Mechanical characterization of *Abutilon Indicum* fiber nonwoven fabric epoxy composite materials

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Abstract: The effect of nonwoven *Abutilon Indicum* fiber content (20, 25, 30, 35, and 40 wt%) on the structure (FTIR, SEM) and selected mechanical and thermal (TGA) properties of epoxy resin was investigated. The best mechanical properties were obtained with a fiber content of 35 wt%. The tensile strength of the composite was about 40 MPa, the flexural strength over 60 MPa, and the compressive strength about 48 MPa. Moreover, the composite showed the fracture energy about 0.44 J.

Keywords: *Abutilon Indicum* fiber, nonwoven fabric, mechanical properties, FTIR, TGA, SEM.

Wpływ zawartości naturalnych włókien z *Abutilon Indicum* na właściwości mechaniczne kompozytów epoksydowych

Streszczenie: Zbadano wpływ zawartości włókna *Abutilon Indicum* (20, 25, 30, 35 i 40% mas.) na strukturę (FTIR, SEM) oraz wybrane właściwości mechaniczne i termiczne (TGA) żywicy epoksydowej. Najlepsze właściwości mechaniczne uzyskano przy zawartości włókna 35% mas. Wytrzymałość na rozciąganie tego kompozytu wynosiła ok. 40 MPa, wytrzymałość na zginanie powyżej 60 MPa, a na ściskanie ok. 48 MPa. Natomiast energia pęknięcia wynosiła ok. 0,44 J.

Słowa kluczowe: włókno *Abutilon Indicum*, włóknina, właściwości mechaniczne, FTIR, TGA, SEM.

The effects of environmental degradation of synthesized fibers in composites has paved the way for the utilization of natural fibers in strengthening the composites [1]. The natural fibers namely bagasse, jute, kenaf, ramie, flax and banana fiber are preferred in reinforcing the polymer composites owing to their significant properties such as high mechanical strength, low density, recyclable and economical in nature [2–5]. In addition, the fibers are renewable and ecofriendly [6, 7] . The application of these composites is mostly found in construction and automobile sectors [8]. Due to the new societal and environmental policies, there is a need to promote the utilization of biodegradable ingredient (both matrix and fiber) in developing commercially feasible composites. Therefore, attention is focused on utilizing natural fibers in developing polymer composites for commercial applications owing to their greater strength [9, 10], biodegradability, less weight [11], good corrosion resistivity [12] less wear rate [13] and good stiffness [14]. Krishnudu et al. [15] evaluated and recommended the ideal weight percentage of fiber content required to improve the mechanical strength of the composites. Even though, lignocellulosic are the most preferred fibers in manufacturing ecofriendly composites, a lot of hurdles has to be faced while developing natural fiber reinforced composites due to its complicated nature. There are few drawbacks observed during processing such as aggregate formation, poor fiber-matrix compatibility, high moisture absorption and highly affected to microbial attack [16]. The literature review reveals that the application of reinforced composites are mostly found in and automotive and aerospace industries, where weight reduction in component plays an important role [17]. Different methods namely, hot calendaring, stitch bonding, hot-air thermal bonding and needle punching, etc., among these methods needle punching is largely used for jute fibers to manufactured as nonwovens form. In polypropylene composites, jute fiber used as needle punched non-woven fabric, it exhibits excellent sound absorption [18]. Compared to regular and woven fabric developed for specific use, non-woven has less effort fortification to composites. Nonwoven permeable structured sheets are manufactured from liquid plastic or films or from independent fibers. The fibers are treated thermally or mechanically to

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obtain porous structures in nonwoven fabrics. Mechanical holding is classified into i) Hydro-entanglement and ii) Needle punching. The difference between the two techniques is that the metal needles are used in needle punching, whereas columns of water planes are used in hydro entanglement. In needle-punched texture arrangement, different fiber mixes and filaments can be used especially for extreme strands. The polyethylene strands are widely used in non-woven fabrics starting from cover to superior geotextiles. Non-woven-textures are used in composites, which offer great compressive and inter-laminar shear properties [19]. Nonwoven geotextiles and structures from flax and polyster strands, which is manufactured through needle-punched method. Thickness, water absorption and porosity tests were conducted on needle-punched nonwoven mats. It was found that flax geotextiles are less thick as compared with fabricated mat. These types of composites can be used hot framework applications. These applications expect consideration with respect to thermo-mechanical behavior and thermal conductivity [20, 21]. Nonwoven jute fiber mats prepared by an articulate fabric using a pointed needle shows improved mechanical and functional properties [22]. This work overcomes the limitations described earlier by using a simple needle punching technique in making a non-woven banana fiber fabric as a reinforcement material in polymer composites. These products are the first of its kind developed in a variety of forms using banana fibers.

