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Technical Report

# Study of flax hybrid preforms reinforced epoxy composites

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ABSTRACTS

This study investigates the thermal, mechanical and thermomechanical properties of flax hybrid preform reinforced epoxy composites. Flax plain weave fabric and 1 × 1 weft rib knitted structures were together used as reinforcements and the composites were produced using hand lay-up technique. Specimen preparation and testing were carried out as per ASTM standards. Thermogravimetric analysis (TGA) indicates a decrease in thermal stability of the matrix polymer with the incorporation of flax hybrid preform. The dynamic mechanical analysis revealed a shift in the $T_g$ with the addition of flax hybrid preforms. Mechanical data obtained showed that tensile strength and stiffness is a product of the fibre/matrix synergy, whereas the compressive strength and stiffness are contributed by the reinforcing matrix. Additionally, investigation show that laminate with knitted preform as skin layer exhibits superior mechanical properties. However, improved tensile properties at lower fibre volume fraction, reinforces the opinion that hybrid preform composites can offer significant benefits in terms of performance, weight and overall cost. The failure mechanism was analysed, by scanning electron microscope (SEM).



## 1. Introduction

In the latest years the development of sustainable materials has received considerable attention from both industry and academia because of ecological issues pertaining to climate change, greenhouse gasses, etc. [1]. In this context, the need to explore environmentally friendly, sustainable materials to replace existing synthetic fibres to lessen the dependence on petroleum based products is mounting. Further the remarkable increase in production and use of polymeric commodities in every sector of our life is leading to huge disposal dilemma. Of the varied types of biocomposites, presently the use of natural fibre as reinforcement is most practicable because of the high price of biodegradable polymers.

The resumption of inquisitiveness in the use of natural fibre is mainly due to their beneficial properties such as high strength to weight ratio, renewability, biodegradability, lower energy requirements for processing, low cost and relatively less wear and tear in processing over traditional synthetic reinforcing fibres (glass and carbon) [2]. Bast fibres (jute, hemp, kenaf and flax) have been identified as the most promising and potential candidates, because of its acceptable specific properties, low density, low cost, biodegradable nature, renewability, etc. [3–5]. However, applications of natural fibre with all these advantages, has been restricted due to its low thermal stability during processing, hydrophilic nature and poor adhesion with synthetic matrix [6]. Idicula [7] studied the dynamical mechanical properties [8–10] of randomly oriented short banana/sisal/polyester hybrid composites and concluded that higher compatibility was obtained hybridizing these fibres, leading to higher stress transfer ability. Song [11] studied the thermal and viscoelastic behaviour of twill and plain woven hemp fabrics reinforced poly lactic acid (PLA) composites. The authors observed that the thermal co-efficient of thermal expansion of the composites decreased sharply with increasing fibre volume fractions. Further, the composites embedded with twill woven hemp fabrics showed better mechanical, thermal and viscoelastic behaviour than plain woven hemp fabric. It is well known that the mechanical behaviour of the composite material is strongly influenced by the nature and orientation of the fibres. Reinforcements in the form of textiles such as woven, knitted are more advantageous than unidirectional reinforcements. Further, the application of woven and knitted fabric composites in engineering structures has been appreciably increased due to low fabrication cost, ease of handling, attractive balanced in-plane properties and high fracture toughness. However, the looped nature of the knit structure renders knitted composites inferior as structural materials. Moderate improvements to the strength and stiffness of knitted composites are achievable with the incorporation of in-lay yarns into the basic structure [12]. However, a more effective way of enhancing the in-plane properties of knitted composites would be preform hybridization.

Hybrid composites have drawn the attention of many researchers as a way to augment composite properties. The behaviour of hybrid composites is a weighted sum of the individual components in which there is a more favourable balance between the innate advantages and disadvantages, where the advantages of one type of fibre could complement what are lacking in the other(s). As an outcome, a balance in cost and performance can be achieved

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through proper material design [13,14]. Hybrid composites using lignocelluloses materials have not been studied as thoroughly as others. Reports in the literature are almost always referring to the use of natural fibres primarily as filler and only to a lesser extent as reinforcement. Typically in these composites, the natural fibre is combined with glass fibres, which provide the necessary mechanical load bearing capacity. Cicala [15] investigated the hybridization of glass fibres with natural fibres for application in the piping industry. The adoption of this design allowed for a cost reduction of 20% and a weight saving of 23% compared to the current commercial solution. The hybrid lay-up fulfilled the mechanical resistance for the intended use. Paiva Junior [16] experimentally studied the tensile strength of polyester/hybrid ramie–cotton fabric composite by varying the stacking sequence configuration. The results obtained showed that the main parameter governing the tensile properties of the composite was the fibre volume fraction of ramie fibres parallel to the test direction. Mishra [17] experimentally assessed the degree of mechanical reinforcement that could be obtained by introduction of glass fibres into pineapple leaf fibre and sisal fibre reinforced polyester hybrid composites, and observed that the tensile, flexural and impact properties of pineapple leaf fibre and sisal reinforced polyester composites improved and showed positive hybrid effect.

In this study, the aim was to try and overcome the inherent weaknesses of both knitted and woven preforms, to give a new class of hybrids which guarantees an optimum combination of superior mechanical properties, with a right balance of the degree of formability and the prerequisite in-plane properties, with different stacking sequence of knitted/woven preforms and by varying the lay-up architecture.

