Egypt. J. Chem. **Vol. 63,** No. 12 pp. 4987 - 4995 (2020)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Application of Jute Polyethylene Composites for Storage Tank as a Function of Fiber Treatment

Md. Faruk Hossen,* Md. Ali Asraf, Md. Kudrat-E-Zahan and C. M. Zakaria

Department of Chemistry, Rajshahi University, Rajshahi-6205, Bangladesh

Abstract

The jute polyethylene nanocomposites were manufactured using the hot-press technique with different fiber weight fractions. The hydrophilic nature of fiber exhibited poor interfacial interaction to hydrophobic polymer matrix. Three types of chemical reagents such as: benzenediazonium salt (BDS), propionic anhydride (PA), and 3-isocyanatopropyl triethoxysilane (Silane) have been used to reduce hydrophilicity of jute fibers. The chemical resistance tests of prepared composites were performed in order to observe whether these composites are resistant to various chemicals such as: acids, alkalis, and solvents. It was observed that the fabricated composites were resistant to all chemicals except carbon tetrachloride. The treated jute composites showed higher chemical resistance than raw jute composite and silane treated jute composite gave the highest resistance which can be suggested for making the water and chemical storage tanks.

Keywords: Jute fiber; Chemical treatment; Composites; Chemical resistance; Storage tank

Introduction

Natural cellulosic materials are potential alternatives to synthetic fibers due to the fact that cellulose is the most abundant organic raw material on earth, and available from various sources. It is also renewable, inexpensive, biodegradable [1]. Currently, jute polymer composites have been widely considered a potential substitute for synthetic fibers in various industries [2, 3]. The presence of the large amount of hydroxyl groups (-OH) and surface impurities make the fibers hydrophilic in nature, which weaken the fiber-matrix interfacial bonding in the composite system [4]. In order to enhance the interfacial bonding, surface chemical or physical modification of fibers have been done. Many techniques have been used for fiber surface chemical treatments (alkaline, esterification, benzoylation, permanganate, peroxide, and isocyanate treatments etc.) to overcome the incompatible surface polarities between the natural fiber and polymer matrix [5-7]. In order to reduce hydrophilicity, raw jute fiber was chemically treated using three different chemical agents such as: propionic anhydride (PA), benzenediazonium salt (BDS), and silane. Upon chemical treatment, the agents broke the OH groups at C-2 and/or C-3 and C6 positions of the cellulose in the jute. Due to the steric effect, the hydroxyl group at C-3 did not undergo chemical reaction with the bulky diazobenzene group of the salt but the remaining two agents can react with the OH groups at C-2, C-3 and C-6 [8]. It had been reported that the chemically treated natural fiber reinforced polymer composites have shown remarkable improvement in mechanical and thermal properties [6, 9]. On the other hand, composite materials are largely used in many industrial applications that range from offshore structures used by the petroleum industry to common household goods [10, 11].

*Corresponding author e-mail: fhossen.chem@ru.ac.bd
Receive Date: 18 April 2020, Revise Date: 29 April 2020, Accept Date: 30 June 2020
DOI: 10.21608/EJCHEM.2020.28220.2595

The fiber-reinforced composites are finding many applications in the manufacture of chemical and water storage tanks. Chemical resistance behaviors were studied to find out whether these composites can be used in making water and chemical storage tanks that are resistance to chemicals. The chemical resistance behavior of prepared composites has not been reported yet. Thus, the chemical resistance of jute fibers reinforced composites were studied in this work. Therefore, the aim of this study is to investigate the effect of chemical treatments on the chemical resistance behaviors of prepared composites used for storage tanks.

Materials and methods

In this research, three types of chemical agents namely: benzenediazonium salt (BDS), propionic anhydride (PA), and 3-isocyanatopropyltriethoxy silane (silane) have been used for the fiber surface treatment. Polyethylene with outstanding properties like low density, low cost, good flex life, excellent surface hardness, scratch resistance and excellent electrical insulating properties was chosen as matrix materials [12]. Hence, polyethylene (PE) matrix have been used for the manufacturing of composites in this study.

Jute fibers were mercerized using NaOH initially, and then submerged approximately for 1 hour individually with freshly prepared BDS solution, PA solution containing few drops of conc. H_2SO_4, and methanol-water (90/10 w/w) containing 2% silane solution, respectively. Then the fibers were taken out, washed well with distilled water and dried in an oven at 80°C for 12 hours. The fibers were then trimmed approximately into 3 mm in length for composite fabrication.

