PERFORMANCE OF HONEYCOMB SANDWICH STRUCTURE WITH NATURAL FIBRES FABRIC REINFORCED FACESHEETS

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To my beloved family.
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ABSTRACT

The purpose of this study is to investigate the mechanical behaviour and failure mechanisms of sandwich structures with polypropylene (PP) based honeycomb core and natural fibre reinforced polymer (NFRP) facesheets as a function of facesheets. Flax fibre/epoxy facesheets with PP honeycomb core was fabricated by vacuum bagging hand lay-up technique. The properties of sandwich constitution is investigate by using tensile and flexural test for facesheet and flatwise test for core. Three-point bending (3PB) tests were performed to evaluate the mechanical behaviour of the composite sandwich structures. For the sandwich structures, three point bending test results showed that core shear stress, sandwich beam deflection and panel bending stiffness increased with the facesheet thickness increment. The increment of facesheet thickness show significant increase of bending stiffness but also increase the density of the whole sandwich.
ABSTRAK

# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECLARATION</td>
<td></td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td></td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td></td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td></td>
<td>v</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td></td>
<td>vi</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td></td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td></td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF SYMBOLS</td>
<td></td>
<td>xv</td>
</tr>
<tr>
<td>1 INTRODUCTION</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1.1 Background</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1.2 Problem Statement</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>1.3 Objectives</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>1.4 Research Scopes</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>1.5 Significant of the Research</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>2 LITERATURE REVIEW</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>2.1 Definition of Composites</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>2.2 Definition of Sandwich Structures Composites</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>2.3 Application Areas of Sandwich Structures</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>2.4 Natural Fibre as Composite</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>2.5 Constituents of Composite Sandwich Structures</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>2.5.1 Composite Facesheet Materials</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>2.5.1.1 Facesheet Reinforcement Materials</td>
<td></td>
<td>18</td>
</tr>
</tbody>
</table>
2.5.1.2 Facesheet Matrix Materials \( 20 \)
2.5.2 Core Materials \( 22 \)
  2.5.2.1 Honeycomb Core Configuration \( 23 \)
  2.5.2.2 Honeycomb Core Material \( 27 \)

2.6 Failure of Sandwich Structures \( 28 \)
2.7 Manufacturing Methods of Sandwich Structures \( 34 \)
  2.7.1 Hand Lay-Up \( 34 \)
  2.7.2 Resin Transfer Moulding \( 35 \)
  2.7.3 Vacuum Assisted Resin Transfer Moulding \( 35 \)
  2.7.4 Vacuum Bagging \( 36 \)
  2.7.5 Vacuum Infusion \( 36 \)
  2.7.6 Thermoplastic Adhesion Bonding \( 37 \)
  2.7.7 Prepreg Heated Press \( 38 \)

2.8 Behaviour of Sandwich Structures Composites \( 38 \)

3 METHODOLOGY \( 44 \)
3.1 Research Framework \( 44 \)
3.2 Materials \( 45 \)
  3.2.1 Core material \( 45 \)
  3.2.2 Facesheets Material Fabrication \( 45 \)
    3.2.2.1 Fabrication of Facesheets \( 46 \)
    3.2.2.2 Fabrication of Sandwich Structures \( 49 \)
3.3 Characterization Technique \( 51 \)
  3.3.1 Facesheet Materials \( 51 \)
    3.3.1.1 Tensile Test \( 51 \)
    3.3.1.1 Flexural Test \( 53 \)
  3.3.2 Core Materials \( 54 \)
    3.3.2.1 Flatwise Compression Test \( 54 \)
  3.3.3 Composite Sandwich Structures \( 56 \)
    3.3.3.1 Three Point Bending Test \( 56 \)
3.4 Research Flowchart \( 59 \)
RESULT AND DISCUSSION  

