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Mechanical and morphological characterization of discarded fishnet/glass fiber reinforced polyester composite

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Abstract. The present work focuses on the fabrication of glass fiber and multifilament discarded fishnet nylon fiber polymer composites with four different fiber compositions. Composites are molded by means of simple hand lay-up methodology with dissimilar layers of the fiber mat. The mechanical characterization (tensile and impact) and thermal analysis of composites have to be investigated. Among the different patterns, hybrid composites reflected better tensile and impact properties as compared to the conventional materials. Morphological characterization was carried out to figure out the de-bonding of fiber/matrix adhesion characteristics of fractured face of tensile testing samples. The result suggests the potential for reuse of discarded fishnet, which constitutes a better alternative for structural work and for possible applications to be used to develop added-value products.

Key words: fiber reinforced polymers (FRP), nylon fibers, hybrid structures, mechanical properties, thermal analysis, electron microscopy.

1. Introduction

Glass fiber composites have higher impact strength as well as excellent surface finish and high modulus-to-weight ratios as compared with other fiber reinforced composite materials [1], and are therefore used extensively in structural and infrastructure application. GFRP has used both sides of the lamination, which increased the overall mechanical performance along with presenting superior surface behaviors [2]. The effect of using bio-mass fibers, such as bamboo, kenaf, jute and hemp was that of significantly low mechanical properties as compared with synthetic fibers [3–5]. Fiber composites have properties depending on factors such as fiber type, type of resin, fiber-resin proportion and manufacturing type. In indoor applications such as [6] shelves, wash basins, partitions and table tops, composites are a better alternative for wood materials. They are also suitable for other uses like lightweight fishing boats, drainage pipes, roofing and electrical fittings [6, 7]. Balanced strength and stiffness, thermal distortion stability, reduced notch sensitivity, improved fatigue resistance and improved impact resistance are advantages of hybrid composites over composites [8–10]. Interfacial interactions between the reinforcing agent and the matrix material play an important role along with the properties of the constituent components when considering the mechanical performance of fiber glass reinforced composites [11–13].

In order to improve the tensile strength of glass fiber composites, a method is proposed for adding discarded fishnet laminates to the glass fiber. The tensile strength of the laminates of hybrid composites was far better than that of conventional laminates. Increasing fiber content in the composites increases the tensile strength and modulus as well [14–16]. Nylon fibers constitute more attractive reinforcement and provide good conformability for advanced structural applications. Nylon is used for military and commercial vehicles due to its significant elastic modulus, hardness, mechanical stress strength, thermal stability and capacity to absorb impact energy as well as high density [17]. If overall economy in the construction field is to be achieved, modernizing roofing sheets with waste fishnet has to be realized.

The effects of fiber-content and fiber surface modifications on the impact and thermal stability properties of the composites were investigated. Impact strength depends on the mesh sizes alone; smaller mesh size means more fishnet material and better stress transfer [18]. Hybrid composites with added fishnet fibers improved considerably as concerned impact resistance [19, 20]. However, only limited work has been done using glass and fishnet hybrid polymer composites. This work therefore investigates the possibility of using glass and fishnet hybrid polymer composites for the production of roofing sheets. In microscope investigation (SEM), the interfacial adhesion behaviors of cracks and internal structure of the fractured surfaces were evaluated. The materials developed were also evaluated by means of light transmission tests to know the percentage of light intrusion of various pattern compositions and by the machinability test to find the interfacial bonding strength between reinforcement and matrix for composites. The novel composite material is characterized by light weight and low cost proving useful for making roofing sheets with a view to protect our environment.

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2. Experimental details

2.1. Materials. For the present experimental investigation, mesh size of 32 mm discarded multifilament fishnets of 150 g were collected from the coastal area in the Kanyakumari district, Tamil Nadu, India. 8.656 μm twine diameter fishnet with single knotting and 90° orientation were used. The physical and mechanical properties of glass fiber and nylon fiber are listed in Table 1. Matrix used for analysis was isophthalic unsaturated polyester resin, which has an excellent cross-linking tendency, process ability and mechanical properties. For 100 g of resin, 1.5 ml of cobalt naphthenate and MEKP (methyl ethyl ketone peroxide) were used for curing at room temperature. Typical properties of the unsaturated polyester are listed in Table 2. The chemical composition of the glass fiber is presented in Table 3.