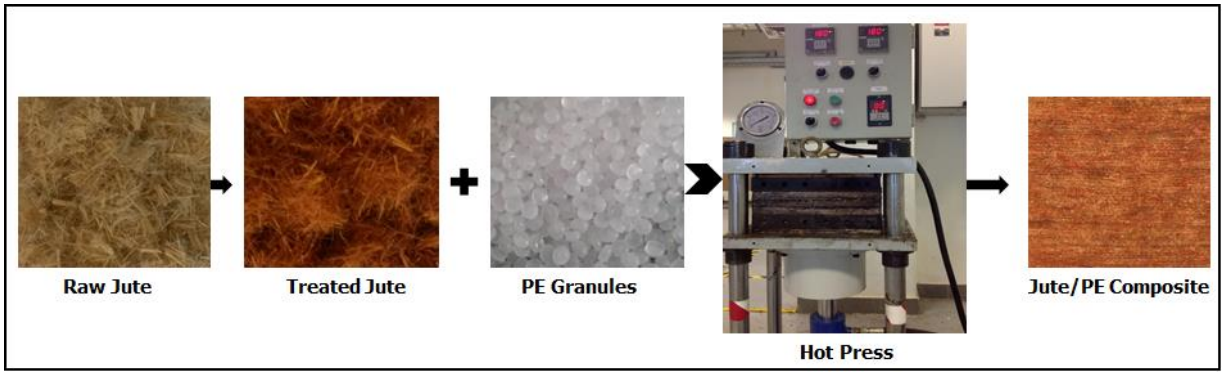
The fabrication process of jute polyethylene (PE) composite is shown in Scheme 1. Jute fibers and PE granules were mixed thoroughly in different weight fractions according to Table 1. The mixture was then settled in a mold and hot press technique was performed for 1 hour at 180°C under the pressure at 7 MPa. The mould was then air cooled at room temperature and the prepared composites were characterised.

The infrared spectra were recorded to determine the functional groups of jute fibers. A Shimadzu 81001 FTIR spectrophotometer was used to scan the samples for 32 times in the range of wave number 4000 to 500 cm^{-1}. Surface morphology of the prepared composites was examined using a Scanning electron microscope (TM3030) supplied by JEOL Company Limited, Japan. The micrographs were taken from the fracture surface to study the interfacial adhesion between fiber and polymer matrices. The samples were sputter-coated with gold and observed under the SEM. The micrographs were taken at a magnification of 500X. To optimize the fiber loadings of prepared composites, tensile tests were conducted according to ASTM D 638 using a Universal Testing Machine (Model: MSC-5/500, Shidmadzu Company Limited, Japan) at a crosshead speed of 5 mm/min. The dimension of the specimen was 115 mm x 6 mm x 3.1 mm. In each case, five rectangular specimens were tested and the average value was reported.

The chemical resistance behavior was evaluated by the chemical absorption which are studied to find out whether these composites can be used in making chemical storage tanks that are resistance to chemicals. The more weight gain indicates the materials are less chemically resistant [13]. The chemical absorption of manufactured composites was tested according to the ASTM D543-87 (standard test method for resistance of plastics to chemical reagents). The effect of solvents **(**benzene (C_6H_6), toluene ($C_6H_5CH_3$), carbon tetra chloride (CCl_4) and distilled water (H_2O)**)**; acids **(**hydrochloric acid (HCl), nitric acid (HNO_3) and acetic acid (CH_3COOH)**)** and alkalis **(**sodium hydroxide (NaOH), sodium carbonate (Na_2CO_3) and ammonium hydroxide (NH_4OH)**)** on raw and treated jute composites were studied. In each case, five samples were weighed and dipped in the respective chemical reagents for 24 h. They were then removed and immediately washed with distilled water and dried by pressing them on both sides with a filter paper at room temperature. The samples were then weighed and the percentage of weight gain/loss ($W_{g/l}$) was determined using the following formula.

$$W_{g/l} = \frac{W_f - W_i}{W_i} \times 100$$

Where W_i and W_f are the initial and final weight before and after immersion respectively.



