Research Article

Effect of Fiber Orientation on Physical and Mechanical Properties of *Typha angustifolia* Natural Fiber Reinforced Composites

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Received: 29 August 2022; Revised: 1 October 2022; Accepted: 8 November 2022; Published online: 29 November 2022

Abstract
Natural fiber-reinforced polymer composites (NFRPC) are sustainable, renewable, and potential replacements in lieu of non-renewable and non-biodegradable synthetic fiber-reinforced composites. The application spectrum of natural fiber composites is widening day by day due to rigorous research carried out on these materials. Accordingly, the current study aims to determine the mechanical properties like impact and compressive strength and physical properties like water absorption behavior for *Typha angustifolia* (TA) fibers reinforced composites (TFRC). Composites were fabricated using the compression molding method with fibers in unidirectional (UD) and bidirectional (BD) orientation with a weight fraction of 10, 15, and 20%. X-ray diffraction studies were carried out on the fabricated composites to ascertain the presence of micro constituents. All the tests were conducted according to ASTM standards. Results indicated that 20% of TFR composites in BD orientation outperformed other composites. Failure surface morphology was analyzed using scanning electron microscopic analysis (SEM).

Keywords: Natural fibers, Compression molding, Mechanical properties, Water absorption

1 Introduction

The utilization of renewable and biodegradable materials is the most common aspect of current-day research. Polymer matrix composites with synthetic fiber reinforcements such as carbon, Kevlar, nylon, and glass are under the radar of environmental pollution [1]–[3]. The use of such synthetic fiber-reinforced composites can be mitigated using natural fibers as reinforcements that cater to the needs of renewability, biodegradability, and sustainability. Usually, natural fibers are obtained from plant and animal sources. Various parts of plants such as leaves, stems, stalks, petioles, fruits and seeds can be used as a source for plant-based natural fibers while animal-based natural fibers can be extracted from hair, egg waste, and so on [4]–[7]. Many researchers have already carried out enough experiments to prove the utilization of natural fibers as reinforcements in polymer matrices. Plant-based fibers like hemp, sisal, banana, jute, ramie, henequen, pineapple leaf, and kenaf are the most widely used natural fibers in structural and semi-structural applications with low and medium loads [8]–[12]. Besides, plant-based fibers with high lignocellulosic content are in high demand in many advanced industrial applications. Identification of plants that renders natural fibers with high cellulose content is the trend in ongoing materials research [13]–[15].

Evaluation of the mechanical properties of natural fiber composites was carried out by many researchers. Owing to the inherent disadvantage of natural fibers such as hydrophilicity, low or weak interfacial bonding with matrix, presence of lignin, wax, and other carbohydrates, and less effective stress distribution, natural fibers are usually hybridized or chemically modified to obtain better final characteristics [16]–[20]. Various researchers pointed out that the orientation of fiber reinforcements plays a significant role in deciding the final characteristics of natural fiber-reinforced composites. Woven, cross-ply, alternative stacking, and bidirectional (BD) orientation was proven to render better results than unidirectional (UD) and random orientation [21]–[23]. Mechanical properties like tensile strength and modulus, flexural strength and modulus, impact strength, inter-laminar shear strength and hardness were determined by many researchers conforming to ASTM/ISO standards. In most of the studies, it was stated that composites with high content of fiber and medium to larger fiber lengths rendered better properties of the composites [24]–[28].

Many experimental studies were carried out to evaluate the moisture absorption of natural fiber composites. Typically, every natural fiber is hydrophilic in nature and it reduces the interfacial bonding of the natural fibers with polymer matrices. The water absorption behavior of novel *Calotropis gigantea* (CG) fiber-reinforced composites was analyzed by a few studies. The water absorption behavior of individual fibers and fiber-reinforced composites was analyzed. It was concluded that the CG fibers absorbed more water than CG fiber-reinforced composites due to the hydrophilic nature of individual CG fibers [29]–[31]. Some other experimenters identified new natural fibers such as *Phoenix pusilla* (PP) fibers and conducted water absorption studies for the fiber-reinforced composites. It was stated from the experimental results that the rate of water absorption reduced with the increase in the content of PP fibers thus enhancing the hydrophobicity of the composites [31], [32]. It was also stated from many studies that the constraints posed by the natural fiber reinforcements at a higher volume fraction of fibers towards the polymer chain mobility, the penetration of water is restricted at higher fiber Vf and the composites turn hydrophobic [33]–[35].