Table 1
Physical and mechanical properties of glass and nylon fiber

Properties	Glass fiber	Nylon fiber
Density (g/cm^3)	2.5	1.15
Young's modulus (GPa)	70–73	2–4
Elongation at break (%)	4.8	15–45
Tensile strength (MPa)	2000–3400	415.7

Table 2
Properties of the isophthalic polyester resin [21]

Properties	Range
Density in (kg/m^3)	1125
Flexural strength in (MPa)	30
Tensile strength in (MPa)	18
Shrinkage in (%)	0.004–0.008
Specific gravity	1.1–1.46

Table 3
Chemical composition of glass fiber (Wt. %)

Fiber type	SiO_2 (% Wt.)	CaO (% Wt.)	Al_2O_3 (% Wt.)	B_2O_3 (% Wt.)	Na_2O & K_2O (% Wt.)	MgO (% Wt.)
Glass fiber	55	16–25	12–16	8–13	0–1	0–6

2.2. Composite fabrication. The hybrid fishnet and glass fiber reinforced composites were molded using hand layup methodology. The waste fishnet required was cleaned and washed with water thoroughly and dried with direct sun light for an hour. Figure 1 shows the different mesh sizes with T 90° orientation of discarded fishnets. Alternate layers of different fibers were used as reinforcement and a polyester matrix was applied in between each layer by means of the hand layup technique. Air bubbles were removed by using 45 kg dead weight placed on the mold. The composites were allowed to cure for a day. Figure 2 shows the number of layers used for synthesis composites, composite (a) being prepared with 3 layers of glass fiber $(300\ g/m^2)$, composite (b) being prepared with the bottom and top two layers of glass fiber and polyester matrix and the middle layer of waste fishnet of 32 mm mesh size. Composite (c) is prepared with the top and bottom two layers of fishnet of mesh 32 mm with isophthalic polyester resin matrix and the middle layer of glass fiber. Composite (d) is prepared with three layers of fishnet of 90° orientation and 32 mm mesh size with isophthalic polyester resin matrix.

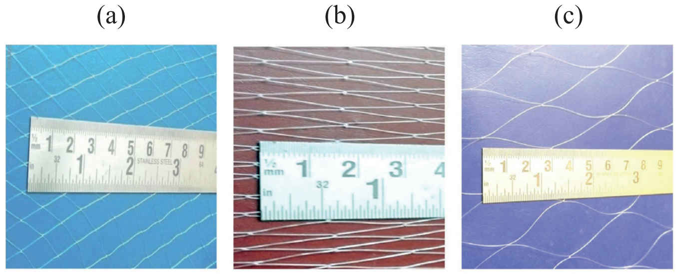

Fig. 1. Different mesh sizes of (a) 16 mm (b) 32 mm (c) 60 mm of discarded fishnets

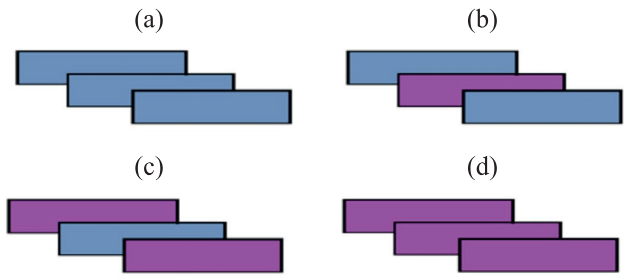

Fig. 2. Different sets making up composite specimens: a) 3GF, b) 2GF/1FN, c) 2FN/1GF, d) 3FN

2.3. Mechanical testing.
2.3.1. Tensile strength. The vital mechanical property of composite materials is their tensile strength. The tensile test was conducted by the UTMDRX 3 KN machine. The ASTM D-3039 was followed to prepare the tensile specimens; specimens were cut from the composite plate to the dimensions required. The 100 mm gauge length and 5 mm/min testing speed is used, and five specimens with the dimensions of 300×10×3 mm were tested in each case.

