A Study on Water Absorption Behavior of Jute and Ramie Hybrid Composites with and without SiC Filler

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ABSTRACT

Natural fiber reinforcements have attracted interest in sustainable manufacturing as a replacement for synthetic fibers in polymer composites. In this study, two natural fibers – jute and ramie were reinforced in three different proportions with epoxy resin and hardener to fabricate polymer matrix composites. Silicon Carbide (SiC) was used as a filler material in the three different compositions with jute and ramie fibers. All the composite specimens were fabricated using the hand-lay-up technique. The water absorption property of the fabricated composites was examined. Test results indicate that jute and ramie fiber composite with epoxy resin possesses high water absorption properties; further addition of SiC as filler material into the composite fabrication shows a decrease in water absorption percentage. The work also presents linear regression models (LRA) for forecasting the natural composites' water absorption behavior.

Keywords: Composites, Filler, Natural fibers, Tensile strength, Water absorption, Linear regression models

1 Introduction

Natural fibers are widely available around the world as sustainable resources and thus their use is essential to the developing green economy. Natural fibers like jute, sisal, banana, and coir are renewable, environment-friendly, non-abrasive, low-in-cost, and biodegradable [1]. They have a lower density, decreased solidity, and are less expensive than synthetic fibers; hence natural fibers reinforced polymer composites are used in the construction and automotive industries [2], [3]. Because of their lightweight, excellent mechanical performance, vibration dampening, and sound attenuation, they are extensively used in aircraft, packaging, sporting goods, electrical parts, and medicinal industries. [4]. However, it may be inferred from the literature that there are certain drawbacks to utilizing natural plant fiber composites, such as water absorption, non-linearity in fiber dimensions, poor interfacial adhesion, and less fiber strength [5]. They have considerably lower mechanical properties than synthetic fiber-reinforced composites. Hybridization, however, offers a solution to these issues. Additionally, filler materials can overcome the aggregation and localized agglomeration issues to which hybrid composites are susceptible [6]. Microcrystalline cellulose (MCC) powder as filler with ramie fibers in the polyester resin might prevent crack propagation on interlaminar surfaces of laminated composites [7]. According to Sekar *et al.*, the hybridization of Calotropis Gigantea and Palmyra fibers was effective with greater fiber volume and lower water absorption [8]. Researchers have suggested that the mechanical behavior of composites made of natural fibers with reinforcement from industrial waste, like sponge iron slag, is improved as the amount of SI slag in the composite increases [9]. A study showed that water absorption significantly reduces composite materials' tensile and flexural strength, affecting their mechanical properties. Additionally, the connection between the matrix and fiber is weakened by water absorption [10]. Alomayri *et al.* found that the maximum measure of water gain characteristics and the diffusion coefficient of CF-reinforced geopolymer composites improved with fiber content, and the water absorption decreased mechanical properties [11]. However,

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Natrayan *et al.* reported that mechanical and water retention of pineapple leaf and coconut fiber-reinforced polymer composite under ambient conditions were improved with the addition of aluminum oxide [12]. Hamdan *et al.* used the woven ramie, jute, and roselle for reinforcement in UPE resin and MEKPO hardener, revealing that the prevention of water absorption improved significantly toward hybridization [13]. Jute is a viable natural fiber reinforcing material because it is cheap and commercially available. Gujjala *et al.* stated that by reinforcing jute fiber, the composites become ductile and semi-brittle [14]. Also, ramie fiber-based composites outperformed other alternatives regarding economic and environmental performance [15]. Siregar *et al.* reported that the five-layer sugar palm fiber composite had lower flexural and tensile strength than the five-layer ramie composite [16]. Ramie fiber has good mechanical properties, i.e., 849 MPa tensile strength and 16 MPa toughness [17]. The ramie fiber reinforced PLA - Polylactic acid biological composites showed that ramie fiber improved the tensile strength and young's modulus of the PLA without compromising thermal stability [18]. Tezara *et al.* showed that a single jute fiber's mechanical behavior and water gain characteristics are lower than that of a single ramie fiber. But the jute–ramie hybrid increased the composite performance compared to pure jute composites [19]. Biswas *et al.* showed that the production of 100% ramie and 100% jute yarns resulted in strong enough fibers to sustain subsequent fiber processing [20]. Mohanavel *et al.* fabricated a hybrid composite by hand lay-up technique, reinforcing ramie and jute in SiC and cellulose filler added epoxy polymer matrix. Mechanical tests revealed that the hybrid composites had improved tensile and flexural strength [21]. According to Tezara *et al.*, the upcoming growth of the automotive industry could be greatly aided by the jute and ramie hybrid composite [22]. The Swelling behavior of jute–banana fiber reinforced in epoxy composite was studied by Pujari *et al.* In their study, the effectiveness of ANN and regression analysis was assessed with experimental and predicted values [23]. Mayyas *et al.* addressed the simulation of the machinability of self-lubricated hybrid composites made by powder metallurgy of aluminium, alumina, and graphite. Multiple regression analysis (MRA) and artificial neural networks (ANN) were utilized in this study to examine the effects of various parameters [24].

