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Investigation of the Mechanical Properties of Repurposed-Net-Bag Reinforced Plastic

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ABSTRACT

This study investigates the potential of recycling grocery net bags for reinforcing epoxy matrix composites, leveraging their favorable strength-to-weight ratio and offering a cost reduction and non-biodegradable waste reduction method. A composite material was made by combining 90 layers of fiber mesh with Lapox Metalam System B epoxy and hardener. The primary objective was to explore major mechanical properties, including ultimate tensile strength, yield strength, flexural strength, and impact strength. The ASTM-specified standards were maintained for the fabrication and testing of the specimen, utilizing a universal testing machine (UTM) and a pendulum impact tester. Test results show that elastic modulus of the composite ranges from 0.72 to 0.88 GPa and shear modulus ranges from 1.73 to 2.26 GPa. Also, the impact tests show an average impact strength of 66.27 kJ/m^2.

1. INTRODUCTION

Non-biodegradable and synthetic polymer-based materials are being used more and more often across a variety of industries. Synthetic polymers are one of the most prevalent pollutants in the environment. Grocery net bags made of such non-biodegradable synthetic material often go to waste after a single use and ultimately end up in landfills. These materials are difficult to recycle, and their unplanned disposal adversely affects the ecological system. But because of their extraordinary strength-to-weight ratio, these mesh bags might work well as the reinforcing phase of a composite. Epoxy resin can be used as the matrix material, together with mesh or net bags, to create an inexpensive alternative to conventional composite materials. Adding a porous mesh or net-bag layer into an epoxy-based lay-up offers both improved resin distribution and basic reinforcement at a fraction of the cost of woven fiber fabrics and such composites fabricated by simple hand-lay-up demonstrate significantly improved tensile and flexural properties over neat epoxy sheets (Islam et al., 2022). Different composite materials are manufactured with different reinforcing phases, including graphite, aramid, jute, and carbon fiber, depending on the required application (Rajak et al., 2019). The expense of utilizing glass fiber or carbon fiber is high, and treating natural fibers for manufacturing composites is a costly and time-consuming process (Peijs et al., 2022; Sathish et al., 2021; Suriani et al., 2021). By reusing used net bags, the challenge of waste disposal and recycling is minimized as well. For evaluating the usability of composite, a proper investigation of the mechanical properties is crucial.

Different types of composite materials comprising different reinforcing phases such as carbon fiber, aramid fiber, jute fiber, Kevlar, graphite, etc. in matrix phases like polycarbonate, polyether ether ketone, polyether imide, polyethylene terephthalate, phenoplasts, epoxy resin, polyether sulfone, polyether ketone, and polyurethane are well studied and frequently used in industries (Kaw, 1997; Hsissou et al., 2021; Barbero, 2010). Mesh materials such as carbon fiber mesh, aramid fiber, or steel mesh are commonly used in the reinforcement of concrete and concrete slabs to increase their impact and shear strength (Zhang et al., 2022; Hulimka et al., 2017).

The Ultimate tensile strength of composites reinforced with jute fiber ranges from 43-98 MPa (Wang et al., 2019). Izod impact strength of epoxy matrix natural fiber composites ranges from 15- 115 KJ/m^2 (Navaranjan and Neitzert, 2017). According to Karahan and Karahan (2015), natural fiber composites have significantly lower strength and toughness than carbon epoxy composites. They also observed that natural fiber composites are highly influenced by environmental factors like moisture and have poor thermal stability. Results also demonstrate that jute-epoxy composites exceed the tensile strength, impact strength and toughness of flax-epoxy composites. The mechanical properties of hemp, sisal, coir, and jute were tested by Wambua et al., (2003) using the film stacking method, and compared with the properties of polypropene composite reinforced with glass mat. Among them, hemp reinforced composites showed the highest mechanical properties which shows the potential to replace glass with natural composite for certain applications. Raj, Nagarajan and Elsi (2016) compared the properties of glass fiber composites with those of hybrid composites that included partial substitution of discarded fishnet of various mesh sizes with woven roving and polyester matrix. The research reveals that the composite loses tensile strength when fishnet is substituted, but impact strength increases significantly as fishnet has better elastic properties. Fishnet exhibits enhanced water absorption as well. According to compressive and tensile testing, the research conducted by the mechanical behavior of the cementitious fiber-reinforced composite was demonstrated by Park, Kim, and Kim (2021) which were generated with leftover fishnet. Their experiment demonstrated that these composites' compressive strength depends on fiber volume and fiber diameter. The first crack strength, which is primarily dependent on matrix properties decreases with increasing volume, whereas the post-cracking strength, which is primarily dependent on fiber properties, exhibits the opposite behavior. However, the composite with large-diameter fiber displayed the opposite outcomes in each of these cases.

