INFLUENCE OF AGEING IN DIFFERENT MEDIUMS ON THE MECHANICAL PROPERTIES OF JUCO/CARBON EPOXY COMPOSITES

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ABSTRACT

Natural fiber-based green composites are getting enormous attention in recent times because of their attractive properties like high specific strength, lightweight, lower cost, and biodegradability. The application of natural plant-based fibers together with synthetic fibers can potentially replace synthetic fiber-based composites without much loss in desired mechanical properties. This type of hybrid composite is now being used in the interior and exterior parts of various automobiles and for lightweight load-bearing structural applications. The hand lay-up with cold press process has been utilized in this study to fabricate unidirectional JUCO/Carbon fabric-reinforced epoxy composites of different types. JUCO fibers were chemically treated with a 5% NaOH solution before the fabrication of the composites. Tensile, flexural, impact, and water absorption tests have been conducted to evaluate the mechanical properties of the fabricated composites and hybrids. Composite samples were also immersed in an acidic medium and artificial seawater for more than 150 days to observe the impact of ageing on the mechanical properties of the composites. The obtained results have shown that hybridization with carbon fiber enhanced the mechanical properties and durability of the natural fiber-reinforced hybrid composites due to the strong and stiff nature of carbon fiber. However, a reduction of strength was observed when the composite samples were immersed in the corrosive mediums. The tensile and flexural strength of the composites was reduced as the reinforced natural fibers degraded and became ductile because of the corrosive and acidic effects of the immersion mediums. Whereas, the impact strength of the composites was enhanced. It was found that ageing in the seawater medium has a higher adverse effect on tensile strength, on the other hand, the acidic medium has a higher impact on flexural strength. Increment in impact strength was observed to be greater in the case of the acidic medium. Chemical treatment of JUCO fibers and hybridization with carbon fibers also improved the moisture absorption behavior of the composites due to the improvement in the hydrophobic nature of the constituent fibers.

Keywords: *Hybrid composites, JUCO/carbon fiber, mechanical properties, ageing*

1. INTRODUCTION

Natural plant-based fibers have been getting ample consideration as reinforcement material in composites in recent years. The application of natural fibers in place of non-recyclable synthetic fibers is increasing due to the applied environmental regulations, and the consumer's demand for recyclable and eco-friendly materials (Sujon et al., 2020; Hosen et al., 2023; Ferdous et al., 2023). Natural fiber reinforced composites (NFRCs) are environment-friendly sustainable materials that have gained a lot of interest in the past decade due to their excellent mechanical properties, corrosion resistance, biodegradability, lightweight, and low price (Turjo et al., 2023; Bhuiyan et al., 2023; Khalid et al., 2020). During the hybridization process, natural fibers are combined with synthetic fibers to obtain enhanced mechanical and moisture absorption properties and reduce the cost of the hybrids (Khalid et al., 2020). Natural fiber-reinforced hybrid composites are being used in automobiles, defense, railways, furniture, packaging, shipping pallets, and civil engineering (Turjo et al., 2023).

Because of its superior properties like low density, high strength, good elasticity, and fire resistance, carbon fiber is widely used as reinforcing material in many areas, for example, automotive, aerospace, marine, construction, and sports equipment (Si et al., 2020; Guo et al., 2019). However, due to the brittle nature of the carbon fibers, stress concentration can affect them in real-life applications (Park & Jang, 1999). Furthermore, the production of carbon fiber is costly and not eco-friendly. Replacing some of the layers of carbon fibers with ductile natural fibers in carbon fiber-reinforced composites (CFRCs) can maintain strength and reduce the cost of the composites at the same time. Therefore, the JUCO mat is incorporated with the carbon fiber mat in this research.

Researchers have performed many studies on composite materials with different polymer matrices like epoxy resin, polyethylene, polypropylene, and polyester. Epoxy resin is the most used one among them because of its excellent adhesive strength, high mechanical strength, low shrinkage, and good corrosion resistance (Sujon et al., 2020).

NFRCs have to sustain different types of environments during the service life as they come in contact with various types of corrosive fluids i.e. acidic, basic, oxidizing, and reducing. However, not many studies have investigated the sustainability and durability issues of natural fiber-reinforced composites in different mediums. Previous studies have found that corrosive fluids cause degradation of the mechanical properties of NFRCs to a large extent compared to synthetic fiber-reinforced composites due to the higher water absorption tendencies and organic nature of the natural fibers (Thwe and Liao, 2002; Liao et al., 1999).

JUCO fabric is a combination of jute fiber and cotton fiber which contains 50% jute and 50% cotton by weight. The jute fibers are aligned parallel in a particular direction and the cotton fibers are also aligned parallel but along the direction perpendicular to the direction of the jute fibers (see Figure 1).

