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# Effect of fiber content on flexural properties of fishnet/GFRP hybrid composites

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**Abstract.** In the present paper, glass fibers are substituted partially with monofilament fishnet and polyester matrix for making the composites. The composite specimens were prepared in accordance with ASTM for analyzing the flexural strength and dynamic mechanical properties. Furthermore, machinability revealed the interaction of glass fiber and partial substituted monofilament fishnet fiber with the matrix. Fiber pullouts on the fractured specimen during the physical testing of the composites are also investigated by COSLAB microscope. The results reveal that the fishnet based composites have appreciably higher flexural properties. Furthermore, the glass fiber, woven roving and fishnet composite has more storage modulus and significant mechanical damping. The composite specimens were fabricated by hand lay-up method. Hence, these composites are the possible applications to develop the value added products. The results of this study are presented.

**Keywords:** composite structures; damage/damage identification; debonding separation; dynamic analysis; elasticity; fabrication; fiber reinforced polymers (FRP); hybrid structures

## 1. Introduction

Composite materials have longer life, higher strength, lower weight and less maintenance compared to traditional monolithic materials. These properties have led to many engineering applications, particularly the transport sector to reduce energy consumption. Rout *et al*. (2001), Rana *et al*. (2003), Guzas and Earls (2010) and Joshi *et al*. (2004) discussed that the natural fiber composites offer various advantages such as low cost, low density, acceptable specific properties, biodegradability, better insulating and thermal properties, renewable and environmental friendly. These properties constrain the market of this material. The natural fiber composites (Peng *et al*. 2011) are dependent significantly in dimension and strength factors such as source, age, retting and separating techniques. Most of the natural fibers are moisture sensitive and their strength could change dramatically (Netravai and Chabba 2003, Cheung *et al*. 2009, Ma *et al*. 2005 and Dhakal *et al*. 2007) when they absorb or desorbs moisture. That is the main disadvantages of using natural

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fibers during applications. The use of natural fiber composites for certain engineering applications fail because certain characteristics cannot be meet for (Sapuan and Maleque 2005) specific engineering application. Hence, specific materials should be used to meet certain specifications for specific applications. Some natural fibers such as sisal, coir, jute, ramie, kenaf and pineapple leaf have used as a replacement of glass fiber or other traditional reinforcement materials (Karnani *et al*. 1997 and Paul *et al*. 1997) in composites has improved the mechanical properties based on the fiber volume fraction.

In recent years, numerous research programs have been carried out to develop environmentally friendly composites (Griffin and Ashwill 2003 and Ma and Zhang 2014) with desirable properties. The main purpose of hybrid composite is to combine the best mechanical property of brittle fibers with the excellent impact resistance of ductile fibers (Akhbari *et al*. 2008 and Wang *et al*. 2008). Hybridization of natural/synthetic fibers helps in the utilization of some inherent properties of the individual fiber to progress the properties of the composites (Selvin *et al*. 2004 and John and Sabu 2008). The properties of the composite depend not only on the properties of the fiber, but are also controlled by the properties of the matrix and the design (Moe and Kin 2000, Xin *et al*. 2015 and Alizadeh and Dehestani 2015) of the hybrid system. An improvement in the flexural behavior of polymer composites with brittle reinforcements of glass fibers was attempted by mixing ductile organic fiber.

Hybrid laminates of basalt fibers and plant fibers are studied when it comes to the need for sufficient impact resistance (Santulli 2007). Flexural strength and modulus of glass/hemp/basalt fiber composites are studied and reported better properties than (Petrucci *et al*. 2013) conventional materials. The sisal/GFRP, jute/GFRP, sisal/jute/GFRP composites are studied for the mechanical testing such as tensile, flexural and impact; characteristics increased significantly (Ramesh *et al*. 2013) due to the fiber volume fraction. Stretched orientations of fishnet have more fiber content per unit area of composites and usually meshes formed by knotting or knotless of a relatively thin thread. Modern nets are made of artificial polyamides like nylon. Gill nets are the most popular commercial fish net in the world (Ayaz *et al*. 2006). The mechanical property of the waste fishnet incorporated composites (Raj *et al*. 2014, 2015 and 2016) is higher than the glass fiber composites, irrespective of the mesh size. The present work is focused on the new monofilament fishnet fiber as an alternative material of glass fiber with polyester matrix and to study the flexural, dynamic mechanical properties of GFRP composite with a view to safeguard our environment.

