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Article

Synthesis of a New Natural Fiber Composite Material Based on Human Hair and Coir Fibers

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Abstract: Human hair, with its high strength-to-weight ratio, can replace expensive materials like glass fibers in composite materials. We developed a novel natural fiber composite material by mixing human hair and coir fibers with polyester resin. To investigate its mechanical properties, the new material was tested for bending strength, impact strength, and water absorption. The specimen IL3, with human hair and coir in a 3:2 ratio, showed a maximum impact strength of 13.174 kJ/m^2. The developed material was almost completely water resistant with a maximum water absorption of only 2.13% in the WCH1 specimen. Fiber content, not orientation, was determined with water resistance. The maximum flexural strength obtained was 36.270 MPa. Investigation results showed that relative volume percentage of fibrous materials, fiber orientation, and aspect ratio affected natural fiber composite properties. After repeated testing on specimens of different compositions and fiber orientations, the best specimens were identified for future usage. The substance is biodegradable and eco-friendly.

Keywords: Natural fiber composites, Mechanical properties, Water resistant test, Bending test, Impact test

1. Introduction

The term "fiber-reinforced composite" (FRC) refers to a well-known composite material made up of fibers that function as reinforcing agents and a matrix phase used to bind the fibers together. This creates a new material that possesses combined properties of each of its constituents. When two or more materials having distinct properties (physical, chemical, thermal, etc.) are combined, a new material is generated with characteristics that are different from those of the original constituents. This unique material is a composite [1]. Several desirable qualities distinguish composite materials, including high strength to weight, low weight, and design flexibility. The fine inter-phase region, also known as the interface, is one of the three components that make up an FRC, which is a composite building material that is made up of the following three parts: (1) the fibers as the reinforcements, which are in the dispersed phase; (2) the matrix as the binding material, which is in the continuous phase; and (3) the fine interphase region. They are a member of the advanced composite group, which uses rice hull, sawdust, and plastic as parts in their products. The production of a high-strength fiber composite material may be accomplished through the use of this technique by refining, mixing, and compounding natural fibers that have been derived from cellulosic wastes. The waste raw materials designated for use in this process include waste thermoplastics and several categories of cellulosic waste. These cellulosic waste categories include rice husk and sawdust, amongst others.

FRCs are high-performance fiber composites generated by cross-linking the cellulosic fiber molecules with the resins in the matrix using a patented molecular re-engineering technique. This approach results in a product that has remarkable structural, physical, and chemical qualities. Using this technology of molecular re-engineering, wood's selected physical, chemical, and structural properties are cloned and vested in the FRC products. In addition, various other critical attributes are incorporated into the process, resulting in superior performance properties than those of contemporary wood [2]. This newly discovered material, in contrast to existing composites, has the potential to be recycled up to 20 times, which means that scrap FRC is used repeatedly. FRC materials can fail due to various causes, including intra-laminar matrix cracking, de-lamination, longitudinal matrix splitting or separation, fiber-matrix de-bonding, fiber fracture, or fiber being dragged out. The composites are classified into three types as shown in Fig. 1 [3].

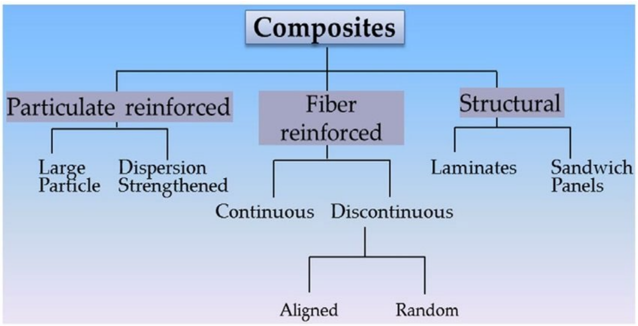


Fig. 1. Types of composites (Reprinted from Ref. [3], with permission from Taylor & Francis with license number 5671440644927).

1.1. Fiber-reinforced Composites

Fiber-reinforced composites are classed as continuous (long fibers) and discontinuous (short fibers) fibers. When fibers are aligned in a particular direction, they provide high strength but only along the direction in which they are aligned. The formed composite has a considerably weaker strength in other directions and exhibits a significant anisotropic behavior. Figure 2 shows the structure of FRCs. This anisotropy is overcome by random orienting and aligning the fibers in all directions. This decreases the effective strength of the material but has the advantage of improving the material's formability and reducing the cost [4]. Aligned fibers are used for forming materials with strength in only one direction, while randomly aligned fibers are used for having strength in all directions. Composites that require fibers to be aligned in only one principal direction are formed by using either continuous or dispersed/discontinuous fibers. In contrast, composites with randomly aligned fibers are mostly made with discontinuous fibers (Fig. 3). Composites can be tailor-made materials with various parameters other than the properties of the fibers and matrix, which are altered to meet the design and application requirements of the manufacturer.

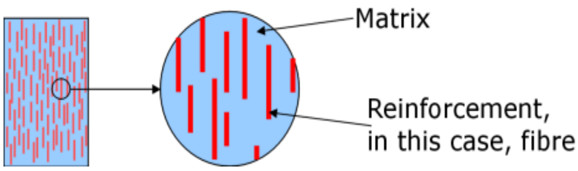
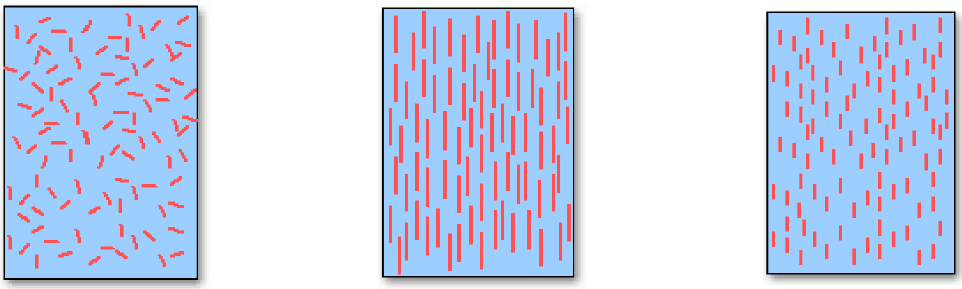


Fig. 2. Structure of fiber-reinforced composites.



(**a**) Continuous aligned (**b**) Discontinuous aligned (**c**) Discontinuous random

Fig. 3. Different types of alignment in fiber-reinforced composites.