EXPERIMENTAL PART

Materials

Abutilon Indicum plants were taken from Chettipalayam, Coimbatore, Tamil Nadu State, India. *Abutilon Indicum* is a medicinal shrub of the Malvaceae family [23]. The isolated fibers of *Abutilon Indicum*, obtained after the microbial degradation process are shown in Figure 1. Fibers of the plant stem were soaked in water for 21 days to permit microbial breakdown. The soaked stems were then cleansed with distilled water and kept in open space for a week for the purpose of drying. Finally, the fibers were removed by combing method using a wire brush. The characteristics of *Abutilon Indicum* fiber are presented in Table 1.

Table 1. ***Abutilon Indicum*** **fiber characteristics**

Chemical composition	Content, %
Cellulose	72.28
Lignin	17.27
Wax	0.19
Ash (on dry basis)	1.58
Moisture	8.53
Density(g/cc)	1.37

Needle punching technique

To make the fabric, a needle-punching process was applied to mechanically entangle webs or batts of 30 mm long fibers. This was accomplished by interlocking the strands with reciprocating barbed (felting) needles. Through inter-fiber friction, the consolidated structure retained its integrity. A triangular needle with a spacing of 9 barbs in a 300 mm length of blade was utilized for punching. A 8 mm depth of punch penetration and a density of 100 punches/cm^2 was chosen as the optimal parameters. The Figure 2 shows that the *Abutilon Indicum* fiber nonwoven fabric.

Fig. 1. ***Abutilon Indicum*** **plant and extracted fiber**

Fig. 2. ***Abutilon Indicum*** **fiber nonwoven fabric**

Composite laminate fabrication

Compression molding method was used to make the composite laminates for this study, as shown in Figure 2. The specimens were prepared for 20, 25, 30, 35 and 40 wt% reinforcement, and the percentage of different fibers was modified to fabricate the different composites. The mould surfaces were first coated with a releasing agent (wax). The *Abutilon Indicum* fiber composite fabric was fabricated by hand layup method by stacking the laminates on a flat mould and applying the resin in between each layer.

After the completion of the layup process, the top die was placed. Then the, mould was closed and 1500 PSI of pressure was applied on it. The composite was maintained at 80°C for an hour for complete curing of the fabrics. Next the laminated fabric was removed from the mould and the test specimens of the required dimensions were prepared.

Methods

FTIR Spectroscopy

An FTIR machine, model Perkin-Elmer Spectrum 100 FTIR Spectrometer, was used to observe the spectra in the range of 4000 to 500 cm^{-1}. The materials were crushed into tiny pellets by potassium bromide. The spectrum was used to identify the various functional groups of the specimen of the composites .

TGA

Thermogravimetric Netzsch STA 409 apparatus was used to test the composite's thermal stability. To avoid undesired oxidation ,2–5 gm of sample was heated from 24°C to 980°C in an alumina pan at an average rate of 10°C each minute. The entire process is carried out in an environment containing nitrogen flowing at a constant flow rate.

Mechanical characterization

All test samples were prepared using hydraulic shearing machine. Tensile test samples were prepared according to ASTM D3039 standard. The strength was determined using Kalpak UTM (model 121101) that has a crosshead speed of 2 mm/min. Next the unnotched Izod impact testing was conducted in accordance to the ASTM D256 standard. The highest energy of the hammer employed for testing polymer composites is 5 J. In addition, the flexural and compression properties of the specimen were determined in accordance with ASTM D790 and D 3410 standards, respectively.

Morphological properties

The surface morphologies of the specimens were analyzed using SEM (SEM, CARL ZEISS V18Model). The surface is gold coated before analyzing the morphology.

RESULTS AND DISCUSSIONS

Chemical structure

The FTIR spectra of *Abutilon Indicum* fiber nonwoven fabric epoxy composites are shown in Figure 3. The peak around 1701 and 1689 cm^{-1} is specific assigned to C=O stretching in hemicelluloses of Abultilon Indicum fiber woven fabric epoxy composites of 20 wt% and 35 wt% respectively. In addition, the peak 1519 and 1565 cm^{-1} is assigned to aromatic skeleton vibrations of lignin [24]. The peaks observed for 20 wt% and 35 wt% Abultilon Indicum fiber woven fabric epoxy composites at around 1396 and 1398 cm^{-1} are assigned to CH deformation in lignin.

