Experimental Investigations on Flexural and Fracture Behaviors of Flax Fiber Reinforced Sandwich Panels

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Abstract – Natural fiber reinforced sandwich composites have been of keen interests to researchers as a result of their low cost, moderately good mechanical properties, and biodegradability. The main attention of the present work lies on the eco-friendly honeycomb structures for sandwich panels. This paper investigates the mechanical characteristics of flexural and fracture strengths of the sandwich panels involving polypropylene as its core and treated flax fabric fiber reinforced polymer matrix composites as face sheets. Taguchi’s design of experiments is implemented in the experimental analysis. The influence of fabric orientation and surface treatment on the properties is reconnoitered. Analysis of Variance (ANOVA) is employed to study the influences of different parameters on flexural and fracture strengths of sandwich panels. Copyright © 2018 Praise Worthy Prize S.r.l. - All rights reserved.

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I. Introduction

Composite materials, comprising of a polymer matrix and high-strength fibers, have been used since decades [1]-[29]. Two classes of polymers namely, thermoplastics and thermosets have been employed with high strength and high modulus synthetic fibers like glass aramid and carbon. The mounting concern towards issues related to environment and the need for more versatile polymer-based materials has led to a growing interest in natural fiber reinforced polymer matrix composites. These "green" composites are coming into use for numerous applications. Additionally, these organic fillers used are very cheap and are less abrasive so as to facilitate easy machining as compared to their inorganic counterparts.

Jute, coir, banana, hemp, sisal, flax are being frequently utilized as reinforcements for low load applications like cordage, fishnets, mats etc. [1]-[3].

Due to their decent energy absorption potential and their ability to provide an increase in flexural inertia amongst many other upright applications without many consequences in terms of weight, sandwich structures have become popular in aerospace and automotive industry [30]-[34]. Railroad and marine industry have also used sandwich structures due to which there has been an increase in payload carrying capacity and performance enhancement [4]-[6]. Of late, in the automobile industry, much attention is being given to fabrication and utilization of environment-friendly novel lightweight sandwich structures [7].

In a sandwich structure, transverse shear loads are carried by the core and in-plane loading is carried by the face sheets. For the fabrication of sandwich structures, several types of the core material and core shapes can be utilized. [8]-[9]. Owing to their high flexural rigidity and damping characteristics, honeycomb structures are being widely used for different applications [10]-[12], [30].

In order to obtain desired performance, the honeycomb core thickness can be altered and face sheet material can also be varied. In this paper, polypropylene core is being used. The polypropylene core consists of regular hexagonal cells perpendicular to the facings.

Zuhri et.al. [13] investigated the tensile and compression properties of flax fiber reinforced polypropylene and polylactide polymers and highlighted the superiority of polypropylene-based composite as compared to its PLA equivalent. The polypropylene core offers many advantages, corrosion resistance, moisture resistance and sound and vibration dampening being some of them. The properties of polypropylene core have been listed in Table I. It has good mechanical properties and impact resistance, high-temperature resistance and excellent machinability [14]-[17]. Du et al. [18], in their study on light-weight honeycomb core sandwich panels containing bio fiber-reinforced thermoset polymer composite skins, found out that the PRP/honeycomb sandwich panels had flexural load bearing capacity comparable to commercial products and light areal weight and thus suggested their use as a substitute for glass-fiber reinforced polymer composites.

Flax fiber: The face sheets are made of flax fiber reinforced polymer matrix composites. Flax fabric fiber composites have been revealed to have specific mechanical properties comparable to those of glass fiber reinforced composites [19]. Tensile properties of flax fiber reinforced epoxy composites and glass fabric reinforced composites fabricated by the use of hand lay-
up technique were compared by Assarar et al. [20] and it was learned that the tensile strength of flax composites reached up to 380 MPa which is very close to the tensile strength of glass fabric reinforced epoxy composites.

Pillin et al. [21] carried out work on the oleaginous flax fibers and found that the specific Young’s modulus of linseed flax fiber was better than that of glass fibers and suggested oleaginous flax fibers to be good contenders for supplanting glass fibers in polymer matrix reinforcements. In the review work carried out by Yan et al. [22], it was stated that promising mechanical properties were exhibited by flax fiber with thermoplastic, thermoset, and biodegradable matrices.