2.3.2. Impact strength. The impact tests were analyzed in accordance with ASTM D-256 with the size of 70×12.7×3 mm. The breaking load of the specimen was noted and the test was repeated with 5 trails.

2.3.3. Scanning electron microscope. The morphological study of fracture face of tensile test specimens of polyester composites was analyzed using SEM (Model: SEG100).

2.3.4. Thermal stability analysis. Thermal stability of the material developed was studied by using thermogravimetric analyzer (model: Jupiter STA449F3). The instrument was used for testing in a nitrogen atmosphere with a heating rate of 10°C/min from 0°C to 1000°C.

2.3.5. Machinability. In this study, drilling was performed on a composite material for the diameter of 2 mm, 4 mm, 7 mm and 9 mm using an HSS drill bit at 300 RPM for analysis of machining properties of the glass fiber and fishnet fiber reinforced polyester composites using a dynamometer. The specimens were cut into a square shape of 40×40×10 mm and fitted in the drilling machine with a tool dynamometer attachment to measure the thrust force.

2.3.6. Water absorption test. Moisture uptakes in polyester composites were analyzed with respect to ASTM D-570. A 50×50 mm specimen size was tested for each composite. The samples were submerged at room temperature of 26°C in both sea water (pH 8.9) and fresh water (pH 7.8). Then the specimens were removed and the surface was cleaned before weighing at different time intervals

2.3.7. Light transmission test. The test was conducted to know the percentage of light intrusion through the samples with the dimensions pf 10×40 mm, and it was determined using a double beam (Perkin Elmer, model Lambda 3B) UV-visible spectrophotometer with a 60 nm/min scanning rate.

3. Results and discussion

3.1. Tensile test. The tensile strength of a material is the maximum amount of longitudinal stress that it can withstand before failure. Tensile failures occur due to brittle failure or fiber pull-out. The tensile properties of the pure fishnet, glass fiber and hybrid composites are illustrated in Fig. 3. As indicated there, the tensile strength of 1GF/2FN composites is higher than of all other composites. The tensile strength of 2GF/1FN and 1GF/2FN composites is far better than that of 3FN and 3GF. The first two composites are made up of three layers of glass fiber and discarded fishnet and therefore named hybrid composites. Results revealed that these two reinforcements complement each other to produce better composites. The highest value of tensile strength is presented by the system with nylon fiber polyester composites materials and this property increases as the amount of nylon fiber increases [22]. These pores will be stress concentrators and will lead to failures. This greatly affects the fiber matrix interface [23]. Nylon is hydrophilic, so it absorbs a certain amount of resin. Insufficient resin will lead to incomplete resin impregnation. In the area where above-mentioned impregnation was not possible, no interface will exist.

Moreover, the hybrid fishnet and glass fiber reinforced polyester composite shows a significant raise in tensile strength over the pure fishnet and glass fiber reinforced polyester composites. As shown in Fig. 3, highest tensile strength of 74.4 MPa is exhibited by the fishnet hybrid composites of one layer of glass fiber and two layers of fishnet. One layer of glass fiber and two layers of fishnet composites gave 47% higher levels of tensile strength as compared with 3FN composites. On the other hand, this increase was only 25% for 3GF composites. This increase is due to the difference in the load-sharing properties of fishnet and glass fibers along the longitudinal and transverse directions. The orientation of nylon fiber in the longitudinal direction reflects higher mechanical strength. So the composite of maximum mechanical strength was attained in 1GF with 2FN hybrid composites.

