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Behavior of Water Absorption Characteristics of Non-Biodegradable and Biodegradable Polymeric NFRC's

Kanishka Jha[1], **Hari Om Maurya**[2],
Himanshu Bisaria[3] **and Y.K. Tyagi**[4]
[1,2,4]DIT University
[3]MNNIT Allahabad
E-mail: [1]kanishkaero@yahoo.com, [2]engghom@gmail.com,
[3]himanshubisaria20@gmail.com, [4]yogesh_tyagi30@yahoo.co.in

Abstract—*Water resistant properties of green/natural composites are now a day attracts many researchers especially for their potential applications in daily life. In the present study different fiber reinforced non-biodegradable and biodegradable polymer composites were fabricated to understand the behavior of water resistant properties. Water absorption tests were conducted as per the ASTM standards, samples were placed into distilled water for 132hrs. Percentage of water uptake (W_∞), Sorption Coefficient (S), Diffusion Coefficient (D) and Permeability Coefficient (P) were evaluated to understand water resistance properties of different composites. It was observed from the results that water absorption percentage was maximum for large size fiber and for higher wt% of particle in composites. The Particle reinforced NFRC showed minimum resistance to water and the maximum (upto 20%) water absorption at 40wt% sample. Among Sisal and Jute Fiber NFRC's, Jute absorbance was found to be more than Sisal fiber, but lesser than Pine Cone particle reinforced NFRC's at 30wt%.*

Keywords: Natural Fiber, Biodegradable Polymer, Epoxy, Water Absorption.

1. INTRODUCTION

Nature give us abundance of materials that can be used to meet the life's daily requirements. By using such resources, we can overcome the accumulation of plastic waste. Strict government regulations against plastic usage and its harmful aftermaths, encouraged many researchers to develop green materials that can find their application in daily life. Presently, synthetic fibers like glass, carbon and aramid are widely being used as reinforcements in polymer composites, as they have better strength and stiffness properties [1]. However, synthetic fibers on the other hand have drawbacks in terms of recyclability, biodegradability, initial processing cost, energy consumption, health hazards etc. [2]. Nowadays, the most commonly used natural fibers as reinforcement are flax, hemp, sisal and jute due to their specific strength, modulus and availabilities. These natural fibers are plant based and are lignocellulosic in nature. They are composed of cellulose, hemicelluloses, lignin, pectin and waxy substances [3].

The natural fiber reinforced composites are comparably strong, lightweight, cost effective and free from health hazards. Despite the advantages, they undergo water absorption especially moisture absorption which hampers their overall properties. However, major factors that presently restrict the large-scale manufacturing of green/natural fibers composite are poor interfacial adhesion between the fiber and matrix and the hydrophilic nature of fibers. A weak interfacial adhesion at the matrix interface which acts as a binder with the fibers, does not results in desired mechanical properties in the composite [4].

Exposure to the atmosphere is very common phenomenon, every material is somehow bound to witness it and that's make understanding of the water resistance very crucial. Hygroscopicity is an undesirable property of natural fibers caused by its own constituents. To get a better understanding of the mechanisms of moisture absorption, hygroscopicity is one factor that has to be addressed. The moisture absorption by composites in a certain course of action containing natural fibers can affect their performance on a long-term basis. The hydrophilic nature of fibers is a major problem for their use as reinforcement in polymers. Hydrophilic behavior of plant fibers depends on their composition and specific structure [5]. There are other various chemical methods to enhance the performance of natural fibers as reinforcement in polymer composite materials. The modifications enhance the structures of the fiber and that changes their compositions. As a result, absorption characteristics of the fiber is decreased and this facilitates better interfacial adhesion with the polymeric matrix materials. This provides better mechanical and thermal properties of fiber and composites [6]. The effect of hybridization on glass fiber with sisal and pineapple leaf fiber were analyzed and observed that alkali treated fibers shows improvement in tensile and flexural strength whereas cyano-ethylation treatment improves the impact strength of the composite [7].

Mechanical properties of sisal/banana hybrid composite were analyzed by Idicula et. al. and it was observed that tensile strength of the hybrid composite was higher when sisal fibers sandwiched between banana fibers. Study also compares the experimental tensile properties with the Hirsch Model [8]. Many researchers found jute as a promising reinforcing material because of its availability and it is less expensive, its mechanical and thermal properties are highly and depend on its origin, climatic and fabrication techniques [9]. Tensile, flexural and chemical resistance properties of the Sisal/Carbon hybrid composite were studied by Khanam et al., and it was found that fibers treated with 18 % alkaline solution (NaOH) showed improved the properties. Further, it also observed that except carbon tetra chloride, untreated and treated composites is resistant to all chemicals [10].