4.1 Properties of Facesheet Material  
4.1.1 Tensile Properties  
4.1.2 Flexural Properties  

4.2 Properties of Honeycomb Core  
4.2.1 Flatwise Compression Properties  

4.3 Properties of Composite Sandwich Structure  
4.3.1 Flexural Properties  
4.3.2 Performance Comparison  

CONCLUSION  

REFERENCES
<table>
<thead>
<tr>
<th>TABLE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Natural fibre properties. Source: Natural fiber'09 Proceedings (University of Bath)</td>
<td>14</td>
</tr>
<tr>
<td>2.1</td>
<td>Natural fibre composition [44].</td>
<td>15</td>
</tr>
<tr>
<td>2.3</td>
<td>Mechanical Properties of Natural Fibres.</td>
<td>19</td>
</tr>
<tr>
<td>4.1</td>
<td>The average values of the mechanical characteristics measured in the flexural test.</td>
<td>61</td>
</tr>
<tr>
<td>4.2</td>
<td>The average values of the mechanical characteristics measured in the flexural test.</td>
<td>64</td>
</tr>
<tr>
<td>4.3</td>
<td>The average values of the PP honeycomb core mechanical characteristics measured in the flatwise test.</td>
<td>66</td>
</tr>
<tr>
<td>4.4</td>
<td>The maximum values of the sandwich structure mechanical characteristics measured in the three point bending test.</td>
<td>71</td>
</tr>
<tr>
<td>4.5</td>
<td>Physical and flexural properties of the flax/epoxy/honeycomb core sandwich panels and three commercial products for automotive interior applications</td>
<td>75</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Common forms of fibre reinforcement [31].</td>
<td>7</td>
</tr>
<tr>
<td>2.2</td>
<td>Main Sandwich Structure with honeycomb core.</td>
<td>9</td>
</tr>
<tr>
<td>2.3</td>
<td>Sandwich panel with (a) corrugated (b) honeycomb and (c) foam core.</td>
<td>10</td>
</tr>
<tr>
<td>2.4</td>
<td>Sandwich structure in comparison with an I-Beam [35].</td>
<td>11</td>
</tr>
<tr>
<td>2.5</td>
<td>The relative stiffness and weight of sandwich panels compared to solid panels [35].</td>
<td>11</td>
</tr>
<tr>
<td>2.6</td>
<td>How a Sandwich Beam Works [35].</td>
<td>12</td>
</tr>
<tr>
<td>2.7</td>
<td>Natural fibre hierarchal structure</td>
<td>16</td>
</tr>
<tr>
<td>2.8</td>
<td>Honeycomb cell terminology [31].</td>
<td>24</td>
</tr>
<tr>
<td>2.9</td>
<td>Honeycomb cell configurations. L, length; T, thickness, W, width.</td>
<td>25</td>
</tr>
<tr>
<td>2.10</td>
<td>Honeycomb orientation: L (length or ribbon), W (width), and T (thickness).</td>
<td>26</td>
</tr>
<tr>
<td>2.11</td>
<td>Typical load deflection curve for honeycomb.</td>
<td>27</td>
</tr>
<tr>
<td>2.12</td>
<td>Core junctions in sandwich beams/panels subjected to (a) axial load, (b) pure bending and (c) transverse load [56].</td>
<td>29</td>
</tr>
<tr>
<td>2.13</td>
<td>Sandwich failure modes [57].</td>
<td>31</td>
</tr>
</tbody>
</table>
Honeycomb failure modes (a) skin compression failure, (b) excessive deflection, (c) panel buckling, (d) shear crimping, (e) skin wrinkling (f) intra cell buckling, and (g) local compression

Schematic of vacuum-bag assembly [61].

Vacuum infusion process principle.

Composition of a polypropylene sandwich structure. In the case of all-PP laminates being used for the sandwich face panels, together with PP based hot melt adhesives [62].

Flatwise compression (a) strength and (b) modulus values of PP-based honeycomb core material as a function of core thickness [45].

Variation of the panel bending stiffness of composite sandwich structures with honeycomb core material and glass fibre/epoxy facesheets under three-point bending loading in accordance with core thickness increment. [45].

Load-Displacement curves under compressive test for (a) polyurethane foam and (b) polypropylene honeycomb [63].

Load-Displacement curves under shear for (a) polyurethane foam and (b) polypropylene honeycomb [63].

Balsa cored specimen (right) and honeycomb cored specimen (left) test results

Balsa cored specimen (top) and honeycomb cored specimen (bottom) testing

Illustration of PP based honeycomb core material.

Flax fabric specification and fibre properties.

Applying release wax.

Vacuum infusion setting.
3.6 Epoxy are pump into the vacuum bagging.