## 2. Experimental details

### 2.1. Materials

Plain woven and rib-knitted preforms were manufactured using flax yarn (38 Tex) procured from M/s Jaya Shree Textile Mills, Kolkata, India. The fibres were used as-received. The mean physical properties of flax yarn, woven preform and the knitted preform is listed in Table 1.

### 2.2. Manufacturing of composite laminates

The composite laminates were fabricated by hand lay-up method. The fabric preforms were cut to 250 mm × 250 mm size and layers stacked as per the stacking sequence shown in Table 2. The laminate plates were fabricated using 2 mm thick spacer between the press plates with the fibre volume fraction of 23% and 34%, the fibre volume fractions, were evaluated using constituent densities. The amount of resin used to impregnate the fabric was adjusted, so as to obtain a complete impregnation. Laminates were cured in a hot-platen press for 2 h at 50 °C with a pressure of 3 bar, and post cured in an oven at 120 °C for 1 h.

## 3. Characterisation methods

### 3.1. Thermogravimetric analysis (TGA)

Thermal stability of samples was assessed by thermogravimetric analysis (TGA) using Q50 series (T. A. Instruments) apparatus. TGA measurements were carried out on 10–15 mg sample placed in a platinum pan, heated from 20 to 700 °C at a heating rate of 20 °C/min in a nitrogen atmosphere with a flow rate of 60 ml/min to avoid unwanted oxidation.

### 3.2. Dynamic mechanical analysis (DMA)

A dynamic mechanical analyzer (SEIKO, Model DMS 6100) was used to determine the viscoelastic behaviour of hybrid flax preform reinforced epoxy composites in bending mode over a temperature range of 0–300 °C according to ASTM D 5023. The hybrid flax preform epoxy composites were cut into samples having dimensions of 40 mm × 10 mm × 2.6 mm (length × width × thickness). The experiment was conducted at five different frequencies, namely

**Table 1**
Mean physical properties of flax yarn, flax woven and knitted preforms.

| Yarn particulars | Properties | Woven preform particulars | Warp properties | Weft properties | Knitted preform particulars | Properties |
|---|---|---|---|---|---|---|
| Linear density (Tex) | 38 | Threads (cm) | 16 | 18 | Course density/cm | 7.2 |
| Tenacity (cN/tex) | 24.12 | Crimp (%) | 9.67 | 1.20 | Wale density/cm | 4 |
| Failure strain (%) | 4.97 | Failure stress (MPa) | 28.39 | 39.94 | Tightness factor | 2.52 |
| Modulus (cN/tex) | 561.67 | Failure strain (%) | 14.39 | 4.88 | Thickness (mm) | 1.2 |
| | | Young's modulus (GPa) | 0.615 | 1.349 | Areal density (GSM) | 346 |
| | | Fabric thickness (mm) | 0.39 | | | |
| | | Fabric weight (GSM) | 130 | | | |

**Table 2**
Laminate stacking sequence and the specific tensile and compressive properties.

| Symbol | Stacking sequence | Lay-up angle | Laminate thickness (mm) | Total fabric | | Tensile strength ($MPa\ g^{-1}\ cm^3$) | | Tensile modulus ($GPa\ g^{-1}\ cm^3$) | | Compressive strength ($MPa\ g^{-1}\ cm^3$) | | Compressive modulus ($GPa\ g^{-1}\ cm^3$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Weight fraction (%) | Volume fraction (%) | 0° | 90° | 0° | 90° | 0° | 90° | 0° | 90° |
| H1 | k/wwww | [0°/0°] | 2 | 31.43 | 27.1 | 40.52 | 38.62 | 2.13 | 2.82 | 11.08 | 11.98 | 0.535 | 0.347 |
| H2 | k/wwww | [90°/0°] | 2 | 31.43 | 27.1 | 51.60 | 47.40 | 2.57 | 3.07 | 8.19 | 6.611 | 0.754 | 0.153 |
| H2′ | wwww/k | [90°/0°] | 2 | 31.43 | 27.1 | 32.29 | 26.41 | 2.43 | 1.99 | 11.50 | 11.157 | 0.501 | 0.434 |
| H3 | k/wwww/wwww/k | [0°/0°/0°/0°] | 4 | 25.58 | 21.8 | 38.37 | 31.10 | 2.20 | 2.29 | 46.05 | 54.622 | 0.678 | 0.884 |
| H3′ | wwww/k/k/wwww | [0°/0°/0°/0°] | 4 | 25.58 | 21.8 | 35.26 | 38.40 | 1.76 | 2.90 | 40.94 | 56.723 | 1.101 | 0.823 |
| H4 | k/wwww/wwww/k | [0°/90°/90°/0°] | 4 | 25.58 | 21.8 | 53.35 | 29.26 | 2.52 | 2.57 | 37.54 | 57.563 | 0.902 | 0.935 |
| H4′ | wwww/k/k/wwww | [0°/90°/90°/0°] | 4 | 25.58 | 21.8 | 24.44 | 48.77 | 1.93 | 1.92 | 42.71 | 51.681 | 0.342 | 0.649 |
| H5 | k/wwww/wwww/k | [0°/+45°/−45°/0°] | 4 | 25.58 | 21.8 | 38.15 | 24.74 | 1.98 | 1.96 | 50.15 | 45.378 | 0.654 | 1.956 |
| H5′ | wwww/k/k/wwww | [0°/+45°/−45°/0°] | 4 | 25.58 | 21.8 | 25.02 | 42.51 | 1.82 | 2.779832 | 48.51 | 47.479 | 0.473 | 0.687 |