**Flax fabric and polypropylene (PP) core sandwich panel:** Garkhail et al. [23], in their work on Natural fiber-mat-reinforced thermoplastics (NMT) based on flax fiber and polypropylene fabricated using film stacking method found that the NMT had high stiffness per unit weight. In the study relating to the microstructure of injected flax fiber reinforced PP, Bourmaud et al. [24] have thrown light on the influence of fiber orientation on the mechanical properties of the composite. It has been discovered in the study that though the degree of crystallinity has an influence on the mechanical properties of core and skin, fiber orientation is the predominant parameter that leads to the difference in mechanical properties of the composites.

**Chemical treatment on flax fibers:** One of the major problems of composites made out of natural fiber is the discordance between the fibers and matrix due to the hydrophobicity of the fiber and the hydrophobicity of the matrix. The reason being the pendant hydroxyl and polar groups present in the fiber components tend to increase moisture uptake and this leads to decrease in the tensile properties of the fibers themselves and hence affects the performance of the composite. In order to cleanse the surface of the fibers and alter the chemistry so as to assist in the interlocking and improve the fiber matrix adhesion, alkali treatment is done on the fiber.

Flax fiber, treated with alkali has been stated to advance adhesion between the fiber and matrix [22].

Hosur et al. [25] studied the effect of alkali treatment on polyester reinforced with polyester and determined that the fibers treated with alkali had improved flexural properties. They used different concentrations of NaOH for coming to a conclusion on the effect of alkali treatment of the fibers. Wu et al. [26] studied the effect of maleic anhydride-polypropylene (MAPP) and vinyltrimethoxy silane (VTMO) on tensile, flexural and impact properties of flax fiber reinforced polypropylene composites and the results showed that there was an improvement in tensile due to MAPP treatment while the VTMO surface treatment showed higher flexural properties. KMnO₄ treatment of sugar palm fibers reinforced polyurethane resulted in better tensile behavior with the increase in concentration [27]. Silva et al. [28], in their paper on Fracture toughness of natural fibers/castor oil polyurethane composites, found out that the fracture toughness decreased for sisal composites after alkaline treatment but it was enhanced for coconut fiber composites. Venkatachalam et al. [29] investigated the flexural stress of sandwich panels of jute fiber hybrid polymer matrix and discussed the possibility of substituting many synthetic resin composite sandwich panels taking into account recyclability and cost factors.

In the present investigation, on the basis of the aforementioned charter, the flexural stress and fracture toughness of the sandwich panels with polypropylene as honeycomb and flax fiber reinforced polymer matrix composites as face sheets have been explored. The influences of fiber orientation, chemical treatment and type of resin on the flexural and fracture characteristics have been investigated.

### II. Experimental Procedure

For determining the set of tryouts to be carried out for the experiment, Taguchi’s design of experiments procedure is used. Taguchi’s design of experiments helps in obtaining an optimal set of parameters. Fabric Orientation, type of alkali treatment used and resin are the parameters chosen. The values for orientation of the fibers are taken as 0, 30 and 45 degrees. Epoxy, isophthalic ester and vinyl ester are used as resins and the fibers are treated with KMnO₄, NaOH, and KOH.

Using these variables, the Taguchi’s L₉ array is listed in Table I.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>TAGUCHI’S METHOD FOR DETERMINING THE DESIGN OF EXPERIMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Resins (X)</td>
<td>Fabric Orientation (Y)</td>
</tr>
<tr>
<td>X1</td>
<td>Epoxy</td>
</tr>
<tr>
<td>X1</td>
<td>Epoxy</td>
</tr>
<tr>
<td>X2</td>
<td>Y3</td>
</tr>
<tr>
<td>X2</td>
<td>Y1</td>
</tr>
<tr>
<td>X2</td>
<td>Isophthalic Ester</td>
</tr>
<tr>
<td>X2</td>
<td>Y3</td>
</tr>
<tr>
<td>X3</td>
<td>Y1</td>
</tr>
<tr>
<td>X3</td>
<td>Vinyl Ester</td>
</tr>
<tr>
<td>X3</td>
<td>Y3</td>
</tr>
</tbody>
</table>

The fabric obtained is cut into the dimensions as per ASTM C393/393 for preparing the skin layers. Length of the specimen is taken as 250mm and breadth is taken at 75mm. Span length is 200 mm. These standards are followed for specimens of flexural tests. For the fracture toughness measurement, the dimensions are in agreement with ASTM E399 standards. The flax fabric fibers are then chemically treated.