Li et al. (2022) conducted a study comparing the shear behavior of concrete beams while it is reinforced by carbon fiber-reinforced polymer mesh fiber and steel respectively. The result showed that they exert almost the same shear capacities. Meshed reinforcing materials used in reinforcing large concrete slabs show geometric similarity with the meshed geometry of net bags. But documented investigation on the properties of such composite can hardly be found. There is rarely any study related to repurposed-net-bag composite or repurposed-net-bag reinforced plastics as well. But composites constructed of fibers that are geometrically close to them yield good mechanical properties. Besides, compared to other fibers, repurposing net bags will lower the cost as well as the environmental harm brought on by the unplanned disposal of these non-biodegradable bags. Therefore, this study focuses on the synthesis of a synthetic fiber-epoxy composite using commonly used net bags, and analysis of the synthesized composite's tensile strength, yield strength, flexural strength, and toughness by conducting standard tests.

2. MATERIALS AND METHOD

2.1. Materials

The reinforcing material of the composite is synthetic knitted nylon mesh, which is used for making grocery net bags. The net bags used to make the composite was collected from different sources, which were to be discarded after a single use. The mesh structure reduces the weight but preserves the load carrying capacity of the bags. Figure 1 shows a single layer of the repurposed grocery net bag mesh placed over a 10mm x 10mm grid. The mesh of the net bags has square pattern, and varies from 6mm to 7mm in size. Each net bag has 2 plies, and the mass of the net bags ranges from 3.0g to 3.4g. Under tensile loading, each ply can withstand a 42.56 kg load before failure. Epoxy resin is used as the matrix material. Lapox Metalam system B resin of 1.00 to 1.20 g/cm^3 density and hardener of density 0.95–1.00 g/cm^3 are used for making the matrix solution, which is an ambient temperature curing hardener**.**

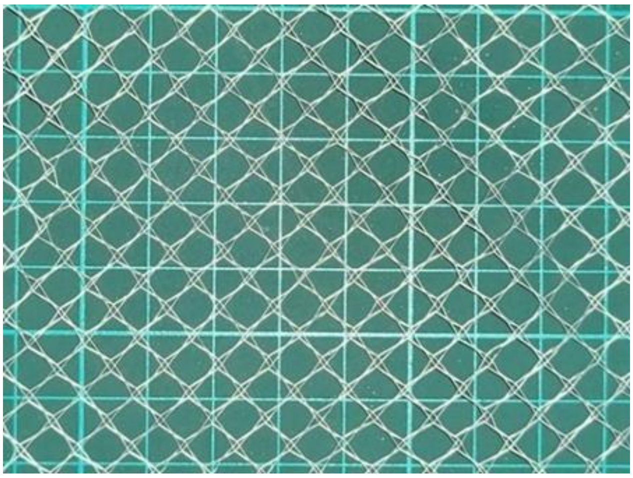

Figure 1: A layer of the used mesh net-bag on top of a 10mm×10mm grid

2.2. Composite Production

Utilizing the hand lay-up method this composite was prepared, by submerging the layers of the meshed fibers in an epoxy resin matrix. Initially, a liquid solution comprising of resin and hardener (Lapox Metalam System B) in a 2:1 ratio was mixed. A mold with 305mmX330mm internal dimension was made using MDF boards. Subsequently, layers of the meshed net bags were cut into the required dimensions and soaked in epoxy and then placed one by one inside the mold. Additional resin was also poured after 4 or 5 layers so that all the parts are well soaked. Each layer of net bags was oriented at a 90-degree angle from the previous layer. A total of 45 net bags, resulting in 90 layers of fiber were incorporated into the composite structure.

Following this, a second wooden plank was placed on top of the composite, and the entire assembly was secured using four clamps. A silicone mold release agent (Sprayway 946) was used on all surrounding surfaces of the mold to prevent the sticking of epoxy on the mold. The setup was then allowed to undergo a curing process, which lasted 48 hours.