Typha sp. of plants belongs to the Typhaceae family and genus Typha. These plants usually grow in aquatic and semi-aquatic conditions, in damp and moist conditions, and in swamp lands. These plants have many species such as *Typha latifolia*, *Typha catifolia*, *Typha angustifolia*, and so on. The TA plants are termed narrow cattail plants and grow up to a height of 2.1 to 2.8 m. They are characterized by low density and high cellulose content ranging between 61 and 69%, which is on par or higher than other natural fibers [36], [37]. Few authors studied the thermal behavior of TA fiber-reinforced composites. It was concluded from the study that Typha fibers enhanced the thermal stability of the composites [38]. Some other studies on the mechanical and physical behavior of TA fiber powder-reinforced composites were carried out to analyze the feasibility of using them in thermal insulation boards. It was stated in the study that the use of TA powders reduced energy consumption in buildings [39], [40]. Despite all the above, very limited analysis was carried out so far to evaluate the physical and mechanical behavior of TA fiber-reinforced composites. Hence, the current work aims to investigate the mechanical and water absorption behavior of TA fiber-reinforced (TFR) composites manufactured through the compression molding method. Composites were manufactured with 10, 15, and 20% fiber volume fractions with UD and BD as fiber orientation, and the influence of fiber orientation on water absorption and mechanical behavior of TFR composites was analyzed.

2 Materials and Methods

2.1 *Extraction of fibers and manufacturing of composites*

Typha angustifolia fibers are extracted from the Typha plants whose stalk length varies between 6–8 feet. Plant stalks are cut at 0.25 feet from the bottom and the collected plants are water retted for around 7 days. Fibers were extracted from the retted plants through the mechanical decortication process. Extracted fibers were dried in sunlight for about 3 h before using them to manufacture composites. Composite plates were manufactured using the compression molding method with a fiber weight fraction of 10, 15, and 20%. Dried fibers were chopped to the required length, weighed, and then placed in a frame. Epoxy resin and hardener (LY and HY 556 grades respectively) were mixed in a ratio of 10:1 and coated over the fibers. This is repeated until the required number of plies is attained and the mold is closed. These contents were placed in the compression molding machine and a pressure of 32 MPa and a temperature of 165 ºC were applied and the composite was allowed to cure. Composites were prepared with 0º (UD) and 0º/±90º (BD) fiber orientations. The aforementioned procedure was repeated for all the composite plates. Then the specimens of required dimensions were cut for various characterization and testing of the TFR composites. Figure 1 shows the process of extraction and manufacturing of UD and BD TFR composites.

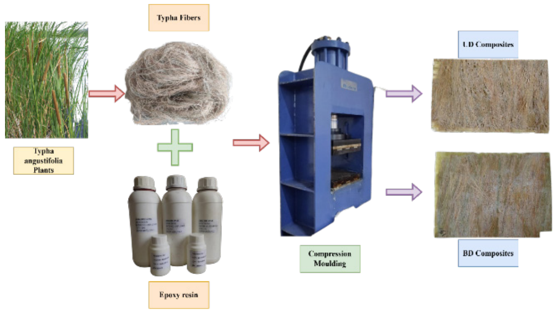

Figure 1: Extraction and manufacturing of TFR composites.

2.2 *X-ray diffraction analysis*

Micro constituents present in the UD and BD TFR composites can be ascertained by the peaks obtained from X-ray Diffractometer. D8 advance X-ray Diffractometer (Make: Bruker) with CuKα monochromatic radiation wavelength 1.54 Å was used. Bragg's angle (2θ) used for the recording of diffraction data ranged between 10° to 80°. Peaks obtained between 14° to 16° denote the presence of amorphous material while the peaks present between 23° to 27° denote the amorphous material [27].