These results prove that, it constituent of Abultilon Indicum fiber woven fabric epoxy composites contain cellulose, lignin and hemicelluloses in their chemical structure. The region 3500-2500 cm^{-1} is related to OH and CH_2 groups. The peaks located at 2978 and 2893 cm^{-1} are attributed to (CH) and CH_2 groups in 20wt. And 35 wt% of *Abutilon Indicum* fiber woven fabric epoxy composites respectively. The peak at 2893 and 3012 cm^{-1} belongs to C-H stretching of cellulose of 20 wt% and 35 wt% of composites respectively [5].

Thermal properties

The TGA curves of the composites are presented in Figure 3. A plot between weight percentage and temperature is shown in Figure 4. It is observed that the weight loss percentage of the *Abutilon Indicum* fiber composite specimen decreases with increasing temperature due to the evaporation of carboxyl, moisture and water-soluble hydroxyl particles of the material [25]. The major degradation takes place in the temperature range of 250°C to 500°C. A remarkable loss in weight about 71.65% and 68.57% for 20 wt% and 35 wt% fiber composites is observed due to the decomposition of cellulose content [26]. Beyond 500°C and up to 680°C only a minor loss in weight is observed. Final residual of 10.31% and 7.52% of 20 wt% and 35 wt% respectively. The critical temperature of the specimen with 35 wt% is 423.43°C and 20 wt% is 438.07 °C as shown in Figure 4.

Tensile behavior

Figure 5 shows the influence of fiber weight percentage on the tensile characteristics of *Abutilon Indicum* nonwoven specimens. The *Abutilon Indicum* 35 wt% nonwoven composites exhibit a greater tensile strength (39.765 MPa) than the 20 wt% composites (27.478 MPa). Thus, the 35 wt% specimen can be declared as the optimal fiber content of the nonwoven composites. Since the *Abutilon*

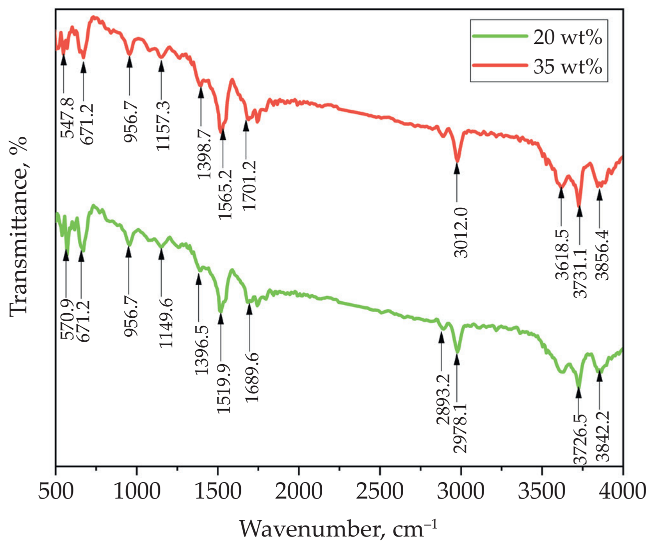

Fig. 3. FTIR spectra image of *Abutilon Indicum* fiber nonwoven fabric epoxy composites

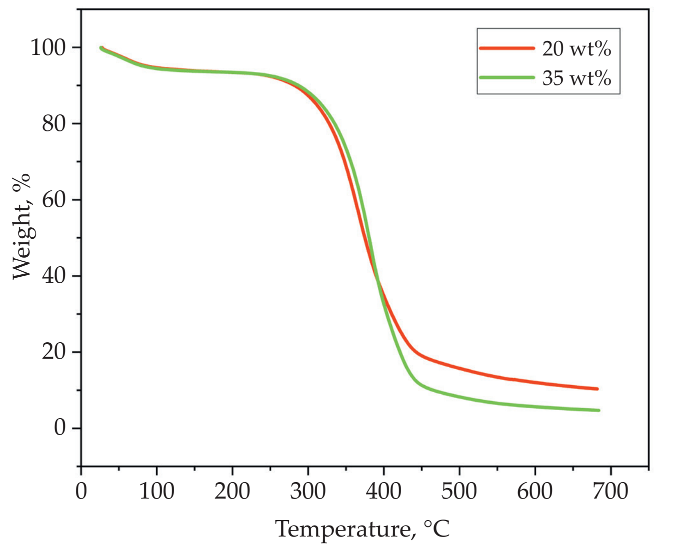

Fig. 4. TGA of *Abutilon Indicum* fiber nonwoven fabric epoxy composites

Indicum fibers have a lower aspect ratio and smaller surface area, they require less matrix for effective wetting. In the present work we have observed that the 35 wt% sample exhibits the highest strength compared to the 40 wt% specimen [27].

