IMPACT STRENGTH OF WOVEN KENAF FIBRE REINFORCED POLYESTER COMPOSITE PLATES

SITI NOR AZILA BINTI KHALID

UNIVERSITI TUN HUSSEIN ONN MALAYSIA
IMPACT STRENGTH OF WOVEN KENAF FIBRE REINFORCED POLYESTER COMPOSITE PLATES

SITI NOR AZILA BINTI KHALID

A thesis submitted in fulfillment of the requirement for the award of the Doctor of Philosophy

Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

AUGUST 2017
“Special dedication to my beloved family Khalid Mat Ali and Bedah Md Ali, to my supportive siblings, to my fiancée Ayub, to my research team, and to my entire friends, thanks for everything”.
ACKNOWLEDGEMENT

I would like to express my gratitude to all those who gave me the possibility to complete this thesis. Firstly, special thanks to my Supervisor, Associate Professor Dr Al Emran bin Ismail for his consistent encouragement, advice, precious guidance throughout the course of this research and writing this thesis.

I also would like to record my sincere appreciation and gratitude to my Co-Supervisor, Associate Professor Dr Muhd Hafeez bin Zainulabidin, whose help and encouragement throughout the time of this study. In addition, special appreciation the contribution is made to En. Zakaria, En. Adam, En. Nizam, for their cooperation is in handling tools in the UTHM laboratory, and onwards makes this research going smoothly.

Very special thanks to my beloved family for their support, encouragement and payer to Allah S.W.T. Similar appreciation goes to my team member’s work for their advice and sharing their experience together. Finally to others who have contributed either directly or indirectly towards the successful completion of this research. May Allah blessing give and happiness is upon you always. Amin
ABSTRACT

Natural fibre composition is a brilliant option for the most widely applied fibre in the composite innovation such as covers; car doors panel and car roofs. The advantages of natural fibre composites are renewable, low cost, low density and tend to decompose (biodegradability). In the recent years, there have been many researchers involved in the field of natural fibre reinforced plastic. Most of them studied based on composite reinforced with short and non-woven fibres related to issues such as poor fire resistance, variable quality and lower strength properties. This study focused on the composite woven structure from the woven kenaf fibre based on their higher capability to absorb energy. This method using Taguchi for optimization which can reduce the time consumed rather than using experimental approach. Composites were prepared using the hand lay-up method with three different weaving patterns, namely plain, twill, and basket. The hardened composites were cured for 24 hours before it was shaped according to specific dimensions ASTM D3763 and D3039 for impact and tensile tests. The highest energy absorption for plain, twill, and basket were 30.412, 36.026 and 32.509 Joule respectively. The effect of weave patterns and orientations was significant on energy absorption performance. Although, from three woven weaving patterns the twill types showed an improvement on impact strength of energy absorption compared to the plain and basket woven in all orientations among the others composites. After optimization, the value of energy absorption with percentage ratio of plain, twill and basket woven was 27.681 (9.86%), 32.770 (8.26%) and 29.893 (8.75%) Joule respectively. The result was still under acceptable range since it was below 10% deviate value from actual result which was due to material yarn size under control and sensitivity to dynamic loading. Result on tensile test shows the highest mechanical behaviour after using new orientation which is increasing 3.77%. It indicated that, the natural fibre was very sensitive with impact loading.
ABSTRAK

CONTENTS

DECLARATION iii
DEDICATION iv
ACKNOWLEDGEMENT v
ABSTRACT vi
ABSTRAK vii
CONTENTS viii
LIST OF TABLES xii
LIST OF FIGURES xiv
LIST OF SYMBOLS AND ABBREVIATIONS xx
LIST OF APPENDICES xxi

CHAPTER 1 INTRODUCTION 1
1.1 Background of Study 1
1.2 Problem Statement 3
1.3 Objective of Study 4
1.4 Scope of Study 5
1.5 Outline of the Thesis 6
1.6 Summary 6

CHAPTER 2 LITERATURE REVIEW 7
2.1 Introduction 7
2.2 Fundamental of Crashworthiness 7
CHAPTER 3 METHODOLOGY

3.1 Introduction 44
3.2 Woven Fabrications 46
   3.2.1 Plain Weave 48
   3.2.2 Twill Weave 49
   3.2.3 Basket Weave 50
3.3 Composite preparations for impact test 51
3.4 Composite Preparations for Tensile Test 55
3.5 Taguchi Method Parameters and Variables 56
3.6 Testing Method 60
   3.6.1 Tensile Test 60
   3.6.2 Impact Test 63
3.7 Fracture Observation and Analysis 65
3.8 Summary 65

CHAPTER 4 RESULTS AND DISCUSSION 67

4.1 Introduction 67
4.2 Impact Tests 67
   4.2.1 The Effect of Different Angle Orientations on Energy Absorption for Plain Woven 68
   4.2.2 The Effects of Fibre Orientations on Force-Displacement Curves 70
4.2.3  The Effects of Fibre Configurations on Force-Displacement Curves  74
4.2.4  The Effects of Orientations on Energy Absorption  78
4.2.5  The Effects of Orientations on Force Peak  81

4.3  Taguchi Method Results  85
4.3.1  Signal to Noise (S/N) ratios for energy absorption optimization  85

4.4  After optimization  92
4.4.1  Energy Absorption after optimization  92
4.4.2  The Effects of Impactor Velocity on Energy Absorption  96
4.4.3  The Effects of Impactor Speed on Force-Displacement  97

4.5  Tensile Test  100
4.5.1  Mechanical Behaviour of different woven type  100
4.5.2  Stress-Strain Curves of Twill Woven  103
4.5.3  Comparing twill woven with new angle after optimization  105

4.6  Composite Fragmentations  109
4.6.1  Composite Fragmentation on Impact Test using different Orientation  109
4.6.2  Composite Fragmentation on Impact test using different velocity  115
4.6.3  Composite Fragmentation on Tensile Test of twill woven  119
4.6.4  Tensile test after optimization  121