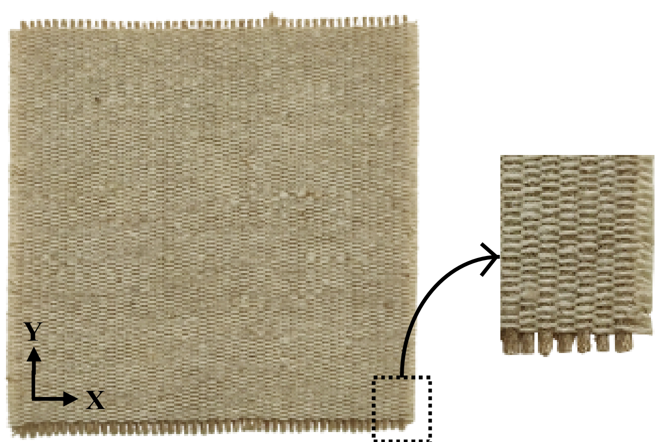


Figure 1: Unidirectional JUCO fabric mat

Many researchers have conducted research on hybrid composites with the combination of different synthetic and natural fibers i.e. jute, cotton, banana, hemp, kenaf, sisal, coir, glass, and kevlar, but the combination of JUCO/Carbon epoxy has not yet been explored and reported in the open literature (Rahid et al., 2020). Therefore, this study has been carried out to evaluate the mechanical and water absorption properties of JUCO/Carbon epoxy composites. Five different types of composite, each having five fabric layers, have been fabricated and analyzed in this experiment. All the composites were fabricated using the hand lay-up with cold press process. The effect of ageing in different corrosive mediums on the mechanical properties of the fabricated composites has also been investigated to analyze the durability of the concerned materials.

2. EXPERIMENTAL PROCEDURE

2.1 Materials Used

The composites in this experiment were fabricated using JUCO fabric and carbon fabric as the reinforcements, along with epoxy resin and hardener as the matrix. The plain unidirectional JUCO fabric of 450 g/m^2 with a density and fabric thickness of 1.294 g/cm^3 and 1 mm, and the carbon fabric of 300 g/m^2 with a density and thickness of 1.822 g/cm^3 and 0.20 mm were collected from Mony Jute Goods and Handicrafts Ind., Dhaka, Bangladesh, and Hangzhou Impact New Materials Co. Ltd., Zhejiang, China, respectively. Epoxy resin Lapox B-11 and hardener Lapox K-6 were collected from M/S Chadpur Traders, Dhaka, Bangladesh. Figure 2 shows the unidirectional JUCO and carbon fabric mats, and resin-hardener used to fabricate the composites.

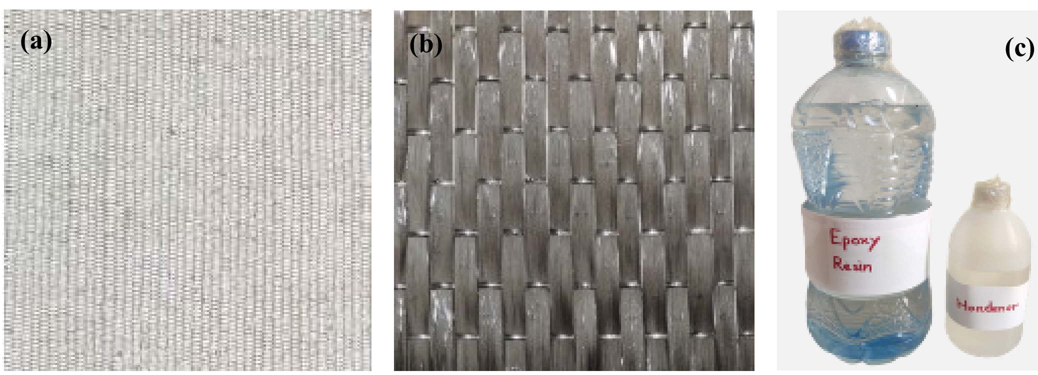


Figure 2: (a) JUCO fabric mat, (b) Carbon fabric mat, (c) Epoxy resin and hardener

2.2 Chemical Treatment

Researchers have found that different chemical treatments on the natural fibers can increase the bonding between fibers and matrix, which may enhance the mechanical properties of the composites (Sanjay et al., 2019; Girijappa et al., 2019; Kabir et al., 2012). Alkaline treatment of natural fibers by sodium hydroxide (NaOH) is one of the most widely used chemical treatment methods. NaOH treatment reduces hydrophilic hydroxyl groups and removes a certain portion of hemicellulose, lignin, pectin, wax, and oil covering the fibers. Therefore, moisture resistance, adhesion between fibers and matrix, and mechanical and thermal behaviors of composites are elevated (Sanjay et al., 2019; Kabir et al., 2012). Sanjay et al. (2019) stated that a 5% (w/v) NaOH solution is optimal for the chemical treatment of most of the natural fibers. Therefore, the JUCO fabric was treated with a 5% (w/v) NaOH solution for 24 hours at room temperature. Later, the treated fabric was washed using distilled water to remove the excess chemicals and dried properly under sunlight.

2.3 Fabrication of the Composites

Composites were fabricated using the hand lay-up with cold press process in this research. Epoxy resin and hardener were used at a ratio of 11:1 by weight as the matrix for the fabrication of the composites (Turjo et al., 2023). Five types of composites were fabricated using five fabric layers in each type. Table 1 shows the stacking sequences of the fabricated composites. Two plates of dimensions 12”×12” were fabricated for each type of composite. Fabrication of all the composites was carried out using dry fiber mats at room temperature.

