Hindawi
International Journal of Polymer Science
Volume 2019, Article ID 3978047, 4 pages
https://doi.org/10.1155/2019/3978047

Research Article

Effect of Silica Aerogel Additive on Mechanical Properties of the Sugar Palm Fiber-Reinforced Polyester Composites

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Received 23 February 2019; Revised 3 October 2019; Accepted 6 November 2019; Published 24 December 2019

Academic Editor: Domenico Acierno

Silica aerogel (SA) was used as fillers in the sugar palm/polyester composite (SPF/PE). Their influence on tensile, flexural, and impact properties of the composite was determined by varying the additive concentration from 1-5 wt% in the resin. The findings from the study indicate that both the strength and modulus of SPF/PE improved significantly by adding SA. Maximum tensile, flexural, and impact strength occurred at an optimum filler concentration of 2-3 wt%. Similarly, the highest tensile and flexural modulus was achieved with 5 wt% and 2 wt%, respectively. The microstructure of SA-infused composites revealed less fiber pullout/slippage compared to the composites without filler.

1. Introduction

Natural fibers possess many advantages in comparison to the synthetic fibers like biodegradability, economical production, and least environmental impacts throughout the commercial life cycle [1]. Among the natural fibers, sugar palm fiber (SPF) is of interest to this study. SPF-reinforced composites were found to have competitive mechanical and physical properties compared to other natural fibers such as palmyrah, kenaf, and coir [2]. However, there is a need for improvement within the SPF-reinforced composites to achieve better performance due to the hydrophilic characteristic of natural fibers and poor fiber/matrix adhesion. Previous studies indicate that the mechanical and physical properties of SPF-reinforced composites were enhanced through the fiber surface treatments [3–6]. However, these properties could be easily improved by adding small quantity of fillers in the matrix of the composite [7–9]. Research by Vahtrus et al. [10], On et al. [11], and Zou et al. [12] highlighted that mechanical properties can be significantly improved with the addition of silica aerogel (SA) in the composite. The novelty of his study is the use of SA as filler in sugar palm-reinforced polyester composites (SPF/PE). To the best of the author's knowledge, the influence of various SA concentrations on the SPF/PE composite was never studied.

2. Materials and Method

2.1. Materials. SPF existing in the naturally woven state was obtained from the Negeri Sembilan region in Malaysia. Reversol P9509 PE resin with Methyl Ethyl Ketone Peroxide (MEKP) and SA was procured from Bintang Timur Sdn Bhd and Maerotech Sdn Bhd, Malaysia. SA derived from the rice husk was purchased from Maerogel Sdn Bhd, Malaysia. SA used in this study had a high specific surface area of 900 m^2/g, average nanoscale size of 20-50 nm, and melting point of 1700°C [13, 14].

2.2. Composite Fabrication. Initially, the obtained SPF layers were stacked together and pressed in the hot press at 80°C for 10 minutes to form the compressed fiber mat. SA at 1-5 wt%

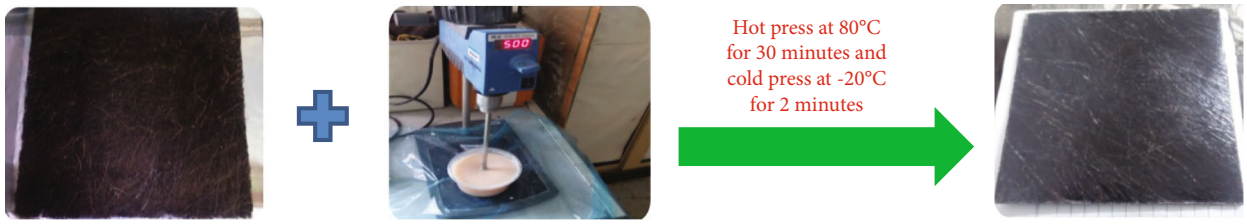


Figure 1: Fabrication process of SA-infused SPF/PE composite.

concentration was introduced slowly in the resin and mixed with the mechanical stirrer at a constant speed of 500 rpm for 60 minutes. The resin mixing process with SA was performed in the air-conditioned atmosphere at 22°C temperature and 50% humidity.

The composite samples with different weight concentration of SA were prepared by the layup and hot press technique as shown in Figure 1. The $300 * 300 * 3$ mm^3 mold used for composite preparation consists of a top and bottom base plate. Prior to fabrication, the mold was sprayed with a release agent. Resin incorporated with SA was mixed with the hardener (1% MEKP) and was slowly poured onto the fiber mat layers placed into the mold. A roller was used to distribute the resin mixture properly within the fiber mat. The mold with the fiber and resin mixture was then covered with the top base plate and placed in the hot press. The sample was then cured in the hot press at 80°C for 30 minutes and subsequently cured in the cold press at -20°C for 2 minutes.

Table 1 shows the notation of the fabricated SPF/PE composite with 1-5 wt% SA.

2.3. Characterization. Tensile, flexural, and impact properties were determined for composites infused with SA at different concentrations and compared to the composite without filler. 5 specimens cut from the fabricated sample with different SA concentrations were tested, and their average results were reported in accordance with ASTM D3039, ASTM D790, and ASTM D6110, respectively. Tensile and flexural test was carried out with 5 KN Blue hill INSTRON. Strength at maximum load and Young's modulus was measured automatically and recorded by the machine interface. The Charpy impact test was performed on V-notched specimens, and the impact energy was recorded. Impact strength was calculated using

$$I = \frac{E}{A}, \tag{1}$$

where I is the impact strength (KJ/m^2), E is the impact energy (KJ), and A is the area under the notch (m^2).