## 2. Experimental details

### 2.1 Fiber materials

Nylon fiber of monofilament fishnet of mesh size 12 mm are obtained from the Vasantham

Fig. 1 Fabricated fishnet and its orientation

Table 1 Physical and Mechanical properties of fabricated resources

| Fabricated materials | Density [g/cm$^3$] | Elongation at break [%] | Young modulus [GPa] | Tensile strength [MPa] |
|---|---|---|---|---|
| Glass fiber | 2.5 | 4.8 | 70-73 | 2000-3400 |
| Nylon fiber | 1.15 | 15 – 45 | 2 - 4 | 415.7 |
| Woven roving | 2.2 | 1.6 | 15.5 | 260 |

Marines, Tamil Nadu, India. The twine diameter of the fishnet is 8.656 $\mu$m, single knotting, white in color and its orientation is shown in Fig. 1. E-glass is the most common reinforcement used in marine laminates because of its strength and resistance to water degradation. The grade of glass fiber and the woven roving is 300 g/m$^2$ and 600 g/m$^2$ respectively. They are obtained from Binani India products, Chennai.

The properties of glass fiber, fishnet fiber and woven roving are given in Table 1.

### 2.2 Polyester resin

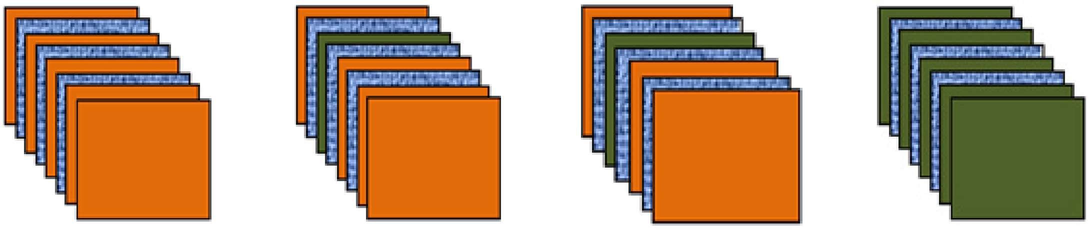
Commercially available isothallic unsaturated polyester resin is used for the investigation. Accelerator (Methyl Ethyl Ketone Peroxide) and the catalyst (Cobalt Naphthalene) are used to cure the resin. Thermoset isothallic polyester resin is one of the economical resins due to its low cost and, excellent bonding tendency as well as mechanical properties. All these AR grade chemicals were obtained from the Ciba Gugye Limited, Chennai, India. The distinctive properties of the isothallic polyester resin are shown in Table 2.

### 2.3 Preparation of hybrid composites

The specimens were made by hand lay-up technique. Glass fiber and woven roving layers were obtained by spreading the mat. The fishnet layer was obtained by spreading at stretched orientation. The polyester resin matrix was coated on these glass fibers, woven roving and fishnet reinforcement layers. The polyester resin was spread to the entire surface by means of brush and roller. The processed composite was pressed with roller and the excess resin was removed. All the composite specimens were cured at room temperature for 3 to 4 hr. After that they were dried and

Table 2 Properties of the isothallic polyester resin (Sathishkuma *et al*. 2012)

| Properties | Range |
|---|---|
| Specific gravity | 1.1–1.46 |
| Density in kg/m$^3$ | 1125 |
| Tensile strength in MPa | 18 |
| Tensile modulus in GPa | 0.8–1.1 |
| Compressive strength in MPa | 90–250 |
| Flexural strength in MPa | 30 |
| Flexural modulus in GPa | 1.2–1.5 |
| Shrinkage in % | 0.004–0.008 |



(a) (b) (c) (d)

Fig. 2 Various layers of fabricated composites. (a) 5GF/3WR; (b) 4GF/3WR/1FN; (c) 3GF/3WR/1FN; and (d) 5FN/3WR (GF-Glass fiber, FN-Fishnet and WR-Woven roving)

cut into size of 300 × 300 mm. In total, four composite specimens were prepared as shown in Fig. 2. The conventional material is 5 layers of glass fiber and 3 layers of woven roving with polyester matrix are shown in Fig. 2(a). The proposed composites structures are 4 glass fibers 3 woven roving 1 fishnet layer, 3 glass fibers 3 woven roving 1 fishnet layer and 5 fishnet layers 3 woven roving. They are shown in Fig. 2(b), (c) and (d) respectively.

### *2.4 Flexural test*

The flexural test was performed by the three point bending technique according to ASTM D-790 using the UTM TUE-CN-400 (Sl. No: 2014/136, Fine Spray Associates and Engineers, India) instrument at 28°C with 40 ± 2% relative humidity, and crosshead speed of 5 mm/min. The specimen size is 127 × 12.7 mm. five specimens were tested, and the average value was calculated. The specimen was freely supported by a beam, the maximum load was applied in the middle of the specimen, and the flexural modulus was calculated from the slope of the initial portion of the load deflection curve.

### *2.5 Machinability*

In this study, the drill hole was made of composite material by using diameter 3 mm, 5 mm, 8 mm and 10 mm 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 into the tool dynamometer hub to measure the thrust force.