Scheme 1. Fabrication of jute polyethylene composites.

Table 1

Different composition of jute fibers, PE for composites fabrication.

No	Treatment method	Composition by weight (wt%)		Specimen name
		Jute	Polyethylene (PE)	
1	Raw jute polyethylene composites	5	95	RJPEC
		10	90	
		15	85	
		20	80	
2	BDS treated jute polyethylene composites	5	95	BDSJPEC
		10	90	
		15	85	
		20	80	
3	PA treated jute polyethylene composites	5	95	PAJPEC
		10	90	
		15	85	
		20	80	
4	Silane treated jute polyethylene composites	5	95	SJPEC
		10	90	
		15	85	
		20	80	

Results and discussion

FTIR study

The compositions of jute fibers include mainly cellulose, hemicelluloses, and lignin. Anhydro-*d*-glucose is the elementary unit of cellulose macromolecule, which contains three hydroxyls (–OH) groups [14]. The hydroxyl groups of cellulose make the fibers hydrophilic in nature which caused poor performance in the mechanical properties of the composites. Hemicellulose and lignin are amorphous, contained hydroxyl and acetyl groups and have the water sorption ability into the natural fibers [15]. The FTIR spectra of untreated and treated jute fibers were shown in Figure 1. The characteristic features of the spectrum for its constituent lignin, hemicelluloses and α-cellulose. In this study, in each treatment, the reactions were carried out in alkaline medium or jutes were pre-treated with 5% NaOH solution which removes a certain amount of lignin, hemicellulose and some impurities from fiber. A broad common absorption band in the region of 3600-3200 cm^{-1} is the characteristic of hydrogen bonded O-H stretching vibration [16]. The intensity of O-H stretching vibration shifted to lower value due to the chemical treatment of jute fibers and the lowest value observed for silane treated fiber. The C-H stretching vibration of methyl and methylene groups in cellulose and hemicelluloses was observed at 2902 cm^{-1}. The decrement may be due to the pre-treatment of fibers with NaOH [17]..

The band near 1751 cm^{-1} is assigned to the C=O stretching of the carboxyl and acetyl groups in

hemicelluloses of the jute fiber that was prominent in raw jute fiber [18]. This band further decreased and became weak after chemical treatment, which is mainly due to the removal of acetyl group present in hemicelluloses. The bending vibration at 1641 cm^{-1} indicated the absorbed water in crystalline cellulose [19], which disappeared due to the chemical treatment of fiber. The band at 1512 cm^{-1} is considered to be due to the presence of aromatic rings in lignin. The absorption band at 1359 cm^{-1} is assigned to C–H bending in hemicellulose and lignin [14]. The band 1048 cm^{-1} indicates C–O deformation for primary alcohol in lignin, was found with higher absorption intensity in raw jute compared to treated jute fibers. The chemical treatment reduced the hydrophilic -OH groups resulting in increased interfacial bonding between the fiber and PE matrix in the composites [19].