2.3. Sample Testing

The samples for the tensile test, flexural test, and impact test are CNC cut using Step craft Q204 CNC milling machine from the cured sheet of the composite according to ASTM standard dimensions. Samples were prepared from both direction of the composite. Figure 2 shows the prepared samples on top of a 10mmX10mm grid. From top to bottom, the image displays samples prepared for the ASTM D256 Izod impact test, ASTM D790 flexural test, and ASTM D638 tensile test, cut to the required dimensions according to the standards. The equivalent of the recognized standards is tabulated in Table 1.

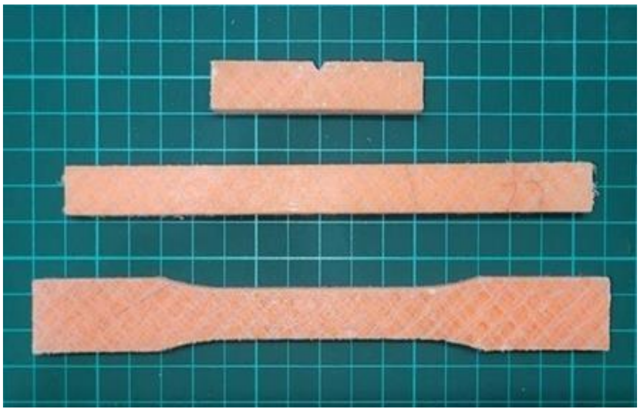

Figure 2: Prepared samples on top of a 10mm×10mm grid. From top to bottom: Izod impact test, flexural test and tensile test sample

Table 1: ASTM and ISO standards for testing mechanical properties of plastics and polymers

Test	ASTM	ISO
Tensile	ASTM D638	ISO 520
Flexural/Bending	ASTM D790	ISO 178
Impact	ASTM D256	ISO 180

2.3.1. Tensile Test

The tensile strength and elastic modulus of the composite were tested based on the ASTM D638 standard, using the PLS-100 Universal Testing Machine (UTM). Three specimens each of gauge length 50 mm were tested at room temperature (35º C). The UTM's crosshead speed was set at 1.5 mm/min. The UTM software obtains values of the Ultimate Tensile Strength (UTS), yield strength (higher yield strength—ReH, yield strength at 0.2% plastic deformation-Rp0.2), breaking stress, and elastic modulus are obtained from the UTM software.

A = Cross sectional area below the notch (m^2).

Fracture toughness is expressed as,

$$KC = \sqrt{G.E} \quad (2)$$

Where, KC = Fracture toughness (MPa.m$^{1/2}$) and E = Elastic modulus of the material (MPa).

2.3.2. Flexural Test

The flexural strength and bending of the composite were tested following the ASTM D790 standard, using the PLS-100 UTM. Three specimens were tested at room temperature (35º C). The support span length was 124 mm. The width and depth of the specimen were 12.7 mm and 8.5 mm respectively. Crosshead speed of 2 mm/min was used during the tests.

2.3.3. Impact Test

The impact behavior of each composite was evaluated according to ASTM D256 standard at room temperature (35º C) using Bulut Makina AIT300 pendulum impact tester. Test method A described in the ASTM D256 standard was used. The energy required for fracture determined the impact strength and fracture toughness in these tests. The impact strength is calculated based on the following equation:

$$G = U/A \quad (1)$$

Where, G = Impact strength of the material (J/m^2), U = Absorbed energy (J), and A = Cross sectional area below the notch (m^2)

3. RESULTS AND DISCUSSION

The composite was made using 950g of matrix (mixture of resin and hardener) and 144g reinforcing mesh (45pcs of net bag, 3.2g each), resulting in a fiber weight fraction of 13.16%. Density of the composite is 1.21g/cm^3. The results of the conducted tests are summarized in Table 2 below.

Table 2: Summary of test results

Property	Average	Maximum
Ultimate Tensile Strength (MPa)	33.33	34.01
Yield Strength, $Rp_{0.2}$ (MPa)	24.10	24.80
Elastic Modulus (GPa)	0.813	0.880
Flexural Strength (MPa)	1.84	2.03
Shear Modulus (GPa)	2.02	2.26
Impact Strength (kJ/m^2)	66.27	83.84
Fracture Toughness (MPa.m$^{1/2}$)	7.31	8.26

3.1. Tensile Test

The stress vs strain curve obtained for the tested samples shown in Figure 3 illustrates the composite material behavior under tensile loading. The ultimate strength of the tested sample, which refers to the maximum allowed stress on the material before yielding, ranges from 32 to 34 MPa.

