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Open Hole Tensile Behaviour of Sisal-Glass Reinforced Epoxy Composite

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Abstract

Research and development in engineering composites are advancing rapidly. The demand for lightweight materials with high specific strength in aerospace and high-energy applications makes composites a prime choice. Using composite materials to reduce structural weight is favored for energy saving and emission reduction, making them popular in automobiles and other fields. However, composites require holes for assembly and fastening in many applications, such as airplane structures and automotive parts. These holes can concentrate stress, potentially reducing tensile strength and compromising structural integrity. Notches, including holes and slots, are inevitable during assembly and may also result from impact damage during service. Ensuring safety and reliability necessitates quantifying residual properties and failure responses. Stress concentration issues will occur around holes, whether in laminates used for interior decoration, outsourced parts, or bearing components. Therefore, notch design must consider the effects on failure mode, mechanical performance, and interlayer damage distribution. This study examines the open-hole tensile behavior of sisal-glass fiber-reinforced epoxy composites, aiming to understand the impact of circular holes on their tensile strength and failure mechanisms.

Keywords: *Inter-Layer Damage; Notches; Open-Hole Tensile Behaviour (OHT); Structural Integrity Sorted;*

1. Introduction

Natural fiber-reinforced composites (NFCs) have gained significant attention in various manufacturing sectors due to their beneficial properties such as high strength-to-weight ratio and biodegradability [1]. Unlike synthetic fibres, natural fibres like pineapple, jute, abaca, coir, sisal, cotton, bamboo, banana, hemp, kenaf, and palmyra palm leaf stalk offer a sustainable alternative in composite manufacturing. However, NFCs face limitations in structural applications due to lower mechanical strength. To overcome this, hybridization of natural and synthetic fibres has emerged as a promising solution, enhancing the mechanical properties of NFCs. Researchers have extensively studied the mechanical and physical properties of NFCs using different matrices and fibre volume fractions. For example, Rassmann et al. evaluated kenaf fibre with epoxy, vinyl ester, and polyester resins, finding that epoxy laminates exhibited good strength, polyester resins had high modulus and impact properties, and vinyl ester laminates showed excellent water absorption. Similarly, Mahjoub et al [2]. observed that the tensile properties of kenaf fibre significantly improved at a 40% volume fraction, with a corresponding decrease in Poisson's ratio. These studies underscore the potential of NFCs in various industrial applications, although challenges remain in optimizing their structural performance [3]. Fibre-reinforced plastics (FRPs) have been widely used for decades in industries such as aerospace, automotive, shipbuilding, and construction due to their versatility and desirable properties. Despite their advantages, FRP structures face design challenges due to complex failure modes and anisotropic properties. Consequently, many structures are hybrid, combining composites and metals, particularly in large vessels, automotive drive shafts, and robotic structures. One critical limitation of FRP structures is joint weakness, with adhesive-bonded, mechanically fastened, and combination joints each presenting unique advantages and challenges. Mechanically fastened joints are preferred for their ease of assembly and ability to handle high loads and environmental conditions without requiring specific surface preparations [4]. However, they can fail due to stress concentrations near the holes, which complicates stress transmission in composite materials (Table 1). This complexity can lead to unpredictable fracture characteristics. Therefore, further research is needed to enhance the theoretical understanding and practical application of FRP structures, particularly in addressing stress concentrations and ensuring structural integrity [5].

1.1. Materials

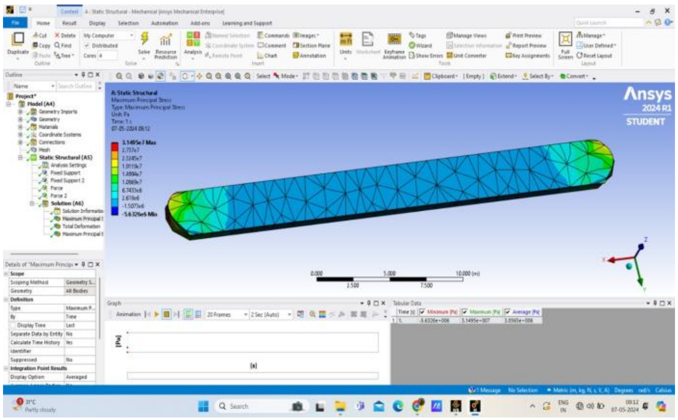
Sisal fibre, derived from the agave sisalana plant, is strong, durable, and lightweight. It's commonly used in rope, cordage, carpets, and textiles. As a renewable resource, the agave plant can be harvested multiple times. The extraction process includes retting, decortication, drying, and bundling. Sisal boasts high tensile strength, low density, biodegradability, moderate moisture absorption, and abrasion resistance (Refer Figures 1 & 2). Glass fibre, made from fine glass strands, is an inorganic, non-metallic fibre known for high strength, good insulation, and fire resistance. Used in construction, transportation, and defense, it features a Young's modulus of 70-73 GPa, high strength, low density, dimensional stability, heat resistance, and electrical insulation. Epoxy resin, a thermoset polymer formed from epoxide and a hardener, offers strength and durability due to its crosslinked polymer network. Characteristics include a density of 1.1-1.2 g/cm³, Young's modulus of 2-4 GPa, high chemical resistance, low shrinkage, strong adhesion, and electrical insulation [6].