1.2. Structural and Chemical Constituents of Human Hair and Coir Fiber

Hair is a protein filament that develops from dermal follicles. Hair is an essential biomaterial comprised primarily of protein, specifically alpha-keratin. The entire chemical makeup of hair consists of 5% sulfur, 7% hydrogen, 15% nitrogen, 28% oxygen, and 45% carbon. The keratin protein is the main structural component of the hair shaft. A hair's keratin is rugged, compact, and durable. Starting in the germ layer, cells begin to generate this fibrous protein gradually over time [5]. There is amorphous keratin in the cuticle cells, but the cortical cells have a filamentous structure surrounded by a sulfur-rich and amino acid-storing keratinous molecular substance. Hydrogen bonds keep the keratin in these filaments coiled up with an average distance of 0.51 nm between each turn. Human hair owes its structure and cohesion to this protein. In addition to the aforementioned, human hair includes up to a moisture of 15% and trace amounts of copper, zinc, calcium, cadmium, iron, chromium, and silicon [6,7]. Blood circulation brings these components to the base of the human hair follicle, where they contribute to the hair shaft's development. The hair is composed of lipid components which account for 3% of its total composition. These lipid components are produced from ceramides, fatty acids, and sterols in the hair bulb. They are found in the cuticle and cortex's intercellular cement, making the hair somewhat watertight and ensuring the cohesiveness of individual hair strands.

Coconut produces coir fibers between its tough inner shell and its outer cover. Each fiber cell is slender, hollow, and has thick walls holding cellulose. As a coating of lignin is formed over young coir fibers, they eventually harden and turn yellow. A typical fiber cell is roughly 1 mm (0.04 inches) in length and 12 to 22 m (0.0004 to 0.0008 inches) in diameter (transverse direction) (transverse direction). A fiber's typical length is between 10 and 30 cm (4 and 12 inches). Coir comes in two colors, brown and white. The brown coir generated from ripe coconuts is sturdy, dense, and suppresses abrasion [8]. They are mainly used for making sacks, mats, and brushes. Mature brown coir fibers are less pliable than other fibers like cotton due to a higher lignin content and lower cellulose content, respectively. White coir fibers are often smooth, delicate, and weak since they are derived from unripe coconuts. Coir fibers are one of the few natural fibers that are salt-water resistant [9–11]. White coir may be manufactured using either fresh or salt water.

In this study, we developed a new composite material using natural fibers (human hair and coir) and studied its mechanical properties. By appropriate study and efficient utilization of human hair and coir as fibers in different compositions together with polyester resin as a matrix, various specimens were prepared using the hand layup technique and were sent for testing at the CIPET lab. After their respective testing, it was found that the properties of the developed material are such that it may replace several existing materials. Through a literature review, it was observed that the bending and impact strength properties of the human hair and coir fibers reinforced composite have not been investigated precisely prior to our work. In this study, we explored the water-resistant property and the maximum permissible break load that the developed composite can bear.

The rest of the paper is structured as follows. Section 2 describes the methodology employed for the fabrication of the composite material, Section 3 highlights the geometry of the developed specimens and the orientation of fibers, Section 4 presents the nomenclature of the specimens, followed by Section 5, which highlights the properties of the materials used to fabricate the composite material, Section 6 describes the tests performed on the specimens, Section 7 reports the results of this study, followed by Section 8 which concludes this study.

2. Methodology: Fabrication and Synthesis of Composite Material

- To create a composite, the reinforcement was wetted, blended, or saturated with the matrix. Then, the matrix was s allowed to bond (through heat action or chemical reaction) to form a rigid structure [12,13]. In the present work, the composite material samples were developed using the hand layup technique. The following procedure was adopted to develop the composite material
- A cleansing action was performed on hair and coconut fibers with NaOH.
- Then hair fibers were divided into pieces of uniform length for ease of dispersion.
- Dividing the hair and coir fibers as per the weight percentage in an appropriate quantity utilized in manufacturing different specimens was further needed for testing.
- Preparation of mold of required dimension (10 × 4 × 2) cm^3.
- To create a melding event, the reinforcing and matrix elements were mixed, crushed, and then cured (processed) inside a mold. A small amount of hardener MEKP was added for fast preparation of composite.
- The part's shape was finalized after the merging process was finished being carried out.
- Removal of the specimen from mold and cleaning of the specimen was performed.
- Testing the specimen for different mechanical properties
- Critical analysis of mechanical properties
- Utilization of these mechanical properties in the application of packing materials and the development of small windmill blades

The detailed step-wise description of each process in the fabrication of the natural fiber composite is as follows:

2.1. Fiber Extraction

Firstly, the fiber is extracted from its natural sources using simple bare-hand techniques or simple tools. Coir is extracted from coconut, and hair is extracted from the human body.

2.2. Preparation of Fiber

The following procedure was employed for the preparation of fiber:

- Firstly, from the extracted coir, a fiber of appropriate size and length was taken and rubbed using sandpaper.
- After the rubbing action, small fibers were selected in groups for strand preparation.
- Human hair fibers, after extraction, were washed with diluted NaOH and water and then kept for drying.
- After drying, these fibers were cut by scissors for easy dispersion in the mold.

2.3. Preparation of Mold

A mold was prepared by carving out a cavity of the required dimension in a wooden block. A small allowance was given in the mold to overcome the filing action.

2.4. Orientation of Fibers

Orientation means the alignment of fibers in the mold and resin mix. The properties of fabricated composites are defined by the orientations of fibers (Fig. 4). The fiber strands were selected and weighed in the required amount, and aligned as per demand in the mold to withstand that alignment against melding action to be fixed in places using a strong adhesive.

(**a**) (**b**) (**c**)

Fig. 4. Orientation of fibers: (**a**) longitudinal alignment, (**b**) transverse alignment, (**c**) cross-hatched alignment.

2.5. Melding

The reinforcing components and the matrix materials were melted within a mold, then compacted and cured. A small amount of Methyl Ethyl Ketone Peroxide (MEKP) and cobalt catalyst were added for fast preparation of the composite.

2.6. Removal of Specimen and Cleaning

The specimen was removed from the mold and then cleaned by using a filing process. Then, it was filed for a smooth surface finish but also for obtaining dimension accuracy.

2.7. Testing

Obtained specimens were tested, and the resulting data was processed for further analysis to select the most suitable composition for composite preparation. Figure 5 depicts the sequence of operations adopted in synthesizing the composite.

3. Orientation of Fibers and Geometry of Developed Composite Specimens

The estimated weight of the prepared composite was 20g and the ratio of Polyester resin matrix and Fiber Reinforcement was 9:1. The different compositions of hair fiber and Coconut fiber were used for composite preparation as described in Table 1. The pattern was prepared in a mold of dimension (Length × Breadth × Height) cm^3. Each of these patterns had its characteristic mechanical property which was justified by subjecting them to further testing.