**Chemical treatment of the fibers:** NaOH, KOH, and KMnO₄ are used to clean and modify the surface of the fibers. The fibers are dipped in 5% NaOH for 30 mins and then washed and dried. This is followed for KOH and KMnO₄.

Three layers of flax fabrics are used for the fabrication of the face laminate. The laminate is prepared using the vacuum bagging technique.

**Vacuum bagging:** the vacuum bagging process is used
to pressurize the laminate during the curing process. This process facilitates proficient force transmission among
the fiber layers and precludes the fiber layers from
changing their orientation. One of the major advantages
of this process is the optimization of the fiber-to-resin
ratio in the composite.

The laminates are left to cure for 12 hours after the
process. Weights are then employed to stick the
laminates with the polypropylene honeycomb core and
the sandwich panels are prepared.

Mechanical testing of the composite specimens.

Flexural tests: INSTRON testing machine is used for
obtaining flexural stress and modulus values for 9
samples at a constant rate of 6mm/min.

The specimens are monitored for deformation under
the applied load. Figs. 1(a) and 1(b) show the specimen
loaded for the tests before and after the specimen fails.

Fracture tests: the values for fracture toughness of the
samples are determined using the INSTRON testing
machine. Notches are prepared on the samples and a
constant strain rate of 2mm/min is applied. Fig. 3 shows
the specimen during loading conditions.

Stress intensity factor \((K_{1c})\): for the prediction of the
stress rate near the tip, stress intensity factor is used. This
theoretical concept offers a failure criterion for brittle
materials and is typically used for homogeneous and
linear elastic material. The concept can also be utilized
for materials that display small-scale yielding at a crack
tip. It is determined as follows:

\[
K_{1c} = \sigma \sqrt{a\pi}
\]  

where:

\(a\) = crack length (mm)
\(\sigma\) = Fracture stress (MPa)

III. Results and Discussions

III.1. Flexural Testing

III.1.1. Flexural Stress

The flexural testing is performed on the prepared
samples as determined by Taguchi’s method and the
values are segregated according to the chemical
treatment, the resin used and orientation of the fiber in
degrees. Table II presents the value of flexural stress
obtained for all 9 samples. From Table II, it is observed
that combination of EPOXY resin-45 degrees fabric
orientation-KOH alkali treatment offers maximum value
of flexural stress.

III.1.2. ANOVA Analysis and Regression Equation

Analysis of variance (ANOVA) is used to determine
the regression equation that presents the interdependency of the variables and the degree with which they alter.

To assess the impact of these variations, MINITAB software package is used and the acquired results are given in the form of Contour plots and Main Effects Plot.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Resin</th>
<th>Orientation (degrees)</th>
<th>Treatment</th>
<th>Flexural Stress obtained through experimentation (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Epoxy</td>
<td>0</td>
<td>NaOH</td>
<td>6.05344</td>
</tr>
<tr>
<td>2</td>
<td>Epoxy</td>
<td>30</td>
<td>KMnO₄</td>
<td>9.9769</td>
</tr>
<tr>
<td>3</td>
<td>Epoxy</td>
<td>45</td>
<td>KOH</td>
<td>10.0025</td>
</tr>
<tr>
<td>4</td>
<td>Isophthalic Ester</td>
<td>0</td>
<td>KMnO₄</td>
<td>3.46253</td>
</tr>
<tr>
<td>5</td>
<td>Isophthalic Ester</td>
<td>30</td>
<td>KOH</td>
<td>6.21457</td>
</tr>
<tr>
<td>6</td>
<td>Isophthalic Ester</td>
<td>45</td>
<td>NaOH</td>
<td>6.23564</td>
</tr>
<tr>
<td>7</td>
<td>Vinyl Ester</td>
<td>0</td>
<td>KOH</td>
<td>1.32169</td>
</tr>
<tr>
<td>8</td>
<td>Vinyl Ester</td>
<td>30</td>
<td>NaOH</td>
<td>3.21345</td>
</tr>
<tr>
<td>9</td>
<td>Vinyl Ester</td>
<td>45</td>
<td>KMnO₄</td>
<td>4.68009</td>
</tr>
</tbody>
</table>

