Influence of Environment Aging on the Thermal Insulation of Sustainable Ecofriendly Composites

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Abstract: In recent years, researchers are increasingly emphasized the development of sustainable biodegradable composites to minimize environmental impact and broaden their potential in engineering fields. This study investigates the influence of environmental aging including, exposer to tap water, sea water and aqueous (NaOH) solutions, on the thermal insulation behavior of sansevieria /PLA-based biodegradable composites. The water uptake characteristics and diffusion coefficients were determined and analyzed to understand their effects on material performance. Results revealed a significant rise in thermal conductivity after moisture absorption, indicating a decline in insulation performance. the percentage increase in thermal conductivity of S4 in tap water, sea water and aqueous solution compared to dry state are 112.69, 156.03 and 189.36, respectively. The mechanisms responsible for the deterioration of thermal insulation due to water penetration are examined, providing insights in to the durability and environmental stability of these insulation materials.

Keywords: Thermal insulation, Aging, Biodegradable composites, Sansevieria fiber.

1. INTRODUCTION

Investigators for the past two decades have shown interest in using natural fibers as reinforcement. This is due to their biodegradability, low cost, lightweight, and good electrical, acoustic and thermal insulation properties [1]. Total amount of production of different natural fibers all over the world is about 1600 million ton [2]. Biodegradable wastes such as areca fruit husk fiber, walnut shell, sugarcane bagasse, disposable chopsticks have been used as reinforcement for the development of light weight sustainable composites [3-8]. The incorporation of natural fibers is an effective approach to reduce PLA usage, resulting in a cost-effective biodegradable composite material [9]. Ahmad *et al*. [10] developed the composite filaments for 3D printing of sustainable eco- friendly composites by incorporating cellulose nanocrystals in PLA to enhance the thermal properties. Rice straw fiber composite was developed and their mechanical properties were studied. The authors reported that as fiber content increased performance of composites was enhanced [11,12]. Ratna prasad *et al*. developed a light weight composite material by incorporating banana empty fruit bunch fibre (banana-EFB) in to a polyester resin matrix, and concluded that performance of matrix enhanced with the addition of reinforcement [13]. Synthetic fiber based products after their service life disposed of as plastic waste causing to white pollution. To solve this problem, researchers are concentrating on development of biodegradable composites [14-16]. A seven-day absorption study showed optimal performance at 30% sisal and 20% banana fibre loading with reduced water absorption [17], while epoxy composites reinforced with jute, kenaf, and E-glass exhibited maximum moisture uptake in pure water after 150 days compared to saltwater and standard water–composite [18]. The hybrid composite, composed of 30% and 70% fibre, reaches equilibrium after 18–20 days, with bamboo fibre composites showing the highest water absorption at 8% and 10% cellulose, while a 10% bamboo and 20% jute hybrid enhances composite thickness up to 26% [19]. The humidity content and water released from the ingredients in untreated samples were evaluated for both untreated and processed polymer composites [20]. Due to increased water absorption, the composite's bending and compressive strength decline significantly, as the interaction between the matrix and fibre weakens [21].

Several investigators studied the influence of moisture absorption on structural performance of composites. Studies on effect of aging on thermal insulation of composites are limited. But, there is no study on the effect of aging in sea water, aqueous solution on thermal insulation of sansevieria /PLA composites. The novelty of this work is study of the effect of aging in sea water and aqueous solutions on the thermal conductivity of newly developed sustainable sansevieria /PLA composites.

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2. MATERIALS AND METHODS

2.1. Materials

Poly Lactic acid (PLA) granules were purchased from Nature Tec India Pvt Ltd, Chennai, India. Sansevieria fibres were extracted using retting method as explained in previous work [22]. Both PLA and sansevieria fiber were put an oven at 80 °C for 24 hours for the removal of moisture content. Sansevieria fiber has been incorporated as reinforcement in PLA matrix.

Table 1: Composite Samples Designation

Sample	PLA (wt%)	Sansevieria (wt%)
S1	100	0
S2	85	15
S3	70	30
S4	55	45

2.2. Preparation of Composites

The procedure for the fabrication of composite samples using hot press method has been reported elsewhere [11]. The composition and designation for different samples was given in Table **1**. The processing temperature is 190-200°C.

2.3. Moisture Absorption Test

The testing procedure for moisture absorption of composite samples has been reported elsewhere [15]. The composite specimens were immersed in water, sea water and aqueous solution. The aqueous 4% NaOH solution was prepared by dissolving 40g of sodium hydroxide pellets in one liter of distilled water. After 48 hours, samples were removed and weight of specimens was recoded. This is repeated up to the point of saturation level. The percentage of moisture was calculated with the following equation (1).