3.7 Cutting using circular diamond saw.

3.8 Setting parameter of work.

3.9 Hand layup arrangement and sequence.

3.10 Covered with perforated release film and breather layer cloth.

3.11 Covered with perforated release film and breather layer cloth.

3.12 Tensile test specimen during the test

3.13 Flexural test specimen under loading and test configuration.

3.14 Compression test PP honeycomb core specimen under loading and test configuration.

3.15 Sandwich flexural test specimen under loading and test configuration.

3.16 Sandwich structure dimensions.

3.17 Research Flowchart.

4.1 Tensile test result: (a) failure modes, and (b) stress-strain graph.

4.2 Tensile stress-strain for determination of the Young’s Modulus.

4.3 Average flexural stress-strain response of flax fibre/epoxy composite facesheets.

4.4 Flexural load-deflection for determination of the Young’s Modulus.

4.5 Average flexural stress-strain response of flax fibre/epoxy composite facesheets.

4.6 Behaviour of PP honeycomb core structure under flatwise loading: (a) collapse during test, and (b) comparison of core before and after test.

4.7 Flatwise compressive behaviour of PP based honeycomb core material.
4.8 Compressive load-displacement for determination of the Young’s Modulus.

4.9 Failure modes for different layers of facesheets (a) face wrinkling (2 layers), (b) face yield (4 layers) and (c) core crush (6 layers).

4.10 Load-displacement curves measured for different thickness of facesheet.

4.11 Facing bending stress-displacement curves measured for different thickness of facesheet.

4.12 Three point bending test load-deflection curves for determination of the Young’s Modulus.

4.13 Core shear stress and sandwich beam deflection tendency with increasing facesheets thickness.

4.14 Panel bending stiffness and panel shear rigidity tendency of the composite sandwich structures with facesheet thickness increase under flexural loading.

4.15 Bending stiffness and density of sandwich beam against core to face thickness ratio.
**LIST OF SYMBOLS**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$</td>
<td>Stress</td>
</tr>
<tr>
<td>P</td>
<td>Force</td>
</tr>
<tr>
<td>A</td>
<td>Cross Section Area</td>
</tr>
<tr>
<td>E</td>
<td>Modulus</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>Strain</td>
</tr>
<tr>
<td>R</td>
<td>Rate of crosshead motion</td>
</tr>
<tr>
<td>Z</td>
<td>Rate of straining of the outer fibre (0.01mm/mm/min)</td>
</tr>
<tr>
<td>L</td>
<td>Support Span</td>
</tr>
<tr>
<td>d</td>
<td>Thickness</td>
</tr>
<tr>
<td>b</td>
<td>Width</td>
</tr>
<tr>
<td>m</td>
<td>slope of the tangent</td>
</tr>
<tr>
<td>$E_b$</td>
<td>flexural modulus</td>
</tr>
<tr>
<td>S</td>
<td>slope of the initial linear portion of load-deflection curve</td>
</tr>
<tr>
<td>c</td>
<td>Core thickness</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Shear stress</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>Total beam midspan deflection</td>
</tr>
<tr>
<td>U</td>
<td>panel bending rigidity</td>
</tr>
<tr>
<td>D</td>
<td>Panel bending stiffness</td>
</tr>
<tr>
<td>G</td>
<td>Core shear modulus</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, composite sandwich structures have attracted considerable interest as advances composite materials that satisfy high performance requirement of machine design, lightweight structure, aerospace, civil, marine and automobile industries [1-2]. These materials have high structural crashworthiness that are capable of absorbing large amounts of energy under impact loads [3].

In general, sandwich structures composed of two high-rigidity thin stiff facesheets (or skin) and a thick lightweight core bonded possessing less strength and stiffness between them. The role of the core is to transmit the shear between the face sheets and the face sheets provide the flexural stiffness. A sandwich structure will offer different mechanical properties with the use of different types of materials because the overall performance of sandwich structures depends on the properties of the constituents [4]. A core with poor mechanical properties will reduce the performance of the panel but a strong core can contribute to the flexural stiffness and to the out of plane shear and compressive strength of the panel [1, 5].

Generally in a sandwich structure, the bending loads are carried by the force couple formed by the facesheets and the shear loads are carried by the lightweight core material [6]. The core material is low in density that primarily is to maintain a high moment of inertia compared to the facesheets that are strong and stiff both in tension and compression. The low density of the core material results in low panel density,
therefore under flexural loading sandwich panels have high specific mechanical properties whereby loads are supported through facesheets known as the monocoque structures. Therefore, sandwich panels are highly efficient in carrying bending loads. Under flexural loading, one laminate is under compression and the other one under tension which forming a force couple as facesheets act together.

