A 3D MODELLING ON RC BEAMS STRENGTHENED EXTERNALLY BY MENGKUANG LEAVES-EPOXY COMPOSITE PLATE: FINITE ELEMENT ANALYSIS

MUHAMMAD IBRAHIM ADHAM BIN GHAZALI

B. ENG (HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG
SUPERVISOR’S DECLARATION

I/We* hereby declare that I/We* have checked this thesis/project* and in my/our* opinion, this thesis/project* is adequate in terms of scope and quality for the award of the Bachelor Degree of Civil Engineering

________________________________________
(Supervisor’s Signature)

Full Name   :
Position    :
Date        :
STUDENT’S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

____________________________________
(Student’s Signature)

Full Name : MUHAMMAD IBRAHIM ADHAM BIN GHAZALI
ID Number  : AA14078
Date       :
A 3D MODELLING ON RC BEAMS STRENGTHENED EXTERNALLY BY MENGKUANG LEAVES-EPOXY COMPOSITE PLATE: FINITE ELEMENT ANALYSIS

MUHAMMAD IBRAHIM ADHAM BIN GHAZALI

Thesis submitted in fulfillment of the requirements for the award of the Bachelor Degree in Civil Engineering

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

MAY 2018
ACKNOWLEDGEMENTS

First of all, I am grateful for finishing this research as planned. I would like to take this opportunity to express my gratitude to those who helped me during process completing my final year project. To my supervisor, Dr. Chin Siew Choo, my gratitude for constantly shows me support and effort since our first meeting. All those germinal ideas, professional advices and motivation were so valuable for my research progress. In addition, I am truly appreciated for her tolerance of my careless mistakes and her commitment for my research study.

My special thanks for Dr Cheng Hock Tian for providing the software and assisting on how to use it. This research would be more difficult to conduct without his helpful tips. Moreover, my gratitude to all of to all my friends and research partner for contributing in my research even in a small thing. To be mentioned, my biggest appreciation to a Mishmi girl who always motivated me with her advises and opened my mind to think out of the box.

Next, I am appreciated with my sincere indebtedness and gratitude to my family for their loves, motivation throughout my life especially my parents who always there for me. To end, thank you to all who has been helping me throughout my research study which I didn’t mention here. Thank You.
ABSTRAK

The research presents a finite element analysis modelling to investigate the behaviour of reinforced concrete beam strengthened externally using Mengkuang Leaves-Epoxy Composite Plate (MLECP). ANSYS CivilFEM 12.0 is used in this research. The major objectives of the research are to study the structural behaviour of reinforced concrete beams strengthened with MLECP at the flexural zone in terms of load deflection behaviour, crack pattern, failure mode by using finite element analysis and validate the result with experimental result, besides, to determine the effective strengthening method between surface-wrap and U-wrap. A total of three (3) beams with dimension of 100 mm width, 130 mm height and 1600 mm length were modelled as simply supported beams in three-dimensional (3D). The beams were modelled symmetrically. Two types of strengthening methods were used which included surface strengthening and U-wrap strengthening. U-wrap strengthening method was modelled based on validation of control beam and surface wrap strengthening method. The most effective strengthening method was determined from the numerical modelling. Based on the numerical result, all beams failed in shear at reasonable load. By comparing with the control beam, surface and U-wrap strengthening methods have resulted into an increment in the beam bearing capacity by 10% and 15%, respectively. As for the deflection, control beam, U-wrap and surface strengthening method recorded decreasing in value which is 7.48 mm, 6.55 mm and 6.07 mm, respectively. A comparison between the numerical and experimental results showed that a comparable agreement on the load deflection behaviour and strong agreement on the crack patterns. The most effective strengthening method is U-wrap method.
# TABLE OF CONTENT

