The effect of volume fraction on hybrid composites with fiber and trunk powder coconut filler

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Abstract. Hybrid composites are composites composed of multiple matrices and fibers, where the types of fibers include both aligned and randomly oriented fibers. The objective of this study is to investigate the effect of volume fraction variations on the mechanical properties of composites reinforced with a mixture of coconut fiber and coconut trunk powder, in order to obtain a hybrid composite with optimal mechanical characteristics.The materials used for the fabrication of the hybrid composite include coconut fiber, coconut trunk powder, polyester resin, and catalyst. The volume fraction variations of fiber and powder were set at 25%:5%, 20%:10%, 15%:15%, 10%:20%, and 5%:25%, with a constant resin content of 70%. Specimen fabrication and testing procedures followed ASTM D3039 for tensile testing and ASTM D256-03 for impact testing. The tests conducted in this study include tensile test, impact test, and Scanning Electron Microscopy (SEM) analysis. The results showed that the highest impact and tensile strength wre 0.0087 J/mm² and 14,06 MPa for the composition of 70% resin, 25% fiber, and 5% powder. The morphology of the hybrid composite shows a closed surface structure and a fiber diameter of 10 µm. The bonding between the filler and the fiber is formed.

1 Introduction

Composite materials have recently a shift from the use of synthetic fiber reinforcements toward natural fiber-reinforced composites. The demand for environmentally friendly and recyclable composite materials is increasing [1]. One of the most promising composite materials for industrial applications is a composite reinforced with fillers, either in the form of natural or synthetic fibers [2]. A composite is a material formed by combining two or more constituents through a non-homogeneous mixing process, resulting in mechanical properties that are superior to those of the individual components [3]. Composites consist of two main

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parts: the matrix, which functions as the binder or protective phase, and the filler, which serves as the reinforcement [4].

Natural and synthetic fiber-reinforced composites are among the most extensively researched and developed types of composites, considered as potential alternatives to metals. To foster innovation in composite materials, advancements in advanced materials—such as hybrid composites—are essential. Hybrid composites are materials composed of multiple types of matrices and fibers, including both aligned and randomly oriented fibers [5]. In this study, the fibers used for hybrid composite fabrication are natural fibers, specifically coconut coir fiber and coconut trunk powder as fillers.

Coconut fiber is a lignocellulosic fiber that can serve as an alternative raw material due to its abundance and favorable mechanical properties [6]. It is durable, highly resistant to abrasion, and not easily broken, making it a promising natural filler for composite materials [7, 8]. In addition to its easy availability, coconut coir fiber is composed of approximately 44% cellulose, 45% lignin, 3% pectin and associated compounds, and 5% moisture [9]. The high lignin content contributes to its hardness and stiffness. Coconut trunk powder is a natural powder used as a filler in hybrid composites, consisting of organic compounds such as cellulose, hemicellulose, lignin, pentosans, and others [10]. The use of coconut coir fiber and coconut trunk powder offers a viable alternative as fillers in hybrid composites.

This study aims to evaluate the effect of adding coconut coir fiber and coconut trunk powder as fillers in hybrid composite materials. The influence of these fillers is assessed through impact and tensile testing. Additionally, morphological characterization using Scanning Electron Microscopy (SEM) is conducted to examine the bonding between the matrix and the filler.

Method

The hybrid composite was carried out by mixing resin polyester, catalyst, fiber, and coconut shell powder according to the specified volume fraction variations. The mixture was stirred thoroughly and poured into a mold that had been pre-lubricated with wax gel. The mixture was then pressed to ensure uniform distribution of all components and left to dry. The volume fraction variations used were: 70% resin with combinations of fiber and coconut shell powder as follows — 5% + 25% (KS5B25), 10% + 20% (KS10B20), 15% + 15% (KS15B15), 20% + 10% (KS20B10), and 25% + 5% (KS25B5). Characterization of the hybrid composite was conducted through impact testing, tensile strength testing, and Scanning Electron Microscopy (SEM) analysis to evaluate its mechanical and morphological properties. Testing procedures followed ASTM D3039 for tensile testing and ASTM D256-03 for impact testing.