### *2.6 Morphological study*

The microscope has been a well-accepted tool for many years in evaluation of surfaces of the components. After the flexural test of the specimens the microscopic images were obtained from COSLAB (Model: ZSM116) compound light microscope with photo capturing software.

### *2.7 Dynamic Mechanical Analysis (DMA)*

Dynamic mechanical analysis, specification of Q800 V20.6 Build 24, USA is used for the evaluation of loss modulus, storage modulus and mechanical damping (tan $\delta$). The heating rate used is at 2°C/min and frequency was 1 Hz under amplitude control. Liquid nitrogen is used as cooling agent and temperature ranges from 28°C to 200°C. The sample thickness is 4 to 5 mm, width 9 to 10 mm and length 50 to 60 mm.

## 3. Results and discussion

### *3.1 Flexural properties*

The flexural strength and modulus of the glass fiber and fishnet composites as shown in Table 3. The flexural strength of composites 4GF/3WR/1FN and 3GF/3WR/1FN is 259.8 MPa and 254.65 MPa respectively. However, the flexural strength of composite specimen 4GF/3WR/1FN and 3GF/3WR/1FN has small changes when compared to composite 5GF/3WR. Furthermore, flexural strength of composite 5FN/3WR of fishnet alone has more value when compared to 5GF/3WR. The addition of fishnet layers into the glass fiber composites 4GF/3WR/1FN and 3GF/3WR/1FN has comparable values of the flexural strength as shown in Fig. 3. The density of the composite 5GF/3WR is comparable to the composite 4GF/3WR/1FN. Furthermore, the density of the composites 3GF/3WR/1FN and 5FN/3WR are less than conventional composite 5GF/3WR. The density of fishnet fiber is less than that of glass fiber. Therefore the number of layers is reduced in the composite 3GF/3WR/1FN and hence the density is low but it is stronger as shown in Fig. 4.

Table 3 Mechanical characteristics of composites

| Composites | Flexural strength [MPa] | Standard deviation | Flexural modulus [GPa] | Standard deviation |
|---|---|---|---|---|
| 5GF/3WR | 241.24 | 2.254 | 51.25 | 1.240 |
| 4GF/3WR/1FN | 259.80 | 3.147 | 63.25 | 1.860 |
| 3GF/3WR/1FN | 254.65 | 2.869 | 62.48 | 1.657 |
| 5FN/3WR | 322.21 | 3.953 | 105.56 | 1.964 |

GF - Glass fiber, WR - Woven roving and FN - Fishnet

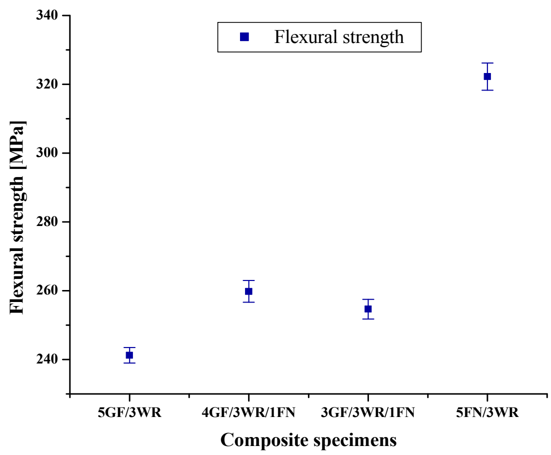



Fig. 3 Experimental results of flexural strength of fishnet and glass fiber composites

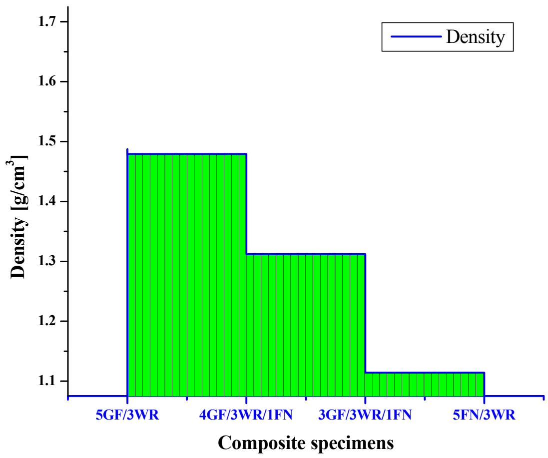



Fig. 4 Density of different layers of fishnet and glass fiber composites

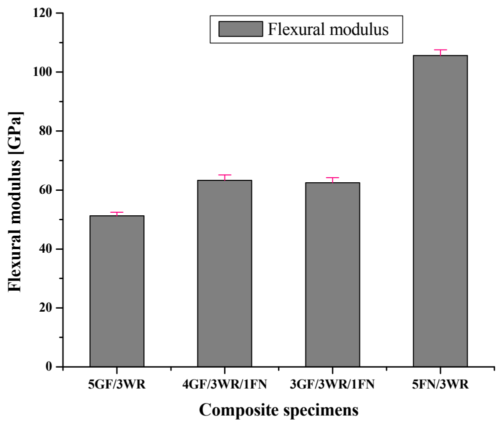



Fig. 5 Flexural modulus of fishnet and glass fiber reinforced polyester composites