DECLARATION

TITLE PAGE

ACKNOWLEDGEMENTS ii

ABSTRAK iii

ABSTRACT iv

TABLE OF CONTENT v

LIST OF TABLES ix

LIST OF FIGURES x

LIST OF SYMBOLS xiii

LIST OF ABBREVIATIONS xiv

CHAPTER 1 INTRODUCTION 1

1.1 Background of Research 1

1.2 Problem Statement 2

1.3 Objectives of Research 3

1.4 Scope of Research 3

1.5 Significance of Research 4

CHAPTER 2 LITERATURE REVIEW 5

2.1 Introduction 5

2.2 Natural Fiber 5

2.2.1 Mengkuang Leaves 8

2.3 Strengthening Using Fiber (Experimental) 11
3.4.3 Loading History and Solution Parameter
48
3.4.4 Monitoring Points
49
3.4.5 Analysis
49
3.4.6 Interactive Window
50
3.5 Validation of Result
51
3.6 Summary
51
3.7 Methodology Chart
52

CHAPTER 4 RESULTS AND DISCUSSION
53

4.1 Introduction
53
   4.1.1 Load-Deflection Behaviour
53
   4.1.2 Crack Pattern
53
   4.1.3 Strain Contour
54
   4.1.4 Stress Contour
54

4.2 Control Beam (CB)
55
   4.2.1 Load-Deflection Behaviour
55
   4.2.2 Crack Pattern
55
   4.2.3 Strain Contour
56
   4.2.4 Stress Contour
56
   4.2.5 Validation with Experimental Work
57

4.3 RC Beam Strengthened by MLECP (RCS1, Surface-Wrap)
59
   4.3.1 Load-Deflection Behaviour
59
   4.3.2 Crack Pattern
59
   4.3.3 Strain Contour
60
   4.3.4 Stress Contour
60
   4.3.5 Validation with Experimental Work
61
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4</td>
<td>RC Beam Strengthened by MLECP (RCS2, U-Wrap)</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>4.4.1 Load-Deflection Behaviour</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>4.4.2 Crack Pattern</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>4.4.3 Strain Contour</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>4.4.4 Stress Contour</td>
<td>65</td>
</tr>
<tr>
<td>4.5</td>
<td>Comparison between FEA Results</td>
<td>65</td>
</tr>
<tr>
<td>4.6</td>
<td>Summary</td>
<td>67</td>
</tr>
</tbody>
</table>

**CHAPTER 5 CONCLUSION AND RECOMMENDATION**

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Conclusion</td>
<td>68</td>
</tr>
<tr>
<td>5.2</td>
<td>Recommendation</td>
<td>70</td>
</tr>
</tbody>
</table>

