Enhancement of Mechanical Properties of PFC by Chemically Modified Areca Fine Fibers

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Abstract

Nowadays, natural cellulose fiber-reinforced polymer composites are recognized by material engineers and researchers as a potential environmentally friendly and cost-effective option to synthetic fiber-reinforced polymer composites. In this communication, the effects of three different chemical treatments, namely alkali, benzoylation and acetylation, on the mechanical properties of the areca fine fiber (AFF) -reinforced phenol formaldehyde (PF) composites were presented. Mechanical properties of composites were evaluated based on the fiber loading. The properties of treated fiber composites were compared with the properties of untreated fiber composites. The results show that all the chemical treatments raise the mechanical properties of AFF/PF composites significantly. The alkali treated fiber composites show the higher range of mechanical properties compared to the other chemical treated fiber composites. Mechanical properties increased from 20 wt% to 40 wt% and then dropped. The fracture surfaces of the treated composite specimens were examined by scanning electron microscope (SEM) to observe the nature of the failure.

***Keywords**: Areca fine fibers; (PFC) Phenol formaldehyde Composites; Chemical treatments; Mechanical properties; SEM.*

1.INTRODUCTION

Polymer composites reinforced with synthetic fibers and particulates are replacing many conventional structural materials such as wood and steel due to its high specific strength and strength-to-weight ratio. Despite the various advantages, synthetic fibers such as glass, carbon and aramid are hazardous for health and pollute the environment. Recently, the materials researchers and scientists are recognizing natural cellulosic fibers as suitable alternative materials for man-made synthetic fibers. The plant based natural fibers have the following number of advantages over synthetic fibers: non-hazardous, ecofriendly and biodegradability, low weight and high specific strength. [1-4]

There are two notable limitations of the natural cellulosic fibers are: their higher moisture absorption tendency and their hydrophilic nature which makes it incompatible with the hydrophobic polymer matrix. The poor interfacial bonding between the natural fiber and the polymer matrix is created due to this incompatibility and moisture absorption

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tendency, which leads to weakening mechanical properties of the natural fiber-polymer composites. These limitations of natural fibers can be remedied by suitable chemical treatments of fibers, which are reducing the hydrophilic nature of the natural fibers and also improve the interfacial bonding between the natural fiber and the polymer matrix, i.e., significant improvements in the mechanical properties of the composites. Chemical treatments and their effects on the properties of natural fiber-reinforced polymer composites have been studied by several authors.[5-9] In this paper, the importance of chemical modification of AFFs and their effects on the mechanical properties of PF composites was studied based on the fiber loading. Three different chemical sources (alkali, benzoylation and acetylation) are used for the treatments of AFFs. Mechanical properties of treated fiber composites are compared with the un-treated fiber composites. The Scanning Electron Microscope (SEM) is used to study about the fractured surface of composite specimens after mechanical tests.

2.MATERIALS AND METHODS

Materials

The AFFs, collected from the Dina Fiber industry, Nagarcoil, Tamilnadu, India, were used as reinforcement with the density range of 1.05-1.25 g/cm3, the diameter range of 0.285-0.89 mm, the ultimate stress range of 89.5-118.67 MPa. The properties of natural cellulose fibers varied depending upon the growing nature. The structure of AFFs was composed of cellulose of 57.52 %, hemicellulose of 33.21 %, lignin of 6.19 %, moisture content of 1.80 % and ash content of 1.28 %. A resole type PF resin was used as polymer matrix and procured from Pooja Chemicals, Madurai, Tamilnadu, India, with the specific gravity of 1.12-1.16, the boiling point of 181.8 oC, flash point of 72.5 oC, the density of 1.3 g/cm3 and elongation at break of 2 %. The divinylbenzene and hydrochloric acid was used as cross-linking agent and acidic catalyst.

Alkali Treatment of AFFs

AFFs were initially prepared from the husk of the arecanut and cleaned manually. The cleaned AFFs were immersed in 10% NaOH solution for 1 hour at room temperature. After that, the fibers were taken over from alkali solution and thoroughly washed with distilled water and subsequently neutralized with 2/3 drops of HCl solution. Finally, the treated fibers were dried in sunlight for 24 hours.