The flexural modulus of composites 4GF/3WR/1FN and 3GF/3WR/1FN are 63.25 GPa and 62.48 GPa respectively. However, the flexural modulus values of composites 4GF/3WR/1FN and 3GF/3WR/1FN are better than that of composite 5GF/3WR as depicted in Fig. 5. Furthermore, the flexural modulus value of fishnet composite 5FN/3WR is more when compared to that of the glass fiber composite 5GF/3WR. Hence, the flexural properties of the fishnet incorporated composites also depend on the orientation of fiber that is more per unit area of composites. The flexural properties of the composite are significantly improved with the fiber content added into the composites (Sathishkumar *et al*. 2012, Sreenivasan *et al*. 2011 and Obi Reddy *et al*. 2010). Both the glass fiber and fishnet fiber have a good interfacial adhesion with the polyester matrix. When the fishnet is added into the composites they have better flexural property.

### *3.2 Machinability study*

The drilling test, to study the thrust forces in the glass fiber and fishnet incorporated polyester composites are shown in Fig. 6. The interfacial bonding strength between reinforcement and matrix for composites 5GF/3WR and 4GF/3WR/1FN is acceptable. However, the composite 5GF/3WR has better dimensional accuracy and thrust force than the composite 5FN/3WR which was studied. The efficient thrust force of various drill bits for the composites 5GF/3WR and 4GF/3WR/1FN has good chemical bonding of the reinforcement fiber with the matrix.

### *3.3 Microscope investigation*

After flexural test the glass fiber/monofilament fishnet fiber and woven roving incorporated composite specimens are analyzed by the micrographic images. The image indicates the monofilament fishnet fiber has good surface finish as shown in Fig. 7. This occurs flexural properties of the fishnet based composite 5FN/3WR are higher than that of composite 5GF/3WR. Because composite 5FN/3WR have better bonding strength than the glass fiber composite. Fig. 8 shows that the images have no crack and fracture appear on the exteriors of the reinforcements in the composites. This is due to the good interfacial bonding between the fishnet and the matrix.

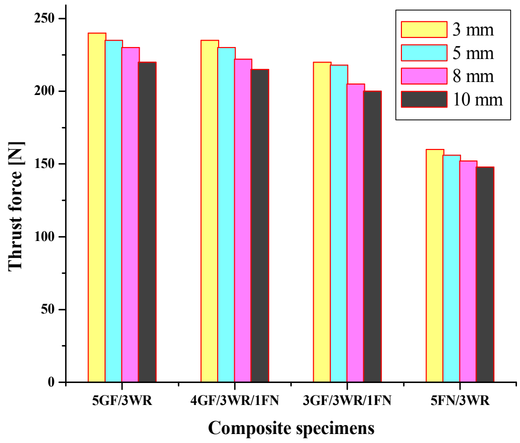
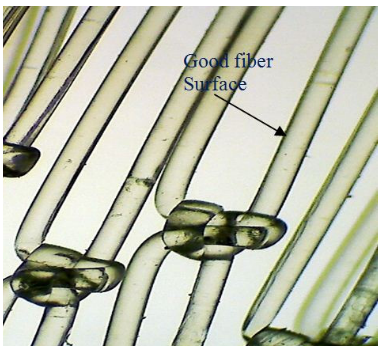
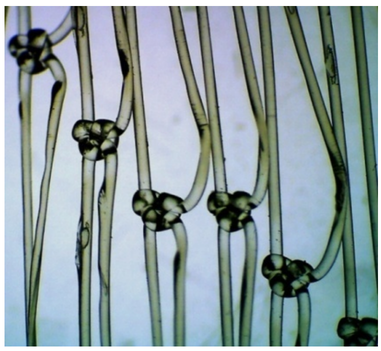



Fig. 6 Study of thrust force of the glass fiber and fishnet fiber reinforced polyester composites




(a)



(b)

