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Exploration of the effects of seawater on the mechanical properties of JUCO/carbon epoxy composites: An experimental and numerical study

Nadim Mahmood Nayeem[1]*, Md. Foisal Hossain[2], Muhammed Sohel Rana[3] and Md. Shafiul Ferdous[4]

[1]Department of Materials Science and Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh.
[2]Department of Electronics and Communication Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh.
[3]Central Engineering Facilities, Atomic Energy Research Establishment, Ganakbari, Savar, Dhaka-1349, Bangladesh.
[4]Independent Researcher, Rockville, Maryland-20852, USA.

*Corresponding author: e-mail address: nadimmahmood1911@gmail.com; ORCID: https://orcid.org/0009-0000-8190-8114

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ABSTRACT

In this current study, five types of strong, stiff, and lightweight composites were developed utilizing hand lay-up and cold press methods by the hybridization of JUCO and carbon fabrics. Before the fabrication of the composites, the surfaces of the JUCO fabrics were treated with a 5% NaOH aqueous solution. To evaluate and compare the mechanical characteristics of the fabricated composites, tensile, flexural, impact, and hardness tests were conducted. Specimens were also aged in artificial seawater (pH 8) for 150 days to explore the effects of seawater aging on the mechanical characteristics of the composites. Numerical analysis of the tensile and flexural properties was also done by the finite element method (*FEM*). The findings from the current study showed that hybridization with carbon fibers considerably enhanced the mechanical properties of the natural fiber-reinforced composites. On the other hand, a decrement in tensile strength, flexural strength, and hardness, and an improvement in impact strength were noticed due to fiber degradation as a result of aging in seawater. Results obtained from the numerical analysis also displayed good alignment with the experimental findings.

1. Introduction

Composite materials are formed when at least two constituents with significantly dissimilar physical and chemical properties are combined. Because of the harmonious contribution of the constituents, composites exhibit superior properties than either of the constituents alone [1]. Natural resources-driven fibers have achieved enormous interest as reinforcement materials for various composites in recent times [2]. As a consequence of increasing consumer demand and environmental awareness, harmful to the environment and non-biodegradable synthetic fibers are being replaced with eco-friendly and biodegradable natural fibers in various products and applications [3, 4].
During the past few years, natural fiber-reinforced composites (*NFRCs*) have been gaining tremendous attention because of their exceptional mechanical characteristics, biodegradability, eco-friendliness, lightweight, and low cost [5]. Without much sacrifice in strength, synthetic fiber-based composites can be substituted by utilizing natural fibers together with synthetic fibers. Hybridization is the process where natural and synthetic fibers are integrated to reduce the production cost and enhance the mechanical, moisture absorption, and thermal properties of the composites [6-8]. Interior and exterior parts of automobiles and airplanes, lightweight load-bearing structures, furniture, and sports goods are some of the sectors in which natural fiber-reinforced hybrid composites are being implemented [9].
Superior strength and stiffness, low density, corrosion and fire resistance, and hydrophobicity of carbon fibers make them the perfect reinforcing agent for composites in many applications including construction, automobiles, marine, and aerospace. But, carbon fibers are not good for the environment and are rather costly. However, the price of carbon fiber-reinforced composites (*CFRCs*) can be reduced by substituting a portion of the carbon fibers with natural fibers without a significant sacrifice in different mechanical properties [10, 11]. With this in mind, natural fiber-based JUCO fabric was hybridized with carbon fabric in this study to fabricate the composites.

JUCO, shown in Figure 1(a), is a unique combination of jute and cotton yarns at a ratio of 1:1 by weight. It is an industrially manufactured fabric in which the jute yarns are weaved as weft (aligned vertically) and the cotton yarns are weaved as warp (aligned horizontally). Just a few researchers have investigated the potential of JUCO fabric as a reinforcing material for the fabrication of different types of composites [5, 12, 13].

Researchers have carried out numerous studies on composites with different polymer matrices i.e. polyester, polyethylene, epoxy resin, and polypropylene. Epoxy resin is one of the most popularly used polymer matrices because of its great adhesive strength, exceptional mechanical strength, minimal shrinkage, and strong resistance to impact, chemical, and heat. [14].

Although natural fiber-reinforced hybrid composites are being used in various marine applications, it has been discovered that moisture diffusion reduces the strength of *NFRCs* because of the degradation of natural fibers [5-7, 11]. For this reason, the effects of seawater on the mechanical properties of *NFRCs* have also been explored in the current study.