2.4 Preparation of Corrosive Mediums

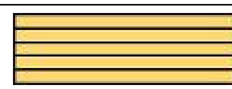
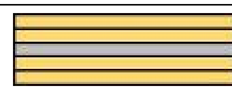
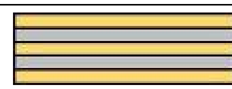
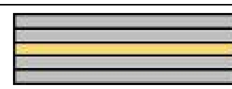
2.4.1 Acidic Medium

99% glacial acetic acid was added with distilled water to prepare the acidic medium of pH 3. The prepared solution was observed for 24 hours before the immersion of the samples to ensure the correct and stable pH.

2.4.2 Artificial Seawater Medium

A 3% NaCl solution was prepared with distilled water to achieve the seawater conditions of pH 8 (Bhuiyan et al., 2023). The artificial seawater solution was also observed for 24 hours before the immersion of the samples to ensure the correct and stable pH.

Table 1: Stacking sequences of the fabricated composites

Composite Type	Stacking Sequence	Schematic Stacking Sequence
A	J-J-J-J-J	
B	J-J-C-J-J	
C	J-C-J-C-J	
D	C-J-C-J-C	
E	C-C-J-C-C	

3. RESULTS AND DISCUSSION

3.1 Weight Fraction and Volume Fraction of Fibers

Weight fraction and volume fraction of fibers have a significant influence on the mechanical properties of the composites. The weight fraction of the fibers and the matrix were calculated based on the weights of fabric layers, used resin-hardener solution (matrix), and fabricated composite plates using the following equations.

$$w_{cp} = w_j + w_c + w_m \tag{1}$$

$$W_j = \frac{w_j}{w_{cp}} \tag{2}$$

$$W_c = \frac{w_c}{w_{cp}} \tag{3}$$

$$W_m = 1 - (W_j + W_c) \tag{4}$$

where, w is the weight, W is the weight fraction and the subscripts cp, j, c, and m denote composite plate, JUCO fiber, carbon fiber, and matrix respectively. As the area of the used fabric mats and the corresponding fabricated composite plates are equal, the volume fraction of the fibers and the matrix can be obtained based on the thickness of fabric layers and fabricated composite plates using the following equations.

$$V_j = \frac{n_j t_j}{t_{cp}} \tag{5}$$

$$V_c = \frac{n_c t_c}{t_{cp}} \tag{6}$$

$$V_m = 1 - (V_j + V_c) \tag{7}$$

where, V is the volume fraction, n is the number of fabric mats, t is the thickness, and subscripts cp, j, c, and m denote composite plate, JUCO fiber, carbon fiber, and matrix respectively. The weight and volume fraction of the fibers and the matrix in the fabricated composites are presented in Table 2.

Table 2: Weight fraction and volume fraction of fibers and matrix in the fabricated composite plates

Type	Plate	W_m (%)	W_j (%)	W_c (%)	V_m (%)	V_j (%)	V_c (%)
A	A_1	76.44	23.56	0	29.28	70.72	0
	A_2	76.15	23.85	0	26.90	73.10	0
B	B_1	73.64	22.49	3.87	22.08	74.21	3.71
	B_2	73.83	22.31	3.86	29.05	67.57	3.38
C	C_1	71.48	19.72	8.80	24.78	66.37	8.85
	C_2	72.65	18.69	8.66	34.36	57.92	7.72
D	D_1	68.78	16.14	15.08	28.77	54.79	16.44
	D_2	69.14	15.30	15.56	40.19	45.45	13.64
E	E_1	67.18	9.38	23.44	52.88	26.18	20.94
	E_2	67.03	9.50	23.47	50.41	27.55	22.04

3.2 Density and Void Content

Void content is an important parameter as it indicates the quality of fabrication and influences the mechanical properties of the fabricated composites. To calculate the void content, both theoretical and actual densities of the fabricated composites are required. Using the densities and weight fractions of the used fibers and matrix, the theoretical density of the fabricated composites can be obtained as per the following equation.

$$\rho_t = \frac{1}{\left(\frac{W_j}{\rho_j} + \frac{W_c}{\rho_c} + \frac{W_m}{\rho_m}\right)} \tag{8}$$

where, ρ_t is the theoretical density, W_j, W_c, and W_m are the weight fraction of JUCO fiber, carbon fiber, and matrix respectively, ρ_j, ρ_c, and ρ_m are the density of JUCO fiber, carbon fiber, and matrix respectively. The actual density of the fabricated composites was experimentally determined by the water immersion method as shown in Equation (9) where ρ_a is the actual density and S_p is the specific gravity.

$$\rho_a = S_p \times 0.9976 \text{ g/cm}^3 \tag{9}$$

Table 3: Physical properties and void content of the fabricated composite plates

Type	Plate	AD (g/m²)	S_p	ρ_a (g/cm³)	ρ_t (g/cm³)	V_v (%)
A	A_1	7904	1.193	1.190	1.213	1.90