2.3 *Impact test*

Low-velocity impact tests were carried out on the UD and BD TFR composites to assess their toughness and resistance to impact loading. ASTM D256 standard was adopted to carry out the test and the specimen dimensions used for the test were 64 mm × 12.7 mm × 4 mm [41]. A 2 mm deep notch was also made using a notch cutting machine as per the ASTM standards. A mini-impactor with a maximum load of 15 J (Make: Santa Engineering) was used for the test. The angle of the impact hammer was maintained between 145° and 155° during the test. A total of 3 specimens were tested in each composition and the average value was taken for the final analysis. Figure 2 shows the TFR composite used for impact testing.

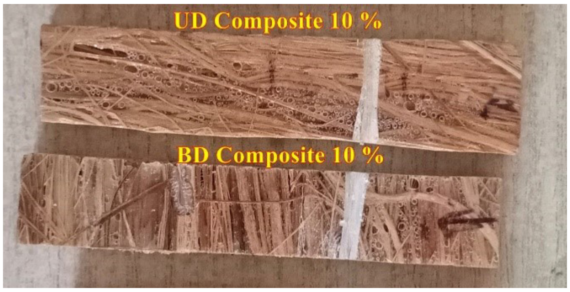

Figure 2: TFR composite specimens for impact test.

2.4 *Compression test*

A compression test was carried out on TFR composites to assess the behavior of the composites under compressive load. ASTM D3410 was adopted to carry out the compression test on the specimen with dimensions 155 mm × 25 mm × 4 mm [42]. A shear load across the cross-section was applied to the specimen to evaluate its compressive strength. Tests were carried out on a computer-interfaced Universal Testing

Figure 3: TFR composite specimens for compression test.

Machine (UTM) (Make: Aimil) with a 1000 kN load capacity consisting of a hydraulic jaw test. A total of 3 samples were tested in each composition and the average value was taken for the final analysis. Figure 3 shows the TFR composite specimens used for the compression test.

2.5 *Water absorption test*

The water absorption behavior of TFR composites was determined to evaluate their hydrophilicity. The tests were carried out according to ASTM D570-98 standard with a specimen dimension of 64 mm × 12.7 mm × 4 mm [43]. The samples were immersed in a container filled with distilled water for about 120 h and the weight of the samples was measured at regular intervals of 30 h. During every weight measurement, the samples were taken out from the water and were dried using a dry cloth. The rate of water absorption (WA) of the samples was quantified by using the following Equation (1):

$$\%WA = \frac{W_1 - W_0}{W_0} \times 100 \tag{1}$$

Where W_0 = Initial sample weight, W_1 = Final sample weight.

3 Results and Discussion

3.1 *XRD analysis*

XRD peaks of UD and BD composites portray the presence of amorphous and crystalline regions. It could also be seen that UD composites have only around 2 prominent peaks but BD composites have repetitive prominent peaks depicting the presence of continuous fiber lamina one below the other in the BD composite. As the UD composites constitute a fiber lamina followed by the epoxy resin, there was only one set of prominent peaks. Less prominent peaks represent the peaks of epoxy resin and the more prominent peaks represent the amorphous and crystalline regions of Typha fibers. Alongside, the peaks of UD composites suggest that the presence of crystalline elements is more in the untreated fibers owing to the presence of cellulose. Some of the previous researchers also reported similar findings for untreated natural fibers [13], [21], [24]. Figure 4 represents the XRD peaks for UD and BD TFR composites.

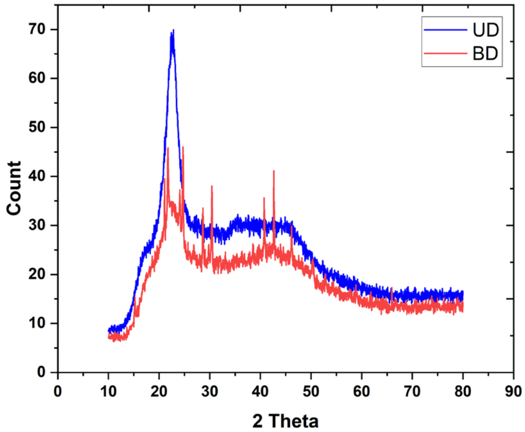

Figure 4: XRD peaks for TFR composites.