Fig. 7 Images of the fishnet fiber and its surface conditions

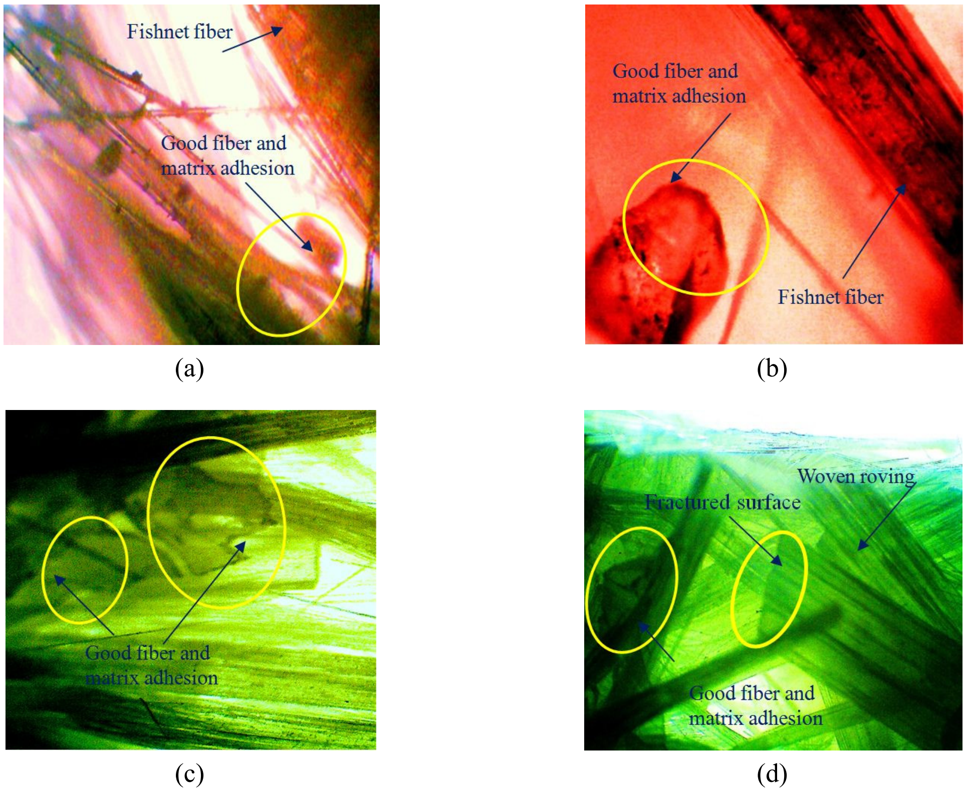



Fig. 8 Micrograph images after the flexural break of glass and fishnet fiber composites

Fiber pullout occurs mainly due to the poor interfacial bonding at the interphase of the fiber and matrix. The improper interfacial bonding of the composites, a smaller amount of the delamination at the interphase is found. It is evident from the micrograph, that the adhesion area between the fiber and matrix is good, so the flexural behaviors is also increased in the composites. Micro-structure observations reveals some roughness on the surface, due to the sense of some air sockets which occurred because of hand molding. Fishnet fiber composites have low density compared to glass fiber composites. However, it is considered as a suitable filler material in the manufacturing of lightweight composite with high strength. Therefore, the flexural property of the composite 5FN/3WR is increased moderately those of other composites.

Also, the microscopic image reveals that the interfacial adhesion of glass fiber and woven roving with polyester matrix has good linkage. The interfacial adhesion of glass fiber composite is lower compared to the fishnet incorporated composites. The reinforcement of monofilament is made of nylon plastic which will help to bond well with the matrix. Therefore, the fishnet-incorporated composites are found to have better adhesion than the glass fiber composite.

### *3.4 Dynamic mechanical analysis*

#### *3.4.1 Storage modulus ($E'$)*

The value of storage modulus ($E'$) for 4GF/3WR/1FN, 3GF/3WR/1FN and 5FN/3WR are 16508 MPa, 15214 MPa and 11142 MPa respectively. However, 4GF/3WR/1FN found higher

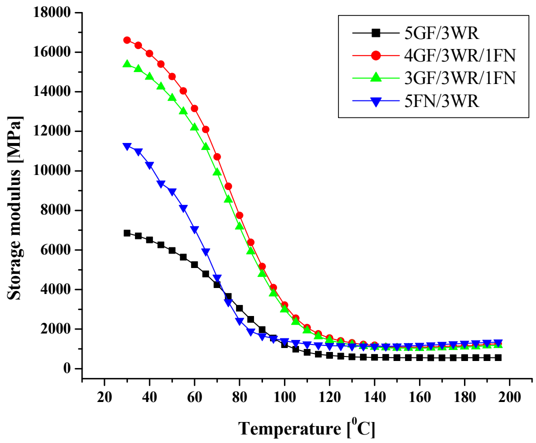



Fig. 9 The deviation of storage modulus with temperature for composites

values of $E'$ at lower temperature in the plastic region compared to 5GF/3WR as shown in Fig. 9. The value of $E'$ decreases with the increase in temperature. Storage modulus of glass fiber alone is 6854 MPa at temperature 31.43°C. With the addition of glass fiber to the fishnet fiber composites the $E'$ value proportionally increased. The increase in $E'$ is attributed to the presence of fishnet fiber in the composites which has more $E'$ than the glass fiber alone.

