Development of Palmyra Fiber Reinforced Polyester Composite

Nasrin Jamine[1], Ferdausee Rahman Anannya[2]* and Farhana Jannat[3]

Abstract

Composite is a kind of material that is produced by using more than one material to achieve better properties than the raw materials in the newly produced material. In general, a matrix and a reinforcing material are most commonly used to produce the composite material, along with some other additives. Natural fibers are very often used as reinforcement by many researchers, previously. In this study, palmyra palm fiber reinforced polyester composites have been made by using different amounts of fiber loading, and the mechanical properties along with morphological structure and water absorbency property of the produced materials are assessed. Results have shown that the addition of fiber improves tensile properties to a smaller extent, but impact property has been improved vastly. Also, the material showed significantly improved elongation properties. The morphological structure showed poor adhesion between fiber and matrix, which improved with the increment in fiber loading. These composites have also shown almost non-absorbent nature in the water absorbency test, which means these materials could be suitable for some specific applications where considerable tensile and impact properties and non-absorbent nature can come to a good use.

Keywords: *Natural fiber, Tensile Strength, Impact Strength, Water Absorbency, Porous Structure*.

1. Introduction

Composite is a kind of material that is made by using two or more different materials and the final product is expected to haveunique propertiescompared to the core materials from which the final product is made (Loos, 2015). Generally, a composite material contains a minimum of two materials, along with some other additives (Anannya & Mahmud, 2019). These two materials include a resin or matrix material and reinforcing material for the matrix. The reinforcing material is required to improve mechanical properties mainly. Other than that, reinforcing material also lowers the weight of the material or sometimesmakes the end product more environment friendly (Loos, 2015; Mwasha, 2009). More than one matrix or reinforcement or both can also be used to produce a much-improved product or product of specific characteristics. The reinforcing material can be a fiber or any particle. Composites can be made by using a matrix and discontinuous short fibers or long continuous fibers or particles of different sizesin the dispersed phase (Loos, 2015). These matrix and reinforcing materials can be biodegradable natural materials or non-biodegradable syntheticmaterials(Amin et al., 2019). Composites made of synthetic resin and natural reinforcing material have become the most commonly made composites which are already in use in many sectors. Natural fibers have become the most preferablereinforcing material even though natural fiber-reinforced composites have many drawbacks but some at the same time, these also have some exceptional advantages such as biodegradability, non-toxicity, and ability to absorb carbon dioxide during growth(Abdelmouleh et al., 2007). On the other hand, resins can be thermoplastic or thermoset. Thermoplastic resins melt when heated and solidify again after being cooled. Thermoset resins have the advantage of being irreversibly cross-linkedwhen cured properly, and that bond is not affected by slightly high temperatures. This property has made thermoset resins most preferable for composites. Somecommon thermoset resins are unsaturated polyesters, epoxies, vinyl esters, etc(Koz?owski & W?adyka-Przybylak, 2008; Mohanty et al., 2006). Polyester may be the most common one among these and the cheapest one too. It is produced by the esterification reaction of dibasic organic acid and dihydric alcohol (Loos, 2015). Polyester resin is a clear viscous liquid as the polymer solution is kept in a monomer, which is generally styrene which helps the resin to cross-link the chains of the polyester(Loos, 2015). This resin is generally unsaturated,with double bonds inside the structure. The liquid resin is cured to form a solid by using a catalyst (Jones, 2017; Loos, 2015). The most commonly used catalyst is Methyl Ethyl Ketone Peroxide (MEKP) and the curing can take place at room temperature. It is difficult to use a natural fiber as

1 Lecturer, Department of Apparel Merchandising & Management (AMM), BUFT

2 *Lecturer, Department of Textile Engineering & Management (TEM), BUFT
Corresponding author email: ferdausee.anannya@buft.edu.bd