Moisture absorption percentage

$$[\%] = \frac{final\ weight(Wt - initial\ weight\ (Wo)}{initial\ weight\ (w1)} \times 100 \quad (1)$$

Where Wt the weight of sample at each is time and Wo is the weight of dry sample

2.4. Measurement of Thermal Conductivity

Thermal conductivity of composite samples was measured using thermal conductivity meter (Figure **1**) as per the previous testing procedure [22]. Three samples were tested for each composition to ensure reproducibility.

3. RESULTS AND DISCUSSION

3.1. Moisture Absorption Bhavior

Maximum moisture content of composite samples immersed in NaOH solution was presented in Figure **2**. It was observed that as fiber content increased amount of moisture absorption increased. Composites with 45% fibre content exhibited the highest moisture absorption of 3.14%, compared to 2.89% for 30% fibre and 2.05% for 15% fibre content.

Maximum moisture absorption of composite samples immersed in sea water was given in Figure **3**. Composites with 45 % sansevieria fiber content shows more water absorption rate (2.82%) compared to pure PLA (1.31%).

Maximum moisture absorption of composite samples immersed in tap water was presented in

Figure 1: Thermal conductivity experimental setup.

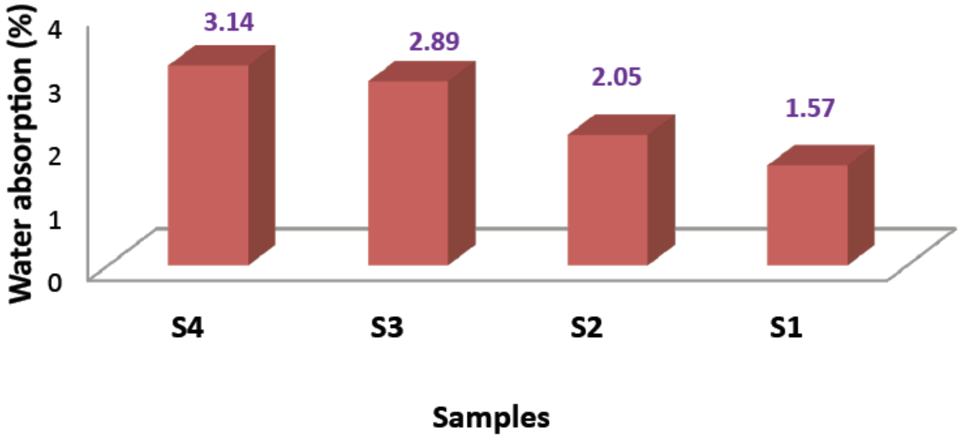

Figure 2: Maximum water absorption of composite samples immersed in NaoH solution.

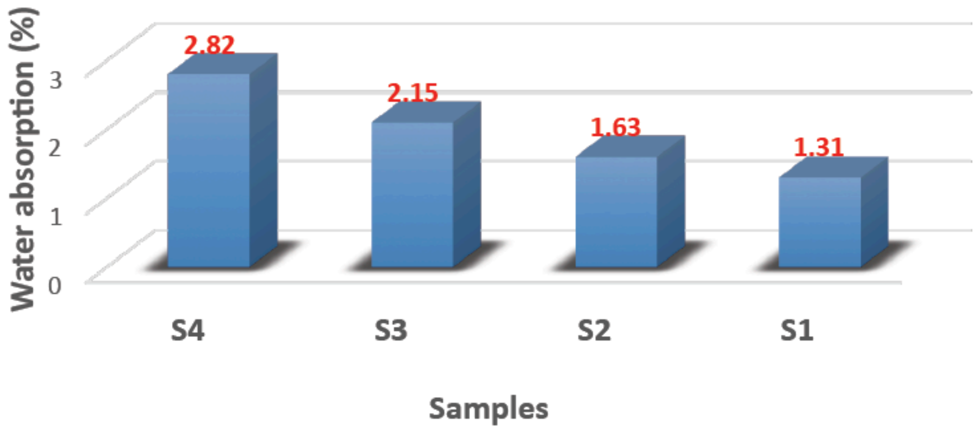

Figure 3: Maximum moisture absorption of composite samples immersed in sea water.

Figure **4**. This is attributed to the hydrophilic nature of cellulose and hemicellulose in sansevieria fibres, which contain accessible hydroxyl groups that readily attract water [25]. The 45% fibre composite exhibits the highest maximum moisture uptake (1.88%), while pure PLA demonstrates the lowest (1.15%), confirming the hydrophilic influence of natural fibre inclusion.