So, it has been seen that jute and ramie fibers are widely used to fabricate desirable composites, and researchers have investigated the hybridization of jute and ramie reinforcement in recent years. Some have included fillers in the composite to enhance mechanical and thermal stability. Water absorption is also important as it directly impacts the mechanical property of the composite and can be improved by incorporating filler material into the composite. Researchers have used woven jute and ramie fibers in the previously discussed literature to reinforce an epoxy composite. Researchers also have used various mathematical modeling to analyze and predict the result of the experiment to obtain a better result with less investment of materials and time. Therefore, the present work is focused on developing hybrid composites made up of different compositions of jute-ramie fibers reinforced with SiC filler in epoxy resin to investigate the water gain characteristics. This study also tries to develop prediction models for the water gain percentage of jute-ramie fiber composite using Linear regression analysis (LRA), a statistical technique for estimating relations between one dependent variable and one or more independent variables. It can be applied to predict how strongly variables will be associated in the future and to gauge how strong that association is. Regression models use the term R-Squared (also known as R^2 or the coefficient of determination) to express the percentage of variance in the dependent variable that can be explained by the independent variable, which means R^2 demonstrates how well the data match the regression model.

2 Materials and Methods

2.1 Materials

The matrix material used to fabricate the composites was AW 106 IN Epoxy resin with HV 953 IN hardener, commonly called Bisphenol – A – diglycidyl – Ether. Specifications of the matrix materials are given below in Table 1. Jute (Corchorus) and ramie fibers (Boehmeria Nivea) were reinforced in the epoxy matrix in different proportions of fabricating composites. The mechanical properties and chemical compositions of the reinforcing materials are shown in Table 2. It has been reported that using appropriate filler material can improve the properties of the composite [25]. In this work, fine technical grade SiC (Silicon Carbide) has been used as filler.The grain size of the selected particulate filler was 68 microns with an elastic modulus of 410 GPa, poisons ratioof 0.14, and compressive strength of 3900 MPa, which can withstand the maximum temperature of 1650 ^{o}C.

The presence of voids in the composite, the interfacial adhesion, and the type of reinforced fibers affect the waterabsorption behavior of the composites significantly [26]. This work prepared samples per ASTM D570 for the water absorption test. The relation used to calculate the water absorption percentage is given by equation 1.

$$\text{Water absorption percentage} = \frac{W - Wo}{W} \qquad (1)$$

Where W is weight of the composite after water gain; W_o is weight of the composite before water gain.

Table 1: *Specifications of matrix material*

Sr. No.	Matrix Material	Colour	Viscosity(at 25^{0} C)	Specific gravity
1.	Epoxy resin (AW 106 IN)	Natural Colour	30-50 Pa-s	1.17
2.	Hardener (HV 953 IN)	pale-yellow	20-40 Pas	0.97

Table 2: *The mechanical properties and chemical compositions of the reinforcing materials*

	Sr. No.	Parameters	Jute	Ramie
Mechanical Properties [27]	1.	Tensile Strength (MPa)	393 – 723	100 – 938
	2.	Elongation (%)	3.50 – 4.50	3.60 – 3.80
	3.	Modulus of Elasticity (GPa)	26.50	61.40 – 128
Chemical Compositions [28]	1.	Cellulose (%)	58 – 63	68.60 – 91
	2.	Hemicellulose (%)	21 – 24	5 – 16.70
	3.	Lignin (%)	12 – 14	0.60 – 0.70
	4.	Pectin (%)	--	1.90
	5.	Microfibrillar angle (^{o})	--	69 – 83

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2.2 Fabrication

(a) (b)

Figure 1: *Chopped fiber **(a)** Ramie **(b)** Jute*

A wooden mold of dimension 250 x 250 x 40 mm^3 was used to fabricate the composite. Jute and ramie fibers were chopped at a predefined length of 10 mm (Figure 1) for the proposed work. The resin and hardener were mixed by simple manual stirring. Next, following various testing circumstances and characterization requirements, the mixture was drained into various molds over a layer of finely chopped jute and ramie fiber. If any air bubbles were entrapped, they were removed by sliding a hand roller on the sample carefully and putting a hardwood plate of the same dimensions on the mold for a 24-hour cure at room temperature under the constant pressure of 20 kg/cm^2. Composite samples with six different compositions were fabricated using the hand lay-up method; among them, three different compositions were without particulate filler materials, and three different compositions were prepared with the addition of particulate filler materials. Table 3 lists the compositions of the six samples.