	A_2	7982	1.196	1.193	1.213	1.65
B	B_1	6975	1.221	1.218	1.229	0.90
	B_2	6890	1.212	1.209	1.229	1.63
C	C_1	5991	1.239	1.236	1.248	0.96
	C_2	5743	1.230	1.227	1.246	1.53
D	D_1	4766	1.263	1.260	1.273	1.02
	D_2	4660	1.255	1.252	1.275	1.80
E	E_1	4707	1.264	1.261	1.306	3.45
	E_2	3674	1.291	1.288	1.306	1.38

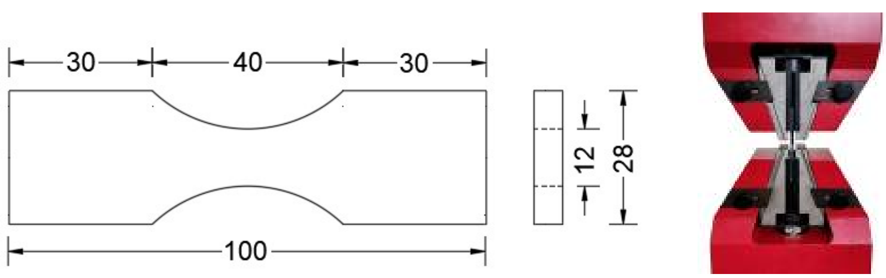
ASTM D-2734-70 was followed to determine the theoretical percentage of void content of the fabricated composites. Equation (10) was used to calculate the volume fraction of voids.

$$V_v = \frac{\rho_t - \rho_a}{\rho_t} \times 100\% \quad (10)$$

where, V_v is the volume fraction of voids, ρ_t, and ρ_a are the theoretical and actual densities of the fabricated composites. Areal density (AD), specific gravity, actual density, theoretical density, and volume fraction of voids of the fabricated composites are listed in Table 3. The minimum void content was found to be 0.90% for the composite plate B_1 and the maximum void content was found to be 3.45% for the composite plate E_1 which is within the acceptable limit (Wang et al., 2006).

3.3 Tensile Test

The dumbbell-type specimens with a dimension of 100 mm × 28 mm were used for the tensile test. The thickness of the specimens varied depending on the type and number of fabric layers used to fabricate the composites. The tests were performed on an Instron Testometric M500-100CT universal testing machine (UTM) using a 100 kN load cell and 0.001 N pretension with a cross-head speed of 10 mm/min. Some important tensile properties were given automatically by the winTest™ software. The geometry of the specimens and the clamping of the samples into the UTM can be seen in Figure 3. At least three specimens of each type of composite were tested to get the actual results. This test was carried out before and after the ageing process. The dry samples (not aged in the corrosive mediums) were considered as control specimens in this study. Three samples of each type of composite were also immersed in each corrosive medium and tested after ageing for more than 150 days to investigate the influence of corrosive effects on the tensile properties.



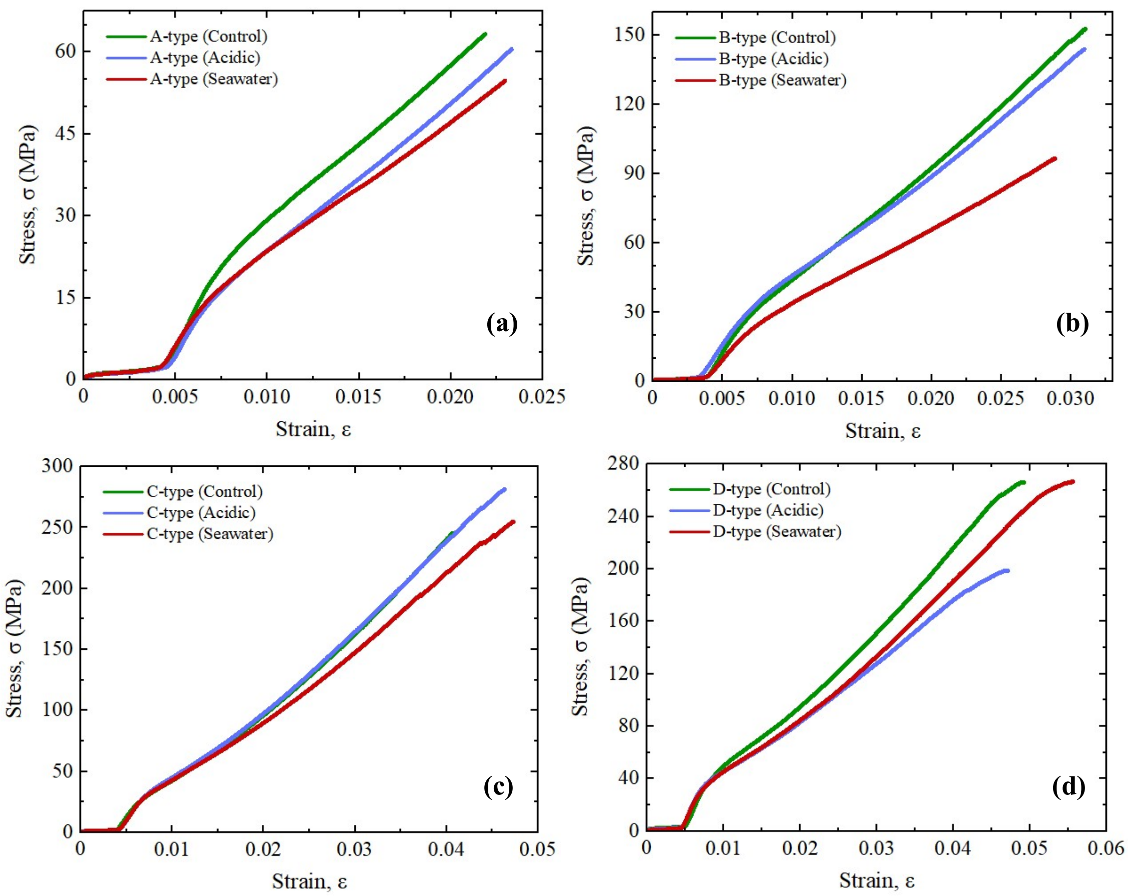
(a) (b)