3.2. Thermal Conductivity Measurement

First, thermal conductivity of samples were measured at dry state (Table **2**), afterward,

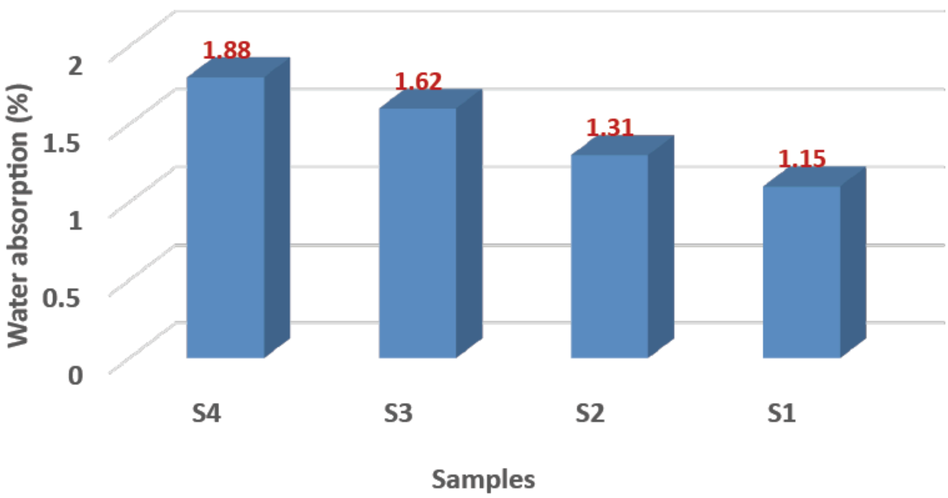

Figure 4: Maximum moisture absorption of composite samples immersed in tap water.

Table 2: Thermal Conductivity of Composites in the Dry State

Temperature (°C)	Thermal Conductivity (W/m·K)			
	S1	S2	S3	S4
30	0.164	0.152	0.148	0.141
45	0.171	0.167	0.160	0.150
60	0.182	0.179	0.174	0.168

measurements were carried out on samples in a saturated state exposed to different environments (Table **3**).

Thermal conductivity values of composite samples at different temperatures in the dry state are presented in Table **2**. The measured thermal conductivity values are decreased with fiber content, where as they increase with increase of temperature. The S4 sample at 30°C exhibited the lowest thermal conductivity 0.141W/mK among all samples and it is 14% lesser than control sample PLA. The percentage increase in thermal conductivity of S4 is 19.15%, in case of control sample (PLA) is 13.41%, when temperature increased from 30°C to 60°C. The thermal conductivity of all samples is in the range of 0.141 W/mK to 0.182 W/mK. The present developed composites exhibited good thermal insulation properties in dry state even at moderate temperatures ranging from 30°C to 60°C. These results are due to the inherent nature of pored sansevieria fiber and the entrapped air. Air entrapped in to the pores of sansevieria fiber within the composites. It is noticed that air act as insulator with a thermal conductivity of 0.026 W.mK. The present results are aligned with published results [27].

Experimental results of 45 wt% of sansevieria fiber reinforced PLA composite after aging are given in Table **3**. Thermal conductivity of S4 at saturated state in water, sea water and aqueous solution are 0.314 W/mK, 0.361 W/mK and 0.408W/mK, respectively. At 30°C, the percentage increase in thermal conductivity of S4 in water, sea water and aqueous solution compared to dry state are 112.69, 156.03 and 189.36, respectively. The thermal conductivity of water (0.63 W.mK) is higher than natural fiber and air (0.026W/mK). Water replaces the air in the open pores of sansevieria fiber, as moisture content increased, while the closed pores continue to trap air. Furthermore, as temperature increased the variation in thermal conductivity is mixed trend and its effect is minimum. Even at saturation different wet conditions, S4 composite retain its thermal insulation, making it feasible insulation material for high-humidity conditions. Hence, S4is a potential substitute to synthetic insulation materials.

CONCLUSIONS

- Moisture absorption increases with fibre content, particularly in NaOH environment.
- The present developed composites exhibited good thermal insulation properties in dry state even at moderate temperatures ranging from 30°C to 60°C.
- Thermal conductivity of S4 at saturated state in water, sea water and aqueous solution are 0.314 W/mK, 0.361 W/mK and 0.408W/mK, respectively. The present developed sustainable composite material is suitable for building and automotive industries.

DISCLOSURE OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Table 3: Thermal Conductivity (W/m·K) of Composite Sample (S4) after Aging

Temperature (°C)	Environment		
	Water	Sea Water	NaOH Solution
	Thermal conductivity (W/m·K)		
30	0.314	0.361	0.408
45	0.311	0.354	0.415
60	0.298	0.347	0.429

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