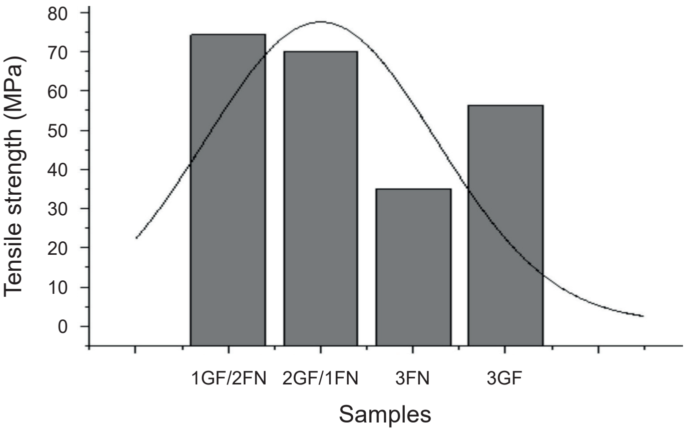

Fig. 3. Comparison of tensile strength of plain and hybrid composites

The plain glass fiber composite manifests higher strength as compared with nylon composites. Statistical tool log-normal distribution was applied to determine whether the tensile strength values obtained are fitted to the confidential level (95%) using the MINITAB package. The analysis showed that all data fell within the confidential level. The mean and standard deviation of the distribution was 59 MPa and 0.3, respectively.

Figure 4 shows the probability density graph of log-normal distribution for tensile strength. The results of the analysis indicated that the location and scale parameter of the distribution was 4 and 0.34. The p value of the distribution was 0.272, which lies below 0.5, so the results obtained were significant.

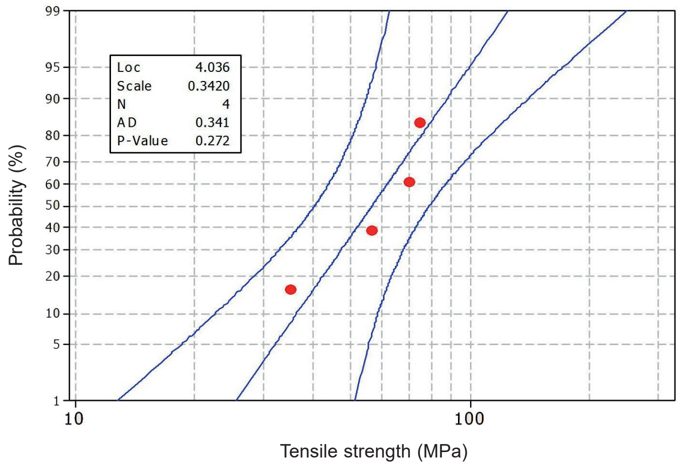

Fig. 4. Probability density graph of log-normal distribution for tensilev strength

3.2. **Impact properties.** The fiber contributes much to impact resistance. The fibers interact with crack formation, and in turn they act as stress transferring media. Interfacial and interlaminar adhesion between the fiber and matrix determines impact properties. The impact strength of nylon fiber, glass fiber and hybrid fabric composites are presented in Fig. 5. Other factors like mesh size and orientation, being of equal impact strength, differ as to the type of reinforcing fibers. A property of the individual fibers used for hybridization in the polymer matrix system determines the impact strength. Idicula *et al.* [24] reported that impact strength of the composite has nothing to do with the layering pattern. Impact strength depends on mesh sizes alone: the smaller the mesh size, the better the nylon material and the better the stress transfer.

It is obvious from the investigation that increased quantity of nylon fiber reinforcement translates into higher stress transfer, which increases the impact resistance. So discarded fishnet nylon can partially substitute glass fibers in manufacturing roofing sheets. The impact strength of a 1GF/2FN hybrid epoxy composite shows a lower value than that for 2GF/1FN hybrid polyester composites. Impact strength is provided by the higher strength of glass fiber even with impingement in a low-strength (polyester) matrix. The impact strength of 1GF/2FN hybrid composites is 43 kJ/m^2 whereas this is 63.5 kJ/m^2 for the 3GF composite and 68.1 kJ/m^2 for the 2GF/1FN composite (Fig. 5). So discarded fishnet nylon can partially substitute glass fibers in manufacturing roofing sheets. The obtained impact strength values were checked for fitness using the log-normal tool. The mean and standard deviation of the distribution was 50.4 kJ/m^2 and 0.42.