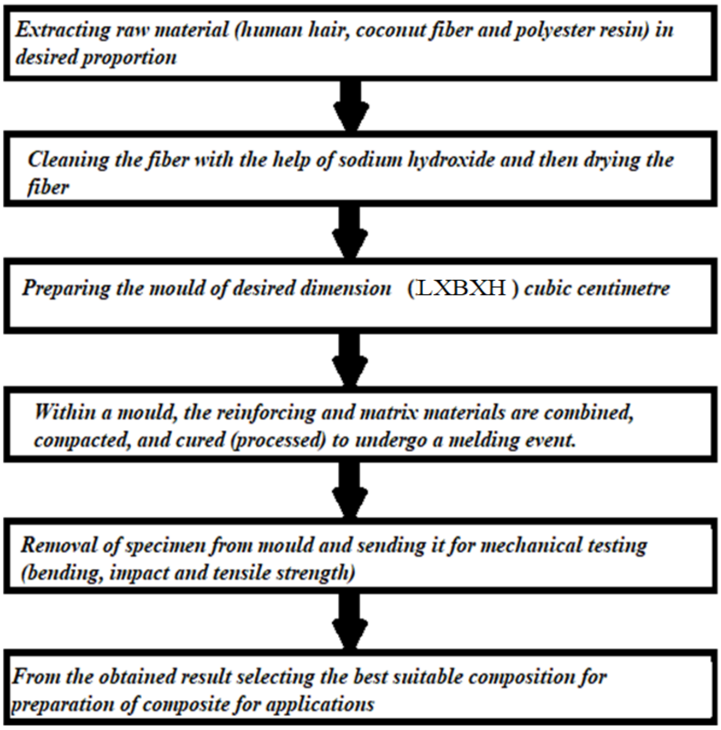


Fig. 5. Flowchart for composite fabrication.

Table 1. Relative percentage of fibers used in composites.

Sample No.	Human hair fiber (%)	Coir fiber (%)
1	80	20
2	60	40
3	40	60
4	20	80

3.1. Longitudinal loading pattern

In this pattern, the fibers of the coconut were placed parallel to one another, the human hair was dispersed, and the fibers were bonded using a polyester matrix (Fig. 6). The was applied axially in the direction of the coconut fiber alignment.

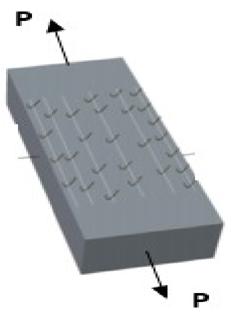


Fig. 6. Longitudinal loading pattern.

3.2. Transverse Loading Pattern

In this pattern, the fibers of the coconut were placed parallel to one another, the human hair was dispersed, and the fibers were bonded using a polyester matrix (Fig. 7). The loading was applied perpendicular to the direction of the coconut fiber alignment.

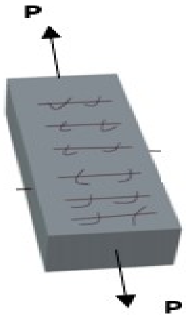


Fig. 7. Transverse loading pattern.

3.3. Cross-hatched Loading Pattern

In this pattern, the fibers of the coconut are placed in a cross-linking manner like a wire mesh, human hair is placed in a dispersed way, and the fibers are bonded using the polyester matrix (Fig. 8). Loading is applied in a horizontal direction perpendicular to the sample face.

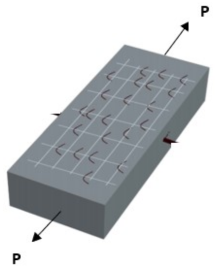


Fig. 8. Cross-hatched pattern.

4. Nomenclature of Specimens

The following system of nomenclature was used for the effective recognition of the specimens for the various experiments. Based on tests being performed, I = impact test, B = bending test, and W= water absorption. Based on the orientation of fibers in the specimen, L = longitudinal, T = transverse, and CH = cross-hatched. Based on the relative composition of hair and coir in the specimen, the samples were taken in the ratio of the composition of the hair to coir as follows: Sample 1: hair: coir = 1:4, Sample 2: hair: coir = 2:3, Sample 3: hair: coir = 3:2 and Sample 4: hair: coir = 4:1. For example, the BT4 means bending test on transverse fiber-oriented hair specimen: coir = 4:1 composition. The samples are tested with suitable mechanical machines to study the properties related to the composite behaviors.

5. Materials

The raw materials used in this study included human hair, coir, polyester resin, hardener MEKP, and catalyst cobalt. Human hairs were collected from the nearby waste dump of a barber's shop. Coir fibers were obtained from the fruit-seller dustbin. Polyester resin, MEKP, and Cobalt were bought from the online seller.

5.1. Human Hair

Hair is a natural fiber made of keratin, a protein with a high sulfur concentration generated from the amino acid cysteine (Young's modulus is between 3.50 and 3.78 GPa). The geometry of hair is the primary determinant of its properties (Fig. 9). Hair's extraordinary strength results from cortical keratin and its long chains, which are compacted to produce a stable structure that is not only exceedingly strong but also flexible. The mechanical properties of hairs include the following.

- Resistance to stretching: It largely depends on the diameter and length of the hair.
- Elasticity: Hair fibers are highly elastic and can bear moderate stretching in wet or dry conditions.
- Hydrophilic nature: Hairs can take in water in both liquid and steam forms. Keratin can take in water at 40–45 % of its weight [5,14]. The fiber's flexibility and temperature play essential roles in the hydration process.

Fig. 9. Human hair.

5.2. Coir Fibers

Coir (Young's modulus between 3 and 4 GPa) is a natural fiber from coconut husks. Coir is a fibrous material created between a coconut's interior shell and its outer husk (Fig.10). The individual fiber cells are thin, dense, and hollow and are primarily composed of cellulose. Its properties are as follows.

- Coir fibers are multi-cellular, hard, and very coarse.
- They are agro-renewable, biodegradable and a good blend of extensibility, strength, length, and moisture regain, and they have high durability against solar radiations [8].

Fig. 10. Coir fibers.

5.3. Polyester Resin

Polyester is an unsaturated synthetic resin that is created by a reaction between dibasic organic acids and polyhydric alcohols [15]. Polyester can be used as a matrix, a viscous material that solidifies and hardens to give a suitable shape and size to the composite product and protect the fibers from deterioration (Fig. 11). Its properties include the following.

