PERFORMANCE EVALUATION OF KENAF-EPOXY CORE SANDWICH STRUCTURE VIA MODELING AND SIMULATION

BY

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ABSTRACT

In this work, the honeycomb core of sandwich panel was reinforced by kenaf fibres. The kenaf fibre was chosen since it has high stiffness-to-weight ratio and is environmentally friendly, cheap and easily machinable. The aim of this work was to determine the orthotropic material properties of the kenaf-epoxy core and to evaluate the performance of the kenaf-epoxy sandwich panel through the simulation of the simple bending test. The orthotropic material properties and performance in simulation of the kenaf-epoxy sandwich panel were compared with those of the glass-epoxy sandwich panel. Also, the objective of this work was to determine the effect of several parameters on the material properties and performance in simulation of the kenaf-epoxy sandwich panel. Two types of kenaf fibre -- short and long fibre –with varying fibre modulus, Ef, and fibre volume fraction, Vf, were utilised. Three different analysis cases were executed; varying cell wall thickness, varying cell wall length and varying core density.The finite element software ANSYS Mechanical APDL v13 was used to simulate the simple bending test. To model the kenaf core sandwich panel, continuum modeling was adopted since it could account for the extension of the adhesives into the composite honeycomb cells. Compared to the glass-epoxy core, the long kenaf-epoxy core had greater values of orthotropic material properties. On the other hand, the short kenaf-epoxy core had greater values of the in-plane moduli but smaller values of the out-of-plane modulus. The maximum displacement of the long kenaf-core sandwich panel obtained through the simulation was lower compared to that of the glass-core sandwich panel. On the other hand, the maximum displacement of the short kenaf-core sandwich panel was generally higher than the glass-core sandwich panel, except when the kenaf fibre was stiffer and fewer. Also, the short kenaf-core sandwich panel had the least higher stressed region compared to other cores as shown by the Von-Mises stress distribution. From the analysis it was concluded that the kenaf cores had better performance than the glass core when the weight and density of the cores were the same. Also, as the fibre volume fraction, Vf increased, the longitudinal and unidirectional fibre reinforcement of the long kenaf-epoxy core became more effective, while the random discontinuous fibre reinforcement of the short kenaf-epoxy core became less effective. Conversely, as the kenaf fibre modulus, Ef increased, the longitudinal and unidirectional fibre reinforcement of the long kenaf-epoxy core became less effective, while the the random discontinuous fibre reinforcement of the short kenaf-epoxy core became more effective. Additionally, when the core density was not altered, significant change did not occur, regardless of the change in the thickness and size of the core. The core density was the most decisive parameter to determine the properties of the continuum core.

