E3S Web of Conferences **724**, 02003 (2026) https://doi.org/10.1051/e3sconf/202672402003
EnCon 2026

Fabrication and Mechanical Properties of Sustainable Sago Pith Waste Fiber Reinforced Polyvinyl Alcohol Composite

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Abstract. This study investigates the development and characterization of sustainable composites reinforced with sago pith waste (SPW) fibers and polyvinyl alcohol (PVA) polymer. The research addresses the underutilization of SPW, a byproduct of the sago starch industry, by evaluating its potential as a reinforcement material in polymer composites. The mechanical properties, surface morphology, and fiber-matrix interactions of SPW/PVA composites were examined at fiber concentrations of 25wt%, 50wt%, and 75wt%. Results indicated that 50wt% SPW fiber content yielded the highest tensile strength of 10.45 MPa, while 75wt% content showed highest value of Young's modulus at 85.19 MPa. Scanning Electron Microscopy (SEM) revealed improved fiber alignment and surface roughness after alkaline treatment, though agglomeration occurred at higher concentrations of fiber content. This study demonstrates the viability of SPW as an eco-friendly reinforcement for applications in packaging and construction, contributing to sustainable waste management and material development.

1 Introduction

The global demand for sustainable materials has been intensified by the escalating environmental crisis over plastic waste and resource depletion. Natural fibers from agricultural waste, such as sago pith waste (SPW), offer a renewable alternative for reinforcing polymer composites. SPW, a by-product of sago starch extraction, is produced at a rate of about 50 to 110 tons daily In Sarawak [1]. SPW is usually discarded into nearby streams, leading to an environmental threat to aquatic lives due to the high consumption of dissolved oxygen for the degradation of the waste via microbial activity [2]. On the other hand, the shift toward bio-based polymers is driven by the need to mitigate the ecological degradation caused by non-biodegradable synthetic materials. Polyvinyl alcohol (PVA) for example, is a water-soluble polymer which can be produced on a large scale by non-petroleum routes, with low price and good film-forming properties [3]. PVA in film form is flexible, transparent, non-toxic, non-hazardous, biocompatible and has good mechanical properties, chemical resistance, and gas barrier, and can be completely biodegradable [4], in

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line with the development of green environmental protection needs. This study explores SPW's potential as a reinforcement in polyvinyl alcohol (PVA) composites, focusing on mechanical properties, surface morphology, and the effect of fiber content. The findings aim to bridge the research gap in SPW applications and promote sustainable material solutions.

2 Methodology

2.1 Raw material and Chemicals

Raw SPW fibers were obtained from a sago processing plant in Mukah, Sarawak. NaOH pellets were supplied by Sigma Aldrich and processed to be 10% solution for treatment of SPW fibers. PVA powders (99+% hydrolyzed) were supplied by Sigma Aldrich.

2.2 Material preparation

The raw SPW obtained was dried in an oven for 2 hours at 80°C to remove moisture. Then, the raw SPW was lightly ground to separate dirt and fibers, and then strained to separate debris and obtain the fibers. The obtained SPW fibers underwent alkaline treatment using a 10% sodium hydroxide (NaOH) solution to remove impurities and enhance surface roughness. After treatment, the fibers were washed, dried in oven for 2 hours at 80°C and ground into smaller fiber size. A PVA solution of 2% was produced by dissolving PVA powder in distilled water. Three composite samples were prepared with varying fiber concentrations (25wt%, 50wt%, and 75wt%) mixed into a PVA matrix. The composites were fabricated using an evaporation method, where the fiber-PVA mixture was poured into trays and dried to form thin films. The thin film's thickness was measured to be at the range of 0.07 to 0.13mm. The composition of the SPW-PVA composite films are shown in Table 1 below.

Table 1. Composition of treated SPW fiber reinforced PVA composites.

Sample	Composition of SPW/PVA	SPW fiber content (wt%)	PVA content (wt%)
1	27/75	25	75
2	50/50	50	50
3	75/25	75	25

2.3 Testing and characterization

Mechanical testing was conducted using a Universal Testing Machine (UTM) following ASTM D882 standards to evaluate tensile strength, elongation at break, and Young's modulus of SPW-PVA composite samples. Cross head speed was set to 10mm/min for all specimens. Additionally, Scanning Electron Microscopy (SEM) was employed to analyze the surface morphology and fiber-matrix interactions of the composites.