4.7  Summary  122

CHAPTER 5 CONCLUSION AND RECOMMENDATION  124
5.1  Introduction  124
5.2  Conclusion  125
5.3  Recommendation  126
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>REFERENCES</td>
<td>127</td>
</tr>
<tr>
<td>LIST OF PUBLICATIONS</td>
<td>140</td>
</tr>
<tr>
<td>Appendix A</td>
<td>142</td>
</tr>
<tr>
<td>Appendix B</td>
<td>147</td>
</tr>
<tr>
<td>Appendix C</td>
<td>152</td>
</tr>
<tr>
<td>Appendix D</td>
<td>157</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Comparison between natural and glass fibres (William et al. 2000)</td>
<td>15</td>
</tr>
<tr>
<td>2.2</td>
<td>Natural fibre properties (Rome, 2009)</td>
<td>16</td>
</tr>
<tr>
<td>2.3</td>
<td>Natural fibre composition (William et al. 2000)</td>
<td>17</td>
</tr>
<tr>
<td>2.4</td>
<td>Properties of kenaf fibre and polyester resin (Rassmann et al., 2000)</td>
<td>20</td>
</tr>
<tr>
<td>2.5</td>
<td>Tensile strength of kenaf bast fibre under different alkali treatment (Hashim et al., 2014)</td>
<td>25</td>
</tr>
<tr>
<td>2.6</td>
<td>Experimental setup for sample orientation (Alam et al., 2010)</td>
<td>27</td>
</tr>
<tr>
<td>2.7</td>
<td>Design with degraded column L934 (Roy, 1990)</td>
<td>39</td>
</tr>
<tr>
<td>3.1</td>
<td>The arrangement of angle [-15°/40°/75°] using Taguchi method</td>
<td>58</td>
</tr>
<tr>
<td>3.2</td>
<td>The arrangement of angle [0°/45°/90°] using Taguchi method</td>
<td>58</td>
</tr>
<tr>
<td>3.3</td>
<td>Taguchi method rules</td>
<td>58</td>
</tr>
<tr>
<td>3.4</td>
<td>Trial angle of experimental using Taguchi method [-15°/40°/75°]</td>
<td>59</td>
</tr>
<tr>
<td>3.5</td>
<td>Trial angle of experimental using Taguchi method [0°/45°/90°]</td>
<td>59</td>
</tr>
<tr>
<td>4.1</td>
<td>Taguchi method expresses the experimental results energy absorption for plain1 woven</td>
<td>86</td>
</tr>
<tr>
<td>4.2</td>
<td>Response (S/N) for plain1 woven</td>
<td>86</td>
</tr>
</tbody>
</table>
4.3 Taguchi method expresses the experimental results energy absorption for plain woven 88
4.4 Response (S/N) for plain woven 88
4.5 Taguchi method expresses the experimental results energy absorption for twill woven 89
4.6 Response for Signal to Noise Ratios (S/N) for twill woven 90
4.7 Taguchi method expresses the experimental results energy absorption for basket woven 91
4.8 Response for Signal to Noise Ratios (S/N) for basket woven 91
4.9 Percentage of error before and after optimization 96
4.10 Comparison mechanical properties of kenaf composites from this research with previous research 108
<table>
<thead>
<tr>
<th>Figure</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Road safety and traffic data index 2000=100 (Road safety annual report, 2015)</td>
<td>8</td>
</tr>
<tr>
<td>2.2</td>
<td>Damage stage during impact (Dhakal et al., 2007)</td>
<td>9</td>
</tr>
<tr>
<td>2.3</td>
<td>Formation of composite material using fibres and resin (Mazumdar, 2002 and Safri et al., 2014)</td>
<td>10</td>
</tr>
<tr>
<td>2.4</td>
<td>Scheme of manufacturing of composite materials (Das et al., 2012)</td>
<td>11</td>
</tr>
<tr>
<td>2.5</td>
<td>Examples of use of Natural Fibres in several applications</td>
<td>14</td>
</tr>
<tr>
<td>2.6</td>
<td>Classification of natural fibres (Akil et al., 2011)</td>
<td>14</td>
</tr>
<tr>
<td>2.7</td>
<td>Natural fibre hierarchal structure (Bos et al., 2006)</td>
<td>18</td>
</tr>
<tr>
<td>2.8</td>
<td>Comparison of specific modulus of kenaf fibre with several other fibres (Akil et al., 2011 and Zampaloni et al., 2007)</td>
<td>20</td>
</tr>
<tr>
<td>2.9</td>
<td>Typical image of (a) kenaf plantation (b) kenaf fibre (Saba et al., 2015)</td>
<td>21</td>
</tr>
<tr>
<td>2.10</td>
<td>The result of kenaf treatment under impact test (Suhairil et al., 2012)</td>
<td>23</td>
</tr>
<tr>
<td>2.11</td>
<td>Tensile modulus comparison among virgin and treated composites (Liao et al., 2016)</td>
<td>24</td>
</tr>
<tr>
<td>2.12</td>
<td>Impact strength of untreated, treated, and stretch-treated composite (Saiman, 2014)</td>
<td>24</td>
</tr>
</tbody>
</table>
2.13 Energy absorption against fibre composition (Hashim, 2016) 26
2.14 The energy absorption of five layers of non-woven hemp fibre 27
2.15 Mechanical properties between different orientations of the GRP composite (a) hardness (b) impact strength (c) tensile strength (Alam et al., 2010) 28
2.16 Load displacement curves of axially crushed composite tube with fibre orientation (a) 0°/90° (b) -15°/75° (c) -75°/15° (d) 30°/-60° (e) 60°/-30° (f) 45°/-45° (Mahdi et al., 2014) 29
2.17 Fabric formation by interlacing two yarn sets on a loom 31
2.18 Example of typical weave pattern (a) plain (b) twill (c) basket 32
2.19 Specific flexural strength and specific young’s modulus of woven fibre jute and flax (Bledzki et al., 2001) 33
2.20 Several types of plain woven natural fibre (a) jute woven and (b) flax woven (Meredith, et al., 2012) 34
2.21 Image of (a) unidirectional jute (b) plain woven jute fabric (c) nonwoven jute fabric composite and (d) plain woven jute fabric composite (Arifuzzaman et al., 2013) 35
2.22 Pictorial depiction and additional steps using Taguchi method 38
2.23 Plot of S/N ratio as a function of input parameters for (a) tensile and (b) flexural (Rostamiyan, 2015) 40
2.24 S/N response for parameters; processing temperature (A), processing speed (B),
processing time (C), and fiber size (D) (Shekeil et al., 2013)