3 Assistant Professor, Dept. of Apparel Merchandising & Management (AMM), BUFT

reinforcement for polyester because of the extremely hydrophobic nature of polyester, in that case, a fiber with superior mechanical properties and comparatively waxy or rougher surface can cause considerable improvement in terms of mechanical properties of the composite. From that point of view, Palmyra fiber can be a very good reinforcing material. It is got from Palmyra (Borassusflabellife) tree. It is reported that fibers are obtained from the leaf stem base and leaf stem (Srinivasababu et al., 2014). The length of the fiber varies from 1 to 1.5m and the density of the fiber is generally between 0.4 - 0.6 g/cc. The tensile strength of Palmyra fiber varies from 70 MPa to 250 MPa and it varies a lot (Srinivasababu et al., 2014). Palmyra fiber is lingo cellulosic and the fiber has a waxy, porous,and rough surfaceand these pores help penetration of liquid resin into the fiber structure which may help to obtain better mechanical properties of the composite material reinforced by this fiber (Srinivasababu et al., 2014).In this study, palmyra palm fiber obtained from leaf stalk was used as reinforcement for unsaturated polyester to produce composite material and some common mechanical and some other properties were examined.

2. Previous Works

There have been some researches on palmyra fiber reinforced polyester composites in which different factors were analyzed. But there are not manypieces of researchdone by using palmyra palm fiber extracted from the leaf stalk. Dabade et al. [2], extracted the palmyra palm fibers from the stem(Dabade et al., 2006). They extracted the fibers by chemical treatment of the stem with 1%sodium hydroxide (NaOH) solution. They used fibers of up to 50 mm length for the research and found that the addition of fiber improved flexural strength more or less significantly. At 50 mm fiber length, the composites showed the maximum tensile strength of 42.65 MPa.Thiruchitrambalm et al. produced palmyra palm leaf stalk fiber reinforcedpolyester composite (Thiruchitrambalam & Shanmugam, 2012). They found 60% improvement of tensile strength,because ofthe addition of fiber, which was pre-treated by NaOH in mercerization treatment.This trend was also seen for benzoyl-treated fiber composites too.Shanmugam et al. prepared leaf stalk extracted palmyra fiber reinforced polyester composite and analyzed wear and frictional properties(Shanmugam et al., 2016). They treated fibers with 5% NaOH and washed the fibers with dilute hydrochloric acid (HCl). They found that reinforcing with fiber caused a significant loss in wear test and reduction in coefficient of friction. The maximum length of fiber used in that research was 7 mm. Some other researches have been done by using palmyra fiber extracted from the fruit (Sankar Irullappasamy et al., 2016), leaf petiole (Srinivasababu et al., 2014), sprout leaf (Srinivasababu et al., 2012), etc., which are not similar to this study.

3. Materials and Methods

In this experiment, raw Palmyra fiberobtained from the leaf-stalk has been used without any sort of pre-treatment.The fibers were collected from local palmyra palm trees. The stalks were immersed in water, which helped to loosen up the fibers which could be taken apart from the stalk. Unlike previous researches, the length of fibers was18cm for this study. Unsaturated polyester of Polynt brand (required time for curing: 8-11 min at 25°C with 2% hardener) was collected from a local dealer. Catalyst or hardener Methyl Ethyl Ketone Peroxide (MEKP), a colorless liquid, was also collected from a local dealer.The composite was made by using the hand layup method. Different ratios of fiber and polyester were used. 4%, 8%, 10%,and 12% fiber loading were used to make four samples and a sample containing pure polyester only of similar thickness was made for comparing the results. The thicknesses of the samples were maintained around 5mm. 10kg or 98N was applied to the composite during the hardening of the composites. Then the samples were kept at room temperature for 24 hours to complete the curing process. The samples were taken to different testing afterward.

3.1. Testing Methods

To identify different properties of the composites, different testing had been performed including imaging by Scanning Electron Microscope (SEM), Tensile, Impact, and water absorbency. All tests were done using specific test standards. The methods are discussed below.

3.1.1. Imaging by Scanning Electron Microscope (SEM)

SEM uses a kind of focused beam of highly energized electrons to generate an image of the sample from a variety of signals at the surface of a solid sample. The signals help to make images that are derived from the interaction between the electron and the sample. The image can reveal various information about the sample, includingexternal morphology (texture), chemical composition, and crystalline structure and orientation of materials that have made up the sample. The results are obtained from the generated two-dimensional image, which shows the spatial variations in these properties. For this test, Hitachi Scanning Electron Microscope was used.