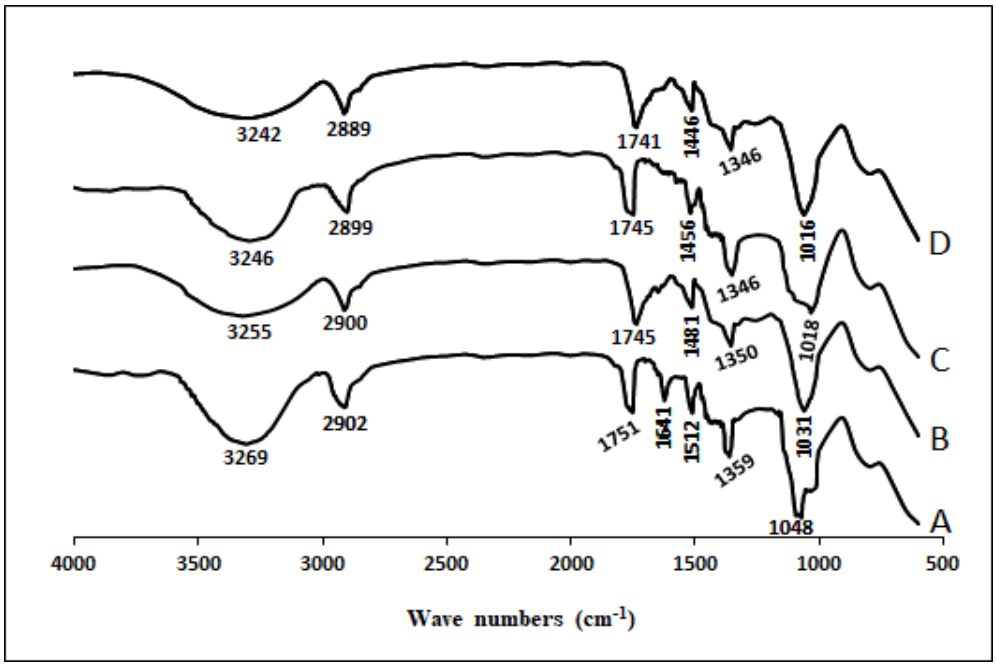


Fig. 1. FTIR spectra of (A): raw jute fiber, (B): BDS treated jute fiber, (C): PA treated jute fiber, and (D): silane treated jute fiber.

Optimization of fiber loadings

Optimization of fiber loadings has been studied through the tensile behavior of the prepared composites. The tensile strength (TS) and tensile modulus (TM) of raw and treated jute reinforced polyethylene composites against different fiber loading are presented in Figure 2. It was observed that both the tensile strength and tensile modulus increase continuously up to 15% fiber loading and then decrease after further addition of jute fiber. The 15 wt% jute content was the optimum composition. The effect of fiber loading on the tensile properties of composites is explained by the homogeneity of fiber and wettability of polyethylene matrix [20]. As the fiber content increases, the stress is more evenly distributed and the strength of the composites increases up to 15 wt% jute content. The composite reveals a decrement after 15% fiber content due to the fiber agglomeration [21]. Significant improvement in tensile properties were observed for treated composites compared to raw one. This is due to the chemical treatment which reduced the hydrophilicity of jute fiber resulting in increased interfacial bonding between the fiber and PE matrix into the composite system [19]. As a result, tensile properties of the treated jute composites were improved. The highest improvement observed for silane treated jute composites. It was observed that at optimum fiber content (15 wt%), the BDS, PA and silane treated jute composites exhibited improvements in tensile strength by approximately 20%, 22% and 24%, and tensile modulus by 37%, 41% and 44% respectively over the raw composites.

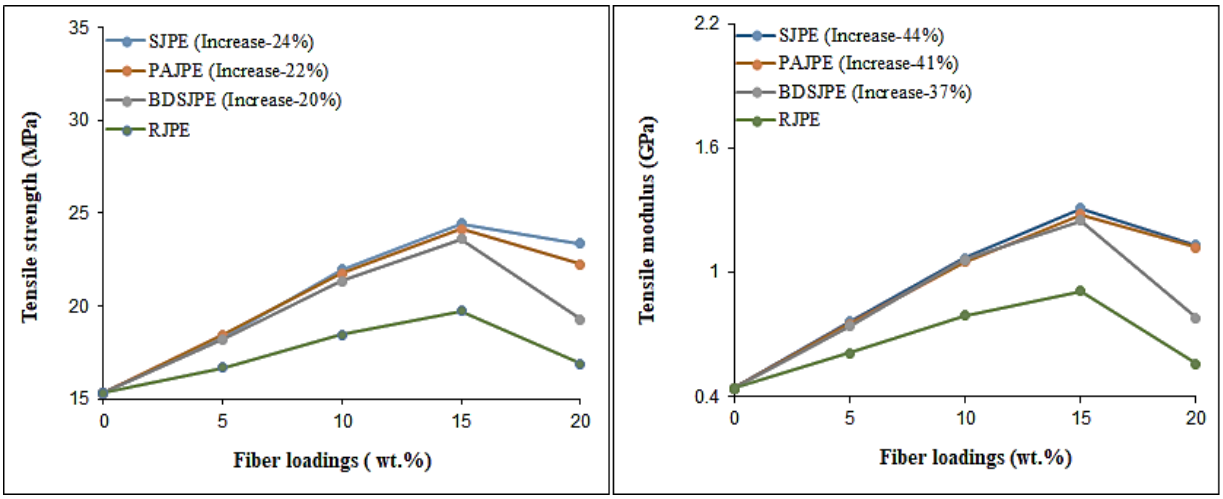


Fig. 2. TS and TM for 15 wt% fiber loaded composites of A: RJPEC, B: BDSJPEC, C: PAJPEC and D: SJPEC.