خلاصة البحث

في هذا العمل، تعزز جوهر لوحة شطيرة العسل بألياف التيل. واختير ألياف التيل حيث لديها نسبة عالية من صلابة للوزن وهي صديقة للبيئة ورخيصة وماتشينابل بسهولة. وكان الهدف من هذا العمل تحديد خصائص المواد التغاير من صميم التيل–الإيبوكسي وتقييم أداء الفريق ساندويتش التيل–الإيبوكسي من خلال محاكاة لاختبار الانحناء البسيط. التغاير الخصائص المادية والأداء في محاكاة للوحة ساندويتش التيل–الإيبوكسي قورنت مع تلك من لوحة ساندويتش الزجاج الإيبوكسي. أيضا، والهدف من هذا العمل تحديد أثر العديد من المعلمات على خصائص المواد والأداء في محاكاة للوحة ساندويتش التيل–الإيبوكسي. نوعين من ألياف التيل–القصير والطويل الألياف — مع معامل الألياف متفاوتة، هو، وكسر حجم الألياف، الخامسو، تم استغلالها. وقد أعدم ثلاثة تحليل مختلف الحالات؛ تتراوح سماكة جدار الخلية، يتراوح طول جدار الخلية ومتفاوتة الكثافة الأساسية.واستخدمت برامج العناصر المحدودة جمعية الميكانيكية **ANSYS v13** لمحاكاة اختبار الانحناء البسيط. واعتمد النمذجة متوالية نموذج لوحة ساندويتش الأساسية التيل، نظراً لأنها يمكن أن تفسر ملحق المواد اللاصقة في خلايا العسل المركب. بالمقارنة مع جوهر الزجاج الإيبوكسي، لب الإيبوكسي التيل طويلة قد القيم أكبر من خصائص المواد التغاير. من ناحية أخرى، كان جوهر الإيبوكسي التيل القصير القيم أكبر من بواقي في الطائرة ولكن القيم الأصغر من معامل الخروج من الطائرة. تشريد الحد الأقصى من لوحة ساندويتش الطويل التيل الأساسية التي تم الحصول عليها عن طريق المحاكاة كان أقل مقارنة بلوحة ساندويتش الزجاج الأساسية. من ناحية أخرى، كان التشريد الحد الأقصى من لوحة ساندويتش التيل النواة قصيرة عموما أعلى من لوحة ساندويتش الزجاج النواة، ما عدا عندما كان ألياف التيل أغلظ وأقل. أيضا، كان الفريق ساندويتش التيل النواة قصيرة المنطقة شددت على الأقل أعلى مقارنة بالنوى الأخرى كما هو مبين بتوزيع الإجهاد فون ميزس. من التحليل كان خلصت إلى أن النوى التيل أداء أفضل من كور الزجاج عند الوزن والكثافة النوى هي نفسها. أيضا، ككسر حجم الألياف، V_f زيادة، تعزيز الألياف الطولية وأحادي الاتجاه الأساسية الإيبوكسي التيل طويلة أصبح أكثر فعالية، بينما التعزيز عشوائي متقطع الألياف من لب الإيبوكسي التيل القصير أصبح أقل فعالية. وبالعكس، كمعامل ألياف التيل، هو زيادة، تعزيز الألياف الطولية وأحادي الاتجاه الأساسية الإيبوكسي التيل طويلة أصبح أقل فعالية، في حين تعزيز عشوائي متقطع الألياف من لب الإيبوكسي التيل القصير أصبح أكثر فعالية. بالإضافة إلى ذلك، عندما لم يتم تغييرها كثافة الأساسية، تغيير كبير لم يحدث، بغض النظر عن التغير في سمك وحجم الأساسية. كثافة الأساسية كانت المعلمة الأكثر حسما لتحديد الخصائص الأساسية متوالية.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate; in scope and quality, as a dissertation for the degree of Master of Science in Materials Engineering.

…..………………………………………
Zuraida bt Ahmad
Supervisor

I certify that I have examined and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate; in scope and quality, as a dissertation for the degree of Master of Science in Materials Engineering.

…..………………………………………
Maizatulnisa bt Othman
Examiner

This thesis was submitted to the Department of Manufacturing and Materials Engineering and is accepted as a fulfilment of the requirement for the degree of Masters of Science in Materials Engineering.

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This thesis was submitted to the Kulliyyah of Engineering and is accepted as a fulfilment of the requirement for the degree of Masters of Science in Materials Engineering.

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Md. Noor Saleh
Dean, Kulliyyah of Engineering

DECLARATION

I have declared that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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I would like to dedicate the first paragraph of this acknowledgement to God, who allow me to finish this time consuming thesis despite all the odds against me. The result of the hard work is anything but spectacular, but I could now appreciate the experience I gained by going through all these pain. Thanks to UIA for making this experience possible.

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LIST OF SYMBOLS

t_c	core thickness
t_f	cell wall thickness
E_x	Continuum in-plane modulus in x direction
E_y	Continuum in-plane modulus in y direction
E_z	Continuum out-of-plane modulus
G_{xy}	Continuum in-plane shear modulus
G_{xz}	Continuum out-plane shear modulus in the x direction
G_{yz}	Continuum out-plane shear modulus in the y direction
v_{xy}	In-plane Poisson's ratio
v_{xz}, v_{yz}	Out-of-plane Poisson's ratios
ρ_c	Continuum core density
ρ_s	Base material density
b	cell wall length
ψ	Fillet ratio (percentage of wall length, b)
θ	Internal angle of cell
V_f	Fibre volume fraction

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW OF NATURAL FIBRES AND KENAF

Growing concerns on environmental issues have brought composite research back to nature. With issues like increasing carbon emission, rising fuel consumption and depletion of fossil fuels to deal with, material scientists and engineers have turned their attention towards green resources, with natural fibres being the focus of attention. Fibres like kenaf, jute, hemp, flax, coir, sisal and cotton have attracted much interest due to their toughness, high specific modulus and specific strength, which are comparable and for some even better than E-glass. They are cheap and abundant, and could be harvested 2 or 3 times per year.

Applications for natural fibres have grown steadily in recent years. Realising the benefit of cost and weight reduction, European automotive companies have been at the forefront in implementing natural fibres into their cars. Flax, kenaf and hemp have found their way in door panels, seat backs, headliners, package trays, dashboards and interior panels. Apart from the automotive applications, natural fibre reinforced composites are gradually replacing wood in their traditional usage like furniture, fences, ceilings and walls, thus reducing the number of deforestation.