On the other hand, the core resists transverse forces and stabilizes the laminates against global buckling and local buckling [7]. Additionally, the core provides increased resistance to buckling and crippling of shear panels and compression members [8]. Sandwich panels are also costs saving other than it’s advantageous as light weight material and structural performance [9]. Especially for sandwich structures for civil applications that’s need large cell size of (typically in the range from 500 mm to 1500 mm) allows the fabrication of cores using fibre reinforced polymers [10]. For example, Ji et al. introduced a glass-fibre reinforced-polymer corrugated-core which is fabricated via the assembly of pultruded and thermoformed shapes [10, 11].

Recent technological developments have expanded the use of composites in industrial, automotive, construction, sports and leisure, and mass production industries which focusing on sustainability and renewable reinforced natural fibres composite [12]. Thus, creating an interest toward substituting glass and carbon fibres by natural fibres [13]. In some research, the use of natural fibres reinforced have been found use in several application, ranging from simple design to complex engineering uses such as building material and automobiles parts [15–17].

The advantageous of natural fibres compared with the synthetic fibres; natural fibres are cheaper, lower mass per unit area, eco-friendly, recyclable and biodegradable by nature, do not produce skin irritation and provide good acoustic insulating properties [17, 18]. On the other hand, natural fibre reinforced composites exhibit inferior mechanical performance and water resistance properties than conventional glass fibre reinforced composites [17–21]. Due to these problems, many research programmes have been undertaken in an attempt to better understand the impact response of these materials [22–24].
Stocchi et al [25] introduced a novel honeycomb core made of a natural fibre reinforced composite that consists of a thermoset-polymer (vinylester) reinforced with jute fabrics. 6 mm and 10 mm cell honeycombs are manufactured using two compression moulding techniques which the best results are obtained for the mould with lateral compression. Experimental tests are conducted to characterize the elastic response of the composite and the core response under flatwise compression. The result of the test show that the core failure mechanisms are yarn pull out and fibre breaking. The large wall thickness relative to the cell size of the jute–vinylester cores, which inhibits buckling, and the heterogeneities in the composite, which are preferential damage initiation sites, explain the observed behaviour. When compared in terms of the specific strengths, the jute/vinylester cores introduced in this work show similar performances to those of their commercially available counterparts. The results from this study suggest that jute-reinforced cores have the potential to be an alternative to standard cores in applications that sustain compressive static loads.

Evaluations are needed for different properties or characteristics of sandwich panels depending on sandwich structure of area application [26]. Thus, it can be concluded that sandwich structure critical properties are depending on area of application. For example, out of plane compressive properties are more critical for automotive industry, whereas in plane compressive properties are more important in wind turbines.

1.2 Problem Statement

Green technologies is a part of the larger process of technological change that comprises invention, innovation and diffusion that reduce the production of waste [27]. Therefore, replacing synthetic fibre for natural fibre are significant due to its lightweight, nonabrasive, non-irritating, combustible, non-toxic, biodegradable properties [28], low energy consumption for production and renewable. It is known that natural fibre reinforced composites exhibit inferior mechanical performance than conventional glass fibre reinforced composites. Hence, this study will determine the mechanical properties of natural fibre as facesheet reinforcing material. The
incompatibility and poor interfacial adhesion of natural fibre reinforced composite with matrix compare to the synthetic fibre (glass, carbon, aramid, etc.) should be investigate in order to replace the synthetic fibre. There are less research regarding the effect of facesheet natural fibre composite on performance sandwich structure, thus making the research an advantage for further development.

1.3 Objective

The objective of this study is to determine the mechanical behaviour and failure mechanisms of sandwich structures with polypropylene (PP) based honeycomb core and natural fibre reinforced polymer (NFRP) facesheets as a function of facesheets thickness. For this purpose, tensile test, flexural test, flatwise test and three point bending tests will be conducted on composite sandwich specimens with various of facesheets thickness. Constituents of the sandwich structures are also tested mechanically.

1.4 Research Scopes

The research project is a study and development of honeycomb sandwich structure with natural fibres fabric reinforced facesheets suitable of mechanical applications. In this research, few sample of honeycomb sandwich structure with NFRP facesheets are fabricated using flax fabrics as the reinforcement phase and epoxy are use as matrix phase. The performance of facesheets are then determine by tensile and flexural test for strength and modulus. The performance of core are then determine by flatwise test for strength and modulus. The performance of sandwiches are then determine by three point bending tests for core shear stress, facesheet bending stress and panel bending stiffness that will be conducted on composite sandwich specimens with 10 mm core thicknesses.
REFERENCES


[42] D. Paukszta and S. Borysiak, “The influence of processing and the polymorphism of lignocellulosic fillers on the structure and properties of