Various natural and synthetic fibers like jute, banana, cotton, hemp, kenaf, sisal, coir, bamboo, aramid, glass, Kevlar, and carbon have been used for the fabrication of hybrid composites over the years [15]. However, the hybridization of plain woven JUCO fabric and unidirectional woven carbon fabric was done in this research work to develop five types of strong, stiff, and lightweight composites employing hand lay-up and cold press methods. Uniaxial tensile, flexural, impact, and hardness tests were carried out to investigate and compare the mechanical properties of the composites. For the exploration of the effects of seawater on the mechanical properties of the composites, specimens were aged in seawater for 150 days. Results found from the tensile and flexural tests were also validated by the finite element method using Abaqus (version 6.14-2) software.

2. Materials and methods

2.1. Materials Used

Lapox B-11 (epoxy resin) and Lapox K-6 (epoxy hardener), carbon fabric, and JUCO fabric were collected from M/S Chadpur Traders, Dhaka, Bangladesh, Hangzhou Impact New Materials Co. Ltd., Zhejiang, China, and Mony Jute Goods and Handicrafts Ind., Dhaka, Bangladesh, respectively. The areal densities of the carbon and JUCO fabrics were 300 g/m^2 and 450 g/m^2, respectively. Meanwhile, the densities of the matrix, carbon fabric, and JUCO fabric were 1.19 g/cm^3, 1.82 g/cm^3, and 1.29 g/cm^3, respectively. **Figure 1** shows the fabrics used in this study for the fabrication of the composites.

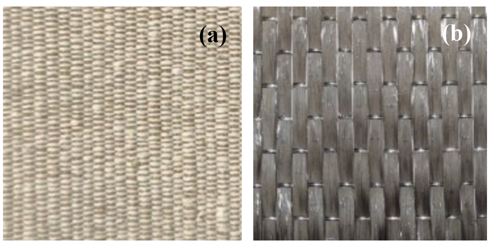


Figure 1. Reinforcements used: (a) JUCO fabric; (b) carbon fabric.

2.2. Chemical treatment of the JUCO fabrics

Researchers have found that using sodium hydroxide (NaOH) for the chemical treatment of natural fibers greatly enhances their moisture absorption resistance by removing hydrophilic hydroxyl groups from the natural fiber molecules [16-18]. It is also proven that the optimal alkaline treatment for the majority of natural fibers is 5% (w/v) NaOH [16]. For this reason, a 5% NaOH aqueous solution was used in this research to treat the surfaces of the JUCO fabrics for 24 hours before their use in composite fabrication. Later, the treated fabrics were properly dried under sunlight after being washed with distilled water.

2.3. Fabrication of the composites

Hand lay-up and cold press methods were utilized to fabricate five types of composites each having five fabric layers. The stacking sequences and weight fractions of matrix (W_m), JUCO (W_j), and carbon fabrics (W_c) in the fabricated composites are presented in **Table 1**. During the fabrication of the composites, unidirectional carbon fibers were placed along the direction of the jute fibers within the JUCO fabric. Epoxy resin and epoxy hardener were mixed at a ratio of 11:1 by weight [4-7]. All the composite plates were cold pressed for 48 hours within the surface plates to ensure proper curing of the matrix.

Table 1. Stacking sequences of the fabricated composites.

Type	Stacking Sequence	W_m (%)	W_j (%)	W_c (%)
A	J J J J J	71.84	28.16	0
B	J J C J J	69.50	26.14	4.36
C	J C J C J	66.46	23.22	10.32
D	C J C J C	64.84	17.58	17.58
E	C C J C C	61.65	10.46	27.90

2.4. Preparation of the artificial seawater medium

To obtain the seawater conditions, a 3% (w/v) NaCl solution was prepared with distilled water, and the pH of the solution was adjusted to 8 using the required amount of NaOH aqueous solution [5-7, 11, 12]. The prepared solution was kept under observation for 24 hours to ensure a stable pH value.