3 Results and discussion

https://doi.org/10.1051/e3sconf/202672402003

3.1 Mechanical properties

The mechanical properties of treated SPW fibers-reinforced PVA composites values are shown in Figure 1. Values of the mechanical properties are averaged from 3 samples for each sample concentration which comprises of maximum load (N), tensile strength (MPa), elongation at break (%) and Young's modulus (MPa). In general, the mechanical testing revealed that the 50% fiber composite exhibited the highest tensile strength (10.45 MPa), while the 75% composite showed the greatest stiffness (Young's modulus of 85.19 MPa). However, elongation at break decreased with higher fiber content, indicating increased brittleness.

Test	Sample concentration (%)	Max load (N)	Tensile strength (MPa)	Elongation at break (%)	Young's modulus (MPa)
1	25%	15.4	7.70	21.13	37.45
2	25%	18.4	7.08	20.2	35.05
3	25%	10.0	4.55	10.48	43.33
Average		14.6	6.44	17.27	38.61
1	50%	18.4	9.20	9.52	96.64
2	50%	26.2	13.79	23.85	57.82
3	50%	18.4	8.36	13.55	61.74
Average		21.0	10.45	15.64	72.07
1	75%	16.2	7.36	9.33	81.87
2	75%	15.6	10.40	12.12	85.81
3	75%	16.0	8.42	9.57	87.89
Average		15.93	8.73	10.34	85.19

Fig. 1. Mechanical Properties of Treated SPW Fibers Reinforced PVA Composites.

The average tensile strength for 25%, 50% and 75% concentration are 6.44 MPa, 10.45 MPa and 8.73 MPa respectively, expressed in bar graph in Figure 2. Based on the bar graph, the tensile strength increases significantly when the filler loading is increased from 25% to 50% SPW content. A further increase of SPW fiber content to 75% led to a decrease in strength, most probably due to agglomeration and poor dispersion of filler in the polymer composite. Thus, the highest tensile strength is at the 50% weight percentage. This result was compared with a study by Toh Wen Yee et al [5] which recorded tensile strength of PVA/SPW composites of 15 MPa for 30% SPW, 6 MPa for 50% and 4 MPa for 75% SPW content. This result clearly showed a decrease in tensile strength as the SPW content was increased up to 75%. This different trend might be due to the different processing of the composite, where Toh Wen Yee et al conducted extrusion method for composite fabrication and incorporated glycerol as plasticizer. However, it can be noticed that the tensile strength range of tensile value was approximately at similar range with this study.

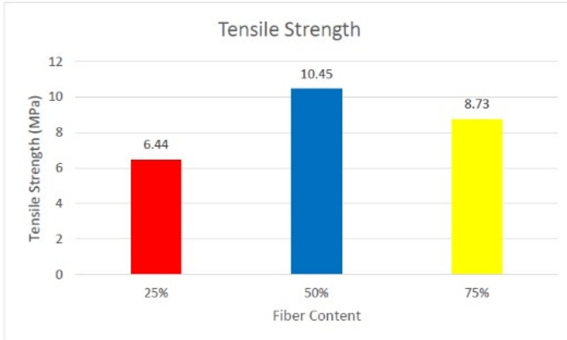


Fig. 2. Average Tensile Strength Results.

The average elongation at break percentage for 25%, 50% and 75% concentration are 17.27%, 15.64% and 10.34% respectively as in Figure 3. Base on the bar chart, as SPW filler increases, the elongation at break reduces constantly. Thus, the increase in SPW content resulted in lower elongation at break of SPW/PVA films which indicates the increase in brittleness of the composite films.

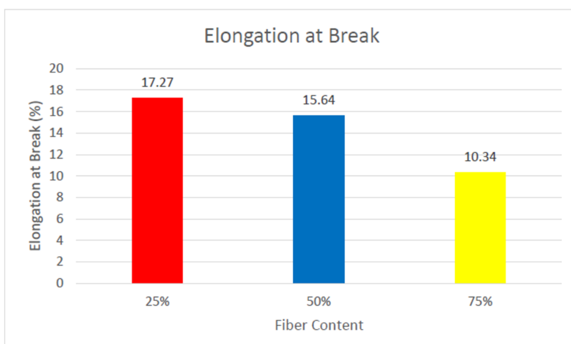


Fig. 3. Average Elongation at Break Results.

The average of Young's modulus for 25%, 50% and 75% concentration are 36.61 MPa, 72.07 MPa and 85.19 MPa respectively as shown in Figure 4. Based on the results, the increase of SPW filler increased the Young's modulus value, which interprets increase in stiffness of the SPW/PVA composite films. The 75% SPW content sample recorded value increase of 120% compared to 25% SPW content samples.