Table 3: *Compositions of prepared composite samples*

Sr. No.	Designation of composites		Compositions			
			Matrix	Reinforcement		Filler
				Jute (%)	Ramie (%)	SiC (%)
1.	S1	without particulate filler material (SiC)	Epoxy	100	0	0
2.	S2		Epoxy	0	100	0
3.	S3		Epoxy	50	50	0
4.	SF1	with the addition of particulate filler material (SiC)	Epoxy	100	0	10
5.	SF2		Epoxy	0	100	10
6.	SF3		Epoxy	50	50	10

3 Results and Discussion

3.1 Analysis of tensile strength

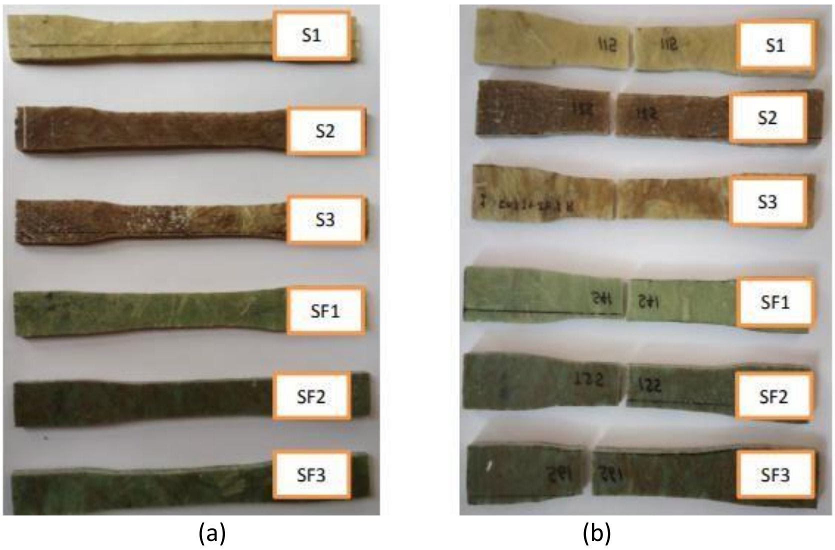

Figure 2: *(a) Tensile test specimens before fracture, (b) Tensile test specimens after fracture*

The prepared and fracture surface of specimens were shown in Figure 2. The nature of composites failure was brittle (Figure 2). The tensile strengths of the tested samples were 20.66, 28.833, 19.27, 25.61, 32.8 & 30.8 MPa for S1, S2, S3, SF1, SF2 & SF3, respectively (Figure 3). The tensile strength of the samples increased by adding silicon carbide (SiC) to the matrix. The interfacial adhesion of the matrix and fibers significantly influences the qualities of the epoxy matrix. The use of filler material improved the efficiency of stress transmission and increased resistance to elongation by increasing the tensile strength of the composite.

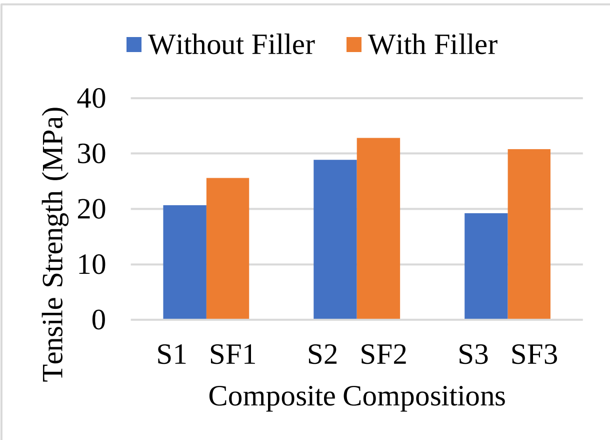

Figure 3*: Influence of filler on tensile strength of the fabricated composite sample*

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3.2 Analysis of water absorption up to saturation point