3. Results and discussion

3.1 Density and void content

Besides indicating the quality of fabrication, the void content or volume fraction of voids has a significant influence on the mechanical properties of the composites. The void content can be calculated using the theoretical and actual densities of the composites. The following equation was used to evaluate the theoretical densities of the fabricated composites:

$$\rho_t = \frac{1}{\left(\frac{W_m}{\rho m} + \frac{W_j}{\rho_j} + \frac{W_c}{\rho c}\right)} \quad \textbf{(1)}$$

where, ρ_t is the theoretical density (g/cm^3), W_m, W_j, and W_c are the weight fractions, and ρ_m, ρ_j, and ρ_c are the densities (g/cm^3) of the matrix material, JUCO fabric, and carbon fabric, respectively. Utilizing the water immersion method, the actual densities of the fabricated composites were determined as per the following equation:

$$\rho_a = S_P \times 0.9976 \quad \textbf{(2)}$$

where, ρ_a is the actual density (g/cm^3) and S_P is the specific gravity of the composites. Following the standard ASTM D-2734-70, the void contents of the fabricated composites were calculated using the following equation:

$$V_v = \frac{\rho_t - \rho_a}{\rho_t} \times 100\% \quad \textbf{(3)}$$

where, V_v is the volume fraction of voids, ρ_t is the theoretical density, and ρ_a is the actual density of the composites. The density and void content of the fabricated composites are listed in **Table 2**. The minimum and maximum amount of voids were found to be 1.56% and 2.22%, respectively for the *A*-type and *C*-type composites. The void content of all the composites is within the acceptable limit [18].

Table 2. The density and void content of the fabricated composites.

Type	S_P	ρ_a (g/cm^3)	ρ_t (g/cm^3)	V_v (%)
A	1.201	1.198	1.217	1.56
B	1.213	1.210	1.235	2.02
C	1.235	1.232	1.260	2.22
D	1.263	1.260	1.288	2.17
E	1.307	1.304	1.330	1.96

3.2. Uniaxial tensile test

The tensile test was carried out according to the ASTM D638-01 standard. The test was performed on an Instron Testometric M500-100CT universal testing machine with a 100 kN load cell. Pretension and cross-head speed were set to 0.001 N and 10 mm/min, respectively. All the important tensile properties were obtained automatically with the help of the winTest™ software provided by the machine manufacturer. At least three specimens of each type of composite were tested both before and after the aging process to ensure the accuracy of the results obtained. Specimens not aged in seawater were named control specimens and specimens aged in seawater were considered seawater specimens in this current research. The findings from the tensile test were also validated by *FEM*. **Figures 2**, **3**, and **4** demonstrate the influence of seawater aging on the tensile properties of the fabricated composites and their validation by the finite element method. The tensile strengths obtained for the control specimens of the *A*, *B*, *C*, *D*, and *E*-type composites were 58.64 MPa, 152.85 MPa, 243.59 MPa, 305.60 MPa, and 332.15 MPa, respectively. An upward trend for the tensile strengths of the fabricated composites was observed with the increasing proportion of carbon fibers since carbon fibers are more rigid and durable compared to JUCO fibers. The tensile strength of the JUCO composite was reported as 68.52 MPa by Ahmed et al. [12]. In an experiment where plain woven twill-type jute fabric was hybridized with unidirectional woven carbon fabric, Khalid et al. obtained the tensile strengths of *CJJJC*, *CJCJC*, and *CCJCC* to be 108.30 MPa, 172.80 MPa, and 257.50 MPa, respectively [19]. The tensile strengths of the *A*, *B*, *D*, and *E*-type composites reduced to 54.73 MPa, 138.61 MPa, 266.43 MPa, and 195.30 MPa, respectively after being aged in seawater. The degradation of natural fibers led to a reduction in tensile strength. Because of their organic nature and higher moisture absorption tendency, the natural fibers within the *NFRCs* degrade whenever *NFRCs* are exposed to an aqueous medium. Ahmed et al. [12] reported