Figure 3: Uniaxial tensile test; (a) Specimen geometry, (b) Machine arrangement

Table 4: Summarized results of the uniaxial tensile test

Composite Type	Sample Status	Peak Force (kN)	Young's Modulus (GPa)	Peak Stress (MPa)	Peak Elongation (mm)	Peak Strain (%)
A	Control	6.30	6.25	63.27	2.21	2.19
	Acidic	5.69	4.40	60.53	2.35	2.33
	Seawater	5.52	4.33	54.73	2.30	2.29

B	Control	12.09	4.79	152.85	3.11	3.10
	Acidic	11.70	6.36	143.93	3.12	3.10
	Seawater	7.59	5.21	96.58	2.91	2.88
C	Control	15.95	5.09	245.41	4.10	4.07
	Acidic	21.56	4.99	281.25	4.69	4.64
	Seawater	20.63	4.39	254.60	4.80	4.73
D	Control	11.96	4.25	266.14	4.93	4.90
	Acidic	9.89	4.04	198.51	4.69	4.67
	Seawater	10.91	3.61	266.43	5.59	5.56
E	Control	9.60	13.65	332.15	3.79	3.71
	Acidic	10.61	5.27	300.46	4.50	4.46
	Seawater	6.40	15.78	195.30	3.92	3.92



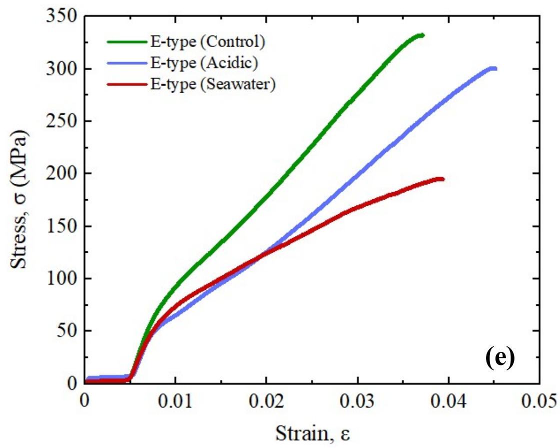


Figure 4: Comparison of tensile stress-strain behavior in different mediums; (a) A-type, (b) B-type, (c) C-type, (d) D-type, (e) E-type

The tensile stress-strain behavior of the fabricated composites is presented in Figure 4. The ultimate tensile strength (UTS) of the composites shows an upward trend with the increasing amount of carbon fiber mat because they are way stronger and stiffer than the JUCO fiber mat. Therefore, JUCO fibers were fractured in a short time, and after that, carbon fibers continued to withstand the load until the ultimate failure. The highest and lowest tensile strengths were found to be 332.15 MPa for *E*-type and 63.27 MPa for *A*-type composites, respectively for control samples. In addition, the results revealed that the strength of the composites decreased when they were aged in the corrosive mediums. From Table 4, it can be seen that the reduction of tensile strength was higher for samples aged in a seawater medium compared to the acidic medium. The reduction of the strength of natural fiber-reinforced composites is associated with the degradation of the natural fibers in corrosive mediums due to their higher moisture absorption tendencies and organic nature (Thwe and Liao, 2002).

3.4 Flexural Test

The three-point bending test was carried out to determine the flexural properties of the composites in both the control and aged conditions. The dimensions of the rectangle-type samples were 100 mm × 20 mm. Sample thickness varied for the different types of composite samples due to the variation in stacking layers. The tests were conducted on a Tinius Olsen 25ST UTM at a span length of 60 mm, cross-head speed of 10 mm/min, and pre-load of 5 N. Maximum deflection was set as 35 mm. Flexural properties i.e. flexural modulus, ultimate stress, ultimate strain, and break distance were given automatically by the Horizon software, which was provided by the machine manufacturer. Figure 5 shows the sample geometry and schematic diagram of the set-up of the samples in the UTM machine for the flexural test. At least three samples of each type of composite in both control and aged conditions were tested to get the actual results.

