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Enhancing solid waste sustainability with iroko wooden sawdust and african oil bean shell particle-strengthened epoxy composites

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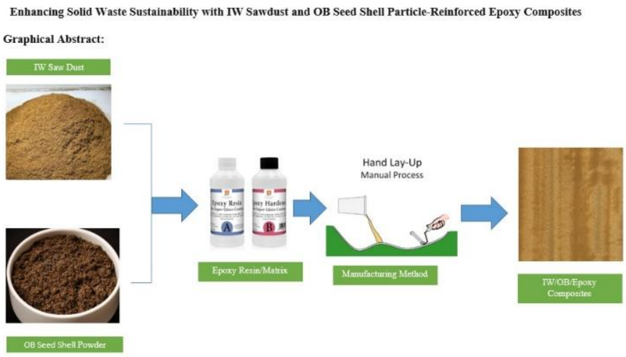
Graphical abstract



Abstract

Bio-composite materials are gaining traction in various industries as sustainable alternatives to synthetic fiber-reinforced composites. This study investigated the impact of fine powders loading on the tensile, transverse, and compressive characteristics of hybrid composites composed of Iroko wooden sawdust and oil bean pod shells. Employing a 1:1 ratio of sawdust and oil bean pod shell particles as fillers, a hybrid composite configuration was formulated. Different reinforcement levels, specifically 20%, 30%, 40%, 50%, and 60%, were employed. The manufactured composites underwent rigorous ASTM testing, and the results revealed that filler reinforcement significantly influenced the tensile, compressive, and transverse properties of the composite material. While the percentage of elongation at fracture increased up to 40% before reaching a decline, the tensile strength, transverse rupture strength, transverse modulus, and compressive strength consistently improved until a 50% filler loading. The findings from this study underscore the potential of composite materials incorporating Iroko wood, oil bean pods, and epoxy as effective alternatives to conventional wood-based materials in various applications, thus contributing to sustainable solid waste management.

Keywords: Oil bean shell, sawdust, hybrid composites, mechanical properties, epoxy resin

1. Introduction

Tropical Africa is home to the African oil bean (Pentaclethra macrophylla Benth), a member of the Leguminosae (Mimosoideae) circle of relatives of trees. The fruit is an extended, green pod that grows 36–forty-six cm lengthy and five–10 cm wide while it's far completely mature. Every pod carries up to 10 seeds, and while it is fully mature, the pod bursts open explosively, dispersing its seeds up to 20 m from the tree (Karthik *et al.* 2023) Despite having exceptional energy and hardness, artificial fibre reinforced composites are costly and not biodegradable. Herbal fibres are becoming extra popular because to their accessibility, acceptable precise energy and modulus (Ramesh *et al.* 2023) light weight, low price, and biodegradability (Baley 2022). Moreover, in comparison to composites made from natural fibres, synthetic fibres like carbon fibres and glass fibres pose extra environmental and fitness dangers to the human beings worried within the production in their associated composites (Jawaid *et al.* 2011). Due to this, herbal fibre reinforced composites have become increasingly more in demand as they play more and more roles in car parts for lightweight components, plastic, and packaging (Fartini *et al.* 2015). This vicinity of the world has get admission to an extensive form of natural composite substances, such as jute, abaca, sawdust, sisal, ramie, hemp, and many others. Similarly, to the low cost of agricultural waste, environmental and biodegradability characteristics of materials are of particular interest these days. So one can actualize the scale up production of agricultural waste plastic composites by means of the formation and synthesis of these filler fibres, diverse methods are needed, which contain blending filler husks at distinct filler loading consistent with weight (Albano *et al.* 2005; Fayaz *et al.* 2022). Natural fibre bolstered polymer matrix composites are visually appealing, but they have got lesser power, decrease modulus, and commonly negative moisture resistance compared to composites reinforced with artificial fibres, including glass and carbon fibre (Ganesh *et al.* 2017). Fibre - strengthened polymer matrix composites are extremely prone to environmental influences, together with the ones from water (Karthik *et al.* 2017). Foremost companies like the car, constructing, and packaging sectors have these days expressed a notable deal of hobby within the advent of novel bio-composite materials and are actively searching out replacements for synthetic fibre reinforced composites (Kumar *et al.* 2015). Numerous researchers that appeared into the mechanical characteristics of composite substances located that that they had suitable dynamic mechanical features for a wide variety of commercial programs. The compressive electricity of unsaturated polyester resin full of Napier grass turned into studied in reference and it changed into found that temperature and filler concentration have a sizable effect on the changed resin's elastic modulus and compressive electricity. In a previous study, as documented in reference (Karthik *et al.* 2022), researchers examined the mechanical performance of innovative bio-based composite materials. These composites featured groundnut shell particles serving as reinforcement within an epoxy resin matrix. They found that samples with 40% by extent and zero.5 mm-sized groundnut shell debris had the best tensile modulus, tensile electricity, transverse energy, and impact electricity. Moreover, (Ramamoorthi *et al.* 2017) investigated how alkali remedies affected the mechanical traits of bagasse fibre biodegradable composites and found that the mechanical residences of the composites crafted from alkali-treated fibres have been superior to the untreated fibres. Composites of handled fibres with NaOH showed higher effects, with about 13% enrichment in tensile power, 14% in transverse power, and 30% in impact electricity having been determined, respectively. To improve their mechanical and thermal traits, the herbal fabric a good way to be utilised to make composite substances should be chemically dealt with. it has been observed that chemically treating fibre with NaOH substantially increases the thermal and mechanical properties of composites and allows fibre to make higher touch with the fibre matrix and reduces thermal contact resistance (Manickaraj *et al.* 2022). Whilst used in a unmarried polymer matrix, the hybridization of two or extra exclusive styles of substances will have some blessings over employing every sort of cloth separately. Hybrid composite substances provide an electricity and modulus aggregate this is either on par with or superior than many natural materials (Ramakrishnan *et al.* 2021). Previous studies have created hybrid composites that integrate natural and artificial fillers. These materials validated superior mechanical traits than monofiller substances (Manickaraj *et al.* 2019, 2023). there is a modern-day statistics gap regarding the hybridization of oil bean shell and tough timber sawdust composite manufacture, so in the current take a look at, epoxy-based hybrid composites had been made the use of difficult timber sawdust and oil bean pod nut shell particle because the reinforcing factors