SEM study

The interfacial adhesion between the jute fiber and polyethylene matrix was investigated by scanning electron microscopy (SEM). Since the fiber loading was optimized by 15 wt%, the SEM images have been taken for optimizing composites in this study. SEM images of 15 wt% raw and treated jute loaded composites are presented in Figure 3. The figure indicates that there appear considerable differences in the interfacial interaction between fiber and polymer matrix in the composite system. The SEM image of raw composite shows the pullout traces of fiber with rough surfaces and voids as well as agglomeration (Fig. 3A). This feature indicates that there was poor dispersion and weak interfacial bonding between fiber and matrix [11]. On the other hand, the treated jute composite shows a better dispersion of filler throughout the matrix, which in turn improved interfacial interaction between fiber and matrix (Fig. 3B-3D) [25]. The highest improvement was observed for silane treated composite (SJPEC). The improvement of interfacial adhesion between jute and polyethylene is due to the chemical modification that enhanced the hydrophobicity of jute fiber [22]. Therefore, it can be seen from the SEM micrographs that the treatment enhanced the interfacial interaction between fiber and matrix in the composite which was evident from FTIR study and also reflected on tensile properties.

Chemical resistance

The chemical resistance behaviors were evaluated through the chemical absorptions by the prepared nanocomposites. The chemical resistance was studied to find out whether these nanocomposites can be used in making water and chemical storage tanks that are resistance to chemicals [15, 23]. More weight gain indicates the materials are less chemically resistant. Figure 4 shows the percentage of weight gain/loss for 15 wt% jute fiber (raw and treated) loaded composites immersed in solvents, acids and alkalis. It was clearly observed that weight gain was observed for almost all the chemical reagents except carbon tetrachloride. In the case of carbon tetrachloride, the cross-linked polymers are easily attracted by chlorinated hydrocarbons [24]. The composites were also resistant to water. The hydrophilicity of natural fibers cause the weight gain due to water and aqueous solutions [25]. From the results, it was seen that the weight gain is higher for raw jute composite compared with treated ones. The highest resistance was observed for silane treated jute composite, SJPEC followed by PAJPEC, BDSJPEC, and RJPEC. The overall change of chemical resistance is due to the change of agent of chemical treatment may change the structure of cellulose anhydroglucose unit of jute. The chemical treatment of jute reduced hydroxyl group of cellulose anhydroglucose unit by coupling with different chemical groups. The hydroxyl group of cellulose in jute fiber is responsible for its inherent hydrophilic nature.