Result and Discussion

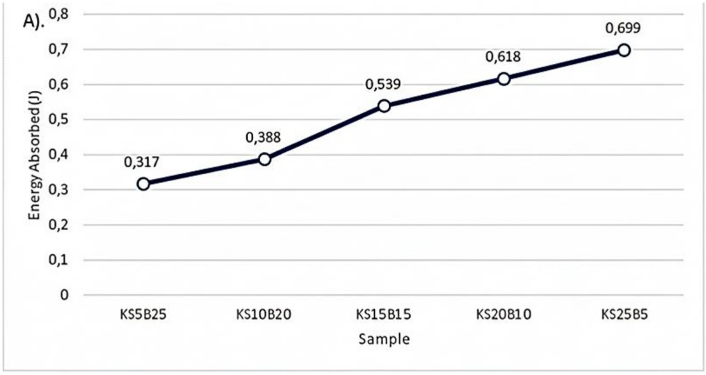
3.1 Impact strength analysis

Impact strength analysis was carried out to determine the resistance of the hybrid composite to sudden impact or shock loads [11]. The results of this analysis indicate the toughness of the hybrid composite material. Table 1 presents the energy absorption and impact strength of hybrid composites reinforced with coconut fiber and coconut shell powder. Figure1A and 1B show the increase in absorbed energy and impact strength in the hybrid composite material.

Table 1. Energy Absorbed and Impact Strength of hybrid composite

Sample	Angle of Pendulum (°)		Energy Absorbed (J)	Impact Strength (J/mm2)
	Start	Finish		
KS5B25	160	155	0,317	0,0024
KS10B20	160	154	0,388	0,003
KS15B15	160	152	0,539	0,0042
KS20B10	160	151	0,618	0,0048
KS25B5	160	150	0,699	0,0055

The energy absorbed by the hybrid composite material increased with the addition of coconut fiber and the reduction of coconut shell powder content. The lowest absorbed energy was recorded for sample KS5B25, at 0.317 J, while the highest was observed in sample KS25B5, at 0.699 J. A similar trend was observed in the impact strength of the hybrid composite materials. The lowest impact strength was exhibited by sample KS5B25, at 0.0024 J/mm², whereas the highest impact strength was observed in sample KS25B5, at 0.0055 J/mm².



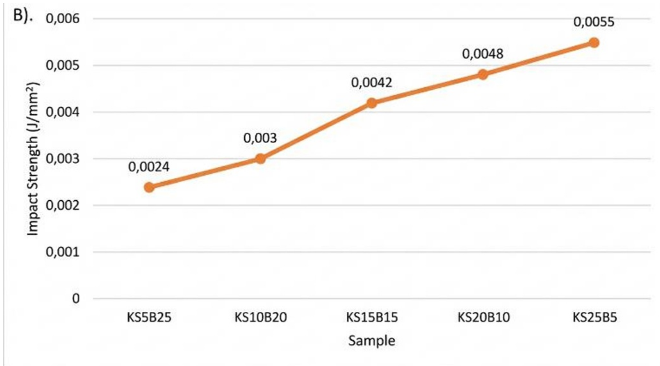


Fig. 1. Energy abLsorbed and impact strength showing of hybrid composite

The addition of coconut fiber in the hybrid composite significantly influenced the increase in impact strength. Fiber length plays a crucial role in the hybrid composite material [12]. During the impact test, the energy from the pendulum is transmitted through the filler in the form of coconut fiber. A higher content of fiber filler enhances the material's ability to absorb energy, thereby increasing its impact strength.

3.2 Tensile strength analysis

Tensile strength analysis was conducted to evaluate the behavior of the hybrid composite material under tensile loading [13]. The analysis provided data on maximum load, tensile strength, elongation, and elastic modulus, as presented in Figure 2. The hybrid composite was subjected to loading perpendicular to the sample surface. Table 2 further summarizes the maximum load, tensile strength, elongation, and elastic modulus of the hybrid composites.

