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SIMULATION ANALYSIS OF A FOLDABLE CARBON FIBER REINFORCED HONEYCOMB SANDWICH COMPOSITE BRIDGE

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Thesis submitted to the Centre for Research and Postgraduate Management, Universiti Pertahanan Nasional Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

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DEDICATION

"Especially for ayah and mak, Syamsir and Alm Naimah.

My beloved wife and son, Vivi Anggraini and Muhammad Athar Al Rafee".

You give me strength to carry on.

ABSTRACT

Portable bridge is very important in the military for mobility. However, it becomes more important nowadays for disaster relief operations. In the early days, military bridges were made from steel causing the weight of the bridge to be huge, thus, need more vehicles to transport the bridge and crane with higher capacity to erect it. Subsequently it will cost more to operate.

Aluminum and metal alloy were introduced to reduce the weight of such structure to overcome these problems. Then new material emerge called composite material, i.e. Carbon Fiber Reinforced Polymer (CFRP) and honeycomb material which is usually used for sandwich structure. CFRP and aluminum honeycomb are being considered to be used as a primary material for the portable bridge. The reason to use the CFRP as a primary material is due to its high strength to weight ratio, thus making it lighter than steel and other alloy. The use of honeycomb is expected will increase the stiffness of bridge beam without additional weight significantly. In this study one layer of CFRP is called as lamina and the stacking of lamina is called as laminate.

Aluminum Honeycomb Hex-Web 5.2-1/4-25(3003) is used as the core in this study, while laminate is used as the skin for sandwich structure of the beam. The laminate is consisting of 31 to 49 plies of lamina, where the lamina thickness is 0.815 mm that produces the laminate thickness from 25 to 40 mm. The thickness of aluminum honeycomb which is used is in the range of 50 to 300 mm that produces sandwich structure thickness from 85 to 340 mm.

Finite Element Analysis (FEA) is used due to unavailability of standard for design of structure using CFRP and honeycomb. Maximum stresses and also the possibility of buckling on the structure have been investigated. Several trials are made to test several lay-up of lamina including use of aluminum honeycomb core to increase stiffness of the member.

The trials produce the maximum stress on the lamina in fiber direction is 104 MPa (compression) , while the maximum stress in perpendicular to fiber direction and shear stress are 4.02 MPa (compression), and -7.44 Mpa, respectively.. The use of failure formulations which is shown in the form of graphic shows that the lamina stresses is in allowable range. The maximum stress of Aluminium honeycomb in z-direction is 0 MPa, while the shear stress in *y-z* and *x-z* planes are -0.844 Mpa and 1.45 Mpa, respectively. The maximum stresses of honeycomb are lower than the strength of honeycomb itself, it means that the aluminum honeycomb is able to support the load without failure.

From the trials can be concluded that, with proper design Carbon Fiber Reinforced Polymer and Aluminum Honeycomb can take the design load similar to steel and aluminum.

ABSTRAK

Jambatan mudah alih sangat penting dalam bidang ketenteraan untuk tujuan mobiliti. Bagaimanapun, jambatan mudah alih menjadi lebih penting untuk operasi bantuan bencana. Pada awal kegunaannya, jambatan tentera diperbuat daripada keluli menyebabkan jambatan terlalu berat, maka, ia memerlukan lebih banyak kenderaan untuk mengangkut jambatan dan kren dengan kapasiti yang lebih tinggi untuk mendirikannya. Kemudiannya, kos operasi menjadi lebih tinggi.

Aluminium dan aloi logam diperkenalkan untuk mengatasi masalah ini dengan mengurangkan berat struktur jambatan. Kemudian bahan baru muncul dipanggil bahan komposit iaitu gentian karbon diperkuat polimer (CFRP) dan bahan sarang lebah yang biasanya digunakan untuk struktur sandwic. CFRP sedang dipertimbangkan untuk digunakan sebagai bahan utama dalam pembuatan jambatan mudah alih. Ini kerana CFRP mempunyai nisbah kekuatan terhadap berat yang tinggi, membuatkannya lebih ringan daripada keluli dan aloi yang lain. Penggunaan bahan honeycomb diharapkan dapat meningkatkan kekukuhan rasuk jambatan tanpa penambahan berat jambatan secara signifikan. Dalam kajian ini satu lapisan CFRP dipanggil sebagai lamina dan susunan lamina dipanggil sebagai laminate.