2. Method

The vacuum bagging method in composite materials refers to a process used in the fabrication of composite structures, such as fiberglass or carbon fibre reinforced composites [7]. This method is commonly employed in industries like aerospace, automotive, and marine for manufacturing lightweight and strong components [8].

Table 1 **Experimental Observations**

Observation	Sisal with Hole	Sisal without Hole	Hybrid with Hole
Load(kg)	2.507	3.258	2.519
Stress (kg/cm^)	2.507	3.949	2.015
Strain (%Elong)	4.633	6.573	8.180



A: Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: Pa
Time: 1 s
07-05-2024 09:12

3.1495e7 Max
2.7574e7
2.3245e7
1.9119e7
1.4994e7
1.0869e7
6.7433e6
2.618e6
-1.5073e6
-5.6326e6 Min

Scope	
Scoping Method	Geometry S...
Geometry	All Bodies
Definition	
Type	Maximum P...
By	Time
Display Time	Last
Separate Data by Entity	No

	Time [s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
1	1.	-5.6326e+006	3.1495e+007	3.0565e+006

Figure 1 **Hybrid with Multiple Hole**

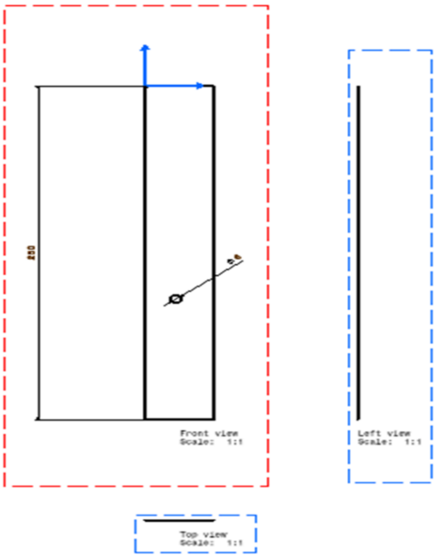


Figure 2 **OHT Specimen**

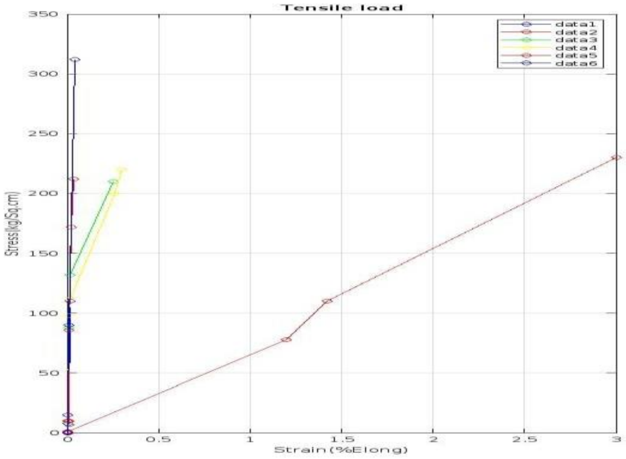


Figure 3 **Comparison Plot**

3. Results and Discussion

3.1. Results

This part explores the core of the study by showcasing the experimental findings from the sisal fibre reinforced composites' tensile testing. A thorough analysis will be performed on the data pertaining to important mechanical parameters, including tensile strength, Young's modulus, and perhaps strain at break and fracture behaviour (Refer Figure 3). We will investigate how the overall mechanical performance of the composites is affected by variations in the sisal fibre content and maybe other processing parameters (such as fibre orientation and surface treatment). In order to demonstrate the connections between processing parameters and the ensuing mechanical behaviour, the results will be presented in an understandable and succinct manner using tables, graphs, and pertinent statistical analysis. The usefulness of sisal fibres as reinforcement in composite materials will be clarified by this analysis. The results of this investigation will be very helpful in understanding how well sisal fibres work as reinforcement in composite materials and will open the door to further property optimisation for particular uses. The mechanical properties of the sisal fibre-reinforced composites were evaluated through tensile testing. The experimental results for tensile strength, Young’s modulus, and other appropriate variables are shown in this section. To comprehend how the sisal fibre content and other processing factors affect the mechanical performance of the composites, the findings are analysed.

3.2. Discussion

Based on the experimental outcomes above,

- We have noted that with a maximum load of 2.507 kg, the strain can reach 4.633% elongation and the maximum stress can reach 2.507 kg/cm^2 in a sisal fibre composite with a 6mm diameter hole.
- When a tensile load of 3.258 kg was applied to the sisal fibre without a hole, we concluded that the composite experienced a maximum stress of 3.949 kg/cm^2, resulting in an elongation of 6.573%.
- Regarding the sisal-glass hybrid composites with a 6 mm diameter hole, which is determined based on the results of the literature survey, we found that they can tolerate a maximum of 2.015 kg/cm^2 of stress and 8.180% elongation of strain at a maximum load of 2.519 kg.
- When a tensile load of 5.217 kg was applied to the hybrid composite without a hole, the specimen's maximum stress and strain values were 3.794 kg/cm^2 and 24.933% elongation, respectively

Conclusion

In experiments involving natural fiber- reinforced composites compared to glass fiber composites, we conclude that, this data is generated using computer simulations that model the behavior of the composite material under various conditions. Finite element analysis (FEA) software is commonly used for this purpose. This data is obtained through theoretical models that describe the mechanical properties of the composite based on the properties of its constituents (fibres and matrix) and assumptions about their interaction.

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