3.1.2. Mechanical Tests

Tensile and impact properties were analyzed for this study. These are discussed below.

3.1.2.1. Tensile Strength

The tensile test was done by using Universal Testing Machine (UTM) of Hounsfield brand. The method followed was ASTM D638 method under 50 KN force.The tensile test specifies the capacity of composite material to resist forces that tweak it apart and the capability of the material to expand priorto failure. Tensile strength varies from material to material is determined through tensile testing. and the tensile properties of any fiber-reinforced composite material depend on the structure of the material, which includes the volume or weight fraction and interfaces between the components. Moreover, thetensile properties of the reinforcing fiber and surface characteristics of the fiber can affect the tensile properties of the composites. The mechanism of failure also depends on the angle between fibers and the specimen's axis or orientation of the fibers.

3.1.2.2. Impact Strength

Impact strength is often the most important factor in materials selection, which actually determines the material toughness or impact strength at the presence of a flaw or notch and fast loading conditions. Materials without good impact strength properties are essential for engineering and other applications. The result is affected heavily byfiber loading, length of fiber, fiber-matrix adhesion, etc.Generally, fiber loading improves the impact properties of a composite. The test was done by using IZOD Impact Energy Tester of Hung Ta Instrument CO. Ltd according to the method of ASTM D256 standard.

3.1.3. Water Absorbency Test

The absorbency of a composite actually means the amount of water a composite can absorb within a specific duration. Absorbency of the composite plays an important role in determining the end-use of the final product. The absorbency of a composite depends on the chemical composition and the structure of the composite. Generally, a composite is found absorbent ifthe material is made of natural polymers and fibers which absorb water,but composite made of synthetic materials is not absorbent usually. If a synthetic material is found as an absorbentone, then it may be because of poor adhesion between the molecules of the composites, poor bonding between fiber and matrix molecules which can create voids or gaps or air bubbles in between fiber and matrix and it can have a detrimental effect on tensile properties of the composite (Muñoz & García-Manrique, 2015). Absorbency of the composite was measured by drying out the samples in the oven drier for taking the initial weight. The dried sample wasmerged in liquid then and after a certain period, the sample was taken out, wiped with felt or any highly absorbent fabric, and then weighed again. ASTM D570-98 was used as the standard for the test. The following equation wasbeing used to determine the absorbency.

$$\text{Absorbency\%} = \frac{W\text{-}D}{D} \times 100$$

Here, D and W are initial or dry weight and weight after a certain time of the composite, respectively.

4. Results and Discussions

Five compositionally different specimens had been made and tested by 4 types of testing methods, such as

imaging by Scanning Electron Microscope (SEM), tensile test, impact test, and water absorbency test. All results are discussed below.

4.1. Imaging by SEM

Images were taken by using SEM to see the morphological structure of the samples. The images are given below in figure 1.