- Adequate resistance to weathering, tearing, and aging over time.
- They are moderately temperature resistant and can survive well up to 800C.
- They undergo relatively low shrinkage of up to 4−8% during curing.
- They have a low thermal expansion coefficient which ranges between (100-200) × 10^{-6} K^{-1}.

Fig. 11. Polyester resin.

5.4. Hardener: MEKP

In terms of explosive potential, MEKP is comparable to acetone peroxide. Compared to acetone peroxide, a white powder at room temperature and pressure, MEKP is a colorless, oily fluid, Hence, it is less sensitive to temperature and shock wave fluctuations and is typically more stable when kept. Depending on the experiment's parameters, hydrogen peroxide and methyl-ethyl ketone can form various products and adducts. The first compound of its type was discovered in 1906, and its formula is C8H16O4. In most cases, commercially available materials from chemical suppliers offer information indicating that a linear dimer is the most prevalent component in the combination of products usually generated. In commercial and DIY settings, MEKP is used in 30–60% dilutions as a catalyst to induce cross-linking between unsaturated polyester resins used in fiberglass and castings. MEKP is dissolved in cyclohexane peroxide, diallyl phthalate, or dimethyl phthalate to reduce its sensitivity to shock. Benzoyl peroxide, likewise, serves the same function. When applied to the skin, MEKP causes severe irritation and, in extreme circumstances, blindness [16]. Therefore, it necessitates cautious application.

5.5. Catalyst: Cobalt

Cobalt catalyst is a highly active reagent, extensively used in the efficient and selective formation of pharmaceuticals, natural products, and other new materials. Cobalt catalyst has a higher reactivity for numerous C-C bond formations. Compared to nickel and palladium, cobalt catalysts with cobalt salts exhibit superior functional group tolerance, gentle reaction conditions, and excellent chemo-selectivity [17]. They are the most commonly used catalyst for metal-catalyzed cross-coupling reactions. By the effective and efficient combination of the properties mentioned above of these fibers, the composite was developed to bear high toughness with a high impact and bending strength. Thus, it can be used in the development of packaging materials and other applications.

6. Testing and Analysis

The following tests were conducted on the fabricated composite specimens.

6.1. Bending Test

Bend testing systems were used to accurately and reliably measure the flexural properties of materials. The transverse bending test is often conducted by using this machine in which a specimen of given dimensions having either a circular, square, or rectangular cross-section is employed for a bending moment using a three-point or four-point flexural test technique until fracture or yielding of material is produced (Fig. 12). The stress was used to measure the flexural strength of a material to be broken.

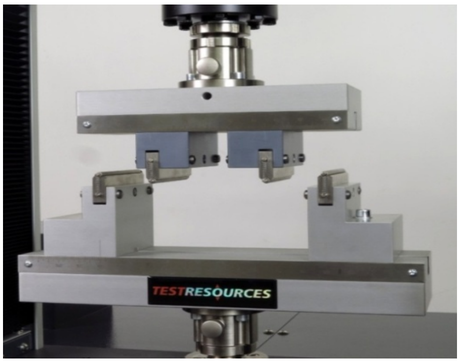


Fig. 12. Four-point bending machine.

6.2. Water Absorption Test

The moisture absorption test of composite involves placing material in a moisture-prone environment and then monitoring the changes in its weight with time. Initially, the weight of the specimen was recorded, and then after regular time intervals, its weight was measured. The relative change in the weight of the specimen provided information about its water-resistant behavior (Fig. 13).

Fig. 13. Water absorption testing machine.

6.3. Impact Test

Impact tests provide information about the toughness of a material. A material's toughness is measured by its capacity to absorb force up to the point when it fractures. The Izod impact test is used to measure a material's resilience to impact, and ASTM has standardized it. It is composed of a pivoting arm lifted to a certain height (constant potential energy) and then released (Fig. 14). The arm swings down to strike a sample with a notch, fracturing the sample. The specimen's toughness or energy absorption is determined by measuring the height to which the arm is elevated after striking the specimen. Typically, a specimen was notched to compute the hardness and notch sensitivity as necessary (Fig. 15).

Fig. 14. Izod impact testing machine.

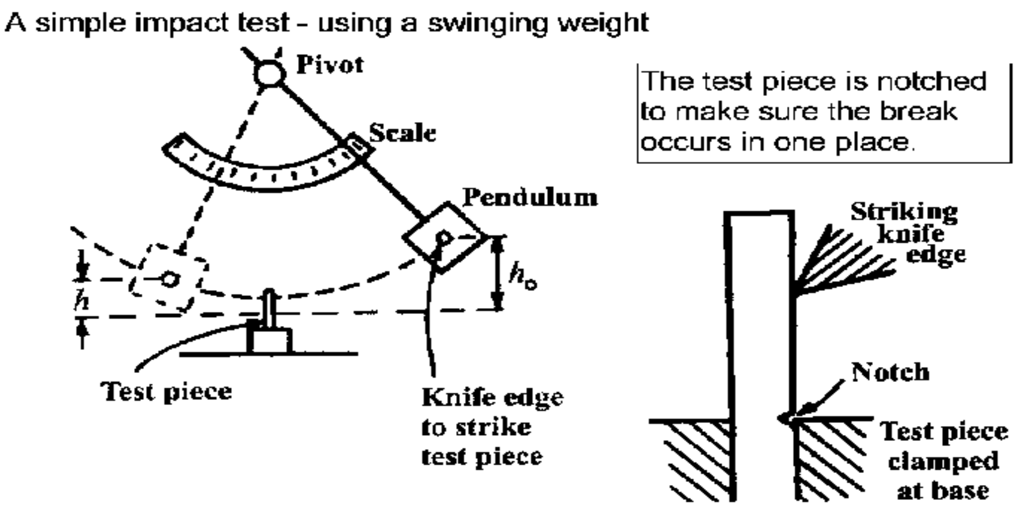


Fig. 15. Impact testing procedure.

7. Results

7.1. Bending Test Results (ASTM D 790)

The following tests were conducted on the fabricated composite specimens.

- **BL1:** Figure 16 shows the result for the BL1 specimen with the dimension of 13 × 25 × 5 cm^3, a ratio of Resin: Fiber = 9:1 and that of Coir: Hair = 4:1.