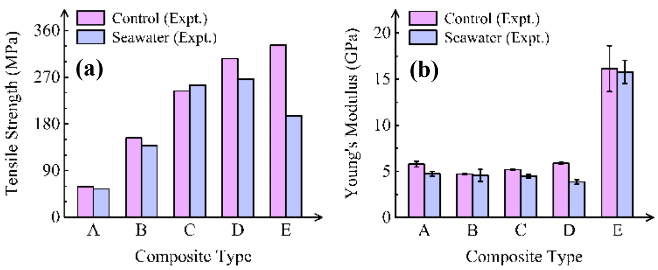
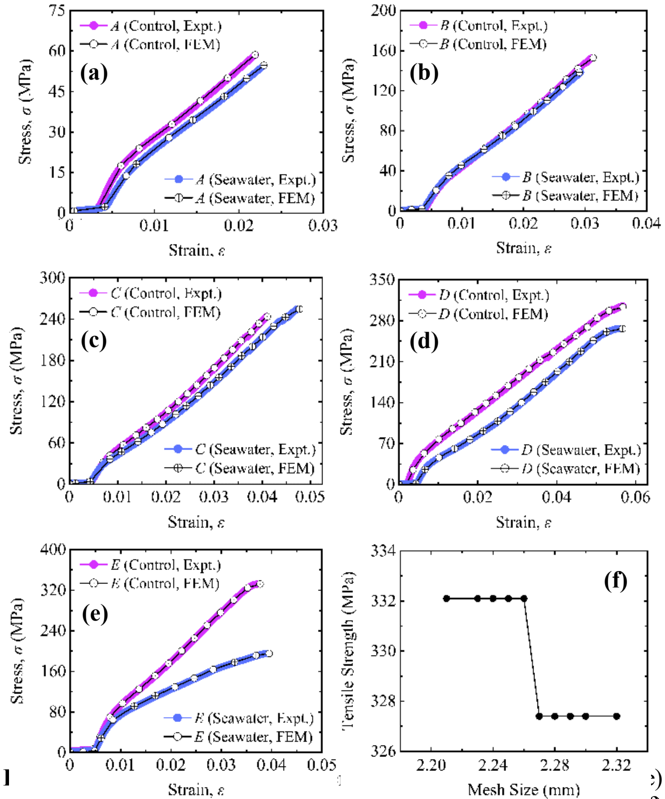


Figure 2. Effects of seawater aging on the tensile characteristics of the fabricated composites: (a) tensile strength; (b) Young's modulus.



comparison of experimental and numerical stress-strain behavior; (f) mesh convergence analysis for the numerical tensile test.

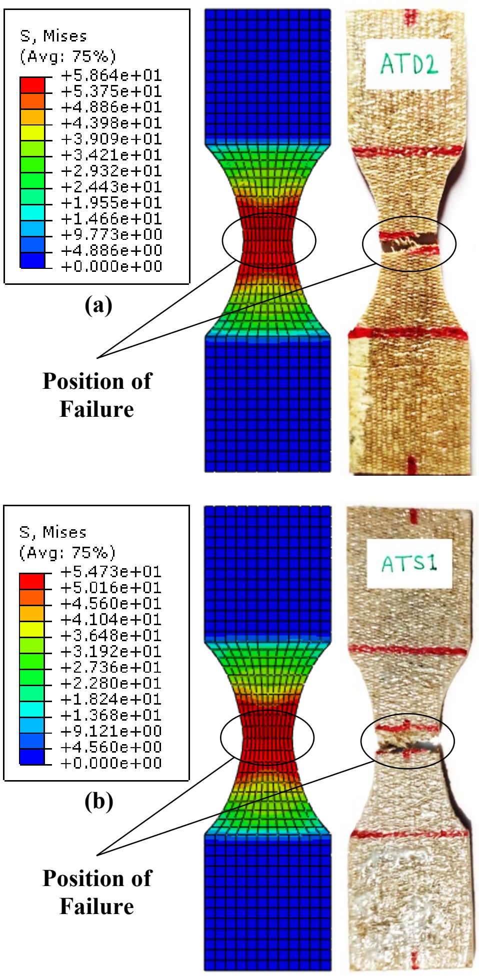


Figure 4. Von-Mises tensile stress distribution (*FEM*) and fractured specimen (expt.): (a) *A*-type (control); (b) *A*-type (seawater).

the tensile strength of the JUCO composite as 49.66 MPa after aging in seawater. The tensile strength for the aged specimen

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of the *C*-type composite was higher (254.60 MPa) compared to the control specimen. The presence of stress concentration sites i.e. micro-voids or inclusions might decrease the strength of the control specimen of the *C*-type composite. The optimal mesh size for the numerical modeling of the tensile test was obtained to be 2.26 from the mesh convergence analysis. The perfect imposition of the experimental and numerical tensile stress-strain curves validates the accuracy of the results found experimentally. The concentration of stress and failure of the specimens during the experiment also occurred at the same location predicted by the finite element analysis.