Fig. 4 represents the main effects plot which illustrates the impact of variation of the resin, the orientation of fabric and the chemical treatment of the maximum flexural stress. It is noted that the maximum value of flexural stress is obtained when the resin used is 1 i.e. Epoxy. Similarly, it could be drawn from the next plot that maximum values are obtained when the fabric in an orientation of 45 degrees and the chemical used for treatment is 1 i.e. KMnO₄. It is also observed that the variation of flexural stress with respect to the type of alkali treatment is very less.

Contour plots enable us to study the variations of two variables on response output.

Figs. 5-7 depict the contour plots which illustrate the variation of flexural stress against the alteration in multiple variables.

Fig. 5 shows the varying flexural stress in contrast with alkali treatment and type of resin. It is noted that the
maximum value of stress is found for epoxy and NaOH as well as for epoxy along with KOH. Similarly, the peak value is reached, as distinguished by the plot, on treatment with KOH.

Figs. 9-11 represent the contour plots, remarking the variation of 2 parameters with the varying value of $K_{lc}$. Figs. 9 estimates the varying value of $K_{lc}$ with the parameters of Resin and Orientation changing. Fig. 10 depicts the variation of $K_{lc}$ with varying parameters of treatment and resin. It is, similarly, noted that maximum value of $K_{lc}$ is obtained with treatment of KOH and epoxy.

Finally, Fig. 11 represents parameters of orientation and treatment varying and their effect on $K_{lc}$.

### III.2. Fracture Testing

#### III.2.1. Stress Intensity Factor ($K_{lc}$)

The fracture test is done using the INSTRON testing machine on the samples prepared using Taguchi’s method. Stress Intensity Factor ($K_{lc}$) is calculated using equation (1) to get a better understanding of the fracture attributes. The results are tabulated in Table III.

The magnitude of depends on sample geometry, the size and location of the crack, and the magnitude and the modal distribution of loads on the material.

#### III.2.2. ANOVA Analysis and Regression Equation

Analysis of variations (ANOVA) is done using MINITAB software. Contour plots are drawn and regression equation is obtained in the similar way to achieve a better understanding of the correlation between the variables and effect on the stress intensity factor ($K_{lc}$). Fig. 8 represents the main effect plot attained via MINITAB software, representing the variation of $K_{lc}$ value with changing variables of (1) Resin, (2) Fabric orientation and (3) Chemical treatment over the fabric.

It is noted that the maximum value of $K_{lc}$ is observed for epoxy. From the subsequent plots, it is noted that the maximum value is yielded for an orientation of 30 degrees.
where:
X= Resin
Y= Orientation
Z= Treatment

IV. Conclusion

In the current study on flax fiber reinforced sandwich panels, the flexural strength has been deducted using flexural stress and stress intensity factor has been used to serve an understanding of the fracture toughness of the samples. ANOVA (Analysis of Variations) is employed to obtain contour plots and regression equations to understand the relationships between predictor parameters and responses. Some of the noteworthy inferences arrived from this work are:

1) the type of resin effects considerably on flexural and fracture behaviors of flax fabric reinforced sandwich panels. Using epoxy resin as a matrix in sandwich panels advances flexural and fracture behaviors of sandwich panels.

2) the influence of fiber orientation on flexural and fracture behaviors of flax fabric reinforced sandwich panels is meager.

3) the type of alkali treatment influences significantly on flexural and fracture behaviors of flax fabric reinforced sandwich panels but the level of influence is less when compared to the type of resin. It is concluded alkali treatment using KOH improves flexural and fracture behaviors of sandwich panels.

4) the results flexural and fracture test shown are applicable only for the aforementioned resins, orientation and alkali treatments done on the fibers.

References


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