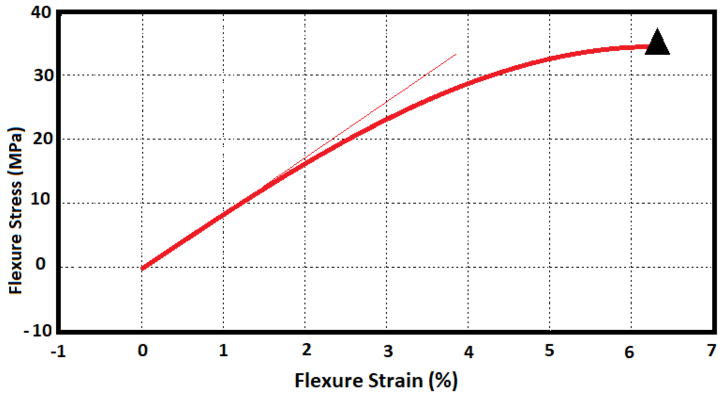


Fig. 16. Graph between flexure stress and flexure strain for BL1 specimen.

- **BL2:** Figure 17 shows the result for the BL2 specimen with the dimension of 13 × 125 × 5 cm3, a ratio of Resin: Fiber = 9:1 and that of Coir: Hair = 3:2.

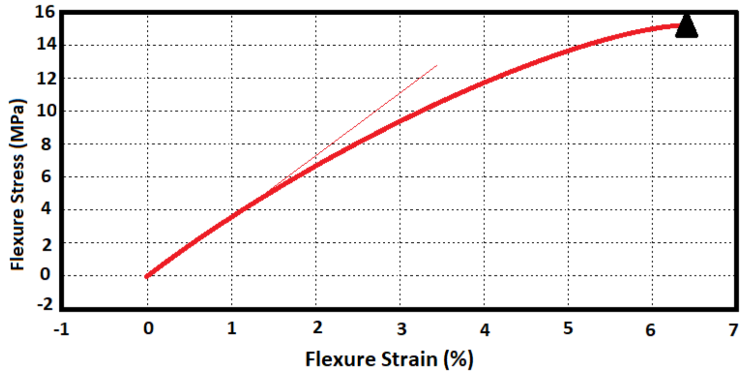


Fig. 17. Graph between flexure stress and flexure strain for BL2 specimen.

- **BL3:** Figure 18 shows the result for the BL3 specimen with the dimension of 13 × 125 × 5 cm^3, a ratio of Resin: Fiber = 9:1 and that of Coir: Hair = 2:3.

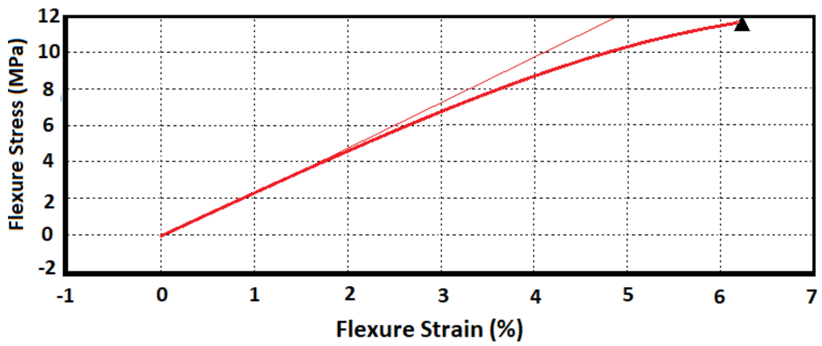


Fig. 18. Graph between flexure stress and flexure strain for BL3 specimen.

- **BL4:** Figure 19 shows the result for the BL4 specimen with the dimension of 13 × 125 × 5 cm^3, a ratio of Resin: Fiber=9:1 and that of Coir: Hair=1:4.

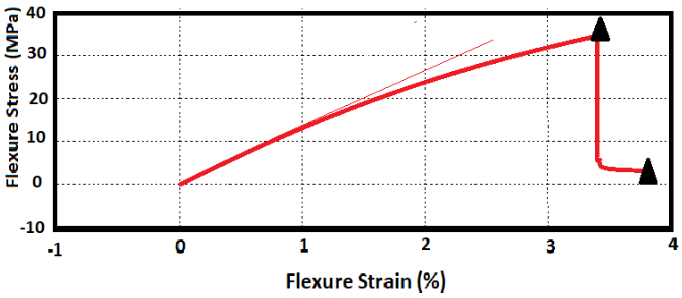


Fig. 19. Graph between flexure stress and flexure strain for BL4 specimen.

- **BT1:** Figure 20 shows the result for the BT1 with the dimension of 13 × 125 × 5 cm^3, a ratio of Resin: Fiber = 9:1 and that of Coir: Hair = 4:1.

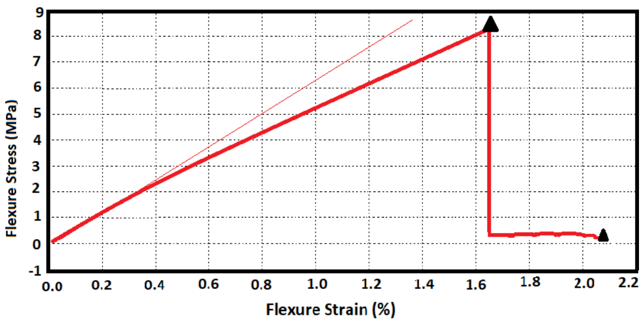


Fig. 20. Graph between flexure stress and flexure strain for BT1 specimen.

- **BT2:** Figure 21 shows the result for the BT2 specimen with the dimension of 13 × 125 × 5 cm^3, a ratio of Resin: Fiber = 9:1 and that of Coir: Hair = 3:2.

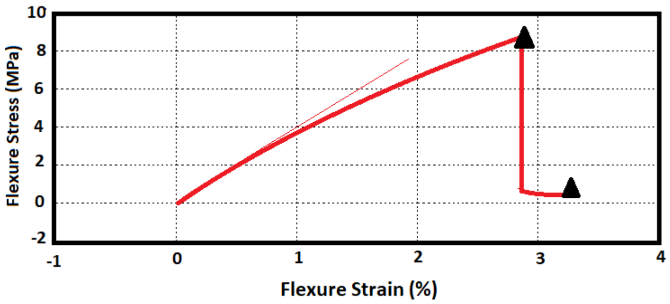


Fig. 21. Graph between flexure stress and flexure strain for BT2 specimen.

- **BT3:** Figure 22 shows the result for the BT3 specimen with the dimension of 13 × 125 × 5 cm^3, a ratio of Resin: Fiber = 9:1 and that of Coir: Hair = 2:3.