Currently, E-glass is still dominating the low-end market of fibres, but natural fibres have the potential to grab a bulk of its market share. The high density of E-glass, an undesirable property for fuel efficiency, is the major catalyst for that change. Furthermore, E-glass is not biodegradable, poor in recyclability and hazardous to workers' health during fabrication in the form of airborne glass particles. Taking into account those issues and the higher cost vis-à-vis natural fibres, not to forget the mechanical properties, it is clear that this is a huge opportunity for the natural fibres to stake a claim in the composite industry. There are certain issues that need to be addressed though, like the hydrophilic nature of natural fibres – moisture absorption could degrade their mechanical properties -- and finding suitable binders for the fibre-matrix adhesion. Also, the search for biodegradable matrices, or at least thermoplastic ones which are recyclable, is of paramount importance for the composites to achieve the coveted "green" status.

Kenaf fibre has been the choice fibre material for a lot of composite researchers at least for the past ten years. Commercial planting of kenaf is also going strong in the United States. In Malaysia, it is grown mostly in Kelantan, where the climate is relatively dry and is touted as the replacement crop for tobacco. Kenaf could be harvested 2 or 3 times per year and has all the advantages associated with natural fibres. The plant consumes a lot of carbon dioxide and could absorb nitrogen, phosphate and heavy metals from the earth. Apart from composites, kenaf has been known to be utilised as bags, ropes, oil absorbent material, agro-textiles and livestock feeds, among others. Not only the large-scale use of kenaf could help to mitigate environmental deterioration, but also to boost the rural economy.

1.2 SANDWICH PANEL

A special type of composite widely utilised these days is the sandwich panel. Basically it is made of two thin and stiff skins (or face sheets) separated by a thick and low density core. Sandwich panel is a highly efficient structure in that it is lightweight while having high stiffness and good strength. Increasing the thickness of the core will result in several fold increase of stiffness, and what is great about this is it only comes with minimal increment of weight.

There are several types of sandwich core structures available in the market today. The most common type is the foam core, which is isotropic and the cheapest. There are also the cellular cores, the most prominent of which is the honeycomb structure. Although the honeycomb core possess the best mechanical properties among the other core types, its usage is more restricted due to high cost and difficulty in manufacturing them. The honeycomb core sandwich panel is widely utilised in higher-end applications, such as in the aviation industry and Formula One racing cars.

1.3 PROBLEM STATEMENT

More and more researchers have now realised the merits of utilising kenaf fibre in composite materials. The advantage that the kenaf fibre have over other natural fibres and E-glass in terms specific modulus and specific strength is well documented. Although the kenaf fibre has been widely utilised in composites, there are still vast potential to be tapped. More effort and research should be done to exploit this potential.

The core of a sandwich panel comes in a variety of forms and materials. The majority of the materials utilised for the sandwich core are synthetic, which include Nomex, aluminium and glass fibre reinforced composite. Natural materials as sandwich core materials are few and far between, with balsa wood among the few established organic-based cores. To date, there is no existing literatures regarding the usage of the kenaf fibres as a constituent material of the honeycomb core of a sandwich panel. This is quite surprising considering the fact that the sandwich panel is a popular structure and no stranger to utilising composite materials. Incorporating the kenaf fibre into the sandwich structure presents a good opportunity to construct a highly efficient and green composite material.

To fully extract the benefit of a kenaf reinforced sandwich structure, one has to be well-versed with the varying factors that could influence the performance and mechanical properties of it. These include length of fibre, fibre volume fraction, fibre modulus, height and size of honeycomb core cells. When analysing the sandwich and composite structure, these factors can be efficiently accounted for through the use of finite element analysis and numerical modeling.

1.4 RESEARCH OBJECTIVES

i. To determine the stiffness of the short and long kenaf-epoxy core sandwich panel with various parameters through existing modeling from other literatures and to compare the determined values with those of E-glass-epoxy sandwich panel.
ii. To evaluate the performance of the short and long kenaf-epoxy core sandwich panel with respect to the E-glass-epoxy sandwich panel through various parameters in a simple bending test by utilising finite element analysis.
iii. The investigate the influence of several parameters -- namely the fibre volume fraction and kenaf fibre modulus, as well as the cell wall thickness, cell wall length, and density of the core -- on the orthotropic material properties and performance of the kenaf core sandwich panel.