Alkali treatment increases surface roughness and the amount of crystalline cellulose in AFF by disturbing the hydrogen bond in the network structure of cellulose, which increasing the mechanical interlocking. Moreover, the amount of cellulose exposed on the fiber surface created the better wetting with polymer matrix. The following reaction (Figure 1), takes place as a result of alkali treatment: [10]

$$\text{Fiber-OH} + NaOH \longrightarrow \text{Fiber-}O^{-}Na^{+} + H_2O$$

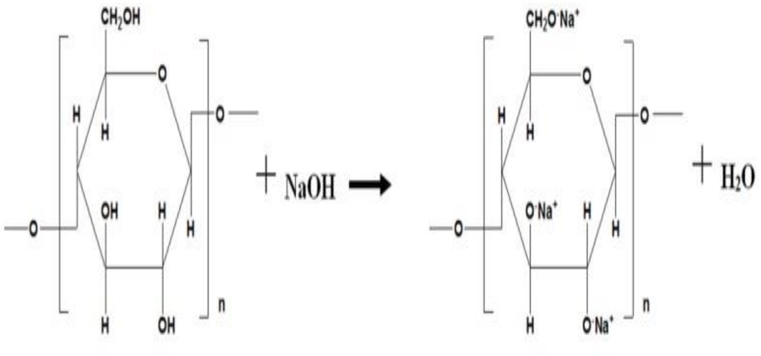


Figure 1. Chemical reaction between the NaOH and cellulose of AFF

Benzoylation Treatment of AFFs

For bcenzoylation treatment, the AFFs are initially pre-treated with 18% of NaOH for 30 minutes and then, the fibers are filtered and washed in running water. The fibers are designated as pre-treated fibers and then, they are soaked at 10% NaOH solution and agitated with benzoyl chloride. After 30 minutes, the fibers are removed from the solutions and filtered and also washed thoroughly with water. Then, the fibers are placed between the tissue papers to ensure to the removal of water particles. Finally, the fibers were suspended in ethanol for 1 hour to remove the benzyl chloride and washed with water, followed by drying in sunlight for 48 hours.

Due to the reaction of benzoyl chloride with the natural cellulose fibers, the hydrophylicity of natural cellulose fibers was reduced, which increase the compatibility of the fibers with the polymer matrix. The chemical reaction (Figure 2) between the benzoyl chloride and AF cellulose fiber is given as: [11]

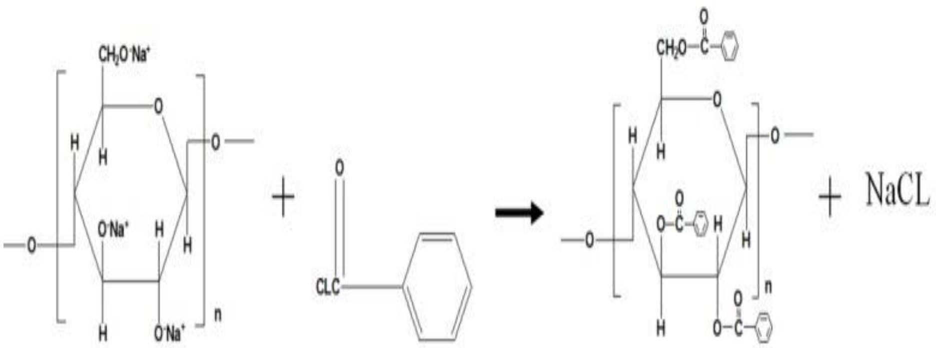


Figure 2. Chemical reaction between the benzoyl chloride and alkali pre-treated AF cellulose fiber

Acetylation Treatment of AFFs

For acetylation treatment, initially, the AFFs are pre-treated with 18% of NaOH for 1 hour at room temperature. Then, the alkali treated fibers are immersed in glacial acetic acid for 1 hour at room temperature. Finally, the fibers are soaked in acetic anhydride containing the two drops of H_2SO_4 for 30 minutes. During the reaction of cellulose fibers with acetic anhydride, the acetic acid was produced as byproducts. The reaction (Figure 3) of acetic anhydride with the AF cellulose fibers is given as: [12]