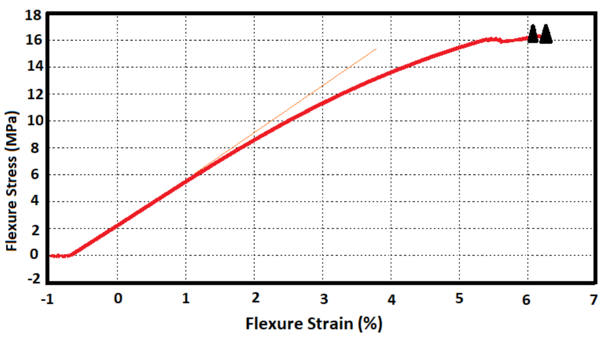


Fig. 22. Graph between flexure stress and flexure strain for BT3 specimen.

- **BT4:** Figure 23 the result for the BT4 specimen with the dimension of 13 × 125 × 5 cm^3, a ratio of Resin: Fiber = 9:1 and that of Coir: Hair = 4:1.

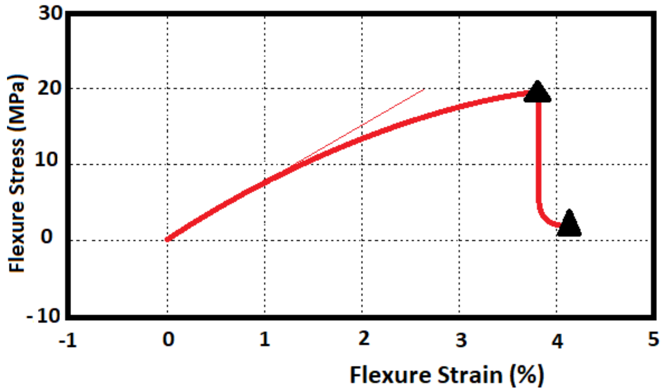


Fig. 23. Graph between flexure stress and flexure strain for BT4 specimen.

- **BCH1:** Figure 24 shows the result for the BCH1 specimen with the dimension of 13 × 125 × 5 cm^3, a ratio of Resin: Fiber = 9:1 and that of Coir: Hair = 4:1.

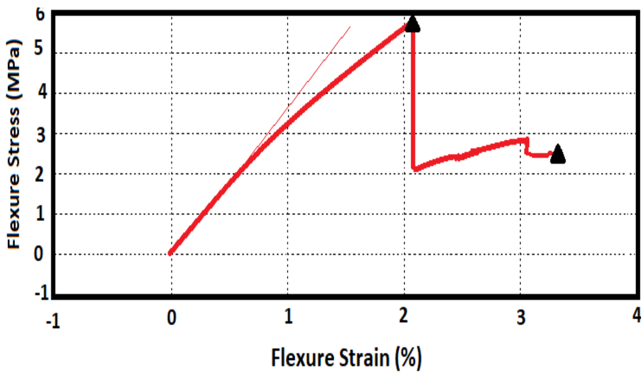


Fig. 24. Graph between flexure stress and flexure strain for BCH1 specimen.

- **BCH2:** Figure 25 shows the result for the BCH1 specimen with the dimension of 13 × 125 × 5 cm^3, a ratio of Resin: Fiber = 9:1 and that of Coir: Hair = 2:3.

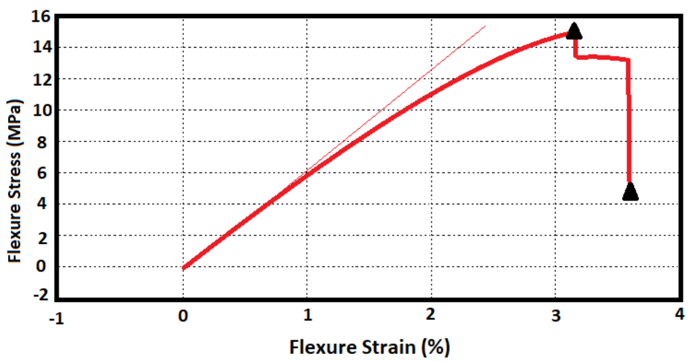


Fig. 25. Graph between flexure stress and flexure strain for BCH2 specimen.

- **BCH3:** Figure 26 shows the result for the BCH3 specimen with the dimension of 13 × 125 × 5 cm^3, a ratio of Resin: Fiber = 9:1 and that of Coir: Hair = 2:3.

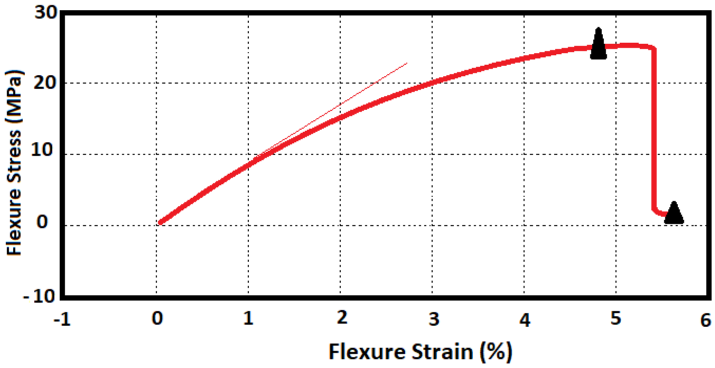


Fig. 26. Graph between flexure stress and flexure strain for BCH3 specimen.

- **BCH4:** Figure 27 shows the result for the BCH4 specimen with the dimension of 13 × 125 × 5 cm^3, a ratio of Resin: Fiber = 9:1 and that of Coir: Hair = 1:4.

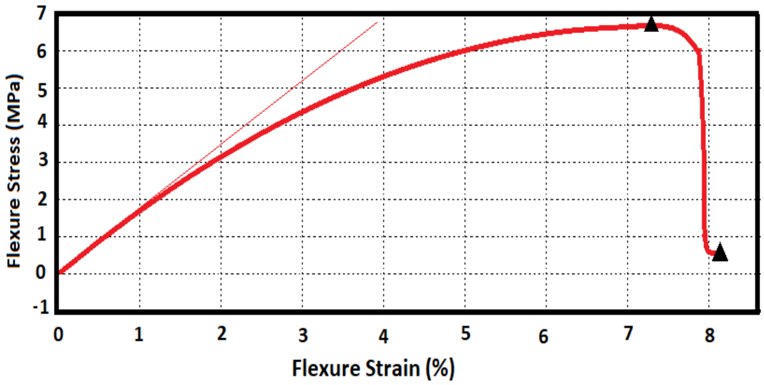


Fig. 27. Graph between flexure stress and flexure strain for BCH4 specimen.

Table 2 presents the detailed results of the bending test for all composite specimens.