1.5 SCOPE OF RESEARCH

i. The appropriate continuum modeling for the kenaf/epoxy core sandwich panel. A proven and experimentally-verified approach and modeling was be taken. This work did not attempt further validation of the values derived from the modeling.

ii. The comparison of the kenaf core and glass core sandwich panel in terms of the orthotropic material properties and simple bending test simulation.

iii. The parameters that were focused on were confined to the fibre volume fraction, kenaf fibre modulus, cell wall thickness and cell wall length of the core and core density.

1.6 ORGANISATION OF THESIS

Chapter 1 gives an overview of composites, synthetic and natural fibres and sandwich panel. In chapter 2, literature review about natural fibres, kenaf, sandwich structure and sandwich modeling is presented. Methodology of analysis and modeling of kenaf core sandwich panel are shown in chapter 3. The results and discussion are in chapter 4. Finally, conclusions are contained in chapter 5.

CHAPTER TWO

LITERATURE REVIEW

2.1 KENAF

2.1.1 Overview

Before the advent of kenaf in the composite industry, kenaf has been traditionally harnessed in the forms of rope, canvas and sacking. Since the last century, this multi-purpose plant known scientifically as *Hibiscus cannabinus*, L.family Malvacea, has been utilised as an alternative source for pulp and paper (Nishino, 2004). Most of the components – ranging from the seeds to the leaves – of kenaf are useful, from which fibres, proteins, oil and alleopathic chemicals could be extracted (Akil et al., 2011).

Kenaf filaments are made of discrete individual fibers, usually in the range of 2 to 6 mm. Sources, age, separating technique and history of the fibres are the variables that determine the filaments and individual fibre properties. The stem is straight and unbranched and consists of an outer layer (bark) and a core. The process to separate the stem into bark and core is through chemicals means and/or by enzymatic retting. The bark constitutes 30– 40% of the stem dry weight and shows a rather dense structure. On the other hand, the core is wood-like and makes up the remaining 60–70% of the stem. The core reveals an isotropic and almost amorphous pattern. However, the bark shows an orientated high crystalline fibre pattern (Akil et al., 2011).

Kenaf falls under the category of bast fibres, which include flax, hemp, jute and ramie. These fibers are derived from wood core and stem materials. The wood core is basically surrounded by the stem, which consists of a number of fiber bundles (Beckwith, 2003). In comparison with other types of plant fibres like leaf and seed, the bast fibers shows a superior flexural strength and modulus of elasticity (MOE). The bast fibres also tend to show approximately the same flexural strength and a higher MOE when compared to glass fibres (Zampaloni, 2007).

2.1.2 Advantages

1) Low Cost

One of the earliest and main impetus for natural fibre, including kenaf, utilisation in composites is low cost. The clear superiority of the natural fibres compared to E-glass in terms of price and density is shown in Table 2.1. This is especially true in countries that actively cultivate kenaf and other types of natural fibres, like in Malaysia and the United States.

Zampaloni et al. (2007) made a comparison between the natural fibres and glass in terms of modulus per cost which further accentuate the former's superiority (Fig. 2.1). The advantage of kenaf in this regard over E-glass is so obvious that it is a little wonder kenaf is one of the most popular -- if not the most -- natural fibres in the United States and elsewhere.

It is not only a question of raw material price that makes kenaf utilisation cheaper, but also other related activities that lead to that utilisation. Natural fibre cultivation, processing and transportation all use lower energy compared to the whole process of making glass fibre, which in turn lower the whole production cost (Joshi et al., 2003).

Table 2.1 Density of the glass fibers and natural/bio-fibers (Zampaloni et al., 2007).

Fiber	Density (g/cm^3)	Cost (kg^{-1})
Flax	1.4–1.5	~\$0.40–\$0.55
Hemp	1.48	~\$0.40–\$0.55
Jute	1.3–1.45	~\$0.40–\$0.55
Sisal	1.45	~\$0.40–\$0.55
Ramie	1.50	~\$0.44–\$0.55
Pineapple leaf	1.53	~\$0.40–\$0.55
Cotton	1.5–1.6	~\$0.44–\$0.55
Coir	1.15	~\$0.40–\$0.55
Kenaf	1.4	~\$0.40–\$0.55
Softwood	1.4	~\$0.44–\$0.60
Hardwood	1.4	~\$0.44–\$0.60
E-glass	2.5	~US \$2
S-glass	2.5	~US \$2