3.1 Flow chart for the experimental works 41

3.2 Simplified drawing of a two-harness shuttle loom (Kadolph, 2007) 47

3.3 Fabrication of woven kenaf (a) yarn kenaf and (b) yarn setup 47

3.4 Kenaf plain woven 48

3.5 Kenaf twill woven 49

3.6 Kenaf basket woven 50

3.7 Preparation of composite (a) fabrics cutting and (b) silicone spray 51

3.8 Illustration of four layers kenaf composite 52

3.9 Schematic diagram (a) ply angle and (b) stacking angle for composite [45°/0°/45°/90°] 53

3.10 Composite fabrication (a) woven arrangement in the mould and (b) poured with polyester 54

3.11 Hydraulic press machine 54

3.12 Final process of composite (a) sample after compression (b) cutting process and (c) final sample 55

3.13 Composite fabrications (a) angle of orientation (b) fabric in mould and (c) final sample 56

3.14 Typical tensile specimen 60

3.15 Schematic diagram of hydraulic universal testing machine (ASM international, 2004) 61

3.16 Universal Testing Machine in UTHM laboratory 62

3.17 The instrumented drop tower arrangement on the impact machine (Dhakal et al., 2007) 64

3.18 SHIMADZU Hydroshot Impact Test Machine in UTHM laboratory 64

4.1 The identification of total energy absorbed 68

4.2 Energy absorption for plain1 and plain2 woven 69
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.3</td>
<td>Force-Displacement of Plain1 woven</td>
</tr>
<tr>
<td>4.4</td>
<td>Force-Displacement of Plain2 woven</td>
</tr>
<tr>
<td>4.5</td>
<td>Force-Displacement of Twill woven</td>
</tr>
<tr>
<td>4.6</td>
<td>Force-Displacement of Basket woven</td>
</tr>
<tr>
<td>4.7</td>
<td>Force-Displacement curves for S1 type orientation</td>
</tr>
<tr>
<td>4.8</td>
<td>Force-Displacement curves for S2 type orientation</td>
</tr>
<tr>
<td>4.9</td>
<td>Force-Displacement curves for S7 type orientation</td>
</tr>
<tr>
<td>4.10</td>
<td>Force-Displacement curves for S8 type orientation</td>
</tr>
<tr>
<td>4.11</td>
<td>Energy absorption with different type of woven</td>
</tr>
<tr>
<td>4.12</td>
<td>Energy absorption for plain1 woven</td>
</tr>
<tr>
<td>4.13</td>
<td>Energy absorption for plain2 woven</td>
</tr>
<tr>
<td>4.14</td>
<td>Energy absorption for twill woven</td>
</tr>
<tr>
<td>4.15</td>
<td>Energy absorption for basket woven</td>
</tr>
<tr>
<td>4.16</td>
<td>Force peak for plain1 woven</td>
</tr>
<tr>
<td>4.17</td>
<td>Force peak for plain2 woven</td>
</tr>
<tr>
<td>4.18</td>
<td>Force peak for twill woven</td>
</tr>
<tr>
<td>4.19</td>
<td>Force peak for basket woven</td>
</tr>
<tr>
<td>4.20</td>
<td>The main effects plot (data means) of S/N ratios for plain1 woven</td>
</tr>
<tr>
<td>4.21</td>
<td>Main effects plot (data means) of S/N ratios for plain2 woven</td>
</tr>
<tr>
<td>4.22</td>
<td>Main effects plot (data means) of S/N ratios for twill woven</td>
</tr>
<tr>
<td>4.23</td>
<td>Main effects plot (data means) of S/N ratios for basket woven</td>
</tr>
<tr>
<td>4.24</td>
<td>Energy absorption of plain1 woven after optimization</td>
</tr>
<tr>
<td>4.25</td>
<td>Energy absorption of plain2 woven after optimization</td>
</tr>
</tbody>
</table>
4.26 Energy absorption of twill woven after optimization 95
4.27 Energy absorption of basket woven after optimization 95
4.28 Energy absorption of woven with different velocity 96
4.29 Force-Displacement for plain1 woven with different speed 98
4.30 Force-Displacement for plain2 woven with different speed 99
4.31 Force-Displacement for Twill Woven with different speed 99
4.32 Force-Displacement for Basket woven with different speed 100
4.33 Young’s Modulus for different type of woven 102
4.34 Tensile Strength for different type of woven 103
4.35 Stress strain curves of twill woven 104
4.36 Schematic of tensile progress 105
4.37 Young’s Modulus for twill woven 106
4.38 Tensile strength for twill woven 107
4.39 Effect on energy absorption on fragmentation length 110
4.40 Fragmentation of plain1 woven 111
4.41 Fragmentation of plain2 woven 112
4.42 Fragmentation of twill woven 113
4.43 Fragmentation of basket woven 114
4.44 Fragmentation different velocity on plain1 woven 116
4.45 Fragmentation different velocity on plain2 woven 116
4.46 Fragmentation different velocity on twill woven 117
4.47 Fragmentation different velocity on basket woven 117
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.48</td>
<td>Fragmentation length with different velocity</td>
<td>118</td>
</tr>
<tr>
<td>4.49</td>
<td>Tensile test fragmentations for twill woven</td>
<td>120</td>
</tr>
<tr>
<td>4.50</td>
<td>Tensile test after optimization</td>
<td>122</td>
</tr>
</tbody>
</table>
LIST OF SYMBOLS AND ABBREVIATIONS

$A_o$ - Original cross section area
$D, d$ - Diameter (mm)
$E$ - Young’s modulus
$E_m$ - Energy at maximum load point
$J$ - Joule
$L$ - Length (mm)
$P$ - Maximum load (kN)
$S/N$ - Signal to noise
$V$ - Volume ($mm^3$)
$V_f$ - Fibre volume
$W$ - Weight
$W_f$ - Weight of the fibre
$\rho_m$ - Density of the matrix
$\varepsilon$ - Strain
$\pi$ - Pai
$\sigma$ - Stress
$\%$ - Pecentage
$^\circ$ - Degree
$\Delta l$ - Elongation of the gage length

ASTM - American Society for Testing and Materials
NaOH - Natrium Hydroxide
NF - Natural Fibre
NKTB - National Kenaf and Tobacco Board
RMP - Royal Malaysian Police
## LIST OF APPENDICES

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Plain1 Woven Impact Test Result</td>
<td>142</td>
</tr>
<tr>
<td>B</td>
<td>Plain2 Woven Impact Test Result</td>
<td>148</td>
</tr>
<tr>
<td>C</td>
<td>Twill Woven Impact Test Result</td>
<td>153</td>
</tr>
<tr>
<td>D</td>
<td>Basket Woven Impact Test Result</td>
<td>158</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Background of Study

In the recent years, industries actively attempt to reduce the dependence on petroleum based fuels and products due to the increasing environmental consciousness. This leads to the need to investigate environmentally friendly and sustainable materials to replace the existing ones. The increases of production and usage of plastics in every sector of our daily life lead to massive plastic wastes. Disposal problems, as well as strong regulations and criteria for a cleaner and safer environment, have influenced such a great part of the scientific research towards eco-composite materials. Among the different types of eco-composites, those which contain natural fibres (NF) and natural polymers are the ones more preferred to be used.

There are few studies which deals with structural composites based on natural reinforcements. These studies are mainly oriented towards housing applications where structural panels and sandwich beams were manufactured out of natural fibres and used as roofs (Akil et al., 2011). Considering the high performance standard of composite materials in terms of durability, maintenance and cost effectiveness, the application of kenaf natural fibre reinforced composites as construction material holds enormous potential and is critical to achieve sustainability. Due to their low density and their cellular structure, natural fibres possess very good acoustic and thermal insulation properties and demonstrate many advantageous properties compared to fiberglass.