3.3. Flexural test

ASTM D790 was followed to conduct the three-point bending test for both the control and aged specimens. A Tinius Olsen 25ST *UTM* with a 25 kN load cell was used to perform the test. The span length, cross-head speed, pre-load, and maximum allowed deflection were set to 60 mm, 10 mm/min, 5 N, and 35 mm, respectively. All the necessary flexural characteristics were automatically obtained with the assistance of the Horizon

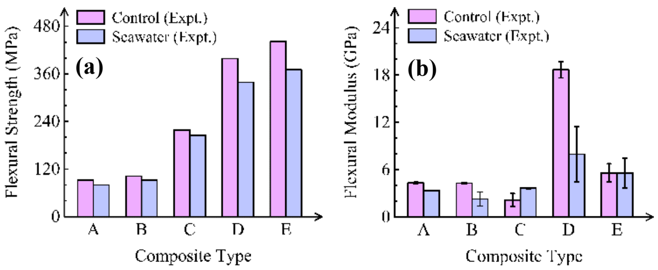

Figure 5. Effects of seawater aging on the flexural characteristics of the fabricated composites: (a) flexural strength; (b) flexural modulus.

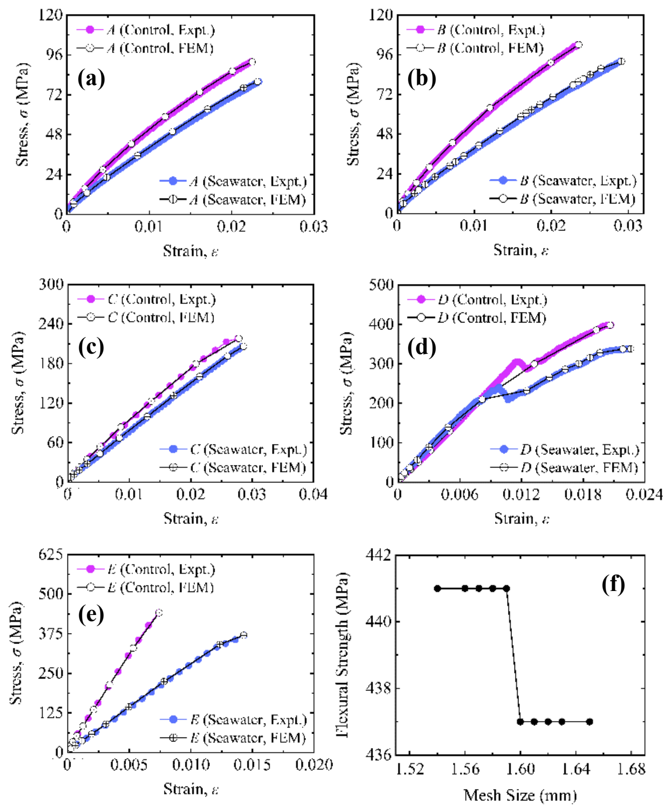

Figure 6. The validation of the flexural test results by *FEM*: (a)-(e) comparison of experimental and numerical stress-strain behavior; (f) mesh convergence analysis for the numerical flexural test.

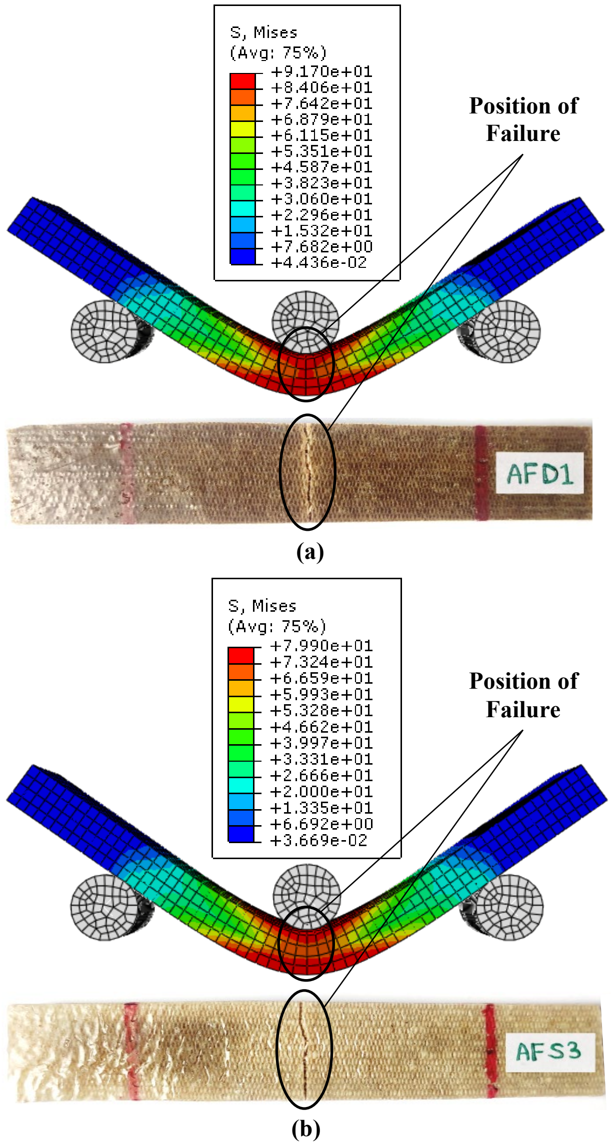

Figure 7. Von-Mises flexural stress distribution (*FEM*) and fractured specimen (expt.): (a) *A*-type (control); (b) *A*-type (seawater).