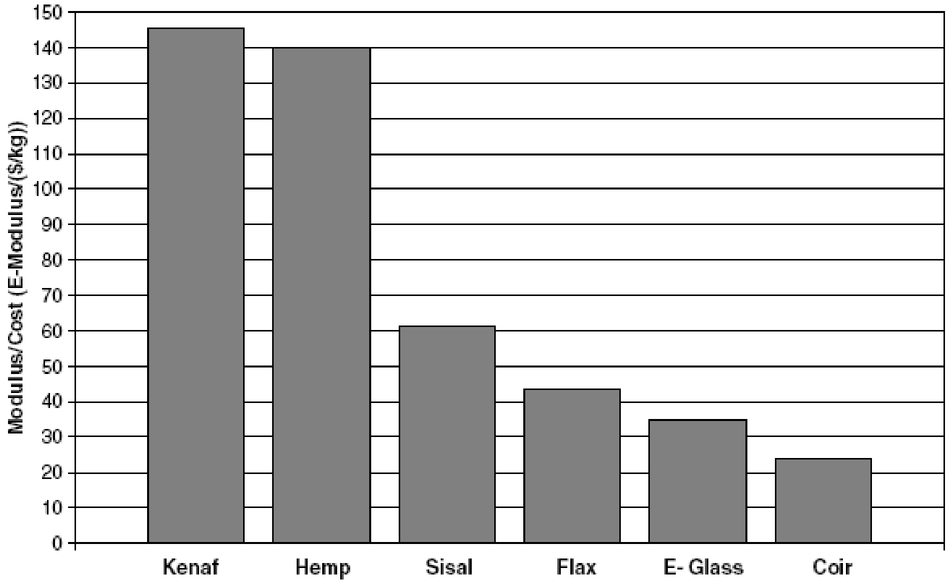

Figure 2.1 Comparison of Modulus Per Cost for Various Fibers (Zampaloni et al., 2007).

2) Low Density and High Specific Modulus

The next major catalyst is the low density of kenaf and other natural fibres. The weight difference between natural fibres and glass is quite considerable (Table 2.1). As the automotive industry is pushing for more lightweight body parts to enhance fuel efficiency, density reduction is of utmost importance. But low density alone would not guarantee good performance of a composite. Natural fibres are actually lagging behind their synthetic counterparts based on strength and stiffness. Also, as shown in Fig. 2.2 and 2.3, the tensile and flexural strength of kenaf is not the highest compared to others. But the encouraging fact is that when taking into account the specific modulus –which is modulus divided by density—of the kenaf fibre, this is where kenaf shows its true worth. Kenaf is clearly better than its other rival fibres, including E-glass, by a huge margin (Fig. 2.4).

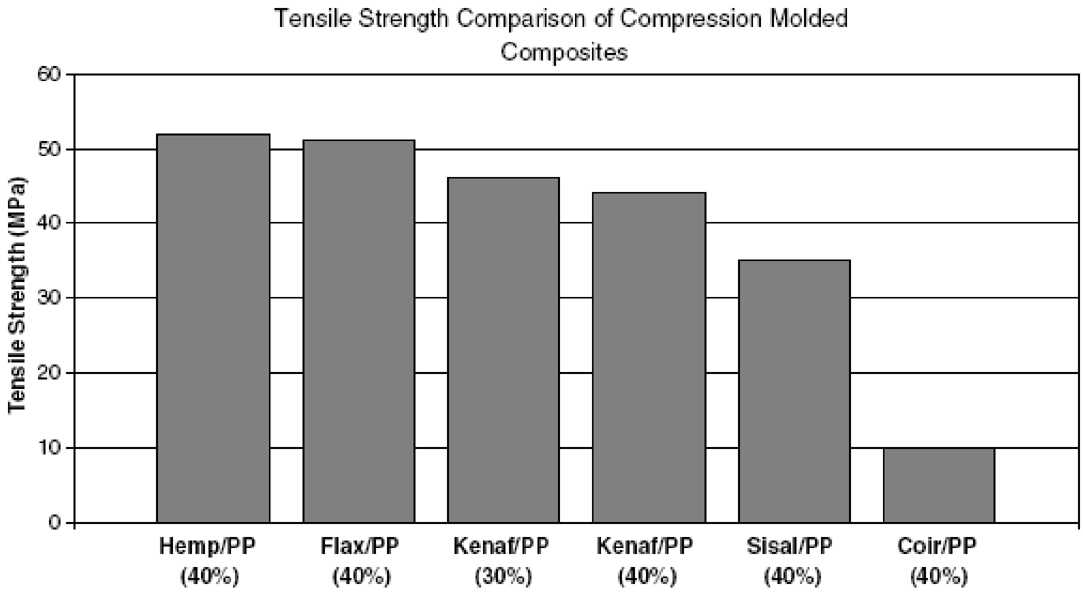

Figure 2.2 Comparison of tensile strength of kenaf/PP–MAPP composites to other natural fiber composites (Zampaloni et al., 2007).