One of the main important aspects of the behaviour of natural plant fibre reinforced polymeric composites is their response to an impact load and the capacity
of the composites to withstand their service life. Such damage may be caused by bumps or crashes, falling objects and debris. Some of the reported work (Bledzki et al., 2002) has suggested that natural fibre composites are very sensitive to impact loading. The major drawback is its low impact strength as compared to glass fibre reinforced thermoplastic and thermosets composites. In a broader context, assessing the impact resistance of a composite material is always hard since the damage manifests itself in different forms such as delamination at the interface, fibre breakage, matrix cracking and fibre pulls out.

Natural plant fibres can be economically and ecologically useful alternative to reinforcement fibres in polymeric composites. Due to their low density and low cost in comparison to conventional fibres, kenaf fibre reinforced composites have great potential to be use in engineering applications. A growing environmental awareness across the world has aroused interest in research and development of environmentally friendly and sustainable materials. Natural plant based fibre were used as reinforcements for composite materials and give various advantages compared to conventional fibres.

Malaysian considered kenaf as the next generation of major industrial crop in line with economic policy and development to create new sources and at the same time heavily promotes its production growth, to make it abundant, inexpensive and readily available. Understanding the importance of kenaf as a potential for profit bio resource, the Malaysian National Kenaf and Tobacco Board (NKTB) announced nationwide cultivation process, which involve wide area and as many farmers in eight states in Malaysia in the year 2013 (Saba, 2015). Based on their growth rate, kenaf are now involved in several provinces of Malaysia such as Pahang, Kelantan, Terengganu, Perak, Johore, Selangor, Negeri Sembilan and Malacca.

From the research reviews, these studies highlight to explore properties of industrial kenaf to project it as a prospective energy absorbing in the Malaysia which could be alternative sources of future energy demands in a growing population. To the best of knowledge (Zampaloni et al., 2007 and Kumar et al., 2014), till now, there are lack significant work has been done in this area by using Taguchi method to optimize higher energy absorption from kenaf reinforcement. In the prospective of the ever increasing demand of the automotive sources, and mechanical strength of kenaf natural fibre (Akil et al., 2011), so kenaf fibre are selected in this research.
Furthermore, in this study, impact tests were carried out on woven kenaf reinforced unsaturated polyester composite. A low velocity instrumented falling weight impact test method was employed to determine load–deformation, load–time, absorbed energy–time and velocity–time behaviour for evaluating the impact performance in terms of load bearing capabilities, energy absorption and failure modes. The post-impact damage and failure mechanism of fractured specimens was assessed by high camera resolution. The impact response of woven kenaf reinforced polyester composites was also analysed using Taguchi method and their impact response characteristics were discussed. Taguchi method to be used in this studied to reduce the experimental work.

### 1.2 Problem Statement

Vehicle crashworthiness has been improving in recent years with attention mainly directed towards reducing the impact of the crash on the passenger. Efforts has been made in experimental research in establishing safe theoretical design criteria for the mechanic of crumpling, providing the engineers with the ability to design vehicle structures so that the maximum amount of energy should dissipate while the material surrounding the passenger compartment is deformed, thus protecting the people inside. The attention given to crashworthiness and energy absorbing has been focused on composite structures.

In the recent years, there have been many researchers (Wambua et al., 2003, Aziz et al., 2005, Shalwan & Yousif, 2013 and Rao & Roa, 2007) who involved in the field of natural fibre reinforced plastics. On the other hand, the increased interest in using natural fibres as reinforcement plastic to substitute conventional synthetic fibre in some structural applications has become one of the main concerns to study the potential of using natural fibre. Most of them are based study on the mechanical properties of composites reinforced with short and non-woven fibres. Several research has been conducted on woven natural fibre composites (Saiman, 2014, Bledzki et al., 2001, Meredith et al., 2012 and Arifuzzaman et al., 2013), normally on hemp and jute, but only a small portion has been exploited for woven kenaf. This would affect the mechanical properties of the composites.
Normally, mechanical properties of kenaf mixed other ingredients, such as fibreglass (Ghani et al., 2012 and Davoodi et al., 2010) were studied. Hybridization with glass fibre provides a method to improve the mechanical properties on natural fibre composites (Yuhazri & Dan, 2008, Jayabal et al., 2011, Salleh et al., 2012 and Sharba et al., 2016). Even though many researchers mentioned that hybrid composite can improve strength, in this study, kenaf was developed personally to find that it can be reach or replace the composites that already have in order to reduce cost instead of glass fibre is an expensive material. However, there are several issues such as their poor fire resistance, variable quality, depending on unpredictable influences such as weather and lower strength properties. In the light and due to the versatility and enormous potential, it is currently being explored by this research by some aspect such as woven and orientation performance. Development of new techniques has always been the most important part in any research activities for improvements in costs and less environmental impacts.

Furthermore, less of work reported in the literature on the Taguchi orthogonal arrays of orientation woven kenaf fibre reinforced composite. In this research various woven types and orientations are applied to study the effects on mechanical properties of natural based composite. Kenaf woven composite with several orientations were exploited to find new composite with higher capability of energy absorption and furthermore can replace the conventional material that were used before. As well known, bonding strength depended on physical absorption, bonding between fibre layer orientation and the matrix resin. This study focused on evaluating the composite from natural fibre woven kenaf with several of orientations. The optimum orientation of composite was obtained to produce non-structural parts for the automotive industry applications such as covers, car doors panels and car roofs.

1.3 Objective of Study

In this study, woven kenaf fibre reinforced composites were developed. Then the composites were impacted to measure the behaviour and failure mechanisms. Therefore, several research objectives were proposed as follows:
1. To evaluate the energy absorption of kenaf woven composites with different fibre orientations.
2. To determine the impact strength of different type of weaving pattern plain, twill and basket.
3. To optimize impact energy absorption by Taguchi method.
4. To correlate the relationship between impact speed and energy absorption on kenaf woven composites.

1.4 Scope of Study

Kenaf fibre was used in this study. It was in the form of yarn 1mm in diameter. There were some types of woven that were used namely plain, twill and basket. Kenaf yarn were weaved into woven with degree of warp 0º and weft 90º for plain and basket, meanwhile 45º for twill woven. The weaving process used handloom machine. Four layers of woven kenaf were studied and orientated using different angles by Taguchi Method before it was positioned into steel mould. Polymeric resin that was used polyester. The resins were poured into the mould and it was then compressed to squeeze out the excessive resin. The hardened composite was shaped into 100 x 100 x 3 mm and 250 x 25 x 3 mm according to ASTM D3763 and D3039 standards for impact and tensile tests.