2. Materials and methods

Polymer composite samples were produced by adjusting the weight percentages of Iroko wood sawdust and oil bean pod shell within the epoxy matrix to reinforce the material, contributing to solid waste management efforts.

2.1. Samples guidance

2.1.1. Epoxy resin (matrix)

The matrix material in this case is composed of Araldite LY556 resins and HY951 hardener. The epoxy resin LY556 has extraordinary alkali resistance, exceptional solvent resistance, and outstanding mechanical, dynamic, and thermal properties. It also has good fiber impregnation capabilities. It also exhibits advantageous electrical characteristics at various temperatures and frequencies. The matrix material was bought from the Seenu and Seenu Company, Coimbatore, India. Table 1 displays the epoxy resin properties.

Table 1. Properties of Epoxy resin

Properties	Epoxy LY556	Hardener HY951
Visual Appearance	Colour less clear liquid	Brownish yellow colour liquid
Viscosity at room temperature	9000-12000 Mpa	500-1000 Mpa
Density at room temperature	1.13-1.16 gm/cc	0.946 gm/cc

2.1.2. Chemical treatment of an oil bean shell

An oil bean seed's outdoors shell is called the OB shell, and the complete oil bean seed is known as an oil bean pod. A good way to remove contaminants, the oil bean shells have been procured from a local agency in Coimbatore and washed. The shells had been solar-dried and pulverized, and the consequent debris had been then handled with 10% NaOH (soaked for 3 hours, then washed with acidified water), and oven dried at 80°C for ten hours. Shell particles of a hundred and fifty, three hundred, and 450 microns have been separated from the debris the usage of a stainless steel sieve.

2.1.3. Chemical treatment of an iroko timber sawdust

Iroko (Chlorophora excelsa), a tough timber, become purchased from a close-by woodworker in Coimbatore and sawed with a sawblade with nice teeth to obtain the excellent sawdust from the timber. After being handled with a 10% NaOH answer at room temperature for 5 hours, the sawdust changed into washed in acidified water and dried in an oven at eighty °C for 10 hours. The debris have been sieved via well-known check sieves measuring 300, 450, and 600 microns to get numerous particle sizes.