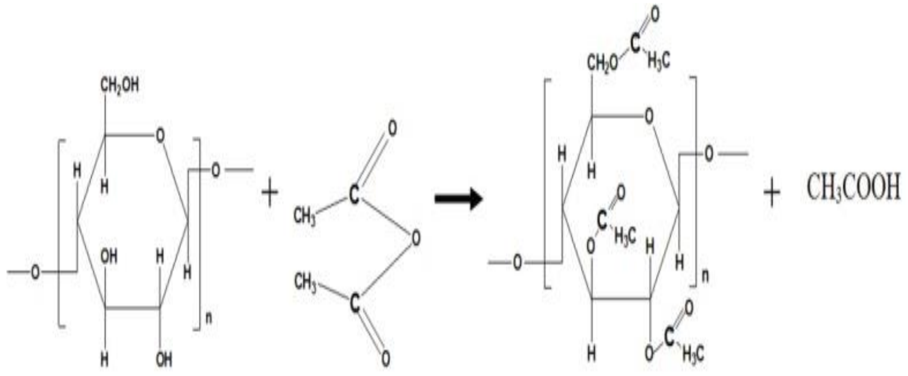


Figure 3. Reaction between the acetic anhydride and alkali pre-treated AF cellulose fiber

The influences of acetylation treatments on the properties of natural cellulose fiber-reinforced polymer composites have been studied and researched by several authors. The hygroscopic nature of the natural cellulose fibers can be reduced by this treatment. Due to this, the dimensional stability of composites reinforced by acetylation treated natural fibers was increased. [13]

Fabrication of Composites

Composite plates were prepared using hand lay-up technique developed in our composite laboratory. First, a releasing agent was applied on the inner side of the mould to ensure easy removal of cured composite plates. The prepared AFFs in a calculated amount were mixed with PF resin and the mixture was stirred by a mechanical stirred for 30 min. After that, the cross-linking agent and acidic catalyst were mixed with the resin mixture and stirred mechanically for 15 min. Then, the mixture was poured into the mould and pressed using a laboratory hot press. Finally, the mould box containing the composite plate was allowed to cure at room temperature under atmospheric pressure for 48 hours.

Characterization of Composite Specimens

Composite specimens are cut from the prepared composite plates for mechanical tests. Tensile tests are performed according to ASTM D 638-10[14] with a gauge length of 50 mm on an FIE universal testing machine at a crosshead speed of 2 mm/min. Flexural tests are also conducted on same FIE universal testing machine according to ASTM D 790-10[15] at a crosshead speed of 2 mm/min. Impact tests are conducted according to ISO 180:2000.[16] The fractured surfaces of composite specimens are examined using the SEM (HITACHI S-3000N).

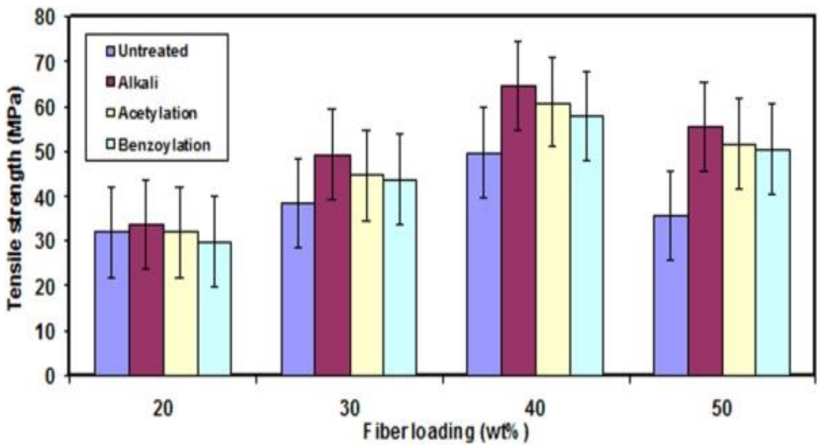
3.RESULTS AND DISCUSSION

In the natural cellulose fiber-reinforced polymer composites, the fibers play an important role in determining the mechanical properties. The fiber-matrix interfacial adhesion is an important factor which affects the mechanical properties of the composites. The efficiency of interfacial adhesion is decided by the nature of fibers and polymers, the geometry of fibers, processing method and chemical modification of fiber and polymers, etc. [17, 18]