The composite plates were testing using different fibre orientations in order to study the composite input resistance. Taguchi method was performed to optimize the fibre orientation with respect to experimental results. After experimental results were obtained, energy absorption of composite was analysed. Finally, the new samples were fabricated as suggested by Minitab software to approximately predict the value of energy absorption of woven kenaf composite. The impact test was carried out with three different velocities which are 1, 2 and 10 m/s. The velocities was varied and applied, in order to observe the correlation between speed and mechanical behaviour of composites. The fragmentation of composites of the composites after impact and tensile loading were observed to examine the relationship between the damaged shape and the impact behaviour.
1.5 Outline of the Thesis

This section has been constructed to give details in order to address the objectives. Five chapters including introduction were composed to present the series of the thesis layout. The following of each chapter are:

- Chapter 1: Introduction. This chapter contains overviews of the research work background, problem statement, objective to archive, scope and aim of study.
- Chapter 2: Literature Review. This chapter consists of some crashworthiness, composite and natural fibre background, as well as relevant experimental studies on the response and impact. This followed by reviews on the related research topics from previous researches.
- Chapter 3: Research Methodology. The details of the experimental work were explained in this chapter. The samples preparation, fabrication method and equipment used in the research activities were described.
- Chapter 4: Result and Discussion. These chapters discuss the result obtained from the methodology flow. Data were analysed and compared with previous research.
- Chapter 5: Conclusion and Future Work. The conclusion of the present work. The conclusions from experimental and investigations are presented. The future works as recommendations are also stated in this chapter.

1.6 Summary

This chapter consisting of general introduction that traditionally organized to explain the background of study, problem statement, objective and scope of study. The aim of this study focused on the process that can demonstrate the energy absorption on impact loading in natural fibre composite namely, kenaf fibre composites based on experimental work using Taguchi orthogonal array method.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presented the literature reviews of past and current works on impact engineering on composite natural fibre under low velocity impact. Natural fibres have gained attention in composite making since they are sustainable, renewable, and environmental friendly. However, there are some drawbacks characteristics such as low tensile strength, low modulus and low flexural strength compared to industrial synthetic fibres. Various techniques had been used included optimization process to improve the mechanical properties of the reinforced composite. From the literature survey, kenaf was one of the selected natural fibres that had been heavily discussed. Good number of journal papers has studied on cultivation of kenaf and its consequent effect, chemical treatment, matrix combinations with glass fibre, processing techniques such as Taguchi method, environmental effects on composites and critical length. Furthermore, it has high potential as industrial fibre due its natural property and driven by the development of kenaf cultivation in Malaysia.

2.2 Fundamental of Crashworthiness

Crashworthiness refers to the quality of response for a certain type of vehicle when it experienced an impact. The less damages the vehicle or its occupants and content after an impact, the higher crashworthiness of the vehicle or the better its crashworthy performance (Johnson, 1990). The physics of impact involves of energy and momentum when a moving object strikes a structure. The kinetic energy of the
impact loading body were be partially converted to strain energy and partly dissipated through friction and local plastic deformation. Thus strain energy radiated away as stress waves (Christopher, 2012). The research and development of energy absorption structure and materials, where kinetic energy during impact or intense dynamic loading dissipated, has received attention since the 1970s especially from the automobile and military industries (Guoxing & Tongi, 2003).

In Malaysia, a lot of concern was directed towards road accident statistic, which rises alarmingly high throughout the years. The Royal Malaysian Police (RMP) is the agency responsible for collecting crash data. Figure 2.1 statistically shows a road safety and traffic index from years 2000 until 2014. Based on provisional data by the RMP, there were 6674 road deaths in 2014. From the data, the injury crashes were increase from years 2000 until 2014. The form covers information on vehicles involved, environment, injury and background of the crash as well as information on the victim. An impact analysis of Malaysia’s safety interventions shows that the road safety programme which started in 1998 was able to significant reduce traffic deaths. This closely related with crashworthiness as well as impact crush, where the vehicles and passengers experienced an impact. In general, the selection of material and composite arrangement is very important for the safety of passenger if any accident occurred.

Figure 2.1: Road safety and traffic data index 2000 = 100
(Road safety annual report, 2015)
There are several researches on impact damage that has been conducted related with crashworthiness (Kamaruddin, 2015, Liu et al, 2011 and Qiau et al., 2006). It is necessary to study the impact damage to examine the affect towards consumer. Figure 2.2 shows the damage stages during impact of a specimen. Correlation between the influence of load level and level of damage was plotted. At stage 1, there is no damage occurred. Matrix cracking occurs at stage 2 as the load increases. As the load further increases, the size and extent of the matrix cracking developed; interfacial debonding occurred at stage 3. This, in turn, leads to delamination, then fibre breakage, and finally perforation of the impacted specimen at stage 4.

The impact performance of target specimens can be characterised by calculating the loss of kinetic energy of the impact mass during impact. By measuring striking velocity and residual velocity, energy absorption by the impacted specimens can be analysed using the following formula:

\[
E = \frac{1}{2} m \left( v_i^2 - v_r^2 \right)
\] (2.1)
where; $E$ is energy dissipated by the target during impact, $m$ the mass of the impactor, $v_r$ is the residual velocity after rebound or perforation and $v_i$ can also be considered as initial and final velocity, respectively.

### 2.3 Composite

A composite consists of an integral combination of two or more material, which were put together in a particular way in order to obtain specific properties superior to those of their constituents. Simple composite materials consist of a reinforcement phase embedded in a continuous matrix (Summerscales et al., 2010). Normally, composite material was formed by reinforcing fibres in a matrix resin as shown in Figure 2.3 (Mazumdar, 2002 and Safri et al., 2014). The reinforcement or filler material enhances and strengthens the properties of matrix while the matrix transfers the applied stresses to the reinforcement. The wide variety of matrix and reinforcing materials allows the designer to choose the optimum combination which produced specified properties for a given application. Figure 2.4 shows the schematic diagram of composite materials manufacturing (Das et al., 2012).

![Figure 2.3: Formation of composite material using fibres and resin (Mazumdar, 2002 and Safri et al., 2014)](image-url)
Most of the mechanical devices and elements, which were made of metals, polymers and composite materials, were designed to absorb impact under axial crushing, bending and/or combined loading. The energy absorbing capability differs from one component to the next in a manner which depends on the mode of deformation involved and the material used (Mamalis et al., 1997).

Researchers (Akil et al., 2011, Grasso et al., 2015, Qiao et al., 2008 and Mohamad, 2016) has studied about the impact and compression test using different target material which include polymer, concrete, alu minium, natural fibre and also laminate composite. Most of the studies proposed composite as the target material, such as Glass Fibre Reinforced Polyester (GFRP) (Catalin et al., 2015, Kotik & Iptina, 2016 and Ramesh et al., 2013), Carbon Fibre Reinforced Polymer (CFRP) (Li et al., 2016) and Fibre Reinforcement Polymer (FRP) (El-Gamal et al., 2016 and Ghasemnejad et al., 2012).