3.2 *Effect of fiber orientation on impact strength*

The effect of fiber orientation on the impact behavior of TFR composites is shown in Table 1. It could be noted that the increase of Typha fiber content increased the impact strength of the composites in both UD and BD orientations. This could be due to the effective energy absorption by the TA fibers at higher volume fractions. The interfacial region of matrix and reinforcement had a good agreement and it facilitated the higher energy absorption for the TFR composites with 20% of Typha fibers. On the other hand, BD composites exhibited higher values of impact strength at all volume fractions relatively.

The presence of TA fibers in ±90° in alternative lamina enhanced the energy absorption capability of BD TFR composites. Hence, it could be seen that composites with 20% Typha fiber in BD orientation had higher impact strength when compared with their

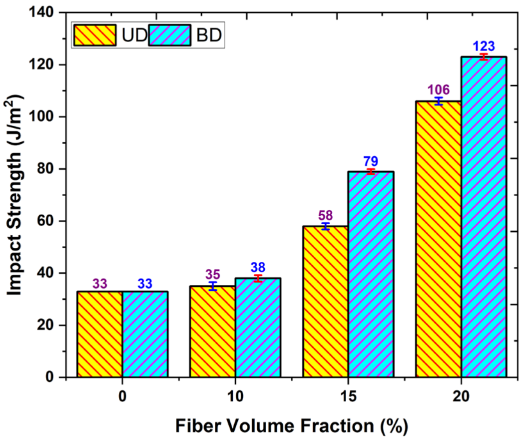

Figure 5: Variation of impact strength of TFR composites.

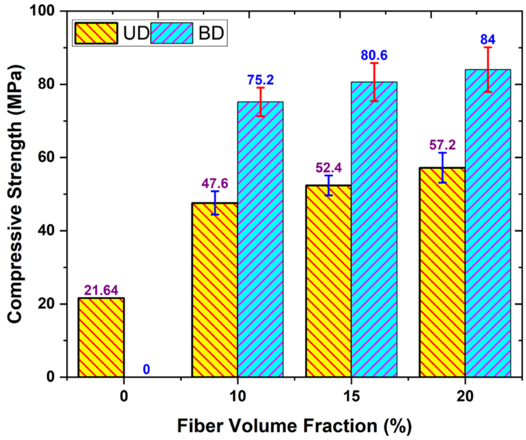

Figure 6: Variation of compressive strength of TFR composites.

counterparts. Figure 5 shows the variation of impact strength with respect to fiber volume fraction for UD and BD TFR composites.

Table 1: Impact strength of TFR composites

S.No	Fiber Volume Fraction (%)	Impact Energy (J/m^2)	
		UD	BD
1	0	33	33
2	10	35 ± 1.5	38 ± 1.2
3	15	58 ± 1.2	79 ± 0.9
4	20	106 ± 1.4	123 ± 1.1

3.3 *Effect of fiber orientation on compressive strength*

Compressive strength values of UD and BD TFR composites are enlisted in Table 2. It could be seen from the values that the compressive strength of the TFR composites increases with an increase in fiber volume fraction. This could be due to the better interfacial adhesion and effective transfer of shear load within the laminates. At higher volume fractions, the fibers easily facilitate effective stress transfer thus protecting the matrix from crack propagation and failure. Meanwhile, BD composites exhibited higher compressive strength than UD composites due to the alternating longitudinal and transverse stress transfer occurring in between +90° and –90° oriented fibers. Due to BD orientation, higher loads were necessary to induce the failure and hence BD composites show better compressive strength when compared with UD composites. Hence, 20% fiber-reinforced BD TFR composites exhibited better compressive strength than their counterparts. Figure 6 shows the variation of compressive strength of TFR composites for UD and BD orientation of the composites.