Table 2. Results of the bending test

S. No.	Nomenclature	Support span (in mm)	Speed (mm/min)	Maximum flexure load (N)	Flexure stress at max. flexure load (MPa)	Flexure load @break (N)	Flexure strength @ break (MPa)	Flexure strain at break (%)	Width (mm)	Thickness (mm)
1.	BL1	100.0	3.0	126.5	35.2	125.8	35.0	6.2	11.0	7.0
2.	BL2	100.0	3.0	53.4	14.8	52.7	14.6	6.2	11.0	7.0
3.	BL3	100.0	3.0	43.0	11.9	42.3	11.7	6.2	11.0	7.0
4.	BL4	100.0	3.0	130.3	36.2	16.7	4.6	3.9	11.0	7.0
5.	BT1	100.0	3.0	83.8	9.0	1.1	0.1	3.1	11.5	11.0
6.	BT2	100.0	3.0	76.5	8.2	2.7	0.2	2.1	11.5	11.0
7.	BT3	100.0	3.0	59.9	16.6	59.4	16.5	6.2	11.0	7.0
8.	BT4	100.0	3.0	73.6	20.4	6.6	1.8	4.0	11.0	7.0
9.	BCH1	100.0	3.0	66.9	5.9	29.9	2.6	3.4	11.0	11.0
10.	BCH2	100.0	3.0	56.9	15.8	16.8	4.6	3.6	11.0	7.0
11.	BCH3	100.0	3.0	85.6	23.8	6.3	1.7	5.6	11.0	7.0
12.	BCH4	100.0	3.0	63.4	6.8	3.3	0.3	8.1	11.5	11.0

7.2. Impact Test Results (ASTM D 256)

An impact test was conducted on 12 specimens of different compositions and fiber orientation of specimen size (13 × 62 × 5 cm^3). Three fiber orientations were selected, and corresponding to each orientation, four specimens of different compositions were prepared for testing and analysis. From the results obtained from the experiment, corresponding graphs were plotted. The obtained results with their corresponding graphs are as follows.

- Longitudinal fiber orientation (Table 3 and Fig. 28)

Table 3. Impact test result for longitudinal fiber orientation

S. No.	Specimen	Impact strength (kJ/m^2)
1	IL1	11.9688
2	IL2	5.4237
3	IL3	13.1744
4	IL4	6.4302

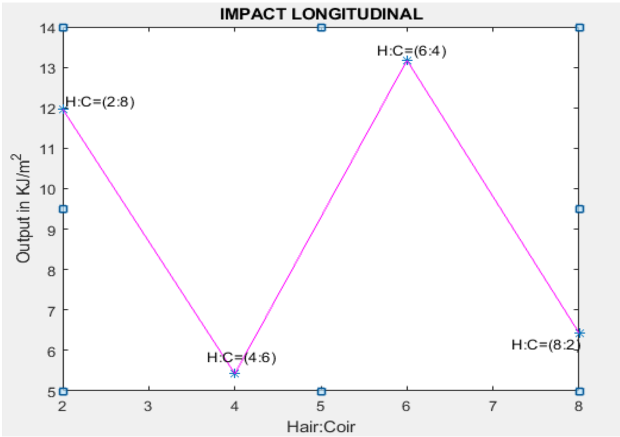


Fig. 28. Graphical analysis of impact test result for longitudinal fiber orientation.

- Transverse fiber orientation (Table 4 and Fig. 29)

Table 4. Impact test result for transverse fiber orientation.

Sample No.	Specimen	Impact strength (kJ/m^2)
1	IT1	3.7342
2	IT2	2.7600
3	IT3	4.5364
4	IT4	10.3982

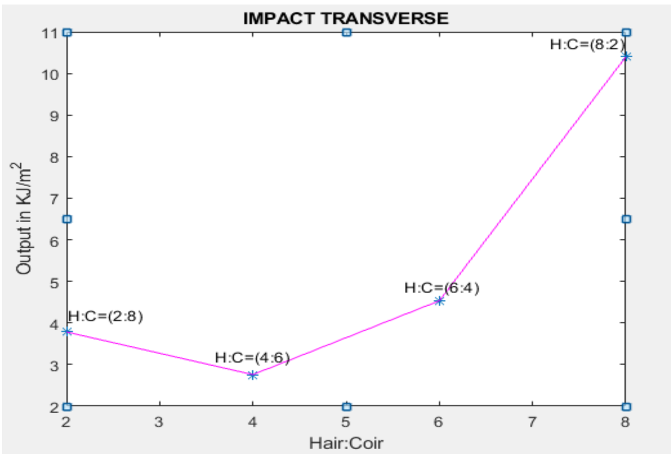


Fig. 29. Graphical analysis of impact test result for transverse fiber orientation.

- Cross-hatched fiber orientation (Table 5 and Fig. 30)

Table 5. Impact test result for cross-hatched fiber orientation.

Sample No.	Specimen	Impact strength (kJ/m^2)
1	ICH1	3.4513
2	ICH2	4.7484
3	ICH3	2.6226
4	ICH4	2.1098

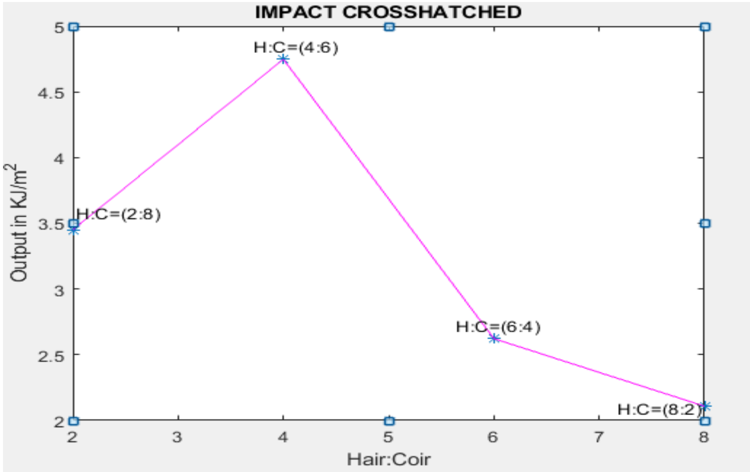


Fig. 30. Graphical analysis of impact test result for cross-hatched fiber orientation.

The above-obtained data indicated that that the specimens with longitudinal fiber orientation better impacted strength than transverse and cross-hatched fiber orientations. Cross-hatched fiber-oriented composite specimens were not impacted in terms of resistance. The maximum and minimum impact strength were: 13.1744 kJ/m^2 in IL3 and 2.1098 kJ/m^2 in ICH4.