The objective of this work is to compare the water resistance characteristics of three different natural fiber reinforced polymer composites, so that their usage can be defined to withstand severe conditions.

2. MATERIALS AND METHODOLOGY

2.1 Materials

Two matrix materials were used, AY-105 and Polycaprolactone(biodegradable). Epoxy AY-105 was purchased from local supplier and Polycaprolactone was purchased from Sigma-Aldrich. Natural reinforcement used were Sisal, Jute (fiber) and Pine Cone (particle). Hardener HY951 was used for curing of Epoxy.

2.2 Fabrication

Three different polymer composites were fabricated, two of them were from non-biodegradable polymer matrix and reinforced in fibrous form, whereas third one from biodegradable polymer matrix and reinforced with particulate form. Particulate composite was developed by varying weight percentage of Pine cone particle in Polycaprolactone matrix (0, 15, 30 & 45), whereas other two types were fabricated using short sisal and jute fibers in epoxy AY-105 by varying their lengths. For epoxy, HY-951 hardener was used for curing.

All specimens were fabricated using hand lay-up technique and sheets were made by placing them in a press under the periodic loading at 1MPa. Water absorption test was carried out with separate specimens for each test and the average values were reported. Sample coding for sisal and jute at 30% weight fraction in epoxy was listed in Table 1 and coding for biodegradable composite at different weight fraction of pine cone in polycaprolactone in Table 1.

Table 1: Nomenclature of composite

S5/J5	Fiber (5 mm length)
S10/J10	Fiber (10 mm length)
S15/J15	Fiber (15 mm length)
S20/J20	Fiber (20 mm length)
P10	Fiber at 10% by weight
P20	Fiber at 20% by weight
P30	Fiber at 30% by weight
P40	Fiber at 40% by weight

2.3 Water absorption test

Water absorption test is carried out by the specimen of size 20 mm × 10 mm × 3.2 mm as per ASTM D570. The specimen specifications are shown in Fig. 1.

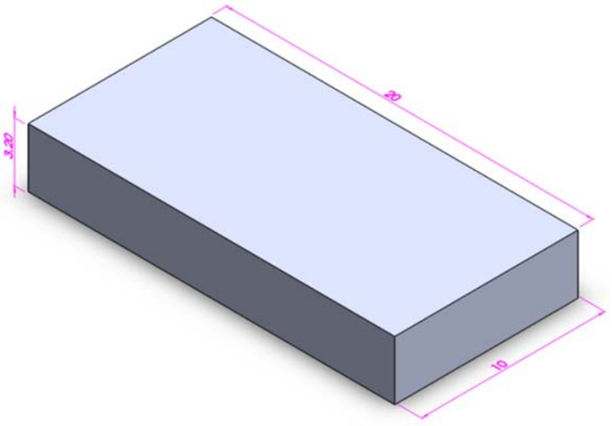

Fig. 1: Solidworks model for water absorption test

The conditioned specimen is immersed in the distilled water at room temperature. All the faces are dipped in the water. The specimens are removed from the water after 12 hours' intervals and dry with tissue paper. The specimen is weighted with a digital balance which had least count 0.0001 g the reading is taken up to 132 hours.

Following formulae used for calculations

- Diffusion coefficient, $D = \pi \left({m^2 l^2}/{16 W_\infty^2} \right)$
- Sorption coefficient, $S = {W_\infty}/{W_t}$
- Permeability coefficient, $P = D \times S$.
- Where m is slope of the linear portion of the sorption curve and *l* is the initial sample thickness
- W_∞ and W_t are molar percentages of water uptake at infinite time and at time t.

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3. RESULT AND DISCUSSION

The use of natural fibers as potential reinforcements in polymer composites are well reported in many literatures. However, the natural fiber-reinforced polymer composites are concerned by the highly polar and hydrophilic nature of lignocellulosic fibers, which result in a poor interfacial adhesion compatibility with hydrophobic polymer matrix, which led to degraded mechanical properties. Therefore, the water absorption characteristics of the sisal, jute and pine cone fiber composites at various loading were investigated [11]. Water absorption properties are tabulated in Table 2, 3 and 4 for the short Sisal, short Jute and Pine Cone composites respectively. And water absorption (%) for different composites were plotted against square root of time in second which were shown in Fig. 2, 3 and 4. In water absorption testing initially water absorb by the specimen was almost negligible for first few hours. The amount of water absorb was increased when the duration of immersion increased. The total time of immersion was taken as 132 hours. A common trend was absorbed among all composites, after 84 hours the water absorption (%) curves flattened, which shows near to saturation point. This state was known as saturation state of composites.