Table 2: Compressive strength of TFR composites

S.No	Fiber Volume Fraction (%)	Peak Load (N)		Displacement (mm)		Compressive Strength (MPa)	
		UD	BD	UD	BD	UD	BD
1	0	2.41		0.98		21.64	
2	10	5.2	9.4	2.91	1.33	47.6 ± 3.2	75.2 ± 3.9
3	15	5.8	9.8	2.75	1.87	52.4 ± 2.7	80.6 ± 5.2
4	20	6.4	10.5	2.49	2.53	57.2 ± 4.1	84 ± 6.1

3.4 *Effect of Fiber orientation on water absorption behaviour*

The hydrophilicity of the composites was assessed by water absorption tests. The rate of water absorption is based on the weight of water-absorbed samples and dry samples. It could be seen that the rate of water absorption increases with an increase in time. This clearly shows the hydrophilic nature of the composites. The rate of absorption decreases with an increase in fiber volume fraction, which could be due to the increase in the content of natural fibers. At 20% fiber volume fraction, the rate of water absorption was found to be lesser owing to the higher resistance for the movement of fibers and penetration of water molecules. On the other

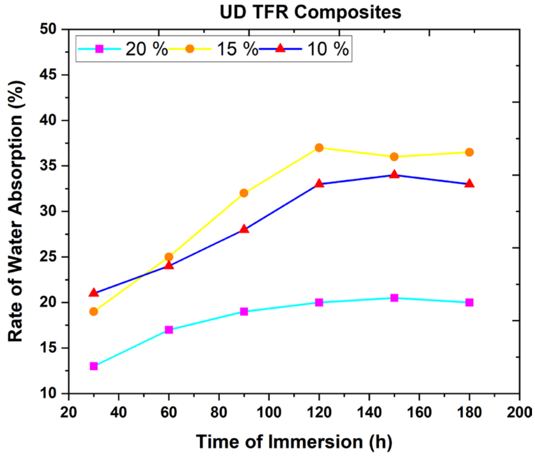

Figure 7: Water absorption of UD TFR composites.

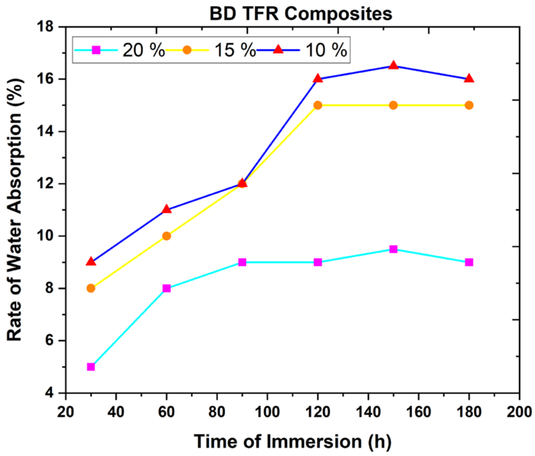

Figure 8: Water absorption of BD TFR composites.

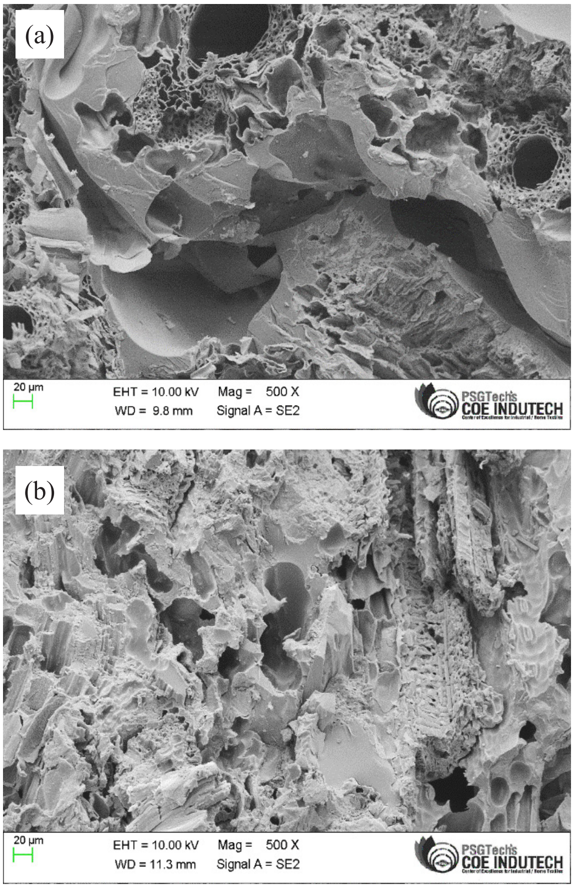

Figure 9: (a) SEM micrograph of impact failure specimen for UD Composites. (b) SEM micrograph of impact failure specimen for BD Composites.