software provided by the machine manufacturer. To find out the actual results, at least three specimens of each type of composite were tested. Results obtained from the three-point bending test were also validated by the finite element method. The effects of seawater aging on the flexural characteristics of the composites and their validation by *FEM* are illustrated in **Figures 5**, **6**, and **7**. The flexural strengths of the *A*, *B*, *C*, *D*, and *E*-type composites were found to be 91.70 MPa, 102.30 MPa, 218.65 MPa, 398.41 MPa, and 441.48 MPa, respectively for the control specimens. Compression, tension, and shear are the reasons for the failure in flexural tests. A similar upward trend analogous to tensile strength was observed since carbon fibers can sustain a very high amount of load compared to JUCO fibers. Ahmed et al. reported the flexural strength of the JUCO composite as 96.11 MPa [12]. When twill-type jute and unidirectional carbon fabrics were used, Ali et al. found the flexural strengths of *CJJJC*, *CJCJC*, and *CCJCC* were about 175 MPa, 245 MPa, and 390 MPa, respectively [20]. The flexural strengths of the *A*, *B*, *C*, *D*, and *E*-type composites decreased to 79.90 MPa, 92.09 MPa, 205.11 MPa, 338.50 MPa, and 370.15 MPa, respectively, after the aging process. The reduction in flexural strength is associated with the degradation of natural fibers within the *NFRCs*. Ahmed et al. found the flexural strength of the JUCO composite to be 85.08

MPa after being aged in the artificial seawater medium [12]. Mesh convergence analysis revealed that the optimal mesh size for the numerical modeling of the flexural test was 1.59. The perfect imposition of the experimental and numerical flexural stress-strain curves and stress concentration position validate the accuracy of the experimental results.

3.4. Impact test

The Charpy impact test was performed utilizing a JB-300B dial display impact testing machine in accordance with the standard ASTM D6110. For both control and aged conditions, at least three specimens of each type of composite were tested. The influence of seawater aging on the impact strength of the fabricated composites can be seen in Figure 8(a). The impact strengths obtained for the control specimens of the *A*, *B*, *C*, *D*, and *E*-type composites were 12.50 J/cm^2, 22.43 J/cm^2, 26.79 J/cm^2, 33.27 J/cm^2, and 33.38 J/cm^2, respectively. Materials' ability to sustain forces applied at a high speed is called impact strength. Carbon fibers can absorb a higher amount of impact force than JUCO fibers and that is why the impact strength of the composites increased with the increasing amount of carbon fibers. The impact strength of the JUCO composite was found to be 13.36 J/cm^2 by Ahmed et al. [12]. The impact strengths of the *A*, *B*, *C*, *D*, and *E*-type composites increased to 13.73 J/cm^2, 23.57 J/cm^2, 27.85 J/cm^2, 33.53 J/cm^2, and 34.60 J/cm^2, respectively, after being aged in seawater. Increased ductility of *NFRCs* due to the degradation of natural fibers improved the impact strength of the composites. The impact strength of the JUCO composite was reported as 15.54 J/cm^2 after being aged in seawater by Ahmed et al. [12].

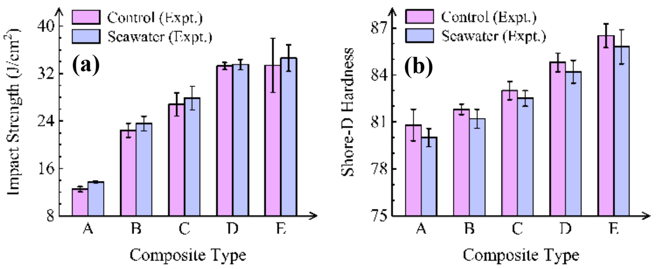

Figure 8. Effects of seawater on the impact and hardness properties of the fabricated composites: (a) impact strength; (b) hardness.