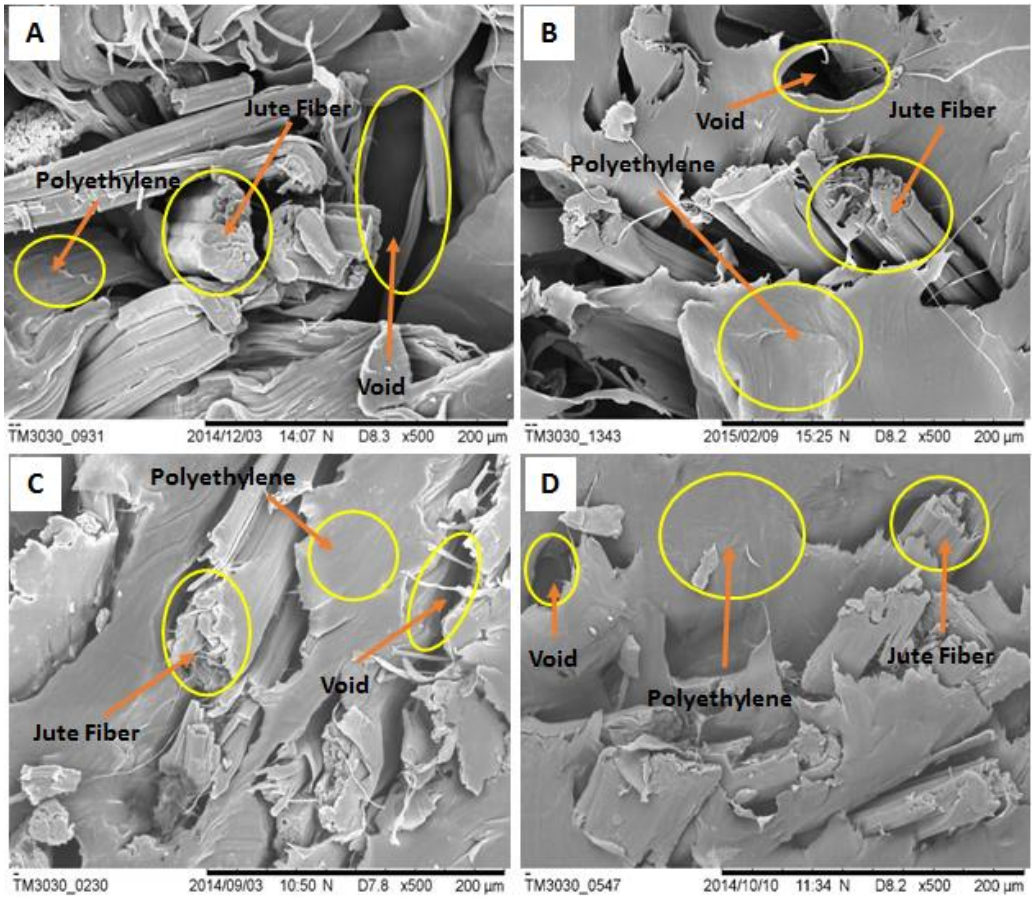


Fig. 3. SEM images for 15 wt% fiber loaded composites of A: RJPEC, B: BDSJPEC, C: PAJPEC, and D: SJPEC.

As a result, it becomes difficult to make composite with it the hydrophobic polymer matrix, resulting in poor performance in the mechanical properties as well as dimensional change of finished products due to moisture absorption of the composite. To avoid these problems raw jute fiber was chemically treated using three different chemical agents (PA, BDS and silane). The reaction between hydroxyl groups of jute fiber and the chemical agents reduced the hydrophilic -OH group resulting in increased interfacial bonding between the fiber and PE matrix in the composites [26] which is evident from FTIR study. As a result, chemical resistance properties of the treated jute composites were improved and the highest improvement observed for silane treated jute composites. It had been reported by other researchers that the alkali treated biodegradable fiber hybrid composites exhibited better improvement in chemical resistance compared with untreated ones [27].