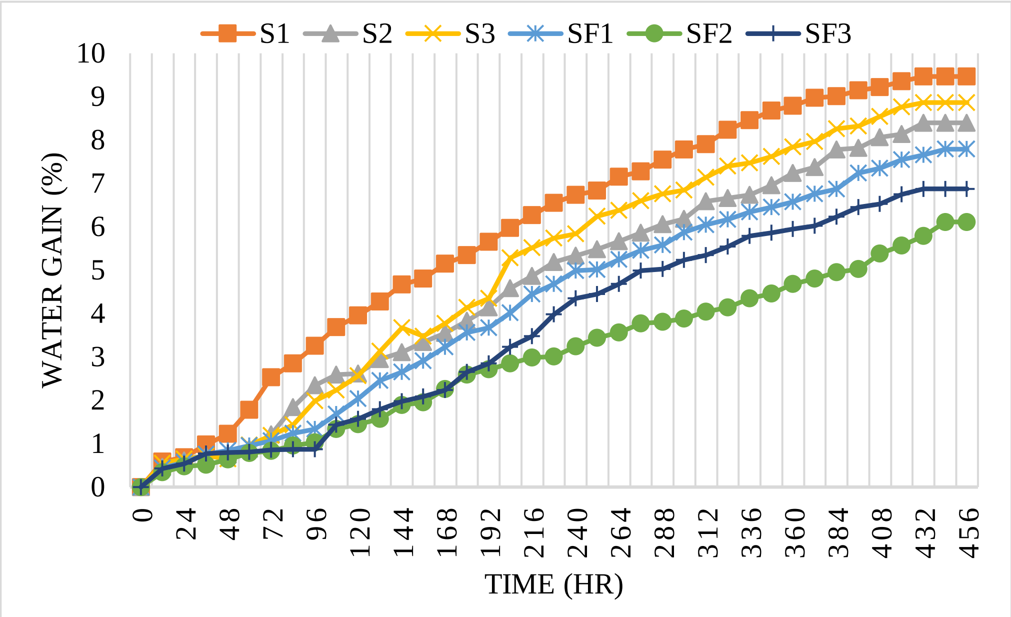
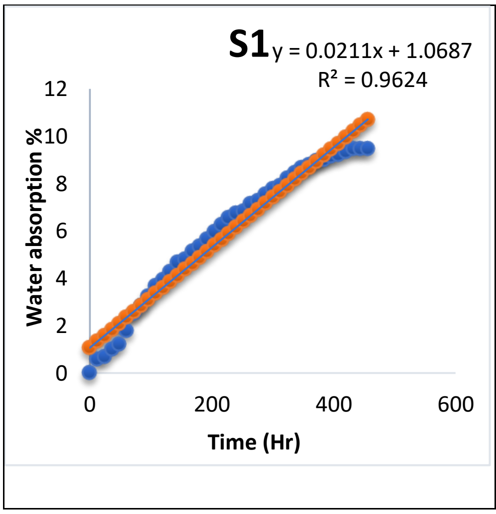
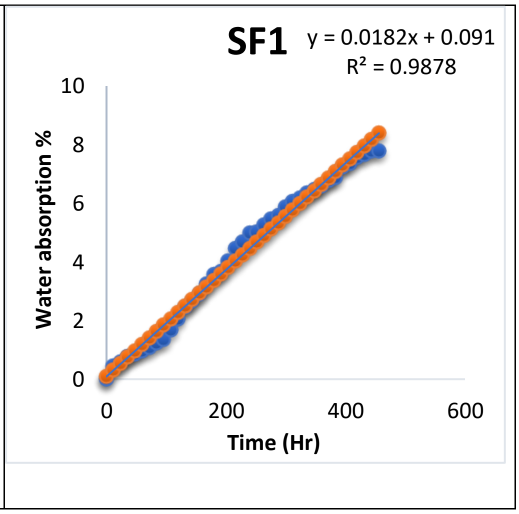


Figure 4: *Effect of filler on water absorption up to saturation point*

The composite with filler has decreased water absorption compared to the composites without filler. Because SiC fillers have high barrier properties, moisture can't spread easily due to this behavior. Adding filler with fiberdecreased water gain in the composites. It also shows better interfacial bonding of filler with the fiber matrix. Figure 4 shows that due to voids, water absorption of composites without filler was more than that of the filler- added composites. The graph shows the increasing trend of moisture gain, which vary with the time of sample emersion in water. A comparison of the experimental and predicted value of water gain percentage up to the saturation point has been shown in Figure 5. The R^2 values are 0.96, 0.98, 0.98, 0.99, 0.99, and 0.98 for S1, S2, S3, SF1, SF2 & SF3 composites. It means that the regression model can account for 96% of the variability in water absorption behavior for S1 and similarly for the others. A greater R^2 typically means the model is better atexplaining the variability.