Composite materials have relative advantages in terms of specific energy absorption, weight and strength (Yuhazri et al., 2015). Research by Reddy (1999) mentioned that composite materials were commonly formed by three different types; fibrous composite which consist of fibres from one material in a matrix material of another. Second are particulate composites, which are composed of macro size particles from one material in a matrix of another. Third, laminated composites, which are made of layers of different material, or different angle for each laminated.
However, there are several specific strength and stiffness which need to be achieved. Moreover, with composites, the designer can verifies the type of fibre, matrix, and fibre orientation to produce composites with improved material properties.

Hence, in this research laminate composite has been chosen as the target material for the test. Combinations of natural fibre with polymer resin were mixed to increase the mechanical properties using Taguchi method. On the other hand, the results of mechanical properties of strength and energy absorption measured were compared with another composite previously studied.

## 2.4 Natural Fibre

Natural fibres have the potential to replace glass fibre in fibre-reinforced composite applications (Joshia et al., 2014 and Igor et al., 2009). Nowadays, natural fibre composites were not exploited only in structural and semi-structural applications of the automotive sector, but also in other fields too. According to their origin as shown in Figure 2.5, natural fibres were classified according to their sources, which are animals, vegetables or minerals (Akil et al., 2011). There were many types of natural fibre being investigated, but commonly used fibres were vegetable source fibres, which was due to their wide availability and renewability in short amount of time with respect to other sources. Commonly used fibres were flax, hemp, jute, wood, rice hust, bamboo, grass, kenaf, ramie, sisal, kapok, banana and pineapple leaf fibre. These fibres were usually used as the reinforcement in the development of natural fibre based composites.

Fully biodegradable, less harmful to the environment, abundant availability, comfy, renewable, cheap and has low density are the advantages of natural fibres compared to other establish materials (Zampaloni et al., 2007, Ku et al., 2011 and Dhakal et al., 2007). These natural fibres composite have higher specific strength than glass fibre, but with similar specific modulus (Bledzki & Gassan, 1999). Furthermore, properties such as lightweight, reasonable strength and stiffness qualify natural fibres as the material of choice in replacing synthetic fibre (Ayre et al., 2009). However, the disadvantages of natural fibre are its low tensile strength as compared to traditional fibres such as fibre glass and carbon fibres. It also has a low decomposition temperature and low tendency to absorb moisture (Mallick, 2010).
The shortcoming has been highly exploited by proponents of natural fibre composites. The replacement of synthetic fibre with fibre composite is beginning to widespread due to their advantages compared to glass fibre such as renewability, low density, and high specific strength as indicated in Table 2.1.

In the past, natural fibres were not taken into account as reinforcements for polymeric materials because of some problems associated with their use which is low thermal stability. In other terms, this resulted in the possibility of degradation at moderate temperature (230-250 °C). Furthermore, hydrophilic nature of fibre surface, due to the presence of pendant hydroxyl and polar groups in various constituents, leads to poor adhesion between fibres and hydrophobic matrix polymers (John & Anandjiwala, 2008 and Kalia et al., 2009). The hydrophilic nature can lead to swelling and maceration of the fibres. In addition, moisture content in fibre’s mechanical properties decrease significantly depending on the quality of the harvest, age and body of the plant from which they are extracted, as well as the extraction techniques and the environmental conditions on the site.

Figure 2.5: Example of use of Natural Fibres in several applications (Akil et al., 2011)
Natural fibres can be classified according to their origin and grouped into leaf fibres (abaca, cantala, curaua, date palm, henequen, pineapple, sisal, banana, seed cotton, bast flax, hemp, jute, ramie, fruit coir, kapok and oil palm. Among them, flax, bamboo, sisal, hemp, ramie, jute and wood fibres are of particular interest because of their physical and mechanical properties (Kalia et al., 2009). Comparison between natural fibre and glass fibres were summarized in Table 2.1. The replacement of synthetic fibre with fibre composites has begun to widespread due to their renewability, low density and high specific strength properties as compared to glass fibre. Physical and mechanical properties depend on the single fibre chemical composition (cellulose, hemicelluloses, lignin, pectin, waxes, water content and other minors), grooving conditions (soil features, climate, aging conditions) and extraction/processing method conditions. Grooving conditions was recognized as the most influent parameter for the variability of mechanical properties of fibres. Composition of several natural fibres was summarized in Tables 2.2 and 2.3.
Table 2.1: Comparison between natural and glass fibres (William et al., 2000)

<table>
<thead>
<tr>
<th></th>
<th>Natural Fibres</th>
<th>Glass Fibres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>Low</td>
<td>Twice that of natural fibres</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>Low, but higher than NF</td>
</tr>
<tr>
<td>Renewability</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Recyclability</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Distribution</td>
<td>Wide</td>
<td>Wide</td>
</tr>
<tr>
<td>CO₂</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Abrasion to machines</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Health risk when inhaled</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Disposal</td>
<td>Biodegradable</td>
<td>Not biodegradable</td>
</tr>
</tbody>
</table>
Table 2.2: Natural fibre properties (Rome, 2009)