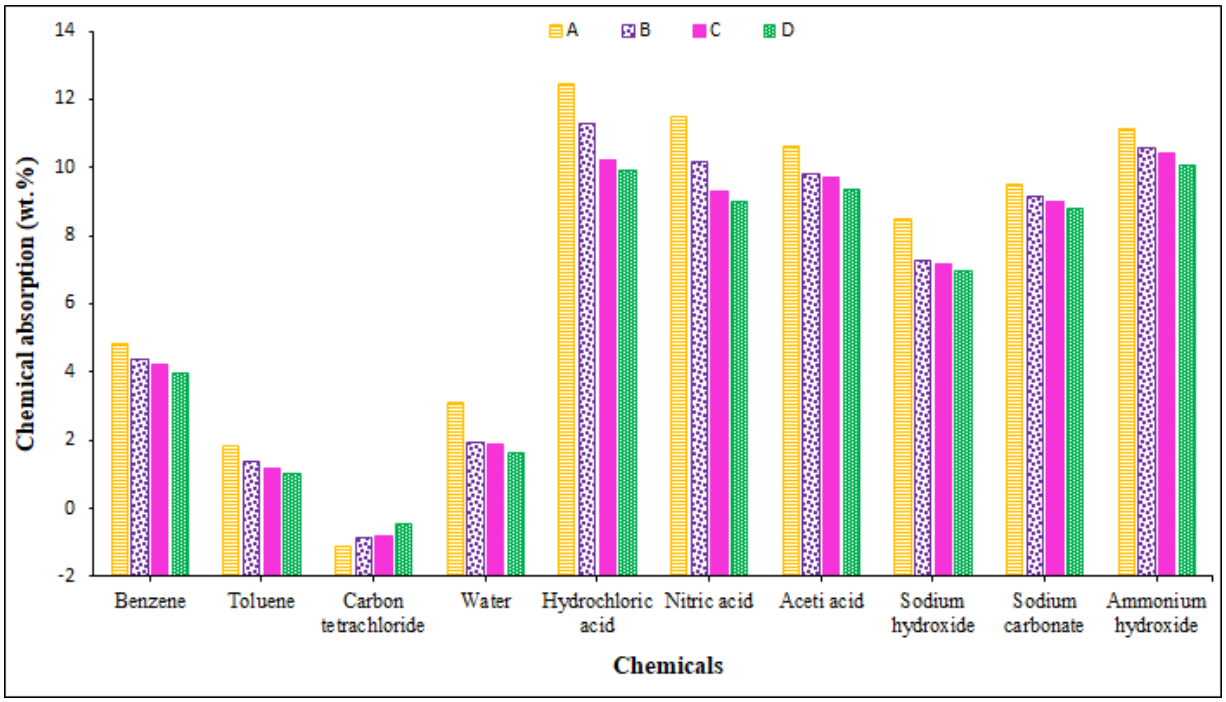


Fig. 4. Chemical absorption behavior for 15 wt% fiber loaded composites of A: RJPEC, B: BDSJPEC, C: PAJPEC, and D: SJPEC.

Conclusion

The hydrophilicity of jute makes poor adhesion with hydrophobic polymer matrices in the composite system. Surface chemical modifications can be applied to enhance bonding and adhesion affinity to polymer matrix. Thus, chemically (BDS, PA, & silane) treated jute fibers were used to prepare fiber polymer composites in this study. The chemical resistance of prepared composites with raw and treated jute fibers have been evaluated using chemical absorption capability. It was seen that the percentage of chemical absorption increased with fiber loadings. The chemical absorption study clearly suggested that the composites are resistant to all chemicals except CCl_4, which may cause of the cross-linked polymers are easily attracted by chlorinated hydrocarbons. The treated jute composite showed lower chemical absorption than untreated composite and silane treated jute composite exhibited lowest value. The above statement suggested that the chemical treatment that make the fiber more compatible with polymer matrix occur into the composite system. The development of composite properties in terms of interfacial adhesion between fiber and polymer matrix has become more favorable due to the chemical modification in the composite system. The manufactured composites can be suggested for making the water and chemical storage tanks and silane treated composite is the most suitable one.

Acknowledgements

The authors would like to acknowledge the financial support in this research work provided by the Faculty of Science, Rajshahi University, Rajshahi-6205, Bangladesh.

Conflicts of interest

The authors have declared that there are no conflicts of interest regarding the publication of this paper.

References

1. Fahmy Y., Fahmy T.Y.A., Mobarak F., El-Sakhawy M. and Fadl M.H., Agricultural Residues (Wastes) for Manufacture of Paper, Board, and Miscellaneous Products: Background Overview and Future Prospects. *International*