Table 2. Tensile strength, elongation and modulus elasticity of hybrid composite

Sample	Max Force (kgN)	Tensile Strength (MPa)	Elongation (%)	Modulus Elastisity (MPa)
KS5B25	861,71	10,25	1,08	949,07
KS10B20	1.007,99	12,14	1,66	731,32
KS15B15	1.020,26	12,89	1,48	870,94
KS20B10	1.141,11	13,58	1,55	876,12
KS25B5	1.181,79	14,06	0,9	1.420,20

The data on maximum load and tensile strength exhibit similar trends. Both values increased with the addition of coconut stem fibers and a reduction in coconut shell powder as the hybrid composite filler. The lowest maximum load was recorded for sample KS5B25 at 861.71 kgN, while the highest was for KS25B5 at 1,181.79 kgN. The lowest tensile strength was found in sample KS5B25 at 10.25 MPa, and the highest in KS25B5 at 14.06 MPa.

The elongation of the hybrid composites exhibited a different trend compared to maximum load and tensile strength. Elongation tended to decrease as the maximum load increased. Distinct elongation trends were observed in samples KS5B25 and KS20B10, with elongation values of 1.08% and 1.55%, respectively. Additionally, the elastic modulus initially showed a decreasing trend, followed by an increase in line with the rising maximum load applied to the samples. A different pattern was observed for sample KS5B25, which had an elastic modulus of 949.07 MPa.

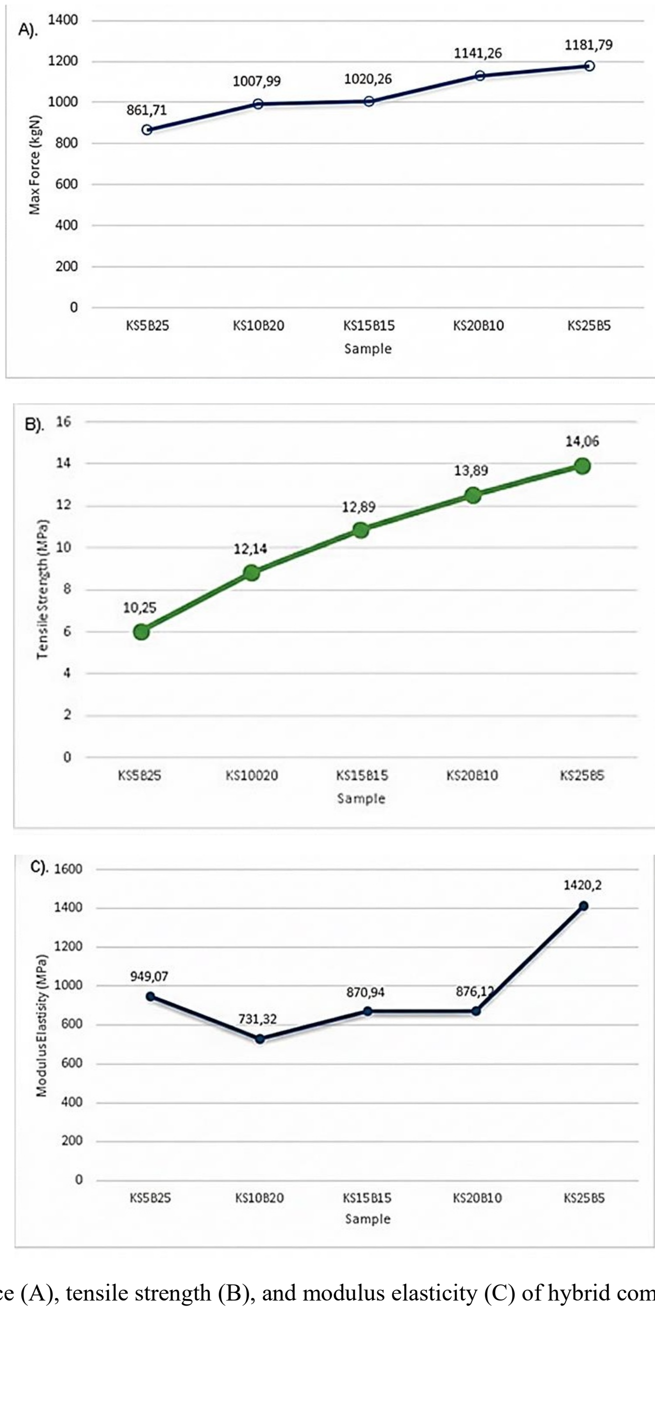


Fig. 2. Max force (A), tensile strength (B), and modulus elasticity (C) of hybrid composite