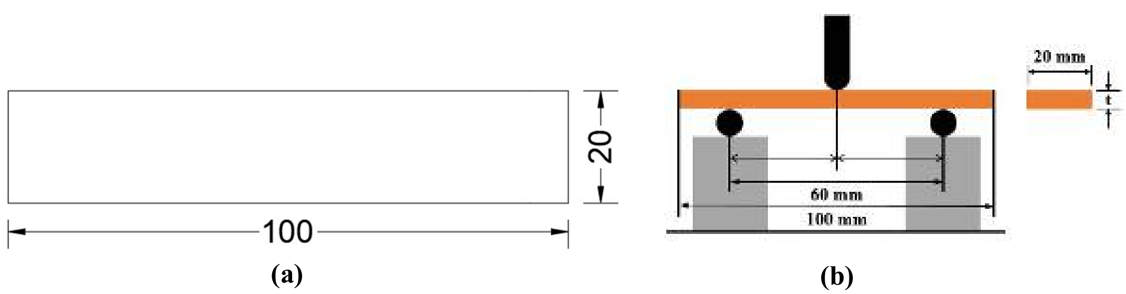
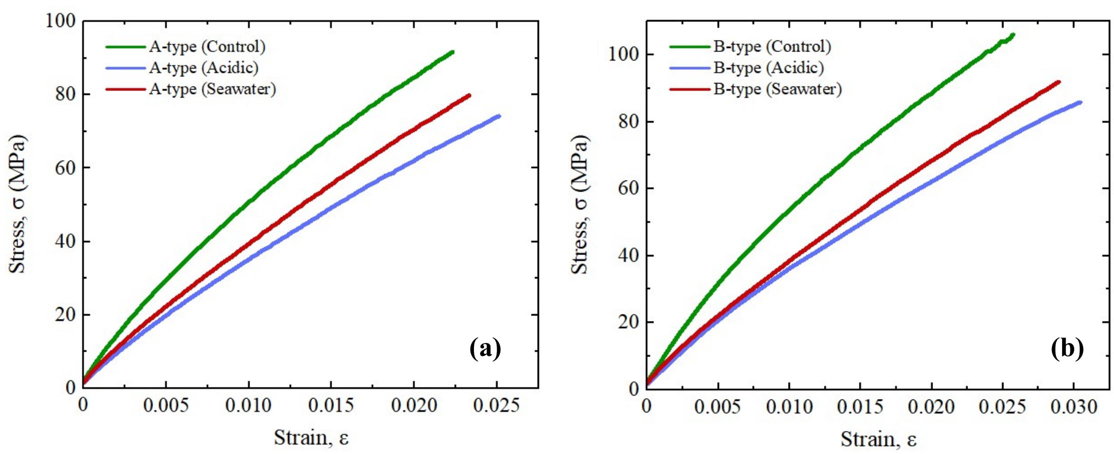


Figure 5: Flexural test; (a) Specimen geometry, (b) Machine arrangement

Table 5: Summarized results of the flexural test

Composite Type	Sample Status	Ultimate Force (kN)	Flexural Modulus (GPa)	Ultimate Stress (MPa)	Break Distance (mm)	Ultimate Strain (%)
A	Control	0.87	4.07	92.76	2.12	2.28
	Acidic	0.73	2.94	75.28	2.38	2.56
	Seawater	0.81	3.42	80.94	2.15	2.37
B	Control	0.77	4.09	107.05	2.83	2.62
	Acidic	0.66	0.43	87.49	21.40	20.16
	Seawater	0.71	3.17	93.09	3.14	2.94
C	Control	1.19	1.45	221.84	18.90	15.31
	Acidic	0.90	1.30	182.97	18.50	14.09
	Seawater	1.02	3.72	202.17	7.59	5.81
D	Control	1.93	18.21	399.41	2.88	2.19
	Acidic	1.05	3.79	322.52	14.40	8.52
	Seawater	1.11	4.26	326.98	12.10	7.68
E	Control	0.86	5.59	458.48	17.40	8.21
	Acidic	1.87	9.41	380.37	5.24	4.04
	Seawater	1.87	8.92	393.61	5.87	4.41

Figure 6 represents the flexural stress-strain behavior of the fabricated composites. Due to the compression, tension, and shear, failure in the three-point bending test occurs (Sujon et.al., 2020). As carbon fibers have a very high load-bearing capacity compared to JUCO fibers, similar behavior like the tensile test was observed. The maximum and minimum flexural strengths were found to be 458.48 MPa and 92.76 MPa for *E*-type and *A*-type composites, respectively for control specimens. The degradation of flexural strength was higher in the case of acidic medium-aged samples (see Table 5).