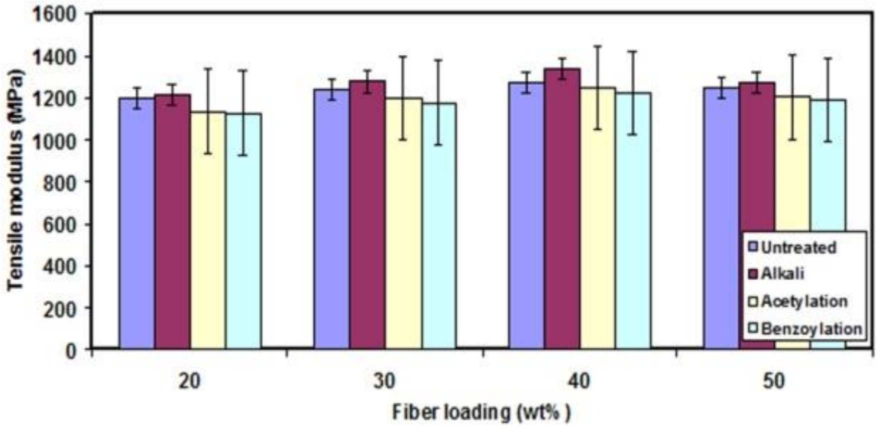
Tensile Properties

The tensile properties of PF composites reinforced with the three different chemicals treated AFFs are shown in Figures 4a and 4b. All the chemical treatments raise the tensile properties of AFF/PF composites significantly. Composites reinforced by alkali treated AFFs show the higher range of tensile properties compared to other chemical treated fiber composites. Composites reach the mechanical properties of the neat resin sample at initial addition of 20 wt% of untreated AFFs. Composite having the alkali treated AFFs of 40 wt% has displayed the highest tensile strength (64.72MPa) compared to untreated fiber composite and the other chemicals treated fiber composites, as shown in Figure 4a. When compared to the untreated fiber composites (40 wt%), alkali treated composite (40 wt%) shows the 30.22% increment in tensile strength. The tensile strength values increased with increase of fiber loading up to 40 wt% and then, started to decrease at 50 wt% in all treated fiber composites. When compared with the neat resin sample, a benzoylation treated composite and acetylation treated composite at 40 weight%, the increments of 106.11%, 11.82%, and 6.2% were obtained at alkali treated composite (40 wt%). This may be due to the interfacial bonding between the fiber and the matrix by the removal of lignin and hemicellulose. Due to the alkali treatment, the hydroxyl groups are reduced, which increases fiber surface roughness.[19-21] The tensile strength values of alkali treated fiber composites were followed by the acetylation treated fiber composites. 40 wt% of composite prepared by acetylation treated AFFs shows the 22.62% of improvement compared to untreated fiber composite (40 wt%). The lower values of tensile strength were observed at benzoylation treated fiber composites at entire fiber loading, but, higher than the untreated fiber composites.

The tensile modulus values of the chemically treated AFF/PF are presented in Figure 4b. It is observed that alkali treated fiber composites show superior tensile modulus compared to the other treated fiber composites. Tensile modulus values also increased from 20 wt% to 40 wt% and then, dropped in all the cases. This may be due to the entanglement, which may lead to the non-uniformity of the fibers spaced across. The alkali treated composite shows a maximum tensile modulus of 1314.5 MPa at 40 wt%. An improvement of 5.33% was obtained when compared with the untreated fiber composite.



(a)



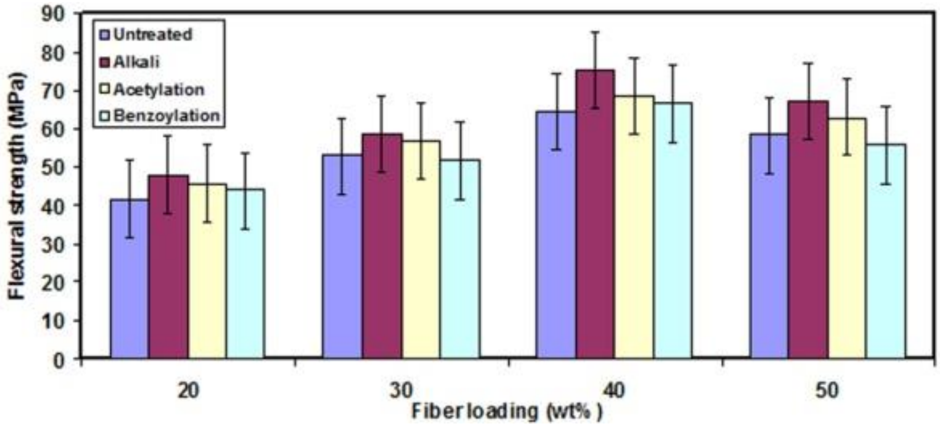
(b)