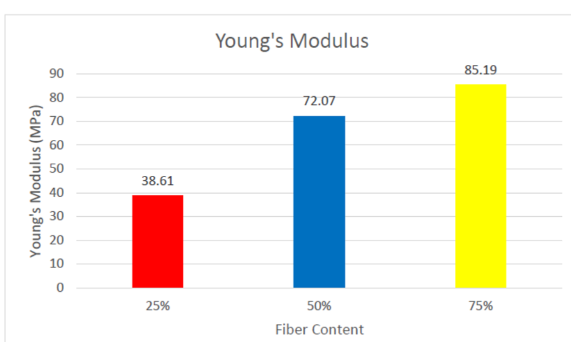
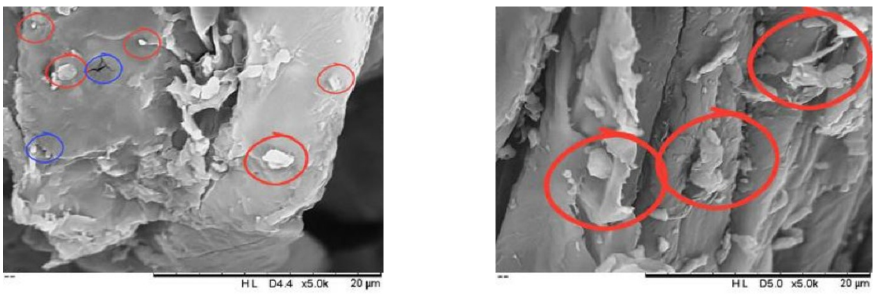


Fig. 4. Average Young's Modulus Results.

3.2 SEM morphological analysis

SEM images of untreated (a) and NaOH treated (b) SPW fibers are shown in Figure 5. In general, the surface of the untreated fiber appears irregular and rough. There are several micro-cracks and grooves which in blue circle indicating a non-uniform structure of untreated fiber. The roughness of the surface is beneficial for mechanical interlocking, but untreated fiber might contain wax which could weaken the mechanical interlocking of fiber with polymer. The white patches on the surface which in red circle are likely non-cellulosic impurities such as lignin, hemicellulose, pith or dust particles. These impurities could affect the fibre-matrix bonding by weaken it. Thus, to improve it, alkaline treatment is carried out to remove the impurities as described earlier.



(a) untreated fiber (b) treated fiber

Fig. 5. SEM Image of untreated (a) and NaOH treated (b) SPW Fiber

After chemical treatment as in (b), the red circles on the fiber surface showed waxy layers on the fibers being torned and separated from the fibers, which makes the fiber surface exposed and allow better interaction with hydrophilic PVA polymer. The rough surface of the fiber could enhance the mechanical interlocking with PVA which increase brittleness and tensile strength. This confirms the results of mechanical properties reported earlier.

4 Conclusion

This study has successfully demonstrated the potential of sago pith waste (SPW) fiber as a reinforcement material for polyvinyl alcohol (PVA) polymer composites. By investigating the mechanical properties of SPW fiber-reinforced PVA composites, the results indicated that the fiber content significantly impacts the mechanical properties. The 50% SPW composite exhibited the highest average tensile strength (10.45 MPa), compared to the 25% (6.44 MPa) and 75% (8.73 MPa) SPW fiber contents. This confirmed the ability of the treated SPW fibers to interlock with hydrophilic PVA molecules at an optimal fiber content. The 50% fiber composite, with its superior tensile properties, is well-suited for applications like eco-friendly packaging. In contrast, the 75% composite, while stiffer, may be limited by its brittleness and agglomeration issues.

The surface morphology and fiber-matrix interaction were examined using SEM. SEM analysis demonstrated that the chemical treatment (alkaline treatment) improved fiber alignment, exposed the fibrous structure, and enhanced surface roughness. This enhancement is important, as it promotes better mechanical interlocking with the PVA matrix. Despite these benefits, the SEM images revealed the presence of agglomeration at higher concentrations, specifically at the 75% fiber content. This indicates imperfect dispersion during composite fabrication, which leads to uneven stress distribution and a negative impact on overall tensile strength. These findings suggest that an optimal fiber concentration exists where the composite balances strength and ductility.

The effect of fiber content provided an understanding of how different fiber concentrations affect the composite's performance. While higher concentrations aimed to increase strength, issues like agglomeration suggest an optimal range for fiber loading to achieve balanced mechanical properties and uniformity.

The authors would like to thank the university grant (UNI/F02/TOC/85607/2023) from Universiti Malaysia Sarawak Tun Openg Chair for providing funds during the conduct of this study.

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