2.1.4. Hybrid composite

The composites had been organized using the hand lay-up technique. To enable short release of the composite, a completely thin layer of wax turned into first positioned to a timber mildew measuring 200 by way of one hundred fifty by five mm3, which was utilised for casting the composite board. The composites were created the use of 1:1 reinforcement of saw-dust and OB shell particle within the quantities of 20, 30, 40, 50, and 60%. (Table 1). To create a uniform combination, measured quantities of IW sawdust, OB shell particle, and resin have been introduced to a plastic field and punctiliously combined for 25 minutes. The casted mould changed into left at room temperature for 24 hours with a weight of 40 kg to release any trapped air, after which it changed into removed from the mould and allowed to remedy for 21 days. Following curing, the composite board become shaped into trendy examples. The epoxy resin and hardener were combined at a weight-to-weight ratio of 10:4. The proportion of sawdust/oil bean shell particulate/epoxy hybrid composite inside the composite board is proven in Table 2.

Table 2. % of composition of saw dust/oil bean shell particulate/epoxy hybrid composite

Sample Designation	Iroko Wood Saw Dust (wt%)	Oil Been Shell (wt%)	Epoxy Resin (wt%)
10IW10OB80M	10	10	80
15IW15OB70M	15	15	70
20IW20OB60M	20	20	60
25IW25OB50M	25	25	50
30IW30OB40M	30	30	40

2.1.5. Mechanical testing

In step with ASTM D638 procedure, the tensile power of the composites turned into evaluated the use of a typical checking out machine (UTM). The specimen become slowly pulled until fracture by using the UTM, which held every stop (figure 1). The common tensile energy and elongation at fracture values for each pattern had been computed after five replications.

2.1.6. Flexural test

In keeping with ASTM D790 - 17 widespread, the flexural take a look at became performed at the general testing machine employing a three-point bending fixture and center loading on a trustworthy supported beam. The subsequent equations have been hired to calculate the values of the rupture and elasticity.

Figure 1. UTM

2.1.7. Compression test

The samples had been subjected to a uniaxial compression take a look at in accordance with the ASTM D695 preferred, utilizing the standard testing system and a go speed fee of 1mm/min. Elastic modulus and maximum compressive strength have been determined as compressive characteristics.

3. Result and discussion

3.1. Tensile strength

The results discovered that the filler loading had a considerable impact on the composite board's tensile energy. In figure 2, the tensile electricity increases with increasing IW and OB as much as 50%, then decreases. This could be attributed to poor bonding or reinforcement substances caused by low extent (percent) of matrix within the aggregate, resulting in maximum void contents and weak interfacial adhesion inside the system. For the duration of tensile loading, partly separated micro gaps shape, obstructing strain propagation between the fibre and the matrix. One of the maximum vast traits of materials used in structural packages is their tensile electricity, or their capacity to undergo a pulling pressure. Table 3 shows the standard deviations of the various strength results.

Table 3. Various strength of the IW/OB composite with Reinforcement

Reinforcement	Tensile Strength (Mpa)	% of Elongation (mm)	Flexural Strength (Mpa)	Compressive Strength (Mpa)
10IW10OB80M	5	1.5	17	30
15IW15OB70M	8	2	28	45
20IW20OB60M	10.5	2.6	35	58
25IW25OB50M	15	3.5	38	80
30IW30OB40M	11	2.7	31	65

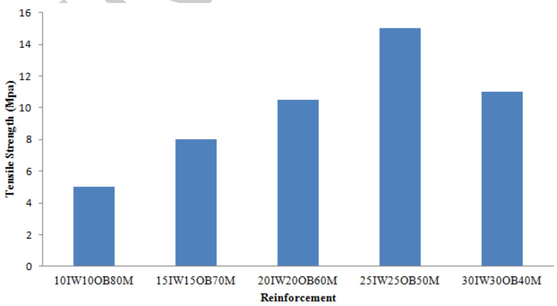


Figure 2. Tensile strength of the IW/OB composite

3.2. Percentage of elongation at fracture

Figure 3 displays the percentage elongation located after performing the tensile check. parent four illustrates how the hybrid composite board's percent elongation at fracture climbed to a maximum at 40% loading and dropped with increasing loading (filler reinforcement). The share of elongation at fracture decreased at 20% filler loading for epoxy hybrid composites strengthened with timber sawdust/oil-bearing seed particles.