Figure 4. The average (a) tensile strength values and (b) tensile modulus of chemically treated AFF/PF composites.

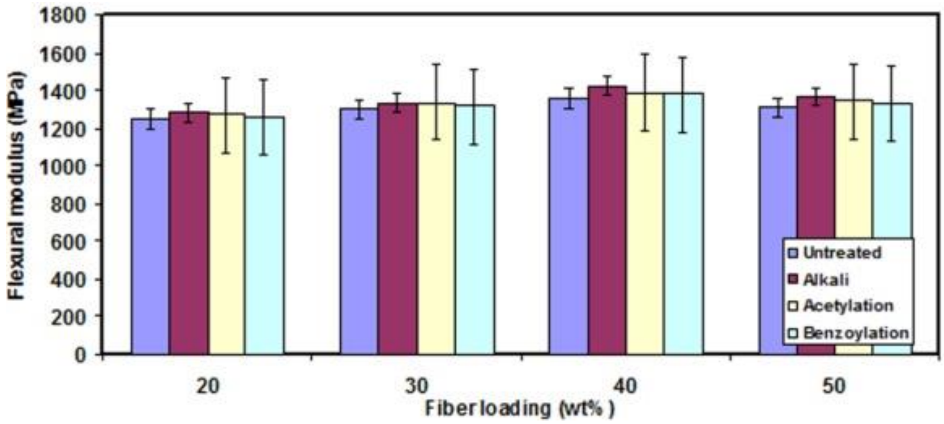
Flexural Properties

The effects of chemically treated AFFs on the flexural properties of AFF/PF composites are illustrated in Figures 5a and 5b. It can be observed from the figures that the composites reinforced with the alkali treated AFFs show the maximum flexural property values (strength and modulus) compared to the others. From Figure 5a, it can be seen that the flexural strength values increased from 20 wt% to 40 wt% and then, decreased in all untreated and treated fiber composites. The maximum flexural strength value is observed at 40 wt% of alkali treated fiber composite, which nearly 104.57% is more than the neat resin sample. An improvement of 16.53% was obtained at the flexural strength of alkali treated fiber composite when compared with the untreated fiber composite. This may be due to the better bonding of the AF with the PF resin matrix, i.e., improved fiber-matrix interaction. Composite reinforced with acetylation treated AFFs show 6.15% of the improvement in flexural strength when compared to the untreated fiber composite. Composites prepared by benzoylation treated AFFs show the lower values of flexural strength at entire fiber loading compared to the others. But, the flexural strength values were higher than the untreated fiber composites. The maximum flexural strength of benzoylation treated fiber composite was obtained at 40 wt%, which is 2.98% higher than the untreated fiber composite.

In the case of flexural modulus (Figure 5b) of AFF/PF composite, the alkali treated fiber composites show the superior properties than the other chemical treated fiber composites. The maximum flexural modulus was obtained at 40 wt% alkali treated fiber composite, which is 17.22% higher than the neat resin sample. The flexural modulus values of acetylation treated fiber composite increased from 20 wt% to 40 wt% and then decreased. The lower values of flexural properties are identified in the benzoylation treated fiber composites. This is due to the poor interfacial bonding between the fiber and the matrix. But, the flexural modulus values of benzoylation treated fiber composites are higher than untreated fiber composites. The maximum value of flexural modulus of benzoylation treated fiber composites was observed at 40 wt%, which is 1.7% higher than untreated fiber composites.



(a)



(b)

Figure 5. The average (a) flexural strength values and (b) flexural modulus of chemically treated AFF/PF composites.