<table>
<thead>
<tr>
<th>Plant fibre</th>
<th>Tensile strength (MPa)</th>
<th>Young’s modulus (GPa)</th>
<th>Specific modulus (GPa)</th>
<th>Failure strain (%)</th>
<th>Length of ultimates, l (mm)</th>
<th>Diameter of ultimates, l (mm)</th>
<th>Aspect ratio, l/d</th>
<th>Microfib angle, θ (°)</th>
<th>Density (kg.m$^{-3}$)</th>
<th>Moisture content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>300-700</td>
<td>6-10</td>
<td>4-6.5</td>
<td>6-8</td>
<td>20-64</td>
<td>11.5-17</td>
<td>2752</td>
<td>20-30</td>
<td>1550</td>
<td>8.5</td>
</tr>
<tr>
<td>Kapok</td>
<td>93.3</td>
<td>4</td>
<td>12.9</td>
<td>1.2</td>
<td>8-32</td>
<td>15-35</td>
<td>724</td>
<td>-</td>
<td>311-384</td>
<td>10.9</td>
</tr>
<tr>
<td>Bamboo</td>
<td>575</td>
<td>27</td>
<td>18</td>
<td>-</td>
<td>2.7</td>
<td>10-40</td>
<td>9259</td>
<td>-</td>
<td>1500</td>
<td>-</td>
</tr>
<tr>
<td>Flax</td>
<td>500-900</td>
<td>50-70</td>
<td>34-48</td>
<td>1.3-3.3</td>
<td>27-36</td>
<td>17.8-21.6</td>
<td>1258</td>
<td>5</td>
<td>1400-1500</td>
<td>12</td>
</tr>
<tr>
<td>Hemp</td>
<td>310-750</td>
<td>30-60</td>
<td>20-41</td>
<td>2-4</td>
<td>8.3-14</td>
<td>17-23</td>
<td>549</td>
<td>6.2</td>
<td>1400-1500</td>
<td>12</td>
</tr>
<tr>
<td>Jute</td>
<td>200-450</td>
<td>20-55</td>
<td>14-39</td>
<td>2-3</td>
<td>1.9-3.2</td>
<td>15.9-20.7</td>
<td>157</td>
<td>8.1</td>
<td>1300-1500</td>
<td>12</td>
</tr>
<tr>
<td>Kenaf</td>
<td>295-1191</td>
<td>22-60</td>
<td>-</td>
<td>-</td>
<td>2-61</td>
<td>17.7-21.9</td>
<td>119</td>
<td>-</td>
<td>1220-1400</td>
<td>17</td>
</tr>
<tr>
<td>Ramie</td>
<td>915</td>
<td>23</td>
<td>15</td>
<td>3.7</td>
<td>60-250</td>
<td>28.1-35</td>
<td>4639</td>
<td>-</td>
<td>1550</td>
<td>8.5</td>
</tr>
<tr>
<td>Abaca</td>
<td>12</td>
<td>41</td>
<td>-</td>
<td>3.4</td>
<td>4.6-5.2</td>
<td>17-21.4</td>
<td>257</td>
<td>-</td>
<td>1500</td>
<td>14</td>
</tr>
<tr>
<td>Banana</td>
<td>529-914</td>
<td>27-32</td>
<td>20-24</td>
<td>1-3</td>
<td>2-3.8</td>
<td>-</td>
<td>-</td>
<td>11-12</td>
<td>1300-1350</td>
<td>-</td>
</tr>
<tr>
<td>Pineapple</td>
<td>413-1627</td>
<td>60-82</td>
<td>42-57</td>
<td>0-1.6</td>
<td>-</td>
<td>20-80</td>
<td>-</td>
<td>6-14</td>
<td>1440-1560</td>
<td>-</td>
</tr>
<tr>
<td>Sisal</td>
<td>80-840</td>
<td>9-22</td>
<td>6-15</td>
<td>2-14</td>
<td>1.8-3.1</td>
<td>18.3-23.7</td>
<td>115</td>
<td>10-22</td>
<td>1300-1500</td>
<td>11</td>
</tr>
<tr>
<td>Coir</td>
<td>106-175</td>
<td>6</td>
<td>5.2</td>
<td>15-40</td>
<td>0.9-1.2</td>
<td>16.2-19.5</td>
<td>64</td>
<td>39-49</td>
<td>1150-1250</td>
<td>13</td>
</tr>
</tbody>
</table>
Table 2.3: Natural fibre composition (William et al., 2000)

<table>
<thead>
<tr>
<th></th>
<th>Jute</th>
<th>Flax</th>
<th>Hemp</th>
<th>Kenaf</th>
<th>Sisal</th>
<th>Cotton</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellulose</td>
<td>61.71</td>
<td>71.75</td>
<td>70.2-74.4</td>
<td>53-57</td>
<td>67-78</td>
<td>82.7</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>13.6-20.6</td>
<td>18.6-20.6</td>
<td>17.9-22.4</td>
<td>15-19</td>
<td>10-14.2</td>
<td>5.7</td>
</tr>
<tr>
<td>Lignin</td>
<td>12-13</td>
<td>2.2</td>
<td>3.7-5.7</td>
<td>5.9-9.3</td>
<td>8-11</td>
<td>-</td>
</tr>
<tr>
<td>Pectin</td>
<td>0.2</td>
<td>2.2</td>
<td>0.9</td>
<td>-</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>Others</td>
<td>-</td>
<td>3.8</td>
<td>6.1</td>
<td>7.9</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Waxes</td>
<td>0.5</td>
<td>1.7</td>
<td>0.8</td>
<td>-</td>
<td>2.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Water</td>
<td>12.6</td>
<td>10.0</td>
<td>10.8</td>
<td>-</td>
<td>11.0</td>
<td>-</td>
</tr>
</tbody>
</table>
Natural fibre mechanical properties depend on the type of cellulose and the geometry of the elementary cell. The celluloses chains were arranged parallel to each other, forming bundles where each bundle contains forty or more cellulosic macromolecules linked by hydrogen bonds, amorphous hemicelluloses and lignin, which confer stiffness to fibre called microfibrils (Rong et al., 2011). The hierarchy of fibres and fibrils found in the bast fibre are shown in Figure 2.7.

Figure 2.7: Natural fibre hierarchal structure (Bos et al., 2006)

Among all natural fibres, bast fibres which were extracted from the stems of plants such as jute, kenaf, flax, ramie and hemp are widely accepted as the best option for reinforcements of composites due to their good mechanical properties. Hemp shows to have very promising tensile properties for applications where mechanical properties are requisite. The two basic parameters that characterize mechanical behaviour of natural fibres are cellulose content and spiral angle (Bogoeva-Gaceva et al., 2007 and Akil et al., 2011).

In general, tensile strength of a fibre increases with increasing cellulose content and with decreasing angle of helix axis. The strength of natural fibre composites is lower compared to the average of synthetic fibre reinforced composites, even under optimized fibre-matrix interaction. However, their lower density and cost make them competitive in terms of specific and economic properties (Akil et al., 2011).
This is basically due to the composite-like structure of natural fibres; they are generally not a single filaments as most manmade fibres but they can have several physical forms, which depend on the degree of fibre isolation. Composite strength also depends on fibre diameter (smallest diameter could achieve higher mechanical resistance due to larger specific contact surface with matrix) and fibre length.

2.5 Kenaf Fibre

Kenaf (Hibiscus cannabinus L.) is an annual crop native to southern Asia. It is grown mainly for bast fibre in China (44%), India (39%), Indonesia, Malaysia, Bangladesh, USA, South Africa, Vietnam, Thailand and some parts of Africa. In Europe, kenaf may be an option for fibre production especially in the Mediterranean zone. Kenaf is very important to promote selected new genotypes resistant to cold and drought. Kenaf was annually harvested and ideal for farm machinery. fibre qualities lay in their air permeability, the ability of members of moisture, free from substances harmful to health, biodegradability, and no allergic effect. In terms of environmentally sustainable, kenaf is better when compared to other crops such as corn and sugar because kenaf requires lower fertilizer (Monti & Zatta, 2009).