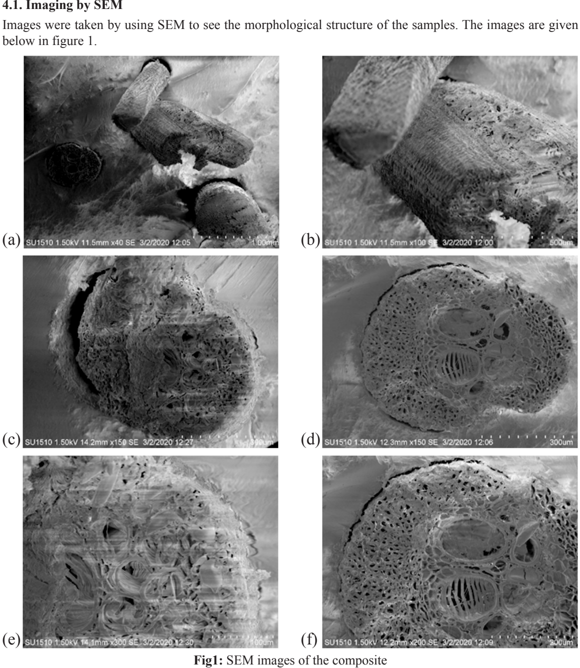

Fig1: SEM images of the composite

The above images above show some important characteristics of the material. All images show that the fiber is very porous and rough, which can come helpful for forming mechanical bonds between fiber surface and matrix. Also, the resin can penetrate the pores of the fiber better (as shown in figure (c), (d), (e),and (f)) to help that process. But still, due to being different, the fiber surface and matrix could not form sufficient bonds to utilize the maximum ability of the fibers, as palmyra fibers are known for quite high strength. That's why there are still gaps or voids in between fiber and matrix (shown in (a) and (c)). A

higher percentage of fiber has made the composite more compact which resulted in comparatively better interfacial bonding (shown in figure (c) and (d) where there is more void in figure (c) which contains 4% fiber whereas figure (d) contains 10% fiber). The pores in fiber cross-section also mean better absorbency and capillary properties of the fibers for which the composites are expected to show slight absorbency at least when fiber percentage increases while pure polyester is not expected to absorb any water.

4.2. Mechanical Properties

A tensile test and impact test was done to find out the mechanical properties of the composites. The results are given below in table 1.

Table 1: Mechanical properties of the composites

Polyester% + Fiber%	Tensile strength (MPa)	Tensile Modulus (MPa)	Max. load (N)	Elongation at break (%)	Impact Strength (kg-cm)
100%+0%	28.28	631	1790	6.37	1.453
96%+4%	30.47	710.5	1896	10.71	12.84
92%+8%	31.66	686.5	2073	15.9	16.968
90%+10%	32.13	619.5	2082	19.2	18.046
88%+12%	32.78	580.3	2095	30.87	19.04

While considering the tensile strength, the pure polyester sample shows the strength of only 28.28 MPa. However, it has increased gradually along with the addition of fiber and ended up by at 32.78 MPa for 12% fiber addition. On the other hand, the tensile modulus shows a downward trend after a peak value of 710.5 MPa at 4% of fiber addition. The lowest was achieved at 12% fiber composite. The initial increase of tensile modulus was resulted because of the low percentage of fiber addition. Palmyra fiber is known as very strong fiber with about average tensile strength of 110-280 MPa while the modulus of the fiber is around 150 MPa (Srinivasababu et al., 2014; Velmurugan & Manikandan, 2007). The cross-linking agent was required for the polyester resin to solidify and increasing amount of cross-linking agent than required level can increase stiffness, which is shown in the increased tensile modulus of the material. The percentage of the cross-linking agent is taken according to the weight of the resin. When very small amount of fiber (for 4% fiber loading) was added in the resin, the percentage of cross-linking agent varied very little or almost none. It caused addition of slightly higher amount of cross-linking agent than the required level and it resulted in slightly improved tensile modulus of the composite. The comparatively high modulus of palmyra fiber also played its part in the process. But with an increasing amount of fiber, the flexible nature of fiber took over the stiff properties of the polyester and made the composite softer with decreasing tensile modulus as shown in the results. Later, the percentage of fiber became enough to improve the tensile properties of the composite as the fibers had superior tensile properties more than the polyester. That's why the poor adhesion between fiber and resin, which was shown in the SEM images, could not deteriorate the tensile properties of the composite. But the percentage could not be increased too much because of the lower density of palmyra fiber(Srinivasababu et al., 2014; Velmurugan & Manikandan, 2007). For that reason, the bulk became too much, even though the mass of the fiber did not increase that much due to the lightness of the fibers.

So, from this experiment, it can be said that increasing the palmyra fiber percentage decreased the tensile modulus which means the composite became flexible with the addition of fiber which is evident on the elongation properties of the composites as it has increased rapidly with the addition of fiber.The addition of fiber improved tensile properties because of two reasons, actually. The first reason is, the palmyra fiber is of quite high strength, which helpedto improve the mechanical properties of the composite which has

already been mentioned before(Srinivasababu et al., 2014). Another reason is the rough and porous surface of thefibers, as shown in SEM images, which helped mechanical bonding between fiber and matrix(Nam et al., 2011). An increasing amount of fiber resulted in better strength because increment of fiber percentage made the composite more compact, which also reduced voids in between fiber and matrix and that resulted in better mechanical properties.