Impact Strength

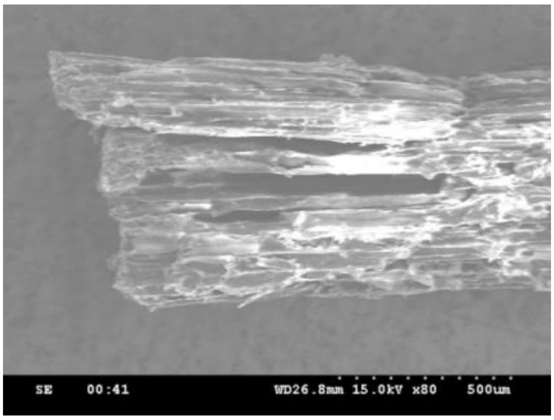
The impact strength of chemically treated AFF/PF composites was presented in Table 1. It can be observed that the composite reinforced with alkali treated AFFs shows the highest values of impact strength compared to the untreated and the other chemical treated fiber composites. The impact strength values increase with the fiber loading from 20 to 40 wt% and then decrease in all cases. The impact strength of 40 wt% alkali treated fiber composite is 3.48 KJ/m^2, which are 118.86% and 39.76% higher than the neat resin sample and the untreated fiber composite, respectively. The acetylation treated fiber composites followed the alkali treated fiber composites in the impact strength. 40 wt% acetylation treated fiber composite shows the maximum impact strength value, which is 30.92% higher than untreated fiber composites. In the case of impact strength values also, the benzoylation treated fiber composites show the lower values compared to the other chemically treated fiber composites, but, higher than the untreated fiber composites. In benzoylation treated fiber composites, the maximum impact strength (2.77 KJ/m^2) was also obtained at 40 wt%.

From the above results and discussion, it can be observed that the mechanical properties of all the chemicals treated AFF/PF composites are higher than the untreated

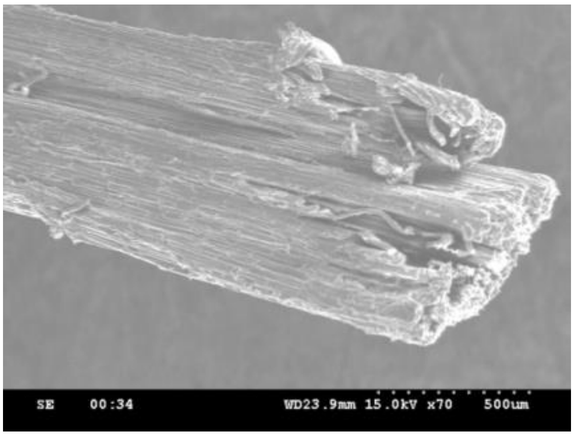
AFF/PF composites. Mechanical properties of composites increased with increase of fiber loading. Among the three treatments, the alkali treated composites show a higher degree of mechanical properties as compared to the others. The possible reasons may be due to the better modification of AFFs which leads to the better interfacial bonding between the AFFs and PF resin matrix.

SEM Study

Chemical treatments of natural fibers in the natural fiber-reinforced polymer composites can be considered in modifying the properties of the composites. In this study, the alkali treated composites showed the higher range of mechanical properties as compared to the others. Therefore, the surface morphologies of alkali treated fractured composite specimens were observed under SEM to identify the mode of failure after mechanical tests. The surface morphology of untreated and treated AFFs was shown in Figure 6. It can be seen that the untreated AFF will be differed to the treated AFF by the level of smoothness and roughness. It can also be seen that the impurities of AFFs are removed by NaOH treatment. Generally, NaOH treatment of the natural fibers increasing the amount of cellulose exposed on the fiber surface and surface roughness, which can help for better interlocking between the fiber and the matrix.