REFERENCES

APPENDIX A
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1.1</td>
<td>Summary of Model Parameter</td>
<td>4</td>
</tr>
<tr>
<td>Table 2.1</td>
<td>Summary of laminates investigated in this study</td>
<td>9</td>
</tr>
<tr>
<td>Table 2.2</td>
<td>Chemical composition of mengkuang leaves at different stages of treatment</td>
<td>10</td>
</tr>
<tr>
<td>Table 2.3</td>
<td>Average cellulose and average tensile strength by using different NaOH concentration treatment and soaking time</td>
<td>11</td>
</tr>
<tr>
<td>Table 2.4</td>
<td>Mechanical properties of FRP composites</td>
<td>15</td>
</tr>
<tr>
<td>Table 2.5</td>
<td>List of materials used</td>
<td>17</td>
</tr>
<tr>
<td>Table 2.6</td>
<td>Summary of test result</td>
<td>18</td>
</tr>
<tr>
<td>Table 2.7</td>
<td>Mechanical properties of simulation models</td>
<td>20</td>
</tr>
<tr>
<td>Table 2.8</td>
<td>Comparison of flexural strength between beam models</td>
<td>22</td>
</tr>
<tr>
<td>Table 2.9</td>
<td>Element Type for Working Model</td>
<td>25</td>
</tr>
<tr>
<td>Table 2.10</td>
<td>Summary of Literature Review</td>
<td>27</td>
</tr>
<tr>
<td>Table 3.1</td>
<td>Details of research parameters</td>
<td>32</td>
</tr>
<tr>
<td>Table 3.2</td>
<td>Element types used in analysis</td>
<td>36</td>
</tr>
<tr>
<td>Table 3.3</td>
<td>Summary of material properties assigned to the elements</td>
<td>38</td>
</tr>
<tr>
<td>Table 3.4</td>
<td>Real constant of steel reinforcement by area of reinforcements</td>
<td>39</td>
</tr>
<tr>
<td>Table 3.5</td>
<td>Coordinate for volume block modelling</td>
<td>40</td>
</tr>
<tr>
<td>Table 4.1</td>
<td>Comparison in term of strength ratio</td>
<td>66</td>
</tr>
<tr>
<td>Table 4.2</td>
<td>Comparison in term of deflection ratio</td>
<td>67</td>
</tr>
<tr>
<td>Table 4.3</td>
<td>Comparison in term of strain and stress value</td>
<td>67</td>
</tr>
<tr>
<td>Figure 2.1</td>
<td>Classification of natural and synthetic fibers</td>
<td>6</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>Chemical composition of some common natural fibers</td>
<td>7</td>
</tr>
<tr>
<td>Figure 2.3</td>
<td>Physio-mechanical properties of natural fibers</td>
<td>8</td>
</tr>
<tr>
<td>Figure 2.4</td>
<td>The variation of the tensile strength of the entire PA (leaf and fibres) reinforced PE. Laminate A (neat PE) is included for comparison</td>
<td>9</td>
</tr>
<tr>
<td>Figure 2.5</td>
<td>Flexural strength of three-point bending test</td>
<td>12</td>
</tr>
<tr>
<td>Figure 2.6</td>
<td>Comparison in terms of ultimate load</td>
<td>13</td>
</tr>
<tr>
<td>Figure 2.7</td>
<td>Load deflection curve of the different beam specimen</td>
<td>14</td>
</tr>
<tr>
<td>Figure 2.8</td>
<td>Comparison in terms of deflection at mid span</td>
<td>14</td>
</tr>
<tr>
<td>Figure 2.9</td>
<td>Ultimate load carrying capacity of beams</td>
<td>16</td>
</tr>
<tr>
<td>Figure 2.10</td>
<td>Comparison of the beams in terms of load deflection</td>
<td>21</td>
</tr>
<tr>
<td>Figure 2.11</td>
<td>Finite element model of reinforcements</td>
<td>22</td>
</tr>
<tr>
<td>Figure 2.12</td>
<td>Meshed finite element model wrapped with bamboo fiber</td>
<td>22</td>
</tr>
<tr>
<td>Figure 2.13</td>
<td>Load v/s Deflection curve for Slab – A (Non-Strengthened)</td>
<td>23</td>
</tr>
<tr>
<td>Figure 2.14</td>
<td>Load v/s Deflection curve for Slab – B (GFRP Strengthened – cut near supports)</td>
<td>24</td>
</tr>
<tr>
<td>Figure 2.15</td>
<td>Load v/s Deflection curve for Slab – C (GFRP Strengthened – throughout the soffit)</td>
<td>24</td>
</tr>
<tr>
<td>Figure 2.16</td>
<td>Deformation Shape of ARFP (sides+bottom)</td>
<td>26</td>
</tr>
<tr>
<td>Figure 2.17</td>
<td>Crack pattern of ARFP (sides+bottom)</td>
<td>26</td>
</tr>
<tr>
<td>Figure 3.1</td>
<td>Schematic diagram of RC beam</td>
<td>30</td>
</tr>
<tr>
<td>Figure 3.2</td>
<td>Schematic diagram of Mengkuang Leaves Epoxy-composite Plate</td>
<td>31</td>
</tr>
<tr>
<td>Figure 3.3</td>
<td>Schematic diagram of RC beam with surface strengthening</td>
<td>31</td>
</tr>
<tr>
<td>Figure 3.4</td>
<td>Schematic diagram of RC beam with U-wrap strengthening</td>
<td>32</td>
</tr>
<tr>
<td>Figure 3.5</td>
<td>Unit used in analysis</td>
<td>35</td>
</tr>
<tr>
<td>Figure 3.6</td>
<td>Material code for concrete strength G25, SOLID 65</td>
<td>35</td>
</tr>
<tr>
<td>Figure 3.7</td>
<td>Element types chosen in analysis</td>
<td>36</td>
</tr>
<tr>
<td>Figure 3.8</td>
<td>Materials properties of model analysis</td>
<td>37</td>
</tr>
<tr>
<td>Figure 3.9</td>
<td>Summary of materials assigned to the element in analysis</td>
<td>38</td>
</tr>
<tr>
<td>Figure 3.10</td>
<td>Input data of area of the steel to define the real constant</td>
<td>39</td>
</tr>
</tbody>
</table>
Figure 3.11  Modelled block on the Cartesian plane along x, y and z directions  