Figure 6 represents the probability density graph of log-normal distribution for impact strength. The analysis results exhibited that location and scale parameter of the distribution was 4 and 0.42. The p value of the distribution was 0.385, which lies below 0.5, so the results obtained were significant.

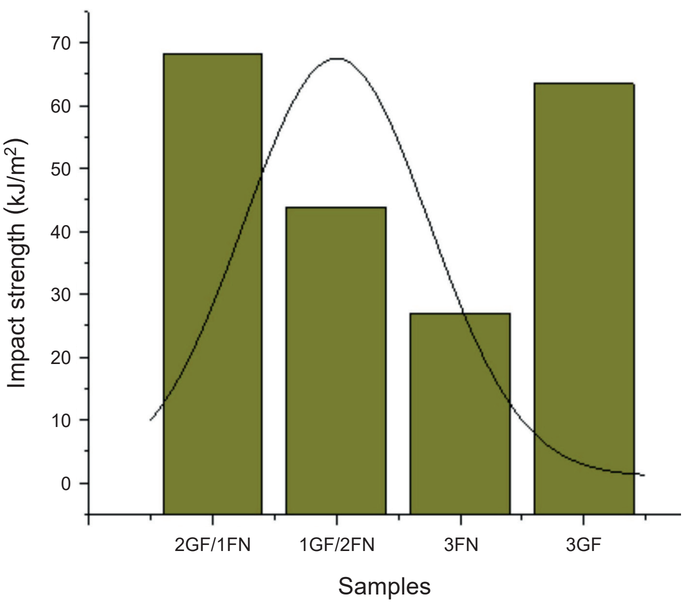

Fig. 5. Comparisons of impact properties of various composites

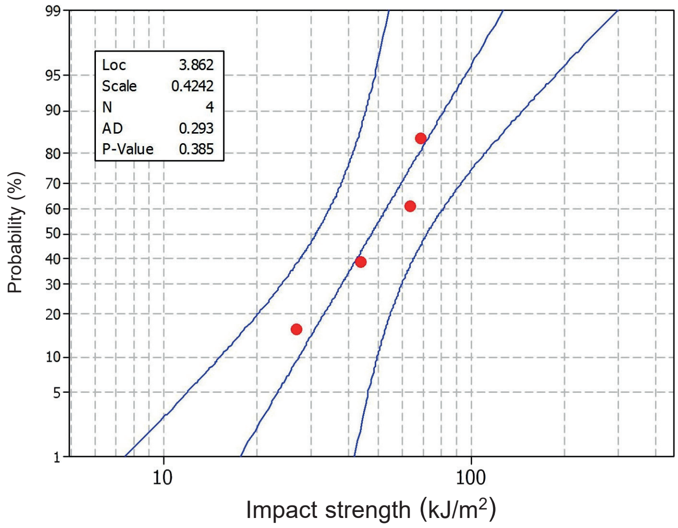

Fig. 6. Probability density graph of log-normal distribution for impact strength

3.3. Scanning electron microscopy. The microstructure graph plays a vital role in studying the overall performance of the composites. Morphological changes on the fiber surface after the tensile load applied are shown in SEM pictures of FN-FN-FN, GF-FN-GF, GF-GF-GF, FN-GF-FN composites (Fig. 7). The failure mechanism started when the tensile load exceeded the maximum attainment of plasticity of the composite. These phe-