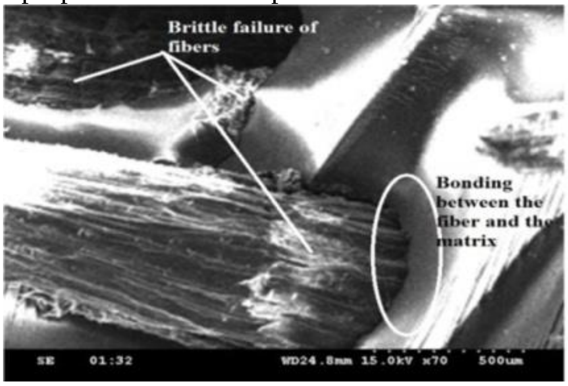
(a)



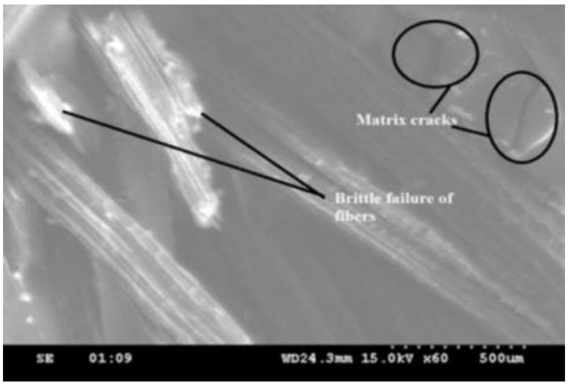
(b)

Figure 6. SEM images of (a) untreated and (b) treated AFFs.

Figures 7a - 7c show the SEM micrographs of the alkali treated AFF/PF composites. It was identified that the interfacial bonding between the alkali treated AFF and PF resin is better, as showed by the SEM Figure 7a. This may be attributed to the higher adhesion between the fiber and the matrix. Hence, the mechanical properties of composite were in the highest degree. Figures 7b and 7c showed the brittle failure mode of composite specimens after flexural test and impact test. It can also be seen that the cracks developed in the matrix during the mechanical tests. Therefore, the alkali treatment affects the mechanical properties of the composites than that of the other treatments.



(a)



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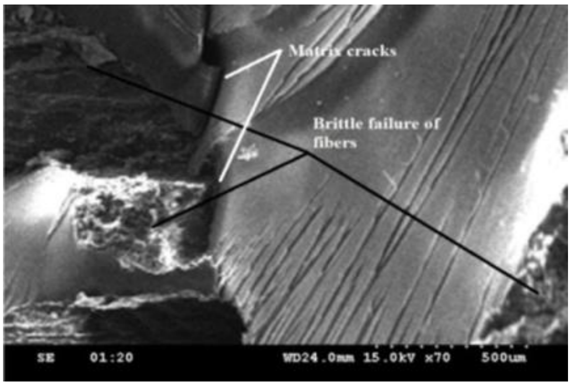

(c)

Figure 7. SEM image of alkali treated AFF/PF composite specimens: (a) tensile test, (b) flexural test and (c) impact test

4.CONCLUSION

AFF-reinforced PF composites has been fabricated at four different fiber loading and characterized by mechanical properties based on the three different chemical treatments. The presence of all three chemicals treated AFFs in the vinyl ester composite significantly increased all mechanical properties (tensile strength, tensile modulus, flexural strength, flexural modulus and impact strength) compared to untreated AFF composites. This remarkable enhancement is due to the better cleaning of AFFs by chemical agents, followed by the better interfacial bonding between the fiber and the matrix. Composites reinforced by alkali treated AFFs show the higher range of mechanical properties compared to the other chemical treated fiber composites. 40 wt% composite shows the maximum level of mechanical properties in all the cases. The fractographic analysis of fractured surfaces of mechanical tested composite specimens proved that the alkali treatment is better than the other two treatments.

5.REFERENCES

[1] Aridi, N. A. M.; Sapuan, E. S.; Zainudin and Faris M. ;AL-Oqla.; Mechanical and morphological properties of injection-molded rice husk polypropylene composites. *Int. J. Polym. Anal. Charact.* (2016), 21(4): 305-313

[2] Snejana Pleshkova-Bekiarska, Aleksandar Vasilev Kirechev Development of Method for Predicting the Influence of Elastic Porous Materials on Coincidence Frequency of Walls for Sound Insulation Based on Composite Structures : *Proc of the Bulgarian Academy of Sciences* (2017) ,70(1):121-128

[3] Navaneethakrishnan,S.; Athijayamani, A.; Analysis of the Tensile Properties of Natural Fiber and Particulate Reinforced Polymer Composites Using Statistical Approach – J. Polym. Engineering. (2015) ,35(7): 665–674

[4] Obi Reddy, K.;Uma Maheswari,C,; Ramakrishna Reddy,K.; Shukla,M,; Muzenda,E.; and Varada Rajulu.A.; Effect of chemical treatment and fiber loading on mechanical properties of borassus (toddy palm) fiber/epoxy composites. *Int. J. Polym. Anal. Charact.* (2015) , 20(7): 612-626.