The entanglement between fibers was efficient at 35 wt% fiber concentration, implying that the matrix wetted the fibers efficiently. The composite was stiff at this point due to an excellent binding between fibers resulting from the matrix's firm hold on the fibers. The entwining of fibers and the effectiveness of wetting, reduced as the matrix content declined with the increase in fiber weight percentage from 35 to 40 wt%. This caused the slippage between fibers, resulting in decrease in the tensile strength of the material.

The decrease in tensile strength of the 40 wt% *Abutilon Indicum* fiber nonwoven composite was predicted earlier due to insufficient matrix wetting of fibers, resulting in poor fiber-matrix bonding [28]. The breakout pattern and fiber pull out seen in the SEM images corroborated the idea that composite tensile strength is influenced by insufficient matrix wetting of the fibers.

Flexural behavior

For lignocellulosic reinforced polymer composites to have acceptable mechanical properties, especially flexural strength, compatibility between the fibers and matrix is critical. The matrix in composites acts as a stress transmission interface between the reinforcement fibers. The flexural strengths of *Abutilon Indicum* non-woven fabric composites are shown in Fig. 6. The *Abutilon Indicum* nonwoven composites' optimal flexural strengths were attained at a fiber content of 35 wt%. At this concentration, the significant matrix wetting of fibers allows the load to be diffused and distributed among the fibers, yielding the maximum flexural strength. Due to inadequate wetting of the matrix on the reinforced fibers, flexural strength decreases at 40 wt% fiber concentration.

The reinforcement in composites was found to reduce due to the inadequate moistening of fibers. The poor matrix dispersion due to the poor wetting thus resulted in creation of weak spots at the region of interface [29].The *Abutilon Indicum* nonwoven composites required a 35 wt% fiber con-

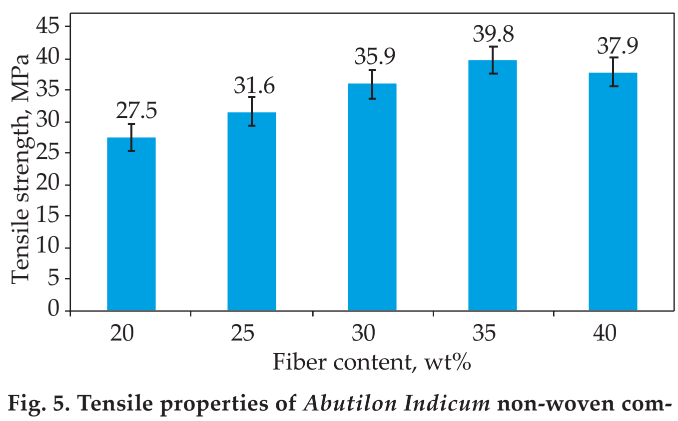

Fig. 5. Tensile properties of *Abutilon Indicum* non-woven composite differing in fiber content

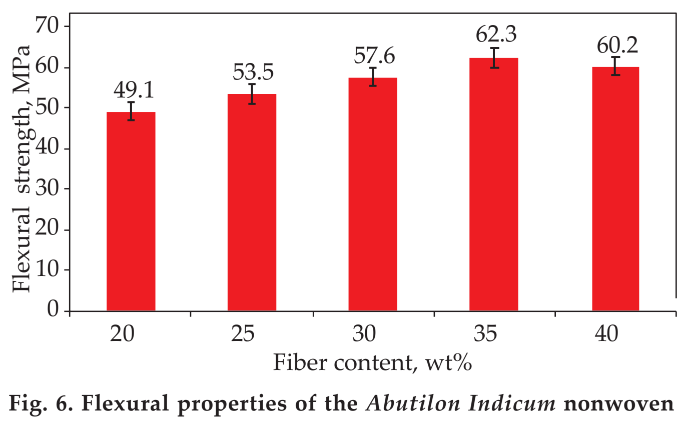

Fig. 6. Flexural properties of the *Abutilon Indicum* nonwoven composite differing in fiber content