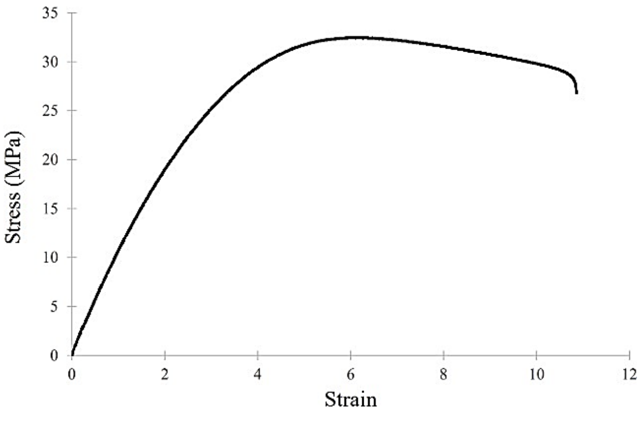

Figure 3: Stress vs. strain curve of tested samples

The average breaking stress of the samples is 21.10 MPa but one of the samples fractured at 10.40 MPa stress. This can be due to non-uniform distribution of the layers during preparing the composite and some amount of trapped air as curing had not been done in a vacuum chamber. The trapped air pockets may have acted as stress concentration point for the sample.

At maximum stress, this composite displayed the highest 5.30% elongation, and an average elongation of 4.66% was obtained from the tested samples. None of the samples showed any significant amount of necking after reaching

UTS and before fracture, and the fracture for all the samples were brittle in nature.

The modulus of elasticity of the material ranges from 0.72 to 0.88 GPa. This composite extracts an average value of 0.813 GPa for elastic modulus. Values of yield strength were taken as both higher yield strength recorded by UTM (ReH) and yield strength at 0.2% plastic deformation (Rp0.2). The value of ReH is almost identical to the UTS since there is very little necking. The value of Rp0.2 ranges from 23.70 to 24.80 MPa. The values of UTS and Yield strength are consistent for all the samples with standard deviation of 1.154 and 0.608 respectively.

3.2. Flexural Test

Three-point bend test was conducted on three samples following ASTM D790 standard to evaluate the flexural strength of the composite. Figure 4 presents the flexural stress versus flexural strain for this composite. The composite showed a maximum 2.03 MPa flexural strength. The maximum applied loads on the test samples range from 188.37 N to 203.62 N.

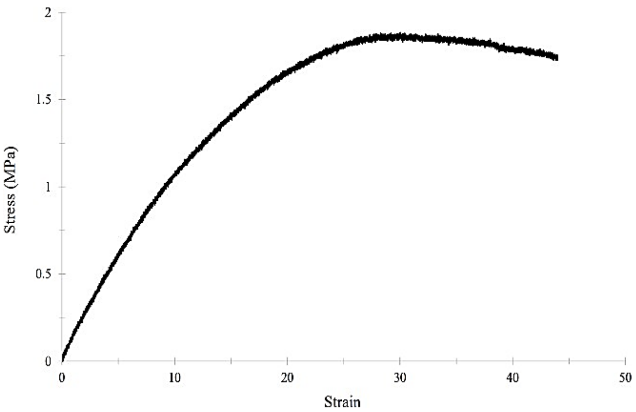

Figure 4: Flexural stress vs. flexural strain curve of samples

Maximum value obtained for shear modulus is 2.26 GPa and the average value is 2.03 GPa with standard deviation of 0.22. Shear modulus describes the resistance of the composite to shear deformation while applying a parallel force to one surface while another remains fixed. It shows the stiffness of material under shear stress. The composite has a relatively high shear modulus, indicating that it is stiff and resistant to shear deformation.
The composite showed an average deflection of 15.21 mm at maximum load but the maximum deflection ranges from21.98 to 25.98 mm with a 24.28 mm average value. This is due to the plastic deformation of the composite during bending.

The plastic deformation of the samples under flexural loading is significantly larger than deformation under tensile loading.

3.3. Impact Test

The composite material was subjected to the Izod impact test to evaluate its response under abrupt or dynamic load conditions, following the ASTM D790 standard.

The Izod impact test was conducted on five v-notched samples of the composite material to evaluate its impact resistance. The samples' cross sections below the notch showed only slight variations. The chart on Figure 5 displays the Izod impact strength results for five individual composite samples tested. The composite is completely broken for all the samples tested and exhibits brittle characteristics.