The reinforcement efficiency of the composites was found to increase with the addition of fishnet fiber in place of glass fibers. This reveals that monofilament fishnet fiber composites are found to be more efficient reinforcement than glass fiber. However, the $E'$ values are found to be high. This suggests that monofilament fishnet fibers can be a good substitute for glass fiber. Further, the addition of fishnet fiber as well as glass fiber has induced good matrix adhesion and thereby stress transfer.

### *3.4.2 Loss modulus (E″)*

Loss modulus is governed by the molecular motions within the composite material. The value of the loss modulus ($E''$) depends upon the category and the quantity of reinforcement. Fig. 10 depicts the values of glass transition temperature (*Tg*). The values of E" are found to vary much for different composites. The $E''$ curve for 5FN/3WR has a less broadening effect because of the *Tg* (51.72°C). The broadening is due to the difference in the physical state of the matrix surrounding the reinforcing fibers. Loss modulus is found to be higher at 88.56°C for 3GF/3WR/1FN which corresponds to *Tg* value. Therefore, the low *Tg* of 5FN/3WR reflects comparatively lesser interaction of the fishnet fiber with matrix than glass fiber.

The increased rigidity of the composites resulting from stronger interface interaction with the reinforcement and matrix is attributed to the value of change in loss modulus; follows the same trend as that of *Tg*. The fact that 5GF/3WR, 4GF/3WR/1FN and 3GF/3WR/1FN are slightly better composite than fishnet based composite 5FN/3WR.

### *3.4.3 Damping factor (tan δ)*

The damping behavior will be influenced by merging of fiber in the matrix and depends on the quantum of fiber matrix adhesion. Hence weaker fiber matrix adhesion will result in higher values of tan $\delta$ as shown in Table 4 and Fig. 11. On the basis, 5FN/3WR composites have moderate

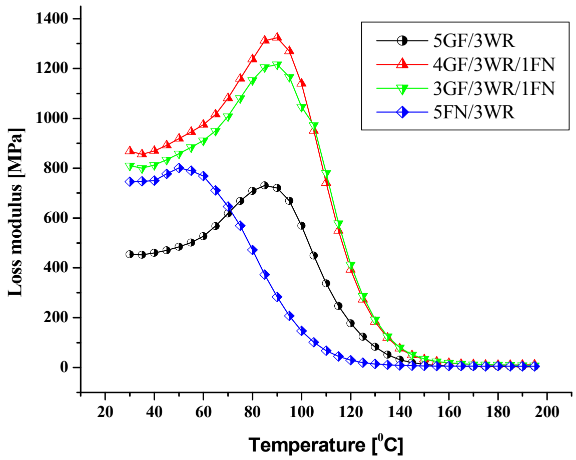



Fig. 10 The deviation of $E''$ with temperature for various composites

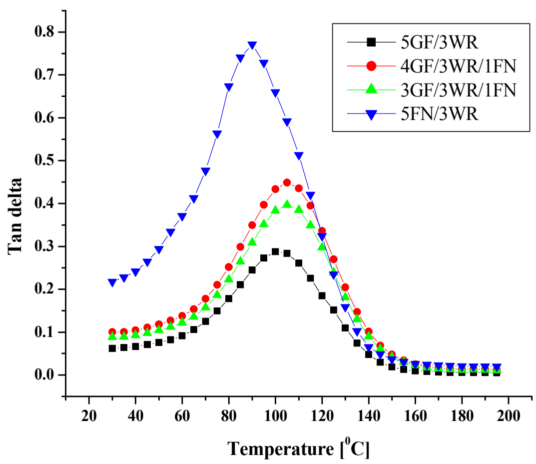



Fig. 11 The variation of mechanical damping with temperature of various composites

Table 4 Dynamic mechanical analysis research obtained from the parameters

| Composites | $Tg$ from $E'$ | $Tg$ from $E''$ | $Tg$ from tan $\delta$ | Peak height of tan $\delta$ curve |
|---|---|---|---|---|
| 5GF/3WR | 31.33 | 88.16 | 100.51 | 0.2671 |
| 4GF/3WR/1FN | 30.17 | 89.53 | 105.54 | 0.4521 |
| 3GF/3WR/1FN | 27.02 | 88.56 | 104.41 | 0.3815 |
| 5FN/3WR | 26.01 | 51.72 | 90.14 | 0.7628 |

adhesion behavior. However, the low tan $\delta$ values of the composite 5GF/3WR have good load bearing capacity. The tan $\delta$ value of hybrid composite 3GF/3WR/1FN has only small variation than composite 5GF/3WR. Hybrid fibers restrict the mobility of the polymer molecules; hence the tan $\delta$ values of composites are reduced.