The increase in maximum load and tensile strength of the hybrid composite indicates strong interfacial adhesion between the filler and the matrix [14]. When tensile loads are applied perpendicularly, the stress is distributed through the polyester resin matrix and the fillers, which include coconut fibers and coconut shell powder. Enhanced interfacial bonding between matrix and filler leads to an increase in internal stress distribution, resulting in higher maximum load and tensile strength values.

The differing elongation behavior in samples KS5B25 and KS20B10 suggests non-uniformity in filler dimensions [15]. Filler geometry affects the stiffness of the material, as reflected in variations in elongation. The individual particles of the coconut shell powder and fibers contribute to the particle–matrix interaction. Furthermore, the variation in elastic modulus observed in sample KS5B25 may be attributed to poor interfacial bonding between the particles and the matrix, resulting in less efficient stress transfer across the interface [15].

3.3 Morphological analysis

Figure 3 shows the SEM results illustrating the surface morphology of the KS25B5 sample. The KS25B5 sample exhibits the highest energy absorption, impact strength, tensile strength, tensile resistance, and elastic modulus. Scanning Electron Microscopy (SEM) was employed to observe the surface morphology of the hybrid composite material [14]. The characterization was conducted using secondary electrons at an accelerating voltage of 15 kV with a magnification of ×23.

The SEM results reveal a relatively closed surface of the hybrid composite, with the presence of fibers, coconut shell powder, and pores on the surface. The fibers appear as long filaments with a diameter of approximately 10 µm. Similarly, the coconut shell powder shows particle dimensions of around 10 µm. The fiber diameter was determined by comparing the fiber diameter with the reference line (white line) located in the lower right corner of Figure 3. Some bonding between the matrix and the filler is observed, as indicated by the absence of voids at the matrix–filler interface [14].

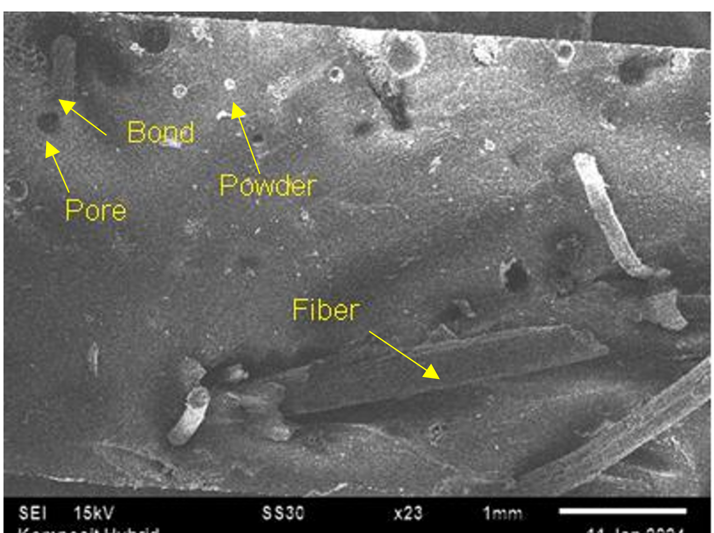


Fig. 3. Scanning electron microscopy (SEM) showing surface of hybrid composite

Conclusion

The variation in volume fractions of coconut fiber and coconut trunk powder significantly affects the mechanical properties of the polyester hybrid composite. The highest impact strength and tensile strength were observed at a volume fraction of 25% fiber and 5% powder. As the volume fraction of the powder increases, both impact strength and tensile strength tend to decrease. Hybrid composite indicates strong interfacial adhesion between the filler and the matrix

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