[5] Navaneethakrishnan,S.; Athijayamani, A.; Measurement and analysis of thrust force and torque in drilling of sisal fiber polymer composites filled with coconut shell powder *International Journal of Plastics Technology*. (2016) ,19 (2): 227-240

[6] Kommula, V. P., K. ;Obi Reddy, M.; Shukla, T.; Marwala, and Varada Rajulu. A. ; Mechanical properties, water absorption, and chemical resistance of napier grass fiber strand–reinforced epoxy resin composites. *Int. J. Polym. Anal. Charact.* (2014). ,19(8): 693-708.

[7] Uma Maheswari, C.; Obi Reddy,K.; Muzenda,E.; Shukla,M.; and Varada Rajulu.A.;). Mechanical properties and chemical resistance of short tamarind fiber/unsaturated polyester composites: Influence of fiber modification and fiber content. *Int. J. Polym. Anal. Charact.* (2013), 18(7): 520-533.

[8] Singha, A. S.; and Rana.AK.;. Improvement of interfacial adhesion in cannabis indica/unsaturated polyester biocomposites through esterification reaction. *Int. J. Polym. Anal. Charact.* (2012),17(8): 590-599

[9] Pothan, L.A., S. Thomas, and G. Groeninckx. The role of fiber matrix interaction on the dynamic mechanical properties of chemically modified banana fiber/polyester composites. *Compos. Part A.* (2006).,37(9): 1260-1269.

[10] Manikandan Nair, K.C., S.M. Diwan, and S. Thomas. Tensile properties of short sisal fiber-reinforced polystyrene composites. *J. Appl. Polym. Sci*. (1996),60(9): 1483-1497.

[11] John, M.J., and R.D. Anandjiwala. Recent developments in chemical modification and characterization of natural fiber-reinforced composites. *Polym. Compos.* (2008),29(2): 187–207.

[12] Paul, A., K. Joseph, and S. Thomas,Effect of surface treatments on the electrical properties of low-density polyethylene composites reinforced with short sisal fibers. *Compos. Sci. Technol.* . (1997),57: 67-79.

[13] ASTM D 638-10. 2010. Standard test method for tensile properties of plastics. Annual Book of ASTM Standards. 08.01:1-16.(2010)

[14] ASTM D 790–10. Standard test methods for flexural properties of un-reinforced and reinforced plastics and electrical insulating materials, Annual Book of ASTM Standards. (2010),08.01: 1-11.

[15] ISO 180:2000. 2000. Plastics-determination of Izod impact strength, Third edition, ISO Central Secretariat, Switzerland.(2000)

[16] Sun, X.F., R.C.Sun, P. Fowler, and M.S. Baird. Isolation and characterisation of cellulose obtained by a two-stage treatment with organosolv and cyanamide activated hydrogen peroxide from wheat straw. *Carbohydr. Polym.* (2004),55: 379–391.

[17] Khalid, M., C.T. Ratnam, T.G. Chuah, S. Ali, and T.S.Y. Choong. Comparative study of polypropylene composites reinforced with oil palm empty fruit bunch fiber and oil palm derived cellulose. *Mater. Des.* (2008), 29: 173–178.

[18] Rokbi M., H. Osmani, A. Imad, and N. Benseddiq. Effect of Chemical treatment on Flexure Properties of Natural Fiber-reinforced Polyester Composite. *Proced. Eng.* (2011), 10: 2092-2097.

[19] Yan L., N. Chouw, and X. Yuan. Improving the mechanical properties of natural fiber fabric reinforced epoxy composites by alkali treatment. *J. Reinf. Plast. Compos.* (2012),31: 425-437.

[20] Navaneethakrishnan .S, Athijayamani.A, Taguchi method for optimization of fabrication parameters with mechanical properties in fiber and particulate reinforced composites - International Journal of Plastics Technology (2015),19(2),227-240.