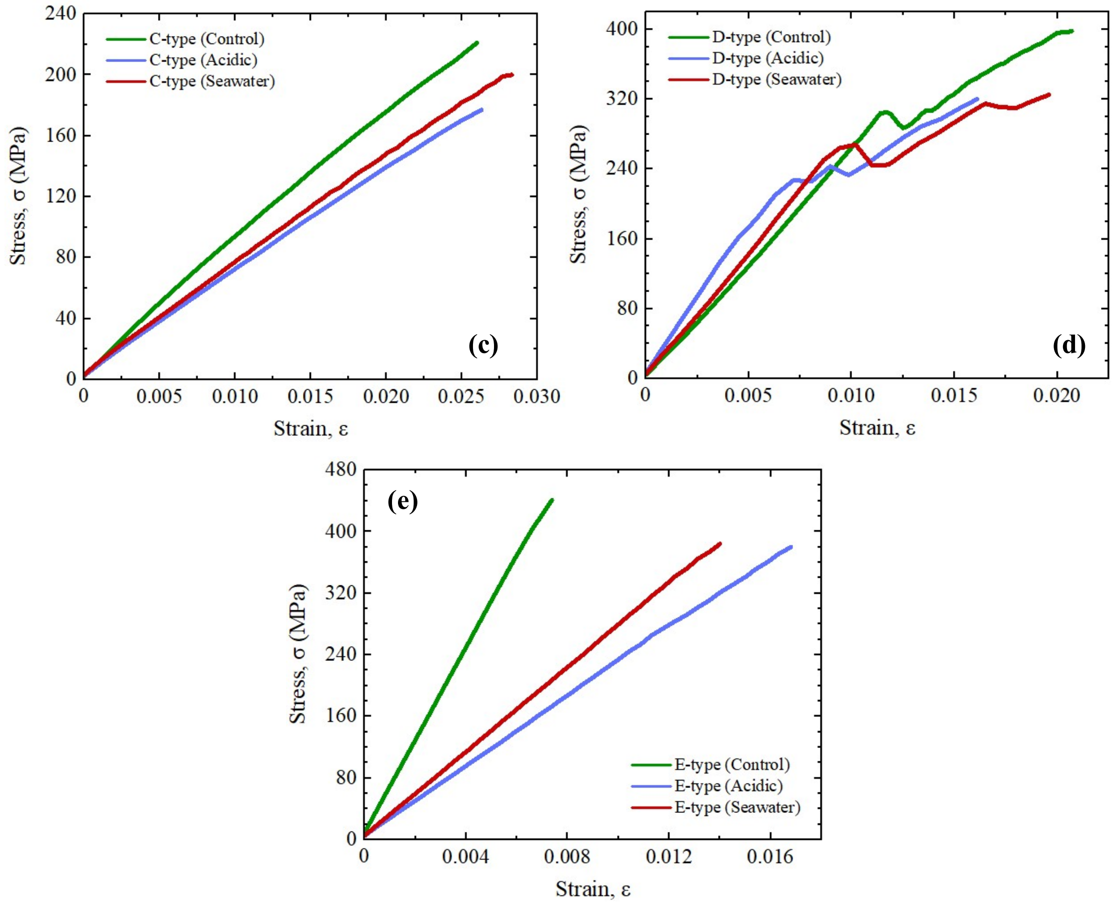


Figure 6: Comparison of flexural stress-strain behavior in different mediums; (a) A-type, (b) B-type, (c) C-type, (d) D-type, (e) E-type

3.5 Impact Test

The specimens for the impact test were prepared in accordance with the standard ASTM D6110. The Charpy impact test has been performed to determine the impact strength of the composites both before and after the ageing process in corrosive mediums using a JB-300B dial display impact testing machine. The average value of impact strength of three specimens is used in this study. Figure 7 shows the geometry of the sample and the set-up of the samples in the impact testing machine.