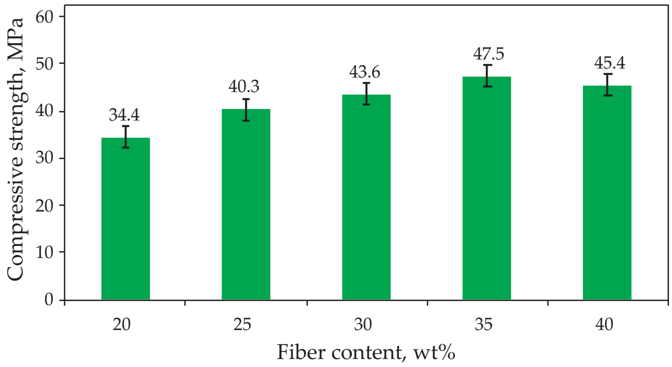

Fig. 7. Compressive properties of the *Abutilon Indicum* nonwoven composite at different fiber content

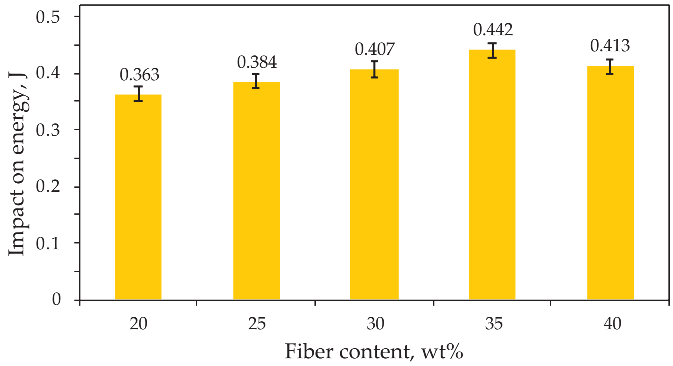

Fig. 8. Impact strength of *Abutilon Indicum* non woven composite at different fiber content

tent to obtain optimum flexural strength, as shown in Fig. 6. Since the *Abutilon Indicum* fiber's thickness was significantly high and aspect ratio was quiet low, less matrix was required for dispersion and wetting due to a lower surface area of the composite. In nonwoven composites, the structure and the fiber surface characteristics greatly influence the interaction between the fiber and matrix material. The flexural strength of 35 wt% *Abutilon Indicum* test sample was found to be the highest (62.293 MPa). The strength started to decrease beyond 35 wt% and was found to be 60.225 MPa for the 40 wt% sample. Flexural strength of *Abutilon Indicum* nonwoven composites, on the other hand, improved linearly as fiber content increased.

Compressive behavior

As shown in Fig. 7, the *Abutilon Indicum* fibers nonwoven composites with a 35 wt% fiber content had comparable compression strength. The identical compression strength is most likely due to the fibers' tensile strength and elongation. According to Hasan and Wei [30], the elongation of the reinforcement fibers affects the compression strength of nonwoven composites, with lower elongation fibers failing earlier and higher elongation fibers transferring the residual load. These two characteristics of the fibers are believed to be responsible for the similarity in compression strength patterns of the 35 wt% Indicum fiber samples.

Impact behavior

Factors such as fiber-matrix bonding and fiber reinforcing toughness have a substantial impact on energy in materials. The impact energy of *Abutilon Indicum* fibers nonwoven composite is depicted in Fig. 8. The figure shows that composite impact energy increases significantly up to 35 wt% fiber loading, but then falls to 0.441 J at 40 wt. % fiber loading. At 20 wt% and 25 wt% fiber loading, respectively, the impact energy was 0.363 J and 0.385 J. As the fiber loading rises from 30% to 35%, the impact energy rises from 0.407 J to 0.441 J.

The enhancement of the composites property is due to the improved fiber and matrix adhesion. The molecular interface chain's flexibility allowed an easy load dispersion and a steadfast avoidance of crack initiators resulting in the enhancement of composite's shock-absorbing capacity. The reinforcing effect, which allows for a uniform stress distribution from matrix to fiber phase, is responsible for the first increase in impact strength. A similar finding was made for natural fiber-reinforced composites with a large volume fraction. The results concluded that crucial fiber weight percent plays a significant role in mechanical property analysis.