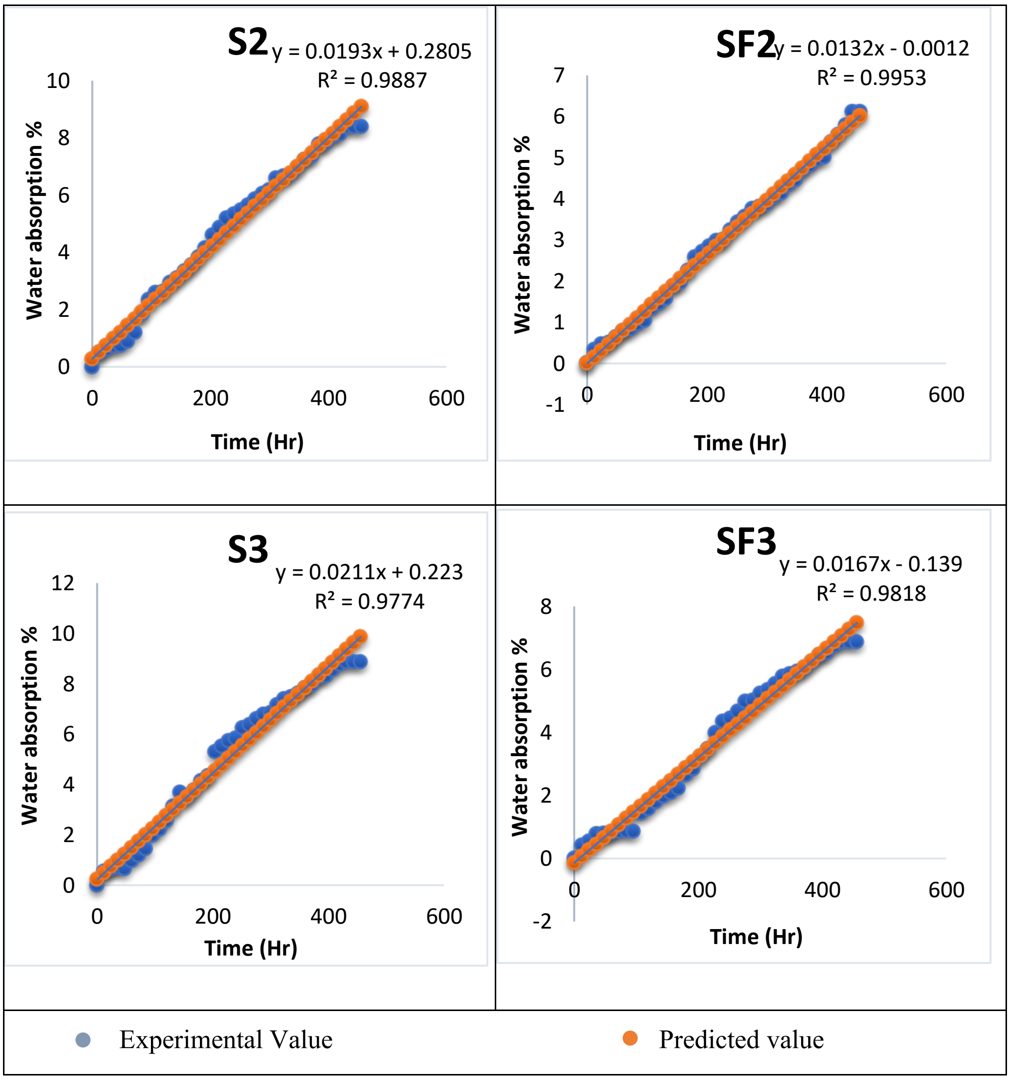


Figure 5: *Figure showing experimental data and regression-predicted test values compared for water absorption up to saturation point*

4 Conclusions

Ramie and jute fiber-reinforced epoxy composites have undergone experimental testing to determine the impact of fiber hybridization and filler addition on mechanical characteristics and water absorption. Tensile strength was increased by 24%, 14%, and 60% for 100% jute, 100% ramie, and 50% jute – 50% ramie composites, respectively, by adding SiC. Water absorption percentage decreased after adding silicon carbide because filler restricts moisture absorption from the atmosphere. The presence of silicon carbide fills the microscopic gap between epoxy, which also acted as a barrier to moisture flow and increased adhesion between epoxy and fiber.The mathematical models predict the water gain behavior by using LRA. The data fit the regression model very well. With the help of this study, the water absorption percentage of these natural fiber composites can be readilydetermined without the need for lengthy testing, thus saving labor, resources, and time.

5 Declarations

5.1 Competing Interests

The authors declare no potential conflict of interest exists.

5.2 Publisher's Note

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