Journal of ChemTech Research, **10**, 424-448 (2017).
2. Yashas Gowda T.G., Sanjay M.R., Subrahmanya Bhat K., Madhu P., Senthamaraikannan P. and Yogesha B., Polymer matrix-natural fiber composites: An overview. *Cogent Engineering*, **5**, 1446667 (2018).
3. Tavares T.D., Antunes J.C., Ferreira F. and Felgueiras H.P., Biofunctionalization of Natural Fiber-Reinforced Biocomposites for Biomedical Applications. *Biomolecules*, **10**, 148 (2020).
4. Wang H., Memon H., Hassan E.A.M., Miah M.S. and Ali M.A., Effect of Jute Fiber Modification on Mechanical Properties of Jute Fiber Composite. *Materials*, **12**, 1226 (2019).
5. George J., Sreekala M.S. and Thomas S., A review on interface modification and characterization of natural fiber reinforced plastic composites. *Polymer Engineering and Science*, **41**, 1471-1485 (2001).
6. Ali A., Shaker K., Nawab Y., Jabbar M., Hussain T., Militky J. and Baheti V., Hydrophobic treatment of natural fibers and their composites-A review. *Journal of Industrial Textiles*, **0**, 1-31 (2016).
7. Sood M. and Dwivedi G., Effect of fiber treatment on flexural properties of natural fiber reinforced composites: A review. *Egyptian Journal of Petroleum*, **27**, 775-783 (2018).
8. Haque M.M., Hasan M., Islam M.S. and Ali M.E., Physico-mechanical properties of chemically treated palm and coir fiber reinforced polypropylene composites. *Bioresource Technology*, **100**, 4903-4906 (2009)
9. Aggarwal P.K., Raghu N., Karmarkar A. and Chuahan S., Jute-polypropylene composites using m-TMI-grafted-polypropylene as a coupling agent. *Materials and Design*, **43**, 112-117 (2013).
10. Corrales F., Vilaseca F., Llop M., Girones J., Mendez J.A. and Mutje P., Chemical modification of jute fibers for the production of green-composites. *Journal of Hazardous Materials*, **144**, 730-735 (2007).
11. Wang W.M., Cai Z.S., Yu J.Y. and Xia Z.P., Changes in composition, structure, and properties of jute fibers after chemical treatments. *Fibers and Polymers*, **10**, 776-780 (2009).
12. Zaman H.U., Khan M.A., Khan R.A., Rahman M.A., Das L.R. and Al-Mamun M., Role of potassium permanganate and urea on the improvement of the mechanical properties of jute polypropylene composites. *Fibers and Polymers*, **11**, 455-463 (2010).
13. Singha A.S. and Thakur V.K., Morphological, thermal and physicochemical characterization of surface modified pinus fibers. *International journal of polymer analysis and characterization*, **14**, 271-289 (2009).
14. Sever K., The improvement of mechanical properties of jute fiber/LDPE composites by fiber surface treatment. *Journal of Reinforced Plastics and composites*, **29**, 1921-1929 (2010).
15. Frederick T.W. and Norman W., Natural fibers plastics and composites. *Kluwer Academic Publishers*, New York (2004).
16. Ganan P., Zulunga R., Restrepo A., Labidi J. and Mondragon I., Plantain fiber bundles isolated from Colombian agro-industrial restudies. *Bioresource Technology*, **99**, 486-491 (2008).
17. Ray D., Sarkar B.K., Rana A.K. and Bose N.R., Effect of alkali treated jute fibers on composite properties. *Bulletin of Materials Science*, **24**, 129-135 (2001).
18. Khan F. and Ahmad S.R., Chemical modification and spectroscopic analysis of jute fiber. *Polymer Degradation and Stability*, **52**, 335-340 (1996).
19. Sinha E. and Rout S.K., Influence of fiber-surface treatment on structural, thermal and mechanical properties of jute. *Journal of Materials Science*, **43**, 2590-2601 (2008).
20. Priyadarsini M., Biswal T. and Dash S., Sustainable Biocomposite Its Manufaturing Processes and Applications. *Egyptian Journal of Chemistry*, **62**, 751 - 766 (2019).
21. Mohanty, A.K., Khan, M.A. and Hinrichsen, G., Surface modification of jute and influence on performance of biodegradable jute-fabric/biopol composites. *Composites Science and Technology*, **60**, 1115-1124 (2000).
22. Miah, M. J., Ahmed, F., Hossain, A., Khan, A. H. and Khan, M. A., Study on mechanical and dielectric properties of jute fiber reinforced low-density polyethylene (LDPE) composites. *Polymer-Plastics Technology and Engineering*, 44(8-9): 1443-1456 (2005).
23. Winkle E., Cowling M.J., Hashim S.A., Smith E.M., What can adhesives offer to Shipbuilding? *Journal of Ship Production*, **7**, 137-152(1991).
24. John K. Naidu S.V., Chemical resistance of sisal/glass reinforced unsaturated polyester hybrid composites. *Journal of Reinforced Plastics and Composites*, **26**, 373-376(2007).
25. Jawaid M., Abdul Khalil H.P.S., Bakar A.A., Khanam P.N., Chemical resistance, void content and tensile properties of oil palm/jute fiber reinforced polymer hybrid composites. *Materials and Design*, **32**, 1014-1019(2011).
26. Hossen M.F., Hamdan S., Rahman M R., Rahman M.M., Liew F.K. and Lai J.C.H., Effect of fiber treatment and nanoclay on the tensile properties of jute fiber reinforced polyethylene/clay nanocomposites. *Fibers and Polymers*, 16(2): 479-485 (2015).

27. Indraja Y., Kumar G.S., Rao H.R., Study of mechanical and chemical properties of biodegradable fibers before and after alkali treatment. *Journal of Information Engineering and Applications*, **4**, 1-5(2014)