The fibre in kenaf was found in the bast and core. The bast constitutes 40% of the plant. These fibres are 2 to 6 mm long and slender with cell wall around 6.3 µm thick. The core is about 60% of the plant and has thickness with diameter 38 µm, but short and thin with 0.5mm and 3µm respectively. The tensile properties of technical kenaf fibre were determined as follow; breaking stress of 433.1 MPa (standard deviation 186.0 MPa), young modulus of 26.9 GPa (standard deviation 8.1 GPa) and elongation at break of 1.8% (standard deviation 0.57%) (Islam et al., 2011).
Figure 2.8: Comparison of specific modulus of kenaf fibre with several other fibres (Akil et al., 2011 and Zampaloni et al., 2007)

Table 2.4: Properties of kenaf fibre and polyester resin (Rassmann et al., 2000)

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Kenaf fibre</th>
<th>Polyester resin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength</td>
<td>MPa</td>
<td>350-600</td>
<td>69</td>
</tr>
<tr>
<td>Elastic modulus</td>
<td>MPa</td>
<td>40000</td>
<td>3800</td>
</tr>
<tr>
<td>Elongation at break</td>
<td>%</td>
<td>2.5-3.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>MPa</td>
<td>N/A</td>
<td>84</td>
</tr>
<tr>
<td>Flexural modulus</td>
<td>MPa</td>
<td>N/A</td>
<td>3930</td>
</tr>
<tr>
<td>Density</td>
<td>kg/m³</td>
<td>1500</td>
<td>1140</td>
</tr>
</tbody>
</table>

Akil et al., (2011) studied on kenaf fibre reinforced composite and concluded that one of the reasons kenaf was favoured in research area is because it has good mechanical properties especially in terms of specific modulus or density. Today, kenaf fibres, which acted as reinforcement of composite material, arouse research interests. In this research, kenaf natural fibre was selected based on their good
mechanical properties. Figure 2.8 shows the comparison of specific modulus of kenaf fibre with several other fibres. Besides kenaf natural fibre, polyester resin was also used in this study. The polyester was used to bind the kenaf weaving composition in a composite. Table 2.4 shows the properties of the kenaf fibre and polyester resin.

Polyester resin was selected in this study because it is suitable for applications where no structural properties are desired. Plus, it is cheap and has a quick cure time, allowing high turnover for businesses such as marinas repairing boat hulls. Vinylester on the other hand, are not suitable for repairing or layering as they bond poorly for dissimilar structure and are more expensive than polyester. Furthermore, epoxy is much suitable for extremely strenuous task such as enduring vibrational load, with higher tensile strength and thermal stability.

![Figure 2.9: Typical image of (a) kenaf plantation (b) kenaf fibre (Saba et al., 2015)](image)

Kenaf fibre has very good characteristic compared to other natural fibres, i.e long fibre, small diameter, and high interfacial adhesion to matrix (Aziz & Ansell 2004). Kenaf is commercially available and economically cheaper amongst other natural fibres (Saba et al., 2015). Other than that, kenaf is compliant to several types of soil to grow effectively and only need nominal chemical treatment (Elsaid et al., 2011). However, there is only a few studies has been done on kenaf fibre to comprehensively understand the possibility of composites especially
crashworthiness loading condition. This research is an attempt made to study the effect of woven kenaf fibre and orientation using Taguchi Method on energy absorption for polyester composites.

2.6 Experimental Method

Experimental studies have been done and mostly concentrated on processing condition, fibre types, coupling agent and fibre treatment. Various of experimentally method has been used in order to improve mechanical properties of natural fibre. In this section are explored the method which is include chemical treatment, layers and orientations, woven and non-woven, vacuum infusion and Taguchi method. Some of the reported work has mentioned that natural fibre composites were very sensitive to velocity and impact loading (Bledzki et al., 2002). Low velocity impact on fibre reinforced plastic has been the subject of several experimental and analytical investigations (Bogdanovich et al., 1994 and Naik et al., 1998). Several research using various methods for optimization. El-Shakeil et al., (2013) which is focused on temperature, speed, processing time and fibre size to improve mechanical properties. Another researcher (Kumar et al., 2014 and Sutharson et al., 2012) that were conducted using Taguchi method involved with various materials for optimization. Optimization is the best element for alternative method to improved material strength with minimum cost and manufacture. In this research Taguchi method was selected in order to optimize the angle and orientation to improve mechanical properties of kenaf fibre composites.

2.6.1 Chemical Treatment

There was several research which uses chemical treatment on natural fibre before continuation to fabricate composite (Yousif et al., 2012). Kenaf can also be chemically retted, where the kenaf was soaked in an alkali solution such as sodium hydroxide (NaOH). Chemical retting was faster than water retting. In this process, it took only several hours for kenaf to be separated. Suhairil et al., (2012) in their research used NaOH to improve tensile properties of kenaf fibres. The fibre was soaked with 3%, 6% and 9% of NaOH for a day and dried at 80°C for 24 hours.
From the result obtained, it can be seen that chemical treatment resulted in smaller effects onto the mechanical properties of kenaf fibre. In other word, the results were almost the same as without chemical treatment. The result of kenaf treatment under impact test is as shown in Figure 2.10.

Figure 2.10: The result of kenaf treatment under impact test (Suhairi et al., 2012)

Liao et al., (2016) also proved that chemical treatment did not affect the tensile modulus of composite. In their research, mechanical properties of various kind of surface treatment agent options or combination of glass woven fabric composites were clarified. Initially, glass woven was fabricated using hand lay-up method and was treated by silane coupling, a series of pick-up ratios of polyurethane dispersion (PUD). Figure 2.11 shows the results after treatment which did not provide any significant effects, thus resulting in the same condition as before the treatment.

Furthermore, Edeerozey et al., (2007) mentioned that by using 9% of NaOH, the average unit break decreased and the strength value recorded was lower than the untreated fibre. They concluded that 9% NaOH was too strong and might have damaged the fibres, thus resulting in lower tensile strength. Some of the reported studies (Saiman, 2014 and Hashim, 2016) also mentioned that chemical treatment did not improve mechanical properties of kenaf reinforcement.
Figure 2.11: Tensile modulus comparison among virgin and treated composites (Liao et al., 2016)

Figure 2.12: Impact strength of untreated, treated, and stretch-treated composite (Saiman, 2014)
REFERENCES


Hashim, M.Y. Effect of Alkali Treatment Conditions Optimization on Kenaf Fiber Polymer Composite Characterization. Thesis Doctor of Philosophy, Faculty of Mechanical Engineering and Manufacturing, Universiti Tun Hussein Onn Malaysia; 2016


Mohamad, Z. Intelligent Signal Processing System to Investigate Damage Severity in Kenaf Fibre Composite. Thesis Doctor of Philosophy, Faculty of Mechanical Engineering and Manufacturing, Universiti Tun Hussein Onn Malaysia; 2016
University, Department Of Textile Engineering, Izmir, Turkey Intem Triko Tekstill, Istanbul Turkey.


Rashid, A.H.A. Low Velocity Impact Response of Laminated Textile Coir-Aramid/Epoxy Hybrid Composite Subjected to Transverse Penetration Loading. Thesis Doctor of Philosophy, Faculty of Engineering and Physic Sciences, Universiti Sains Malaysia.; 2015