## 4. Conclusions

Monofilament fishnets as an alternate material of glass fiber with polyester matrix composites are developed and evaluated for flexural properties and dynamic mechanical properties. The flexural strength increases with the addition of fishnet layers into the composites. The fishnet imparts superior properties of the composites as more fishnet material per unit area of the composites. In drill hole dynamometer analysis, the composite specimen's 5GF/3WR and 4GF/3WR/1FN have showed better dimensional accuracy and thrust force than the composites of 3GF/3WR/1FN and 5FN/3WR.

The storage modulus value of monofilament fishnet composite 3GF/3WR/1FN was compared to the glass fiber composite 5GF/3WR. The value of the loss modulus of fishnet and glass fiber incorporated composites 4GF/3WR/1FN and 3GF/3WR/1FN do not lag far behind. Furthermore, damping values are comparable with composites 5GF/3WR and 4GF/3WR/1FN.

The performance evaluation of the study of various composites reveals that the monofilament fishnet with glass fiber incorporated composites improves the flexural behaviors. It brings to light that, the fishnet incorporated composites have better values than glass fiber. Therefore, partially substituted fishnet-glass fiber composites can serve as an alternate and low cost composite material for manufacturing value added products thus help to sustain green environment.

## References

Akhbari, M., Shokrieh, M.M. and Nosraty, H. (2008), "A study on buckling behavior of composite sheet reinforced by hybrid woven fabrics", *Trans. CSME*, **32**(1), 81-89.

Alizadeh, E. and Dehestani, M. (2015), "Analysis of composite girders with hybrid GFRP hat-shape sections and concrete slab", *Struct. Eng. Mech., Int. J.*, **54**(6), 1135-1152.

Ayaz, A., Acarli, D., Altinagac, U., Ozekinci, U., Kara, A. and Ozena, O. (2006), "Ghost fishing by monofilament and multifilament gillnets in Izmir Bay, Turkey", *Fish. Res.*, **79**(3), 267-271.

Cheung, H.J., Ho, M.P., Lau, K.T., Cardona, F. and Hui, D. (2009), "Natural fiber-reinforced composites for bioengineering and environmental engineering applications", *Compos. Part B-Eng.*, **40**(7), 655-663.

Dhakal, H.N., Zhang, Z.Y. and Richardson, M.O.W. (2007), "Effect of water absorption on the mechanical properties of hemp fiber reinforced unsaturated polyester composites", *Compos. Sci. Technol.*, **67**(7-8), 1674-1683.

Griffin, D.A. and Ashwill, T.D. (2003), "Alternative composite materials for megawatt-scale wind turbine blades: Design considerations and recommended testing", *J. Sol. Energy Eng.*, **125**(4), 515-524.

Guzas, E.L. and Earls, C.J. (2010), "Air blast load generation for simulating structural response", *Steel Compos. Struct., Int. J.*, **10**(5), 429-455.

John, M.J. and Sabu, T. (2008), "Biofibers and Biocomposites', *Carbohydr Polym.*, **71**(3), 342-364.

Joshi, S.V., Drzal, L.T., Mohanty, A.K. and Arora, S. (2004), "Natural fiber composites environmentally superior to glass fiber reinforced composites", *Compos. Part A: Appl. Sci. Manuf.*, **35**(3), 371-376.

Karnani, R., Krishnan, M. and Narayan, R. (1997), "Biofiber reinforced polypropylene composites", *Polym Eng Sci.*, **37**(2), 476-483.

Ma, P.C. and Zhang, Y. (2014), "Perspectives of carbon nanotubes/polymer nanocomposites for wind blade materials", *Renew. Sustain. Energy Rev.*, **30**, 651-660.

Ma, X., Yu, J. and Kennedy, J.F. (2005), "Studies on the properties of natural fibers-reinforced thermoplastic starch composites", *Carbohyd. Polym.*, **62**(1), 19-24.

Michael Raj, F., Nagarajan, V.A. and Vinod Kumar, K.P. (2014), "Evaluation of mechanical behavior of multifilament waste fishnet/glass fiber in polyester matrix for the application of mechanized boat deckhouse in marine composites", *Appl. Mech. Mater.*, **592-594**, 2639-2644.

Michael Raj, F., Nagarajan, V.A. and Vinod Kumar, K.P. (2015), "Mechanical behavior of FRP composites with used Fish net/glass fiber and polyester matrix", *Int. J. Appl. Eng. Res.* (*IJAER*), **10**(8), 6375-6378.