Figure 3.12  Steel Reinforcement Draft from Side View  

Figure 3.13  Steel Reinforcement Draft from Oblique View  

Figure 3.14  Selected lines for shear reinforcement (link)  

Figure 3.15  Selected lines for reinforcement  

Figure 3.16  Size used for element size on picked lines  

Figure 3.17  Result of element size on picked lines  

Figure 3.18  Input for link reinforcement for meshing  

Figure 3.19  The lines that had been meshed  

Figure 3.20  Control Beam  

Figure 3.21  RC beam strengthened by MLECP (surface wrap)  

Figure 3.22  RC beam strengthened by MLECP (U-wrap)  

Figure 3.23  Side view of beam that had been applied with supports and loads  

Figure 3.24  Support that had been restrained with three degree of freedom  

Figure 3.25  Solution controls table to set the option for load applying  

Figure 3.26  Interactive window of initializing the analysis  

Figure 3.28  Graph of analysis  

Figure 3.29  Methodology Chart  

Figure 4.1  Load-deflection curve of control beam (CB)  

Figure 4.2  Crack pattern of CB  

Figure 4.3  Strain contour of CB  

Figure 4.4  Stress contour of CB  

Figure 4.5  Load-deflection curve of CB (comparison)  

Figure 4.6  Crack Pattern of CB (comparison)  

Figure 4.7  Load-deflection curve of RCS1  

Figure 4.8  Crack Pattern of RCS1  

Figure 4.9  Strain contour of RCS1  

Figure 4.10  Stress contour of RCS1  

Figure 4.11  Load-deflection curve of RCS1 (comparison)  

Figure 4.12  Figure 4.12: Crack pattern of RCS1 (comparison)
Figure 4.13  Load-deflection of RCS2  63
Figure 4.14  Crack pattern of RCS2  64
Figure 4.15  Strain contour of RCS2  64
Figure 4.16  Stress contour of RCS2  65
Figure 4.17  Load-deflection curve of all beam models  66
LIST OF SYMBOLS

\begin{itemize}
  \item E \quad \text{Elastic modulus}
  \item v \quad \text{Poisson’s ratio}
  \item G \quad \text{Shear modulus}
  \item E_1 \quad \text{Axial stiffness}
  \item E_2 \quad \text{Transverse stiffness}
  \item v_{12} \quad \text{Poisson’s ratio}
  \item G_{12} \quad \text{Shear stiffness (stress) acting in the 1 direction plane with a normal in the 3 direction}
  \item G_{23} \quad \text{Shear stiffness (stress) acting in the 2 direction plane with a normal in the 3 direction (G_{23})}
  \item f \quad \text{Fiber volume ratio}
  \item K \quad \text{Bulk modulus of the composite}
  \item \psi \quad \text{Dilation angle}
  \item m \quad \text{Flow potential eccentricity}
  \item \sigma_{c0} / \sigma_{b0} \quad \text{Initial biaxial/uniaxial ratio}
  \item K_c \quad \text{Ratio of the second stress invariant on the tensile meridian}
  \item \mu \quad \text{Viscosity parameter}
\end{itemize}
# LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLECP</td>
<td>Mengkuang Leaves-Epoxy Composite Plate</td>
</tr>
<tr>
<td>FRP</td>
<td>Fiber-reinforced polymer</td>
</tr>
<tr>
<td>SFRP</td>
<td>Synthetic fiber-reinforced polymer</td>
</tr>
<tr>
<td>NFRP</td>
<td>Natural fiber-reinforced polymer</td>
</tr>
<tr>
<td>CFRP</td>
<td>Carbon fiber-reinforced polymer</td>
</tr>
<tr>
<td>GFRP</td>
<td>Glass fiber-reinforced polymer</td>
</tr>
<tr>
<td>RC</td>
<td>Reinforced concrete</td>
</tr>
<tr>
<td>KFRWM</td>
<td>Kenaf fiber reinforced woven mat</td>
</tr>
<tr>
<td>JFRWM</td>
<td>Jute fiber reinforced woven mat</td>
</tr>
<tr>
<td>FEA</td>
<td>Finite Element Analysis</td>
</tr>
<tr>
<td>CB</td>
<td>Control beam</td>
</tr>
<tr>
<td>KB</td>
<td>Reinforced concrete beam with Kenaf Fiber Reinforced Woven Mat</td>
</tr>
<tr>
<td>JB</td>
<td>Reinforced concrete beam with Jute Fiber Reinforced Woven Mat</td>
</tr>
<tr>
<td>CDP</td>
<td>Concrete Damaged Plasticity</td>
</tr>
<tr>
<td>UTM</td>
<td>Universal Testing Machine</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Background of Research