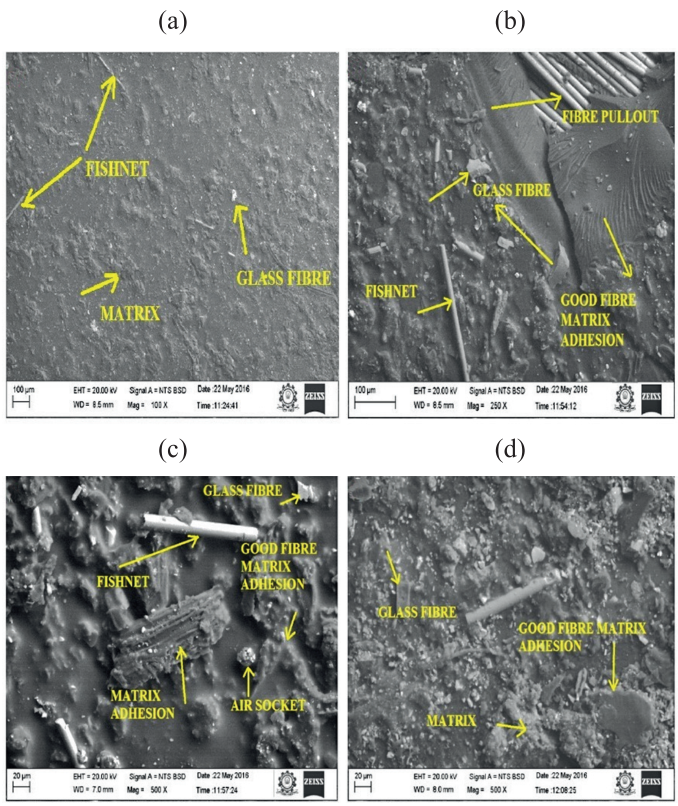

Fig. 7 SEM images of various composite specimens: a) 3FN, b) 2GF/1FN, c) 3GF, and d) 1GF/2FN

nomenon causes fracture of fibers, de-bonding and fiber pullout [25, 26]. The modes of failure are noticed with the support of Fig. 7, which exhibited that failure occurred due to matrix cracking, fiber breakage and fiber pullout.

Scanning electron microscopy observations revealed that the polyester composites manifest good fiber matrix adhesion and some roughness on the surface. This is due to the occurrence of some air sockets, which occurred because of hand molding. Fishnet fiber reinforced polyester composites have low density as compared with glass fiber reinforced polyester composites. Hence, it is considered as a suitable reinforcing material in the fabrication of light weight composite with higher strength.

From Fig. 7a, crack propagations through the polyester matrix and fishnet fibers de-bonding at interface are clearly visible. Figure 7b shows significant amount of de-bonding between the fiber and the matrix for the 2GF/1FN composite after fracture under tensile strength. Figure 7c shows behavior of interfacial mechanisms with respect to fiber arrangement. Figure 7d clearly indicates the absence of crack propagation, which characterizes properties of materials. Removal of complete bundles of fiber along the loading direction is the case of failure occurring at the tensile mode.

3.4. Thermal stability analysis. Figure 8 displays the thermograms of 3GF, 3FN, 1GF/2FN, and 2GF/1FN composites. The first degradation took place for 3FN composites at 250°C and for the remaining composites at approximately 300°C. This may be due to the evaporation process in the composites, and around 10% weight loss can be observed in each of the composites.

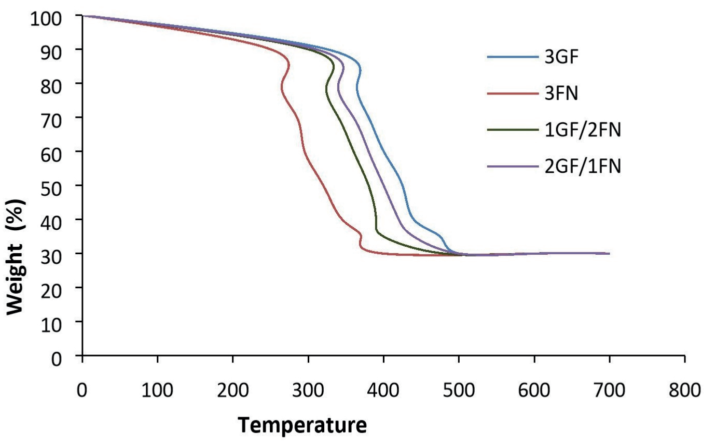

Fig. 8. Thermogravimetric plot of 3GF, 3FN, 1GF/2FN, 2GF/1FN composites

The second stage of degradation was attained between 300°C and 480°C. In this degradation, changes could be carried out in the polymer chain resulting in reduction of molecular weight, cross linking and cyclisation reaction. Table 4 shows thermal degradation of 3GF, 3FN, 1GF/2FN and 2GF/1FN composites. The rapid weight losses have been obtained between T-5% and T-50% and thermal stability can be observed beyond T-70%.