hand, BD composites exhibited relatively lesser water absorption due to the resistance offered by the fibers toward the penetration of water molecules. Mobility of the polymeric chain was blocked in BD orientation due to the fiber arrangement, which hindered the water molecules from penetrating into the composites.

The rate of water absorption reached its highest value after 120 h of immersion, which could be observed in Figures 7 and 8 portraying the rate of water absorption of UD and BD composites, respectively at regular intervals. Beyond 120 h, the water absorption rate of TAFR composites decreased due to the accumulated hydrophilicity of the fibers. It could be stated from the study that composites with 20% TA fibers in BD fiber orientation exhibited better water absorption properties due to the high-volume fraction of fibers. Nevertheless, the water absorption behavior of composites can affect the mechanical properties and hence the hydrophobicity of the fibers can be improved by the surface treatment, which will be carried out in further works.

3.5 *Morphological analysis*

SEM micrograph of 20% fiber-reinforced TFR composite after impact test was depicted in Figure 9. In most cases, fiber pull-out is dominant in case of impact failure [28]. From the image, it could be seen that fiber pull-out occurred as a result of impact loading. Fiber delamination, debonding of matrix and fiber, matrix crack, and grooves cannot be witnessed in the image, which clearly portrays the good interfacial adhesion between fiber and matrix at this composition. It could also be seen that the breakage of fibers was unequal, which portrays the good energy absorption capability of TA fibers. It can also be seen that epoxy resin is good compatibility with TA fibers, which could also be a reason for their good interfacial strength. Hence, it can be concluded that TFR composites possess better mechanical and physical properties at higher volume fractions of fiber reinforcements.

4 Conclusions

Typha angustifolia fibers reinforced epoxy composites were manufactured using a compression molding technique with varying fiber volume fractions of 10, 15, and 20% with unidirectional and bidirectional fiber orientations. Composites were subjected to mechanical and physical behavior evaluations, which rendered the following outcomes:

- TFR composites contained amorphous and crystalline regions, which were evident from the prominent XRD peaks depicting the better compatibility between the fiber and the matrix.
- Impact test results showed that composites with 20% fibers in bidirectional orientation had high impact strength as they exhibited better energy absorption capabilities due to the effective stress transfer occurring between the fiber and the matrix.
- Morphological analysis showed very less fiber pull out, delamination, and matrix crack, which is the obvious evidence of good interfacial adhesion between fiber and the matrix.
- Compression test results portrayed that 20% fiber-reinforced composites in bidirectional orientation had a very good resistance towards shear loading and hence exhibited higher compressive strength.
- Water absorption results showed that the rate of absorption increased to 120 h and then reached saturation. It was concluded from the results that the bidirectional oriented 20% fiber reinforced composites resisted the penetration of water by arresting the movement of polymer chains and so these composites were hydrophobic. Overall, it could be concluded that 20% *Typha angustifolia* fiber reinforced composites in bidirectional orientation can be used in low and medium load-bearing structural applications and in moisture and damp environments.

Acknowledgement

The authors sincerely express their gratitude to the Centre for Machining and Materials Testing for supporting the manufacturing and testing of composites and to the Materials Characterization lab for the characterization of composites.

Author Contributions

V.B.: Conceptualization, investigation, reviewing and editing; L.R.: Investigation, methodology, writing an original draft; T.P.S., G.R.K.: Research design, data analysis; M.R.S., S.S.: Conceptualization, data curation, writing—reviewing and editing, All authors have read and agreed to the published version of this manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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