Morphology

The interface of fiber and matrix can be thought of as a three-dimensional boundary. The interaction occurring at the interface is the influencing factor that dictates the composite quality. Micromechanical interlocking or mechanical locking, physical coupling such as electrostatic interaction or Vander Waals forces and interfacial bonding are the three techniques that can be used to achieve this relationship.

Figures 9 and 10 show the cracked interface of SEM investigation of the *Abutilon Indicum* fibers nonwoven composite specimen for 20 wt%. The micrograph displays primarily matrix holes and peeling at 20% fiber concentration (Figs. 9 and 10). This indicates that matrix failure dominated the failure of the samples, resulting in poor composite specimen strength. A meagre improvement in the interfacial bonding of the sample was found when the fiber weight percentage was changed to 35. The fiber pullout in the test specimen confirmed that the stress transfer from matrix to fiber was very marginal [31].

Similarly, Fig.11 shows SEM images of Tensile and flexural composite specimens of *Abutilon Indicum* fibers. Similar to broken tensile composite specimens, the micrograph indicated a similar pattern. Figure 12 shows the most common failures, which include fiber pullout, fiber breakage, fiber fracture, fiber matrix good bonding [32]. However, even after the fracture, nonwoven composite structure was visible at

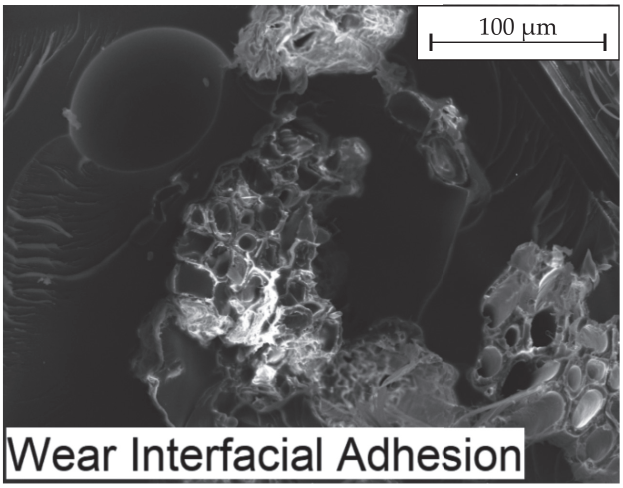

Fig. 9. SEM image of tensile failure of *Abutilon Indicum* fibres composite

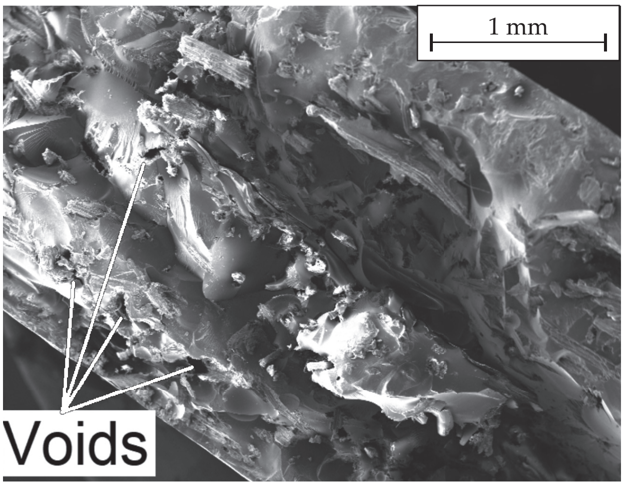

Fig. 10. SEM image of flexural failure of non woven *Abutilon Indicum* fibres composite

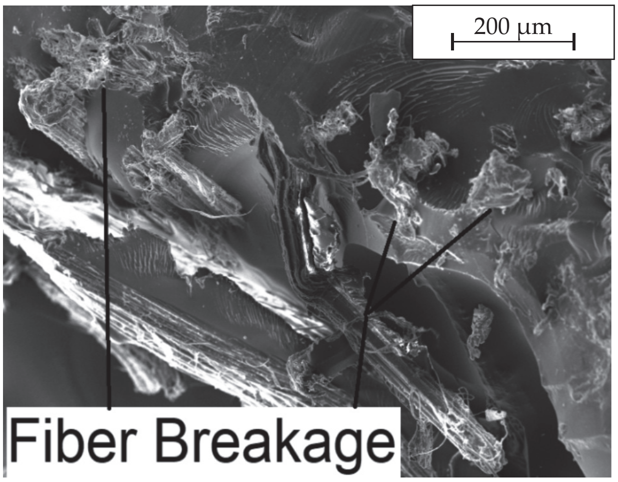

Fig. 11. SEM micrograph of tensile failure of fibers composites with 35 wt% fibre contentcomposite