Finite element analysis (FEA) is originally developed for solving solid mechanics problems. In the field of civil engineering, FEA is usually used for structure analysis such as cantilever, bridge and reinforced concrete. ANSYS CivilFEM 12.0 is one of structural software which can be used to solve dynamic, linear and non-linear problems with various checking code.

Nowadays, fibre-reinforced plastic (FRP) is commonly used as external strengthening material due its several benefits. FRP is the most economical choice given that reduced preparation and labor costs. FRP can usually be installed without taking the structure out of service, extremely high tensile strength, lightweight and user-friendly installation. Potential natural fiber to be used as one of alternatives for strengthening is Mengkuang leaves. Mengkuang leaves or pandanus actrocarpus is widely used for craft industries in weaving for different products such as basket and mat because of its yield. Since mengkuang leaves are very common and can be easily obtained, improvement on mengkuang leaves will allow strengthening production to be expanded vastly and to be cost effectively due to the sustainable source in promoting the use of fiber plate in strengthening concrete structure.

In addition, strengthening of the structures is in demand to increase the safety requirements, changing of social needs, more stringent design standards and the deterioration of existing reinforced concrete infrastructures especially beams, as the vital structure elements to withstand loads, laterally and vertically. External strengthening techniques retrofitted damaged structured by providing extra strengthening on it and lengthen the service period in an easy and convenient method.
Research using finite element analysis to determine the effects of mengkuang fiber in strengthening beam is not being found. Thus, the finite element software, will give different perspective regarding to this study.

1.2 Problem Statement

Over last decades, demand for applications of FRP is getting popular and widely in used for many production sectors. As stated before, synthetic fibers as carbon and glass are used due to high strength-to-volume ratio, flexible and high stiffness (Dong et al, 2013). Despite of that, the ineffective cost for the production of synthetic fiber composite plates and the bad effect to health during its production are issues should be considered.

Nowadays, regarding to several studies and experiments, natural fibers are found as an attracting and potential materials to replace synthetic. Various types of natural fibers are tested to archive result on their mechanical properties. Among the natural fibers, kenaf fiber has higher tensile strength compared to other natural fibers (Ku et al., 2011). When high load bearing capacity is not required, natural fibers are preferred over synthetic fibers. To add, natural fibers are degradable, low cost in production and harmless to health. Mechanical properties of the matrices such as tensile, flexural will be increased with the use of natural fiber reinforcing in polymer (Yan et al., 2016). Therefore, the use of natural fibers will provide significant positive outcome besides decrease the content of polymer than neat polymer.

Limited study on using mengkuang leaves epoxy composite plate for external strengthening. Only Foo (2016) conducted an experimental work on MLECP to study flexural strength of MLECP to gain strength result of mengkuang as strengthening material. Despite of that, further study should be taken to investigate the methods to improve the result of mengkuang fiber properties and mechanical properties of mengkuang fiber composite plate. To obtain this, finite element analysis was used to analyse its properties and validate results with the laboratory test. Finite element analysis can be used to predict outcomes using conditions without going through the laboratory testing. At the same time, there are advantages of doing laboratory test such as time consuming, costly materials and tedious procedure to get the data.
5.2 Recommendation

There are a few precautions and improvements which have to be taken into consideration for further study in similar approach. The recommendations are stated as below:

i. Strengthening method should be diversified and more methods should be considered in the study, e.g. numbers of layers, thickness, dimensions of MLECP attached on the beam.

ii. Smaller steel reinforcement cross section can be used in future research in order to clearly obtain the behaviours of MELCP strengthening.

iii. Analysis should be done using different FEA software such as ABAQUS for comparison purpose.
REFERENCES