Michael Raj, F., Nagarajan, V.A. and Sahaya Elsi, S. (2016), "Mechanical, physical and dynamical of glass fiber and waste fishnet hybrid composites", *Polym. Bull.*, 1-20. DOI: 10.1007/s00289-016-1783-3

Moe, M.T. and Kin, L. (2000), "Characterization of bamboo–glass fiber reinforced polymer matrix hybrid composite", *J. Mater. Sci. Eng. Lett.*, **19**(20), 1873-1876.

Netravai, A.N. and Chabba, S. (2003), "Composites get greener", *Mater. Today*, **6**(4), 22-29.

Obi Reddy, K., Sivamohan Reddy, G., Uma Maheswari, C., Varada Rajulu, A. and Madhusudhana Rao, K. (2010), "Structural characterization of coconut tree leaf sheath fiber reinforcement", *J. Forest Res.*, **21**(1), 53-58.

Paul, A., Joseph, K. and Thomas, S. (1997), "Effect of surface treatment on electrical properties of low – density polypropylene composites reinforced with short sisal fibers", *Compos. Sci. Techno.*, **57**(1), 67-79.

Peng, X.I., Fan, M., Hartley, J. and A-Zubaidy, M. (2011), "Properties of natural fiber composites made by pultrusion process", *J. Compos. Mater.*, **46**(2), 237-246.

Petrucci, R., Santulli, C., Puglia, D., Sarasini, F., Torre, L. and Kenny, J.M. (2013), "Mechanical characterisation of hybrid composite laminates based on basalt fibres in combination with flax, hemp and glass fibres manufactured by vacuum infusion", *Mater. Des.*, **49**, 728-735.

Raj, F.M., Nagarajan, V.A. and Vinod Kumar, K.P. (2014), "Evaluation of mechanical behavior of multifilament waste fishnet/glass fiber in polyester matrix for the application of mechanized boat deckhouse in marine composites", *Appl. Mech. Mater.*, **592-594**, 2639-2644.

Raj, F.M., Nagarajan, V.A. and Vinod Kumar, K.P. (2015), "Mechanical behavior of FRP composites with used Fish net/glass fiber and polyester matrix", *Int. J. Appl. Eng. Res.* (*IJAER*), **10**(8), 6375-6378.

Raj, F.M., Nagarajan, V.A. and Sahaya Elsi, S. (2016), "Mechanical, physical and dynamical of glass fiber and waste fishnet hybrid composites", *Polym. Bull.*, 1-20. DOI: 10.1007/s00289-016-1783-3

Ramesh, M., Palanikumar, K. and Hemachandra Reddy, K. (2013), "Mechanical property evaluation of sisal–jute–glass fiber reinforced polyester composites", *Composites: Part B*, **48**, 1-9.

Rana, A.K., Mandal, A. and Bandyopadhyay, S. (2003), "Short jute fiber reinforced polypropylene composites: effect of compatibiliser, impact modifier and fiber loading", *Compos. Sci. Technol.*, **63**(6), 801-806.

Rout, J., Misra, M., Tripathy, S.S., Nayak, S.K. and Mohanty, A.K. (2001), "The influence of fiber treatment of the performance of coir-polyester composites", *Compos. Sci. Technol.*, **61**(9), 1303-1310.

Santulli, C. (2007), "Impact properties of glass/plant fibre hybrid laminates", *J. Mater. Sci.*, **42**(11), 3699-3707.

Sapuan, S.M. and Maleque, M.A. (2005), "Design and fabrication of natural woven fabric reinforced epoxy composite for household telephone stand", *Mater. Des.*, **26**(1), 65-71.

Sathishkumar, T.P., Navaneethakrishnan, P. and Shankar, S. (2012), "Tensile and flexural properties of snake grass natural fiber reinforced isophthallic polyester composites", *Compos. Sci. Technol.*, **72**(10), 1183-1190.

Selvin, T.P., Kuruvilla, J. and Sabu, T. (2004), "Mechanical properties of titanium dioxide-filled polystyrene micro composites", *Mater. Lett.*, **58**(3-4), 281-289.

Sreenivasan, V.S., Ravindran, D., Manikandan, V. and Narayanasamy, R. (2010), "Mechanical properties of randomly oriented short sansevieria cylindrica fibre/polyester composites", *Mater Des.*, **32**(4), 2444-2455.

Wang, X., Hu, B., Feng, Y., Liang, F., Mo, J., Xiong, J. and Qiu, Y. (2008), "Low velocity impact properties of 3D woven basalt/aramid hybrid composites", *Compos. Sci. Technol.*, **68**(2), 444-450.

Xin, H., Liu, Y. and Du, A. (2015), "Thermal analysis on composite girder with hybrid GFRP-concrete deck", *Steel Compos. Struct., Int. J.*, **19**(5), 1221-1236.

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