Diffusion coefficient is a kinetic parameter. Diffusion coefficient is characteristic of the material in which solvent molecules are move into solid.

Table 2: Water absorption properties of sisal composite

Samples	Percentages of Water uptake at Infinite Time (W_∞)	Sorption Coefficient (S)	Diffusion Coefficient (D) (mm2/s)	Permeability Coefficient (P) (mm2/s)
S5	2.68	3.44	3.94E-06	1.35E-05
S10	2.86	3.25	4.40E-06	1.43E-05
S15	3.25	2.85	5.72E-06	1.63E-05
S20	3.86	3.14	4.72E-06	1.48E-05

Sorption coefficient is related to the saturation of water absorbed by composite. Higher value of sorption coefficient means that composite gets saturated in less time and vice-versa. Permeability coefficient gives the combined effect of diffusion coefficient and sorption coefficient. The diffusion properties of composites were explained by Fick's laws, evaluated by weight gain measurements of dried specimen immersed in water by considering the slope of the first part of the weight gain curve versus square root of time in seconds [12]. The results of water absorption parameters for short sisal epoxy composites were studied (Table 2), it was observed that sorption coefficient was found to be decreased with increase in the length upto 15mm and showed minimum values for composite S15. Then value of sorption coefficient was further increased if length of fiber was increased. The diffusion coefficient and permeability coefficient were investigated and it was observed that values were increased upto fiber length of 15mm (S15) after that values were reduced for 20mm length of fiber (S20).

Table 3: Water absorption properties of jute composite

Samples	Percentages of Water uptake at Infinite Time (W_∞)	Sorption Coefficient (S)	Diffusion Coefficient (D) (mm2/s)	Permeability Coefficient (P) (mm2/s)
J5	2.79	1.74	1.53E-05	2.67E-05
J10	4.77	1.73	1.55E-05	2.68E-05
J15	5.31	1.65	1.70E-05	2.81E-05
J20	5.49	1.66	1.68E-05	2.80E-05

Table 3 shows the evaluated water absorption properties for jute epoxy composites. From the observation it was observed that sorption coefficient followed the same trend as short sisal epoxy composite and showed minimum values for J15. The diffusion coefficient and permeability coefficient were also follow the same trend as short sisal epoxy composites. The higher value of diffusion coefficient and permeability coefficient observed for J15.

Table 4: Water absorption properties of pine composite

Samples	Percentages of Water uptake at Infinite Time (W_∞)	Sorption Coefficient (S)	Diffusion Coefficient (D) (mm2/s)	Permeability Coefficient (P) (mm2/s)
P10	1.90	2.28	8.93E-06	2.04E-05
P20	2.44	1.29	2.78E-05	3.59E-05
P30	8.20	2.77	6.07E-06	1.68E-05
P40	20.96	2.11	1.04E-05	2.20E-05

Water absorption properties for pine cone composite were calculated and shown in Table 4. The sorption coefficient of pine cone composites was observed and it was found that values increased with weight fraction and maximum for 40% weight fraction of fiber (P40). The diffusion coefficient and permeability coefficient shows variation with increasing weight fraction of pine cone. It was observed that value initially increased for P20 then suddenly reduced for P30 and again increased for P40.

By increasing the fiber content whether in terms of weight fraction or their effective length, the percentage water absorption tends to increase. An increased in fiber loading is recognized to increase the number of hydroxyl groups and micro-voids associated with the composites [13]. In contrast to that, the results obtained from the water absorption test for short sisal epoxy composite showed that percentage water absorption was found to be increased with increasing the length of reinforced fiber.