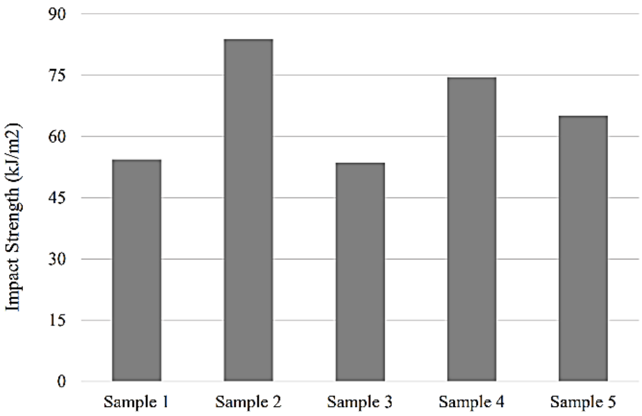

Figure 5: Impact Strength of samples

The composite material shows 83.84 KJ/m^2 maximum and 66.27 KJ/m^2 average impact strength before fracture, with standard deviation of 11.68. Maximum and average fracture toughness of the samples are 8.26 $KPa.m^{1/2}$ and 7.31 $KPa.m^{1/2}$ respectively. The findings have variations because of inhomogeneities such as resin dispersion or fiber alignment inside the specimens, as well as residual stress or deformation from forming the V-notch.

Figure 6 shows the tested specimens after the completion of the mechanical tests. It displays the failure modes: impact test sample shows the complete fracture from the Izod impact test, bending test sample shows deformation from the flexural test, and the tensile test sample shows the brittle failure resulting from the tensile test. Most natural-fiber/epoxy laminates yield almost similar tensile strengths, henequen/epoxy ~13–18 MPa and jute/epoxy ~45 MPa (Torres-Arellano et al., 2020). Hidayah et al. (2022) report tensile strengths 1.7 MPa at low fiber content, rising to around 19.6 MPa at higher fiber loading for composite made with recycled masks with epoxy matrix. The repurposed net-bag reinforced plastic composite has a tensile strength that falls within the range of some natural fiber epoxy laminates.

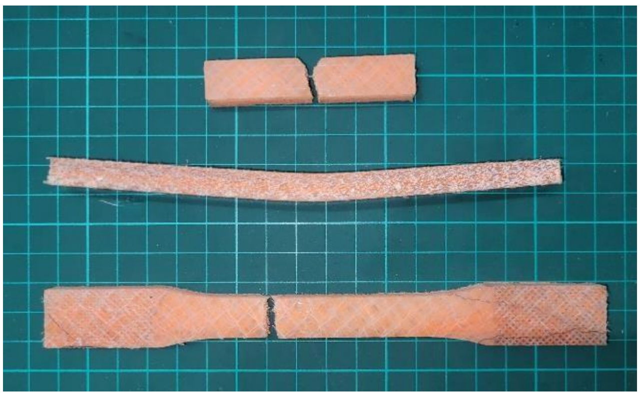

Figure 6: Tested samples on a 10mm×10mm grid. From top to bottom: Izod impact test, Flexural test and Tensile tested samples

3. CONCLUSION

The study investigated the mechanical properties of composite material with recycled net bag reinforcement in an epoxy resin matrix by tensile, flexural, and impact tests. The plastic specimens of recycled net bag reinforced plastic possessed significantly lower elastic modulus and strength compared to commercial carbon or glass fiber reinforced plastics, and lower or similar tensile and flexural strength but near identical impact strength compared to natural fiber reinforced plastics. The composite exhibited brittle characteristics in impact. The lower strength means it is not suitable to replace traditional fiber composites where high strength is required.

Based on these mechanical properties, coupled with the low production cost and near net shape manufacturing capability, the repurposed net-bag reinforced plastic composite appears suitable for applications where high structural loads are not the primary concern, but rather a combination of some mechanical integrity, cost- effectiveness, and the ability to form intricate shapes is required. The low cost and availability of raw materials of this composite provide an advantage for application in sectors like low strength requiring furniture or seatbacks, panelling of automobiles, and splash guards can be some potential sectors for this composite. Investigating the effects of varying compositional parameters, such as the type of net bag material, fiber content, and layer orientation, as well as exploring different manufacturing processes like vacuum curing to reduce voids, would provide a more comprehensive understanding of how these factors influence the mechanical properties of the repurposed net- bag reinforced plastic composite.

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AUTHOR DECLARATION

Authors declare that there is no conflict of interest.

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