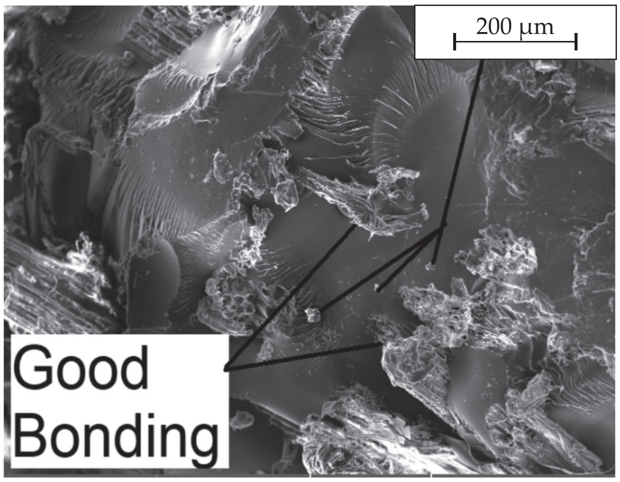

Fig. 12. SEM micrograph of flextural failure of fibers composites with 35 wt% fibre content

35 wt% fiber content. This demonstrates excellent fiber-to-matrix bonding, resulting in increased strength. Meanwhile, matrix holes were seen when the fiber level reached 40 wt%. This was due to a lack of matrix and the creation of agglomerations. As a result, the strength has been diminished.

CONCLUSIONS

Abutilon Indicum nonwoven-reinforced epoxy composite laminates were manufactured by compression molding with various laminate weight percentage in the current study. The conclusions arrived form the findings of this work are highlighted below

When compared to other composite laminates, the *Abutilon Indicum* fibers nonwoven composite has improved mechanical characteristics at 35 wt% fiber loading.

Tensile, impact, compression, and flexural characteristics of *Abutilon Indicum* fibers nonwoven composite obviously increase up to 35 wt%, then begin to decrease the strength.

Tensile, flexural, compression, and impact strength increased by 4.8 %, 3.3 %, 4.2% and 6.6%, respectively; as compared to 40 wt% *Abutilon Indicum* fiber composite laminates.

The thermal stability of the *Abutilon Indicum* fiber reinforcement improved significantly.

The deterioration temperature of the composite with 35 wt% fiber content started at 349°C and terminated at 438°C.When comparing the cotton/bamboo with glass composite to another composite combination, the thermal degradation range increased to 35 wt% fiber content.

The SEM results revealed improved surface adhesion and enhanced fiber – matrix interaction.

REFERENCES

[1} Raghunathan V., Dhilip J.D.J., Ramesh M. *et al*.: *Journal of Natural Fibers* **2021**, 0,1. https://doi.org/10.1080/15440478.2021.1990183.

[2} Nagappan S., Subramani S.P., Palaniappan S.K., Mylsamy B.: *Journal of Natural Fib*ers **2021**, 0,1.

https://doi.org/10.1080/15440478.2021.1932681.

[3} Haque M., Hasan M., Islam S., Ali E.: *Bioresourse Technology* **2009**, 100, 4903. https://doi.org/10.1016/j.biortech.2009.04.072

[4] Ashori A.: *Bioresource Technology* **2008**, 11, 4661. https://doi.org/10.1016/j.biortech.2007.09.043

[5] Bhuvaneshwaran M., Sampath PS., Balu S., Sagadevan S.: *Polimery* **2019**, 10, 1. http://dx.doi.org/10.14314/polimery.2019.10.2.

[6] Aruchamy K., Subramani SP., Palaniappan SK., *et al.*: *Journal of Natural Fibers* **2022**, 19, 105. https://doi.org/10.1080/15440478.2020.1731903.

[7] Mylsamy B., Palaniappan SK., Pavayee Subramani S., *et al.*: *Journal of Materials Research and Technology* **2019**, 8, 6021. https://doi.org/10.1016/j.jmrt.2019.09.076.

[8] Nechita P.: *Journal of Thermoplastic Composite Materials* **2017**, 1497, 31. https://doi.org/10.1177/0892705717738300.