3.5. Hardness test

The Shore-D hardness test was executed following the ASTM D2240 standard. The test was performed utilizing an Insize Shore-D Durometer. For both the control and seawater-aged specimens of each type of composite, at least three readings were taken at a distance of 5 mm apart from one another to ensure better accuracy in the obtained results. The impacts of seawater aging on the hardness of the fabricated composites are displayed in Figure 8(b). 80.8, 81.8, 83.0, 84.8, and 86.5 were the Shore-D hardness for the control specimens of the *A*, *B*, *C*, *D*, and *E*-type composites, respectively. A significant increment in the hardness of the composites was found with an increasing proportion of carbon fibers because of the hard and brittle nature of carbon fibers. Ahmed et al. found the Shore-D hardness of the JUCO composite to be 82 [12]. The Shore-D hardness of the *A*, *B*, *C*, *D*, and *E*-type composites decreased to 80.0, 81.2, 82.5, 84.2, and 85.8, respectively, after the aging process. As a result of the degradation of natural fibers within the *NFRCs*, the ductility of natural fiber-reinforced composites increased and the hardness decreased. Ahmed et al. reported the Shore-D hardness of the JUCO composite as 77.2 after the aging process in the artificial seawater medium [12].

4. Conclusion

The findings from this experimental and numerical research work can be concluded as follows;

- The mechanical properties of the *NFRCs* were elevated significantly by the hybridization process due to the strong and stiff nature of carbon fibers.
- Because of the hygroscopic and organic nature of natural fibers, seawater aging has a substantial influence on the mechanical characteristics of the *NFRCs*.
- The tensile strength, flexural strength, and hardness of the composites decreased after aging in the artificial seawater because of the degradation of JUCO fibers.
- The impact strength of the composites improved because of the increment in ductility of the *NFRCs* as a result of the degradation of JUCO fibers.
- The findings from the finite element analysis showed good alignment with the experimental results of the tensile and flexural tests.

The composites developed in this research work have potential applications in making furniture, sporting goods, wind turbine blades, and different interior and exterior parts of automobiles and ships i.e. hulls and decks.

References

1. Venkatasudhahar, M., Kishorekumar, P., and Dilip Raja, N., (2020). Influence of stacking sequence and fiber treatment on mechanical properties of carbon-jute-banana reinforced epoxy hybrid composites. *International Journal of Polymer Analysis and Characterization*, 25(4): 238–251.
2. Hosen, A., Hossain, M. F., Rana, M. S., and Ferdous, M. S., (2023). Investigation of flexural strength of jute fiber based circular type honeycomb sandwich panel: An experimental and numerical approach. *Results in Materials*, 19: 100423.
3. Sujon, Md. A. S., Habib, M. A., and Abedin, M. Z., (2020). Experimental investigation of the mechanical and water absorption properties on fiber stacking sequence and orientation of jute/carbon epoxy hybrid composites. *Journal of Materials Research and Technology*, 9(5): 10970–10981.
4. Ferdous, F., Hossain, Md. F., Sohel Rana, M., and Ferdous, Md. S., (2023). Experimental investigation with FE analysis on flexural strength of hexagonal-shaped honeycomb sandwich panel. *Modern Physics Letters B*, 2450094.
5. Nayeem, N. M., Hossain, F., Rana, M. S., and Ferdous, S., (2024). Influence of ageing in different mediums on the mechanical properties of JUCO/carbon epoxy composites. *Proceedings of the 7th International Conference on Civil Engineering for Sustainable Development* (*ICCESD 2024*), Khulna, Bangladesh.
6. Bhuiyan, A. B. M. A. H., Hossain, M. F., Rana, M. S., and Ferdous, M. S., (2023). Impact of fiber orientations, stacking sequences and ageing on mechanical properties of woven jute-kevlar hybrid composites. *Results in Materials*, 20: 100477.

