surface and Volume Resistivity of Natural Fiber/Polystyrene Composites. Polymer-Plastics Technology and Engineering. 2007; 46(5): 537–540. doi: 10.1080/03602550701298630
17. Li G, Shang Y, Wang Y, et al. Reaction Mechanism of Etherification of Rice Straw with Epichlorohydrin in Alkaline Medium. Scientific Reports. 2019; 9(1). doi: 10.1038/s41598-019-50860-3
18. Islam MN, Khatton A, Sarker J, et al. Modification of Jute Fiber by Etherification Method for Diverse Textile Uses. Saudi Journal of Engineering and Technology. 2022; 7(2): 107–111. doi: 10.36348/sjet.2022.v07i02.007
19. Thakur VK, Thakur MK, Gupta RK. Graft copolymers of natural fibers for green composites. Carbohydrate Polymers. 2014; 104: 87–93. doi: 10.1016/j.carbpol.2014.01.016
20. Thakur VK, Thakur MK, Gupta RK. Rapid synthesis of graft copolymers from natural cellulose fibers. Carbohydrate Polymers. 2013; 98(1): 820–828. doi: 10.1016/j.carbpol.2013.06.072
21. Xie Y, Hill CAS, Xiao Z, et al. Silane coupling agents used for natural fiber/polymer composites: A review. Composites Part A: Applied Science and Manufacturing. 2010; 41(7): 806–819. doi: 10.1016/j.compositesa.2010.03.005
22. La Mantia FP, Morreale M. Green composites: A brief review. Composites Part A: Applied Science and Manufacturing. 2011; 42(6): 579–588. doi: 10.1016/j.compositesa.2011.01.017
23. Singh T, Tejyan S, Patnaik A, et al. Fabrication of waste bagasse fiber-reinforced epoxy composites: Study of physical, mechanical, and erosion properties. Polymer Composites. 2019; 40(9): 3777–3786. doi: 10.1002/pc.25239
24. Saini G, Narula AK, Choudhary V, et al. Effect of Particle Size and Alkali Treatment of Sugarcane Bagasse on Thermal, Mechanical, and Morphological Properties of PVC-Bagasse Composites. Journal of Reinforced Plastics and Composites. 2009; 29(5): 731–740. doi: 10.1177/0731684408100693
25. Manikandan P, Nayeem Faruqui A, Raghukandan K, et al. Underwater shock consolidation of Mg–SiC composites. Journal of Materials Science. 2010; 45(16): 4518–4523. doi: 10.1007/s10853-010-4547-8
26. Dixit M, Srivastava R. The effect of copper granules on interfacial bonding and properties of the copper-graphite composite prepared by flake powder metallurgy. Advanced Powder Technology. 2019; 30(12): 3067–3078. doi: 10.1016/j.apt.2019.09.013
27. Prasad L, Kumar S, Patel RV, et al. Physical and Mechanical Behavior of Sugarcane Bagasse Fiber-Reinforced Epoxy Bio-Composites. Materials. 2020; 13(23): 5387. doi: 10.3390/ma13235387
28. Sunarsih S, Andaka G, Wahyuningtyas D. Characterization of morphological changes on modified sugarcane bagasse with potassium hydroxide. Journal of Physics: Conference Series. 2020; 1511(1): 012067. doi: 10.1088/1742-6596/1511/1/012067
29. Bakri MKB, Jayamani E, Hamdan S. Processing and Characterization of Banana Fiber/Epoxy Composites: Effect of Alkaline Treatment. Materials Today: Proceedings. 2017; 4(2): 2871–2878. doi: 10.1016/j.matpr.2017.02.167
30. Bartos A, Anggono J, Farkas ÁE, et al. Alkali treatment of lignocellulosic fibers extracted from sugarcane bagasse: Composition, structure, properties. Polymer Testing. 2020; 88: 106549. doi: 10.1016/j.polymertesting.2020.106549
31. Ogah AO, Afiukwa JN. Characterization and comparison of mechanical behavior of agro fiber-filled high-density polyethylene bio-composites. Journal of Reinforced Plastics and Composites. 2013; 33(1): 37–46. doi: 10.1177/0731684413509425
32. Agarwal K, Kuchipudi SK, Girard B, et al. Mechanical properties of fiber reinforced polymer composites: A comparative study of conventional and additive manufacturing methods. Journal of Composite Materials. 2018; 52(23): 3173–3181. doi: 10.1177/0021998318762297
33. Kosedag E, Ekici R. Low-velocity impact performance of B4C particle-reinforced Al 6061 metal matrix composites. Materials Research Express. 2019; 6(12): 126556. doi: 10.1088/2053-1591/ab5815
34. Dogra V, Kishore C, Verma A, et al. Fabrication and Experimental Testing of Hybrid Composite Material Having Biodegradable Bagasse Fiber in a Modified Epoxy Resin: Evaluation of Mechanical and Morphological Behavior. Applied

Science and Engineering Progress. 2021. doi: 10.14416/j.asep.2021.06.002

35. Adeniyi AG, Onifade DV, Ighalo JO, et al. A review of coir fiber reinforced polymer composites. Composites Part B: Engineering. 2019; 176: 107305. doi: 10.1016/j.compositesb.2019.107305
36. Marichelvam MK, Manimaran P, Verma A, et al. A novel palm sheath and sugarcane bagasse fiber based hybrid composites for automotive applications: An experimental approach. Polymer Composites. 2020; 42(1): 512–521. doi: 10.1002/pc.25843
37. Asim M, Saba N, Jawaid M, et al. Potential of natural fiber/biomass filler-reinforced polymer composites in aerospace applications. Sustainable Composites for Aerospace Applications. 2018; 253–268. doi: 10.1016/b978-0-08-102131-6.00012-8
38. Oliveira SL, Mendes RF, Mendes LM, et al. Particleboard Panels Made from Sugarcane Bagasse: Characterization for Use in the Furniture Industry. Materials Research. 2016; 19(4): 914–922. doi: 10.1590/1980-5373-mr-2015-0211