Sarang lebah aluminium Hex-Web 5.2-1/4-25(3003) digunakan sebagai teras dalam kajian ini, manakala lamina adalah digunakan sebagai kulit untuk struktur sandwic rasuk. Laminate mengandungi 31 sehingga 49 lapisan lamina, di mana ketebalan setiap lamina ialah 0.815 mm yang menghasilkan ketebalan laminate dari 25 sehingga 40 mm. Ketebalan sarang lebah aluminium yang digunakan adalah berada dalam julat 50 sehingga 300 mm yang menghasilkan ketebalan struktur sandwich dari 85 sehingga 340 mm.

Kaedah elemen terhad digunakan kerana tak ada standard untuk mereka bentuk struktur menggunakan honeycomb dan CFRP. Tekanan maksimum dan juga kebarangkalian pembengkokan pada struktur telah disiasat. Beberapa ujian telah dibuat untuk menguji beberapa '*lay-up*' lamina termasuk penggunaan teras sarang lebah aluminium untuk meningkatkan kekukuhan rasuk.

Ujian-ujian tersebut menghasilkan tekanan maksimum pada lamina dalam arah gentian ialah 104 MPa (mampatan), sementara tekanan maksimum dalam berserenjang dengan arah gentian dan tegasan ricih ialah 4.02 MPa (mampatan), dan -7.44 MPa, masing masing. Penggunaan formula kegagalan yang ditunjukkan dalam bentuk grafik menunjukkan bahawa tekanan pada lamina berada dalam julat yang dibenarkan. Tekanan maksimum pada sarang lebah aluminium dalam arah *z* ialah 0 MPa, sementara tegasan ricih dalam y-z dan x-z plane ialah -0.844 MPa dan 1.45 MPa, masing-masing. Tekanan maksimum pada sarang lebah aluminium adalah lebih rendah dari pada kekuatan sarang lebah itu sendiri, ini bermakna sarang lebah aluminium mempunyai keupayaan menyokong beban tanpa kegagalan.

Daripada ujian-ujian tersebut dapat disimpulkan bahawa, dengan rekabentuk yang sesuai Carbon Fiber Reinforced Polymer dan Aluminum Honeycomb boleh mengambil beban rekabentuk sama seperti keluli dan aluminium.

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I certify that an Examination Committee has met on **31 May 2010** to conduct the final examination of **Agusril** on his degree thesis entitled **'Simulation analysis of a foldable carbon fiber reinforced honeycomb sandwich composite bridge'**. The committee recommends that the student be awarded the Master of Science.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABREVIATION

CFRP	_	Carbon Fiber Reinforced Polymer
MLC	_	Military Load Class
KMW	_	Krauss-Maffei Wegmann
FRP	_	Fiber Reinforced Polymer
TDTC	–	Trilateral Design and Test Code for Military Bridging
BLF	–	Buckling Loading Factor

LIST OF SYMBOLS

θ	–	Fiber orientation angle
ν	–	Poisson's Ratio
τ	–	The shear stress
σ	–	The normal stress
E_f	–	Modulus of elasticity
G_f	–	Shear modulus of elasticity
ε	–	Normal strain
γ	–	Shear strain
Q	–	The lamina stiffness matrix
S	–	The compliance matrix
F	–	Force
F_1	–	Force in fiber direction
F_2	–	Force perpendicular to fiber direction
M	–	Moment Forces
N	–	Normal forces
κ	–	The bending curvature
t	–	The thickness of lamina
A	–	In plane stiffness of laminate
B	–	Coupling stiffness of laminate
D	–	Bending stiffness of laminate

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

1.1 Background

The work presented in this thesis focuses on design and analysis of foldable bridge using carbon fibre reinforced polymer (CFRP). The use of honeycomb material between CFRP to produce sandwich structure also will be analysed. This will be carried out for 30 meter foldable bridge that able to support the loads up to 63.5 ton or Military Load Class (MLC) 70. In this study one unit of military tank and others loads according to Trilateral Design and Test Code (TDTC, 1996) on the bridge will be considered in bridge design and analysis.

The bridge is important for mobility to transport troops and vehicles through obstacles like river, valley, and lake or when an existing bridge gets damaged because of disaster or enemy attack in military. In this study a portable bridge will use foldable beam concept. The reason behind using the concept is that it has a simple method in launching, retrieving, and storing of bridge, and hopefully this method will save time.

The military bridge usually is made from steel alloy (Bailey bridge, Inc, 2009) and aluminium alloy (The manufacturer, 2003) material. Due to the high density of such materials will produce a weight bridge which is not suitable with portable military bridge requirement. For example, Figure 1.1 and 1.2 shows Bailey bridge which is made from steel alloy and BR 90 Bridge from aluminium alloy, respectively.

Figure 1.1: Bailey Bridge (Bailey bridge, Inc, 2010)

Figure 1.2: Armored vehicle crossing on BR 90 Bridge (Alvis, 2003)