https://doi.org/10.62275/josep.25.1000020

7. Turjo, S. M. K. S., Hossain, M. F., Rana, M. S., Al-Mamun, M., and Ferdous, M. S., (2024). Durability and mechanical characteristics of unidirectional jute/banana and synthetic fiber reinforcement epoxy composite. *Hybrid Advances*, 6: 100232.
8. Saha, P., Hossain, M. F., Rana, M. S., and Ferdous, M. S., (2023). Numerical modeling of kevlar/jute fiber and hybrid composite pressure vessels. *Carbon Trends*, 13: 100304.
9. Turjo, S. M. K. S., Hossain, M. F., Rana, M. S., and Ferdous, M. S., (2023). Mechanical characterization and corrosive impacts of natural fiber reinforced composites: An experimental and numerical approach. *Polymer Testing*, 125: 108108.
10. Islam, M. M., Hossain, M. F., Rana, M. S., and Ferdous, M. S., (2024). Burst pressure prediction of carbon/natural fiber and hybrid composite pressure vessels by theoretical and numerical analysis. *Hybrid Advances*, 5: 100172.
11. Alvy, M. S. A., Hossain, M. F., Rana, M. S., Rahman, M. M., and Ferdous, M. S., (2024). Influence of stacking sequences of woven jute-carbon hybrid composites: Diffusion mechanism and mechanical characterization. *Heliyon*, 10(17): e36632.
12. Ahmed, I., Hossain, M. F., Rana, M. S., and Ferdous, M. S., (2024). An analysis of diffusion mechanism and mechanical properties of jute, JUCO, and banana fiber composites in three different mediums. *Hybrid Advances*, 100291.
13. Haque, M. S., Hossain, M. F., Rana, M. S., and Ferdous, M. S., (2024). Response of circular type sandwich panel using JUCO-glass fiber with PU foam under three-point bending loading. *Forces in Mechanics*, 100290.
14. Alamgir, A., Aranno, T. M., Mia, S., and Ferdous, Md. S., (2020). Effects of the fiber orientation on mechanical properties of jute fiber reinforced epoxy composites. *Proceedings of the 6th International Conference on Mechanical, Industrial, and Energy Engineering (ICMIEE 2020),* Khulna, Bangladesh.
15. Rahid, R. I., Mia, S., Rana, M. S., and Ferdous, S., Characterization and environmental impacts on mechanical properties of woven jute/carbon fiber reinforced epoxy composites. *Proceedings of the 6th International Conference on Mechanical, Industrial, and Energy Engineering (ICMIEE 2020),* Khulna, Bangladesh.
16. M. R., S., Siengchin, S., Parameswaranpillai, J., Jawaid, M., Pruncu, C. I., and Khan, A., (2019). A comprehensive review of techniques for natural fibers as reinforcement in composites: Preparation, processing and characterization. *Carbohydrate Polymers*, 207: 108–121.
17. Kabir, M. M., Wang, H., Lau, K. T., and Cardona, F., (2012). Chemical treatments on plant-based natural fibre reinforced polymer composites: An overview. *Composites Part B: Engineering*, 43(7): 2883–2892.
18. Wang, W., Sain, M., and Cooper, P., (2006). Study of moisture absorption in natural fiber plastic composites. *Composites Science and Technology*, 66(3–4): 379–386.
19. Khalid, M. Y., Nasir, M. A., Ali, A., Al Rashid, A., and Khan, M. R., (2020). Experimental and numerical characterization of tensile property of jute/carbon fabric reinforced epoxy hybrid composites. *SN Applied Sciences*, 2(4): 577.
20. Ali, A., Nasir, M. A., Khalid, M. Y., Nauman, S., Shaker, K., Khushnood, S., Altaf, K., Zeeshan, M., and Hussain, A., (2019). Experimental and numerical characterization of mechanical properties of carbon/jute fabric reinforced epoxy hybrid composites. *Journal of Mechanical Science and Technology*, 33(9): 4217–4226.

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Ethical Approval

This submitted work is a unique contribution to the field, not published elsewhere in any form or language. Results are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation (including image-based manipulation). The authors adhere to the discipline-specific rules for data acquisition, selection, and processing.

Consent of Participants

This entire research project was executed within the laboratory maintaining all the rules and regulations of chemical management. No human subject or living organism/tissue was involved in this research project.

Consent to Publish

All the authors are aware of the submission made. All the authors have shared their consent to publish this submitted work.

Author Contributions

This entire research project was conceptualized by Md Shafiul Ferdous and Nadim Mahmood Nayeem. This project was supervised and administrated by Md Foisal Hossain. Fabrication and experiments were performed by Nadim Mahmood Nayeem. Simulations were performed by Muhammed Sohel Rana and Nadim Mahmood Nayeem. Data analysis was done by Md Shafiul Ferdous and Nadim Mahmood Nayeem. The first draft of the manuscript was written by Nadim Mahmood Nayeem and all the authors commented on the previous versions of the manuscript. All the authors reviewed and approved the final manuscript.

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