Tensile modulus decreased with the addition of fiber because when fiber was added after 4% fiber loading. The reason for the unusual case of that sample containinnng 4% fiber has already been discussed above. Later, the trend became usual, and it went downward with an increasing percentage of fiber loading. It happened due to the flexible nature of fiber, which became more apparent and it resulted in flexible composite material, too. It was also reflected in the results of elongation properties, which improved significantly with an increasing amount of fiber. On the other hand, the addition of fiber resulted ina rapid rise in the impact strength of the composites. Just 4% ofreinforcing fiber increased the strength to roughly eightfold, andit continued to increase at a constant rate on further addition of fiber. And the trend continued in other samples too. It happened due to the low density of fiber. The large bulk of fiber could offer significant resistance to impact force as the fibers could absorb the impact. With increasing amount of fiber, the bulk also increased, and that resulted more absorption of the impact force put on to the composite. That's why the impact strength improved significantly with the fiber loading.

Actually,the addition of natural fibers very often affects the mechanical properties of the composites negatively, especially the tensile properties because hydrophobic natural fiber surface cannot create any chemical bond with hydrophobic resin(Anannya & Mahmud, 2019). But in the case of palmyra palm fiber, its porous surface helped comparatively better penetration of the resin into its structure, which also helpedthe formation of mechanical bonds as the waxy surface of the fiber is better suited to synthetic resin than other typical natural fibers. These were shown in SEM images earlier in the result and discussion chapter(section 4.1). But still, there werea significant amount of voids in between the fiber surface and resin, as shown on SEM image. But the significantly better mechanical properties of the fibers helped to improve the mechanical properties of the composites even with the voids and debonding within the structure due to fiber loading. That's why the mechanical properties did not improve as well as expected.

4.3. Water Absorbency Properties

To observe the behavior of water absorption of the Palmyra fiber reinforced polyester composites, water absorbency tests were carried out. Composite samples were immersed in a 500g water bath at room temperature over a period (24 hours) until the samples became saturated. Five specimens were picked to test and the test results are given below in table 2.

Table 2: Water absorbency of the composites

Polyester % + Fiber %	Weight before soaked (gm)	Weight after soaking (gm)	Absorbency percentage %
0%	209.71	209.71	0
96%+4%	209.75	209.88	0.08106
92%+8%	209.72	210.4	0.32903
90%+10%	209.72	210.63	0.43870
88%+12%	209.78	212.13	1.15397

From the above chart, it is clear that water absorption is negligible. The pure polyester sample did not absorb any moisture at all; however, the increasing percentage of fiber affected moisture absorption to some extent.Amaximum of 2.35 gmof water was absorbed,which resulted in 1.15397% absorbency by composites containing 12% of fibers.The absorbency percentage was increased byan increasing amount of

fiber addition in the structure, due to better absorbent property and capillary property of the fibers in the composites.It was also helped by the porous tube type morphological structure of the fibers, as shown in the SEM images before (in section 4.1).The absorbency percentage did increase, but the rate was quite low, due to the addition of a comparatively lower amount of fiber as the main component of the composites (polyester resin) was 100% non-absorbent(Cook, 1993; Updegraff, 1982).

5. Conclusion

This study was done to analyze the morphology, mechanical properties and absorbency property of palmyra palm fiber reinforced polyester composite. It would a partially biodegradable composite because synthetic polyester is non-degradable material. The resulted materials showed that the addition of fiber improved the mechanical properties of the composites because of the morphology and superior mechanical properties of the fibers. But due to being totally opposite in nature, there was a minimum amount of bonding between fiber and matrix, which improved a bit with a higher percentage of fiber. But still, the results could have been far better if some surface modification was done to fibers to improve fiber-matrix adhesion. Water absorbency was found almost non-existent, but with an increasing amount of fiber, the absorbency increased slightly due to porous morphological stricture of the fiber. So, with slight improvement, these composites are more suited to applications where impact strength is more important than tensile properties and lesser absorbency is mandatory.

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