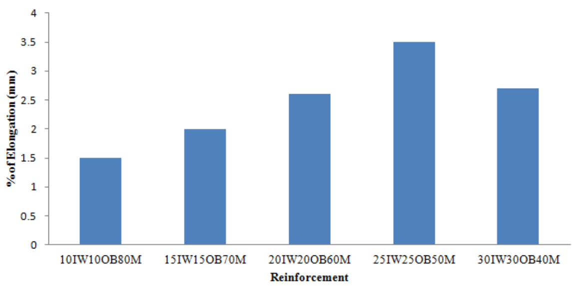


Figure 3. % of Elongation (mm) of the IW/OB composite

3.3. Flexural test

The outcomes of the test reveal that the transverse rupture energy improved as much as 50% reinforcement before reducing over again (Figures 4). This could be related to the fillers' bad adherence to the matrix at more reinforcing stages. Particle size, particle content material, and particle/matrix interfacial adhesion all have an impact on the mechanical traits of particulate-filled polymer micro and nanocomposites (Manickaraj *et al.* 2023; Ismail *et al.* 2022; Varada *et al.* 2005; Nyior *et al.* 2018; Fu *et al.* 2008). Similar findings had been said through earlier studies. They observed that the composites' tensile, flexural, and hardness rose with increasing fiber loading up to forty-three vol.% and deteriorated above this quantity. It changed into found to be sufficient reinforcement to raise the energy of the polypropylene powder at both a fiber content of 30% and forty% via weight. Materials' flexural traits are critical in structural applications.

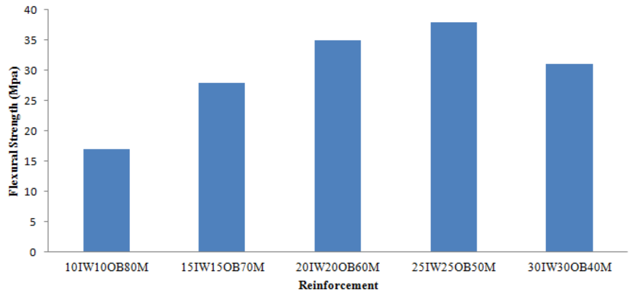


Figure 4. Flexural strength of the IW/OB composite

3.4. Compressive test

Consistent with the experimental findings, the compressive strength of the composite board progressively increases with an increase in filler percent as much as 50% before it declines again (determine 7). This is probably defined by means of the vulnerable touch on the filler-matrix interface, as well as with the aid of voids and filler agglomeration with expanded filler content material (Nyior *et al.* 2018). Moreover, (Haque *et al.* 2009) observed a comparable behavior inside the composite specimens.

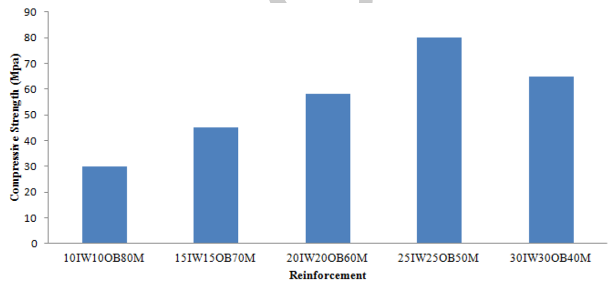


Figure 5. Compressive strength of the IW/OB composite

4. Conclusions

The tensile strength, elongation percentage, flexural properties, and compressive characteristics of the IW/OB composite (consisting of Iroko wood and oil bean) were thoroughly scrutinized, leading to the subsequent discoveries:

- The results of the mechanical tests indicated a significant improvement in the mechanical characteristics of the composite board when IW/OB was added, reaching a maximum at a particular point (50 percent by weight). However, surpassing this threshold led to a decrease in these properties as the weight ratio of IW/OB increased.
- These findings highlight the substantial impact of incorporating IW/OB and the quality of interfacial bonding on various mechanical properties such as tensile strength, elongation percentage, flexural characteristics, and compressive properties in composite materials. The study emphasizes the pivotal role played by the amount of IW/OB and the strength of intermolecular connections in shaping the overall performance of these composite materials. It underscores the interconnected nature of these factors in influencing the mechanical behavior of the composite. The research findings emphasize the possibility of utilizing oil beans (OB), epoxy, and Iroko wood (IW) to skillfully build composite materials for a variety of uses. These composites offer a viable and sustainable alternative to traditional wood-based products, especially when it comes to solid waste management. The creation of robust and environmentally friendly furnishings could serve as an example of how to use these composite materials, demonstrating their adaptability and potential value in supporting eco-friendly practices.

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