Table 4
Thermal degradation of 3GF, 3FN, 1GF/2FN, 2GF/1FN composites

Composite type	Degradation temperature		
	T-5%	T-50%	T-70%
3GN	325	425	500
3FN	250	320	400
1GF/2FN	300	380	480
2GF/1FN	310	400	500

3.5. Machinability study. The machining of fiber reinforced composites is totally different from metals and metallic alloys. In composites, we can get more undesirable issues such as rough surface finish, rapid tool wear, delamination and micro and macro cracks. Thrust force of drilling depends on the tool materials, geometry of the tool, drilling parameter, coolant use and work piece materials. Drilling parameters, tool materials and geometry of the tool are important to reduce the thrust force of drilling in composite materials. In the drilling test, the thrust forces of the glass fiber and fishnet incorporated polyester composites' performances are shown in Fig. 9. The interfacial bonding strength between reinforcement and matrix for composites 3GF and 2GF/1FN is acceptable. However, composite 3GF has better dimensional accuracy and thrust force than composite 3FN, which was studied. The efficient thrust force of various drill bits for composites 3GF and 2GF has good chemical bonding of the reinforcement fiber with the matrix.

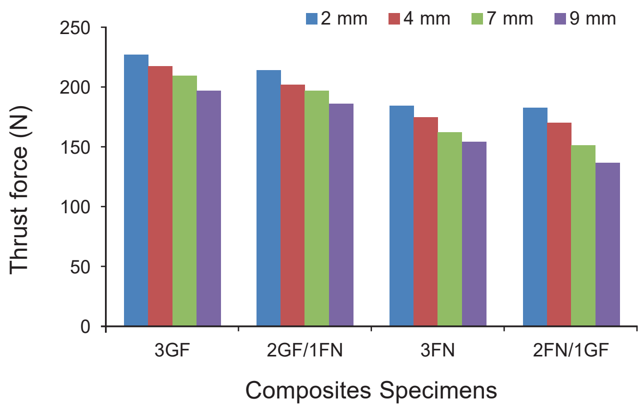

Fig. 9. Study of thrust force (N) of the glass fiber and fishnet fiber reinforced polyester composites

3.6. Water absorption. To perform the water absorption test, normal water and sea water was used. The amount (mass gain) of normal and sea water absorbed with respect to the time period is tabulated in Table 5. The water absorption percentage in the composites was calculated as per equation 1.

$$Mt = \frac{[Wt \_ Wo]}{Wo} \times 100 \tag{1}$$

Table 5
Water absorption of composites

Sample	Dry weight (g)	Weight after fresh water i mmersion (g)			Weight after sea water i mmersion (g)		
		After 4 hrs	After 8 hrs	After 24 hrs	After 4 hrs	After 8 hrs	After 24 hrs
3GF	5.125	5.292	5.293	5.295	5.293	5.295	5.29
3FN	3.012	3.086	3.088	3.092	3.094	3.095	3.096
2GF/1FN	4.979	5.064	5.065	5.067	5.092	6.011	6.01
2FN/1GF	3.012	3.086	3.088	3.092	3.094	3.095	3.096

Figure 10 shows that the water absorption percentage in terms of mass gain is significantly increased over a longer time period. The layer of fishnet fiber gives more space for both normal water and sea water intake because of its polar nature. The rise in water intake will increase degradation and further lead to failure of composites.