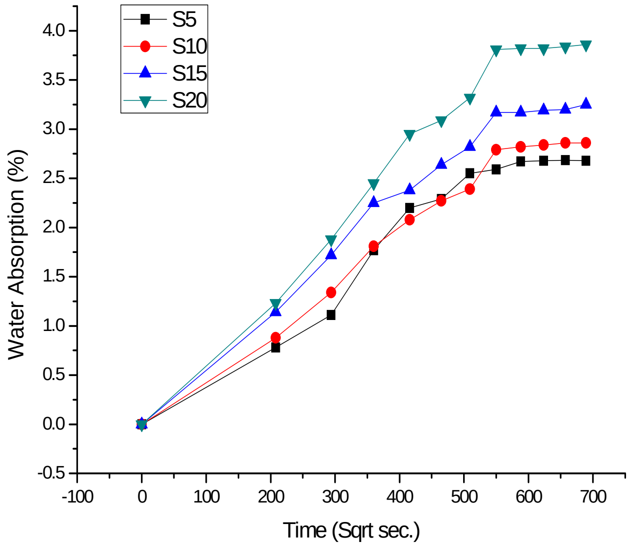

Fig. 2: Sorption curve for short sisal composite

The higher value of percentage water absorption was obtained for the specimen S20 which was 18.77%, 34.97% and 44.03% more than S15, S10 and S5 respectively. The results observed from the water absorption testing of short jute epoxy composite were found to follow same trend. The higher percentage of water absorption obtained for the short epoxy jute composite J20 which was 3.39 %, 15.09 % and 96.77 % more than J15, J10 and J5 respectively.

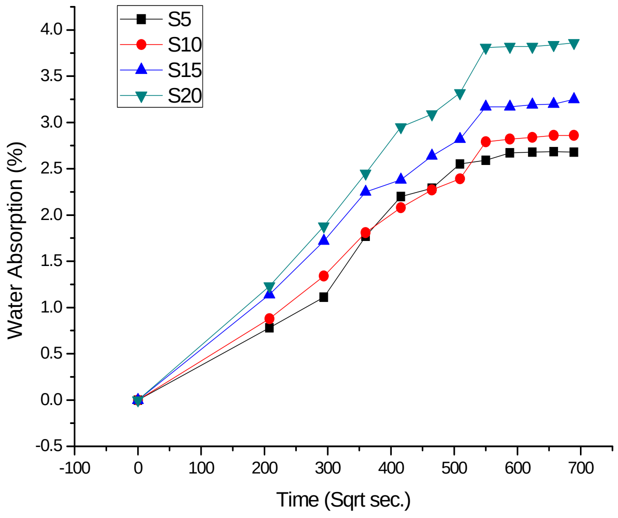

Fig. 3: Sorption curve for short jute composite

In water absorption study of biodegradable composite of Pine Cone particle and Polycaprolactone matrix, same trends were observed whereas percent variation was comparatively higher than fibrous reinforcement at similar weight fraction. In water absorption testing P40 was absorbed 155.61%, 759.02% and 1003.16% more water than P30, P20 and P10 respectively. Similar trends were also observed by Valdes et. al. [14].

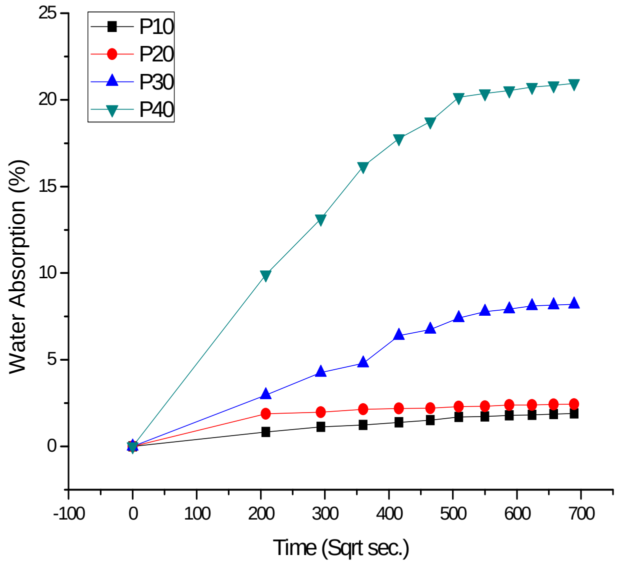

Fig. 4: Sorption curve for bio-composite

4. CONCLUSION

The effect of water absorption on various natural fiber reinforced non-biodegradable and biodegradable polymer composites has been studied. It shows that water uptake increase with fiber weight fraction and fiber effective length increases due to increased voids and ligno-cellulosic content. The water absorption pattern of these composites at room temperature is found to follow Fickian behavior. Water uptake content in particle reinforced composite in comparison to fiber reinforced was found to be higher. Sisal and Jute reinforced composites showed similar behavior. On the other hand, water absorption of Pine Cone composite at 10% and 20% weight fraction was less than the values obtained for sisal and jute composites.

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