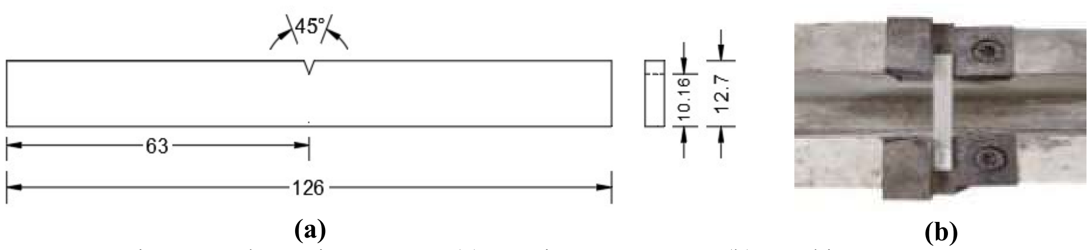


Figure 7: Charpy impact test; (a) Specimen geometry, (b) Machine arrangement

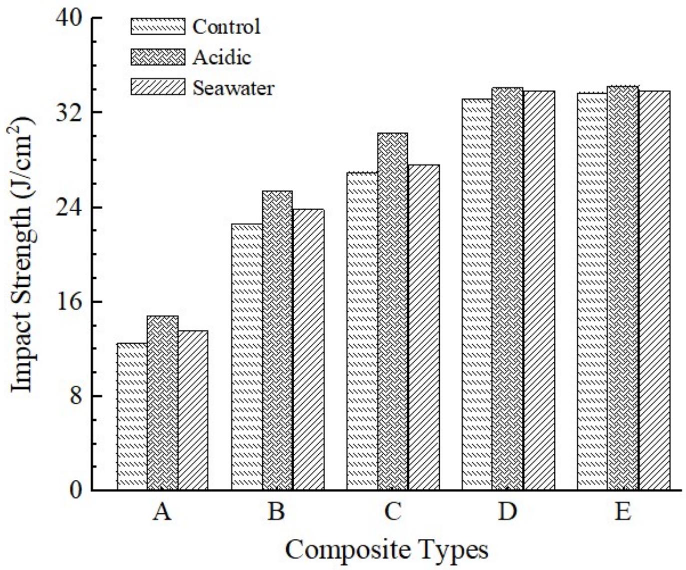


Figure 8: Comparison of impact strength between control and aged specimens

The bar chart in Figure 8 provides information about the impact strength of the composites. Impact strength represents the ability of a material to resist high-velocity applied force. Carbon fibers can absorb a higher amount of impact force than JUCO fibers, and therefore, the impact strength of the composites increases with the increasing amount of carbon fibers. As a result, the *E*-type composite showed higher impact resistance compared with the other types of composite. Ductile materials can deform more before breaking, thus can absorb more impact energy. Degradation of the natural fibers makes them more ductile and that is why the aged samples showed higher impact strength than the control samples. The acidic medium of pH 3 used in this study was more corrosive than the seawater medium of pH 8, thus it caused higher degradation and made the JUCO fibers more ductile. As a result, samples aged in the acidic medium displayed higher impact strength.

3.6 Water Absorption Test

To investigate the water absorption behavior of the composites in different aqueous solutions, samples were immersed in the prepared corrosive mediums for two months at room temperature. The water absorption rate of the fabricated composites was determined following the standard ASTM D570 with specimen dimensions of 76.2 mm × 25.4 mm. The specimens were weighed but no pre-conditioning was done before immersion. A digital balance with an accuracy of 0.001 g was used to measure the weight of the specimens at regular time intervals. The percentage of water absorption (M_m) was calculated using the equation (11).

$$M_m = \frac{M_t - M_0}{M_0} \times 100\% \tag{11}$$

where, (M_t) is the weight of the specimen over time, and (M_0) is the initial weight of the specimens before immersion in the corrosive mediums.

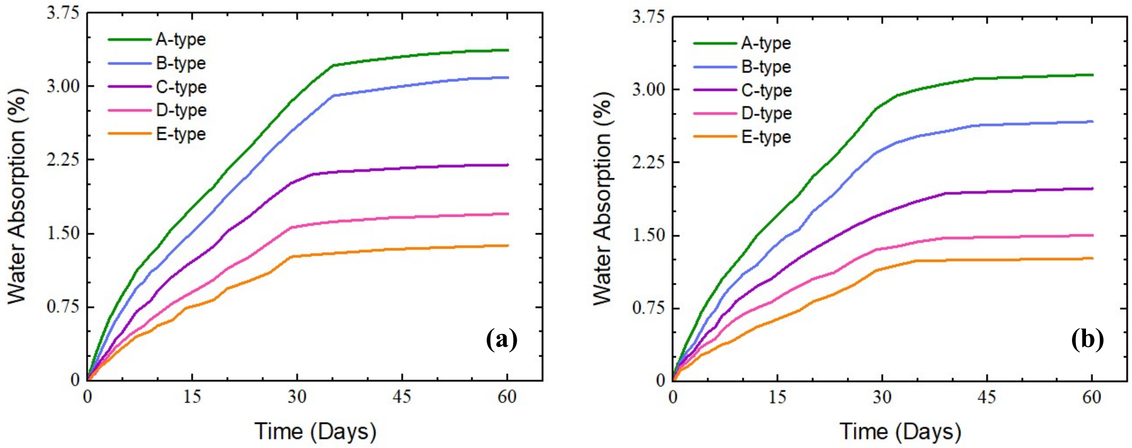


Figure 9: Moisture absorption behavior of the composites; (a) Acidic medium, (b) Seawater medium

Table 6: Water absorption properties

Composite Type	Immersion Medium	Time to Reach Saturation (days)	Absorption at Saturation (%)
A	Acidic	35	3.21
	Seawater	43	3.11
B	Acidic	35	2.91
	Seawater	43	2.63
C	Acidic	32	2.10
	Seawater	39	1.93
D	Acidic	29	1.56
	Seawater	39	1.47
E	Acidic	29	1.27
	Seawater	35	1.24

Figure 9 represents the moisture absorption behavior of the fabricated composites over a time duration of 60 days. It can be seen that the water absorption rate for all the composites increased linearly at the beginning stage until around 35 days, then the rates fell down and eventually reached saturation point. Similar behavior was found for both mediums. From the obtained results, it is also evident that increasing the amount of carbon fibers reduces moisture absorption due to their hydrophobic nature. Therefore, the *E*-type composite displayed higher resistance to water absorption, which is shown in Table 6. Also due to the chemical treatment of the natural JUCO fibers, the water absorption rate in both the acidic medium and seawater falls within 3.21%.

4. CONCLUSIONS

The following conclusions can be made from this experimental analysis.

- The hybridization of JUCO fibers with carbon fibers significantly increased the mechanical properties because of the stiff and strong nature of carbon fibers.
- Acidic and seawater medium has an enormous effect on the mechanical properties of NFRCs due to their hydrophilic nature and the plasticization effect of moisture.
- The tensile and flexural strength of the composites decreased after ageing in the corrosive mediums as a result of the degradation of JUCO fibers.
- The impact strength of the composites enhanced after ageing due to the increase in ductility of JUCO fibers after degradation.

- Improvement in the moisture absorption behavior was observed because of the surface treatment of JUCO fibers with 5% NaOH solution. The highest moisture absorption rate to be found is 3.21% (for A-type composite in the acidic medium).

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