The fractured specimen from the impact test was gold sputtered and observed under HITACHI S-3400N to study the morphological changes and their failure behavior.

Table 1: Notation of SPF/PE composite with various SA concentrations.

Notation	SPF (wt%)	PE (wt%)	SA (wt%)
0% SA	30	70	0
1% SA	30	69	1
2% SA	30	68	2
3% SA	30	67	3
4% SA	30	66	4
5% SA	30	65	5

3. Results and Discussion

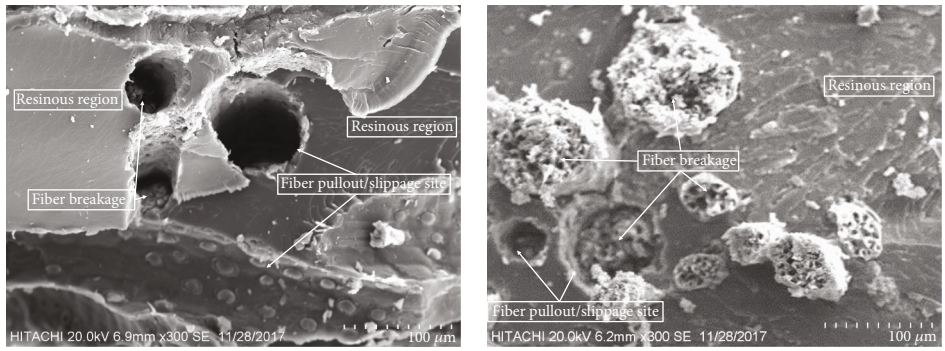
3.1. Mechanical Properties. Table 2 presents the tensile, flexural, and impact properties of the SPF/PE with and without SA.

From Table 2, addition of 1% SA increased the tensile strength of SPF/UPE by 25% followed by 36% improvement for 2% SA in comparison to the composite without filler (0% SA). Further increase in SA concentration led to reduction of the tensile strength. Composite at 5% SA exhibited a tensile strength of 14.17 MPa lower than the 0% SA composite. On the other hand, tensile modulus showed a steady increase in value from 3.28 GPa to 3.52 GPa until 5% addition of SA. Similarly, flexural strength and modulus improved up to 28% and 17% until 3% and 2% addition of SA, respectively. According to Salimian et al. [15], SA addition at lower concentration improves the interfacial bonding of fibers and matrix in the composite by arresting the deformation in the composite to bear more stress.

It could be observed from Table 2 that SPF/PE composite with 4% and 5% SA concentration showed a significant decrease in the strength and a slight decrease in the modulus under tension and bending. This is in contrast to the improvement observed for the composite until 3% SA. The explanation for this reduction in strength and modulus of the natural fiber-reinforced composite at high SA concentration was also observed in the recent studies. The researchers [16, 17] concluded that SA agglomerates within the composite at higher concentrations, hence reduces the filler-wetting effectiveness of polymer, paves way for crack formation, and leads to failure at lower loads. This behavior shows that nanoparticle addition beyond certain concentration on the

Table 2: Mechanical properties of SPF/PE with and without SA.

Properties	SPF/PE composite					
	0% SA	1% SA	2% SA	3% SA	4% SA	5% SA
Tensile strength (MPa)	15.6 ± 1.5	19.5 ± 0.9	21.1 ± 1.2	19.7 ± 1.2	16.9 ± 0.5	14.2 ± 1.6
Tensile modulus (GPa)	3.3 ± 0.1	3.3 ± 0.1	3.4 ± 0.1	3.5 ± 0.1	3.5 ± 0.1	3.5 ± 0.1
Flexural strength (MPa)	44.2 ± 6.8	46.1 ± 1.2	50.6 ± 3.5	56.6 ± 1.7	46.5 ± 1.5	45.1 ± 0.4
Flexural modulus (GPa)	2.7 ± 0.1	2.8 ± 0.1	3.1 ± 0.1	3.0 ± 0.1	2.6 ± 0.1	2.5 ± 0.1
Impact strength (KJ/m^2)	56.2 ± 4.5	51.2 ± 4.0	55.1 ± 3.4	68.3 ± 2.7	66.7 ± 1.8	42.2 ± 2.5



(a) (b)

Figure 2: SEM images of SPF/PE (a) 0% SA composite and (b) 3% SA-infused composite.

natural fiber-reinforced composite could rather have negative effect than the improvement.

In case of the impact properties, a notable increase of impact strength up to 21% was observed for 3% SA in comparison to the composite without SA (Table). Zhang et al. [18] and Zou et al. [12] also showed improvement in impact strength until 3% and 5% addition of silica fillers in the polymer composites. As suggested by Ji et al. [19], the unique mesoporous structure of SA allows temporary deformation of the nanostructure when the impact load is applied. This enables the composite with SA to absorb higher impact energy before failure.

3.2. Fractography. Figures 2(a) and 2(b) shows the SEM images of the fractured specimens with and without SA.

0% SA composite (Figure 2(a)) showed higher length of fiber breakage, larger extent of fiber pullout, and smoother resinous region. 3% SA-infused composite showed comparatively less fiber pullout, lower length of fiber breakage, and higher degree of surface roughness (Figure 2(b)). According to the researchers [14, 20–22], these characteristics were responsible for the better strength and modulus at optimum concentration for the SA-infused composite.

4. Conclusion

SA-infused composite showed higher strength and modulus at their optimum concentrations due to the better fiber-matrix adhesion, lower lengths of fiber breakage, less fiber pullout, and increased degree of roughness in the matrix. The enhancement in properties obtained with the addition of SA will help to increase the usability of otherwise wasted sugar palm fibers as a potential reinforcement for composites in the tertiary structures and household applications.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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