7.3. Water Absorption Test Results (ASTM D 570)

A water absorption test was conducted on eight specimens of different compositions and fiber orientations, each of size 50 × 50 × 5 cm^3. Two fiber orientations were selected, and corresponding to each orientation, and four specimens of different compositions were prepared for testing and analysis. From the results obtained from the experiment, corresponding graphs were plotted. The obtained results with their corresponding graphs are as follows.

- Longitudinal/Transverse fiber orientation (Table 6 and Fig. 31)

Table 6. Water absorption result for longitudinal/transverse orientation.

Sample No.	Specimen	Weight of specimen before testing W_1 (in grams)	Weight of specimen after testing W_2 (in grams)	% Water Absorption = $\frac{W_2 - W_1}{W_1} \times 100$ (in %)
1	WL1	19.3280	19.7750	0.98
2	WL2	17.1229	17.3102	1.09
3	WL3	25.7233	25.9405	0.84
4	WL4	24.0451	24.2450	0.83

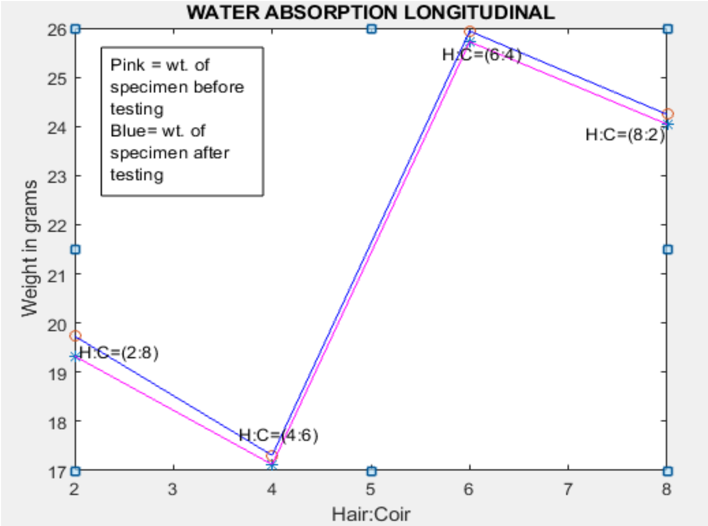


Fig. 31. Graphical analysis of water absorption test results for longitudinal/transverse fiber orientation.

- Cross-hatched fiber orientation (Table 7 and Fig. 32)

Table 7. Water absorption result for cross-hatched orientation.

Sample No.	Specimen	Weight of specimen before testing W_1 (in grams)	Weight of specimen after testing W_2 (in grams)	% Water Absorption = $\frac{W_2 - W_1}{W_1} \times 100$ (in %)
1	WCH1	22.1498	22.6872	2.43
2	WCH2	23.1233	23.3992	1.19
3	WCH3	17.6850	17.9207	1.33
4	WCH4	20.5783	20.7744	0.95

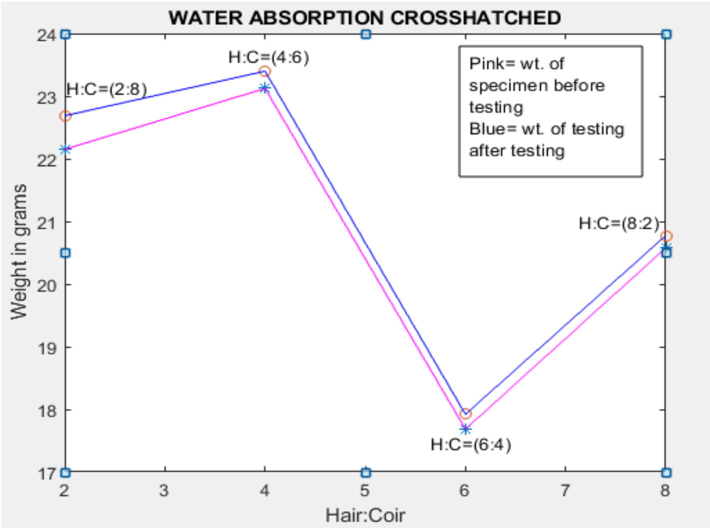


Fig. 32. Graphical analysis of water absorption test results for cross-hatched fiber orientation.

From the obtained experimental results, it was concluded that almost all the specimens were moisture-resistant.

7.4. Brief Comparison of Hair-coir, Glass Fiber, and Carbon Fiber Composites

Table 8 illustrates the fundamental differences among the hair-coir, glass fiber, and carbon fiber composites [18,19].

Table 8. Comparison among hair-coir, glass fiber, and carbon fiber composite.

Sample No.	Parameter	Hair-coir composite	Glass fiber composite	Carbon fiber composite
1	Impact strength (kJ/m^2)	13.1744	11.6	45, but for some grades, 13.4
2	Flexural strength (MPa)	36.27	28.25	500
3	Water absorption (%)	2.13	5-9	0.5
4	Average value of Young's modulus (GPa)	1.194	2.01	250
5	Approximate cost of fibers	Inexpensive	180/kg	3000/piece
6	Applications	Packaging material, etc.	Electrical insulation, etc.	Aeronautical industry, etc.
7	Special advantage	Biodegradable, waste reduction	-	-

8. Conclusion

In the present study, we developed a new composite material using human hair and coir fibers as reinforcements and polyester resin as a matrix. The newly developed material had specific exceptional properties, which justifies that the developed material might replace glass fiber composite and, in several instances, can even replace carbon fibers. The investigation result showed that the maximum impact strength was 13.1744 kJ/m^2 for the IL3 specimen with hair and coir fibers in the ratio 3:2, and the minimum impact strength was 2.1098 kJ/m^2 for the specimen ICH4 with hair and coir fibers in the ratio 4:1. From the results of water absorption test, it was concluded that the developed material was almost completely water resistant with maximum water absorption percentage of only 2.13% in the WCH1 specimen. Fiber orientation did not play a significant role in water absorption. Only fiber content played a vital role in water absorption. The maximum obtained flexural strength was 36.27 MPa for specimen BL4 with hair and coir in the ratio 4:1. The developed composite material, owing to its desirable properties, can be used for essential local and commercial applications such as packaging material development. The developed material showed exceptional properties, which make it suitable to be utilized in future applications such as the development of packaging materials of high-impact strength and blades of low-power generating capacity windmills. The creation and evaluation of prototypes made from the hair-coir reinforced composite material for the aforementioned applications is allowed in future research.

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