The water absorption percentages in terms of mass gain for glass fiber composite 3GF were significantly lower when compared with fishnet multifilament reinforced polyester composites, as shown in the Fig. 10. The addition of fishnet multifilament in glass fiber reinforced polyester composites increases the water absorption percentages significantly. The water absorption properties of the polyester composites with mesh size 32 mm is significantly higher when compared with the 60 mm mesh size due to the fishnet material having more

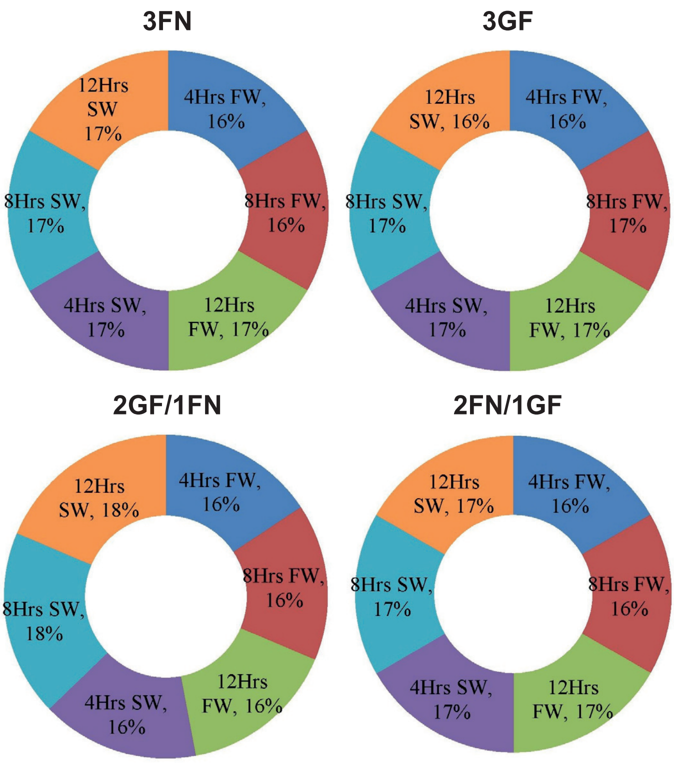

Fig. 10. Water absorption percentages of composites

surface area. The water absorption percentages of the 1GF/2FN composite are not significantly higher. In order to determine the percentage of water absorbed by the fibers, water absorption studies were also conducted. The composite properties changed completely if the water was present. As expected, due to the hydrophilic nature of fiberglass, water absorption percentages decrease with increase in glass fiber percentages in the composite. This can indicate that fishnet material with more surface area of the composites has high stability of the composite for specific application.

The spectrum transmission of the plastic packages on top of deodorants indicates presence of an ultra violet absorber in the roofing sheet of composite 3GF amounting to 56.2% since it is having a high light barrier below 380 nm of wavelength. Secondly, the transmission light of 2GF/1FN is lower. It is 59.1% while light transmission in the visible region of composite 3FN is higher. It stands at 74.8%. The light transmission of composite 1GF/2FN is 61.9%. Hence, the waste fishnet incorporated composite 3FN has better light transmission than conventional composite 3GF.

4. Conclusion

This study focused on the mechanical properties of a hybrid discarded fishnet/glass reinforced composites for utilization in roofing sheets. Composites are fabricated through the hand lay-up methodology with dissimilar layers of fibers. Addition of fishnet fiber to glass fiber reinforced polyester composite increases tensile strength to a significant extent. This study shows that blending glass fibers with fishnet significantly improves impact strength. The log-normal analysis showed that all experimental data were fitted and significant. With morphological characterization, the fracture side of the tensile test sample shows there is good adhesion between the glass/fishnet fiber and polyester matrix. In drilling operation, the composite specimens 3GF and 2GF/1FN showed better thrust force and accuracy of dimension than composites of 3FN and 2FN/1GF. The light transmission of composite 3FN has better values than other composites. Hence blended fishnet-glass fiber composites can become the best option for manufacturing value-added products, thus helping sustain green environment.

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