[9] Cheung H yan., Ho M PO., Lau K tak., *et al.*: *Composites Part B: Engineering* **2009**, 40, 655. https://doi.org/10.1016/j.compositesb.2009.04.014.

[10] Mohammed L., Ansari MNM., Pua G., *et al.*: *Natural Fiber Reinforced Polymer Composites* **2015**, 0, 243947. https://doi.org/10.1155/2015/243947.

[11] Holz K., Wood G., Polymer W.: *Polymer Composites* **2014**, 35, 227. https://doi.org/10.1002/pc.22654.

[12] Gowda TM., Naidu ACB., Chhaya R.: *Composites Part A: Applied Science and Manufacturing* **1999**, 30, 277. https://doi.org/10.1016/S1359-835X(98)00157-2.

[13] Mylsamy B., Chinnasamy V., Palaniappan SK., *et al.*: *Journal of Materials Research and Technology* **2020**, 9, 16423. https://doi.org/10.1016/j.jmrt.2020.11.100.

[14] Sain M., Panthapulakkal S.: *Industrial Crops and Products* **2006**, 23,1. https://doi.org/10.1016/j.indcrop.2005.01.006

[15] Krishnudu DM., Sreeramulu D., Reddy PV., *AIP Conference Proceedings* **2018**, 1952,020058. https://doi.org/10.1063/1.5032020.

[16] Adeniyi AG., Onifade DV., Ighalo JO., Adeoye AS.: *Composites Part B: Engineering* **2019**, 176, 107305. https://doi.org/10.1016/j.compositesb.2019.107305.

[17] Steuernagel L., Ring J., *Composites Part B: Engineering* **2017**,108,325. https://doi.org/10.1016/j.compositesb.2016.10.012.

[18] Velayutham T., Manickam RK., Chung I., Prabakaran M.: *Journal of Natural Fibers* **2021**, 0,1. https://doi.org/10.1080/15440478.2021.1929645.

[19] Wang Y.: *Applied Composite Materials* **1999**, 6, 19. https://doi.org/10.1023/A:1008877110966.

[20] Shabde VS., Hoo KA., Gladysz G.: *Journal of Material Science*, **2006**, 41, 4061, 10.1007/s10853-006-7637-x.

[21] Goertzen WK., Kessler MR.: *Composites Part B: Engineering* **2007**, 38,1. https://doi.org/10.1016/j.compositesb.2006.06.002.

[22] Singha K., Maity S., Singha M., *et al.*: *International Journal of Textile Science* **2012**, 1, 7. https://doi.org/10.5923/j.textile.20120101.02.

[23] Krishnudu DM., Sreeramulu D., Reddy PV.: *Journal of Natural Fibers* **2019**, 0, 1. https://doi.org/10.1080/15440478.2019.1598917.

[24] Alavudeen A., Rajini N., Karthikeyan S. *et al.*: *Materials & Design* **2015**, 5,246. https://doi.org/10.1016/j.matdes.2014.10.067.

[25] Aisyah HA., Paridah MT., Sapuan SM., *et al.*: *International Journal of Polymer Science* **2019**,0,5258621. https://doi.org/10.1155/2019/5258621.

[26] Bhuvaneshwaran M., Subramani SP., Palaniappan SK., *et al.*: *Journal of Natural Fibers* **2021**, 18, 644. https://doi.org/10.1080/15440478.2019.1642826

[27] Shibata S., Cao Y., Fukumoto I.: *Polymer Testing* **2006**, 25, 142. https://10.1016/j.polymertesting.2005.11.007.

[28] Aruchamy K., Pavayee Subramani S., Palaniappan SK.: *Journal of Materials Research and Technology* **2020**, 9, 718. https://doi.org/10.1016/j.jmrt.2019.11.013.

[29] Miao M., Shan M.: *Composites Science and Technology* **2011**,15,1713. https://doi.org/10.1016/j.compscitech.2011.08.001.

[30] Ikbal H., Wei L.: *Textile Research Journal* **2016**, 87,305. https://doi.org/10.1177%2F0040517516629146.

[31] Wang C., Bai S., Yue X., *et al.*: *Fibers and Polymers* **2016**, 17, 1757, https://doi.org/10.1007/s12221-016-6703-5.

[32] Intan N, Anuar S, Zakaria S, *et al.*: *Industrial Crops and Products* **2019**, 127, 55. https://doi.org/10.1016/j.indcrop.2018.09.056.

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