UNIVERSITI PUTRA MALAYSIA

MONOTONIC AND FATIGUE PROPERTIES OF KENAF/GLASS FIBER-REINFORCED HYBRID COMPOSITES

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By

MOHAIMAN JAFFAR KASHKOL

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

Every challenging work needs self efforts as well as guidance of elders especially those who were very close to our heart. Whose affection, love, encouragement and prays of day and night make me able to get such success and honor and the reason of what I become today.
My humble effort I dedicate to my sweet and loving

Father & Mother

To my sisters, my wife (Sura) and my kids (Yousif and Rahaf)

I am really grateful to all of you.

You have been my inspiration, and my soul mates.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman : Zulkiflle Leman, PhD
Faculty : Engineering

The range of applications involving natural fiber composites in engineering design is still limited due to a lack of understanding of the long-term behavior of these materials, especially under cyclic fatigue loading. The primary aim of this research was to experimentally determine the monotonic properties and fatigue life behavior of woven kenaf fiber reinforced unsaturated polyester composites and the effects of hybridization of E-glass fabric on these properties through stages of hybridization and different states of stress. This work was divided into four stages to achieve the specified objectives. The first stage investigated the mechanical properties of a single layer of woven kenaf reinforced unsaturated polyester, fabricated by vacuum infusion and hand lay-up. The results showed an overall improvement in tensile and flexural strengths also their corresponding moduli for composites fabricated by the hand lay-up when compared with the ones fabricated by vacuum infusion. Therefore, hand lay-up method was adopted to fabricate the hybrid composites in the next stages. The second stage focused on comparing the effect of kenaf fiber alignment on the monotonic and fatigue properties of kenaf/glass hybrid composites laminate with glass shell and kenaf core. Three types of kenaf fibers were used, namely, non-woven random mat, unidirectional twisted yarn, and plain-woven kenaf with kenaf/glass weight ratio of 30/70% and a volume fraction of 35%. Tensile, compression, flexural, and fully reversed fatigue tests were conducted. Non-woven mat kenaf hybrid composite showed the poorest properties for all tests, while woven and unidirectional kenaf displayed much higher set of properties. Hybridization with kenaf fibers improved the fatigue degradation coefficient of the final composites to 6.6% and 6.8% for woven and unidirectional kenaf, respectively, compared with 8.4% for non-woven. The third stage was continued with a partial replacement of glass fiber by woven kenaf fabric reinforced unsaturated polyester. The replacement was achieved in three weight ratios of 70/30 (H1), 55/45 (H2) and 30/70 (H3) to fabricate hybrid composites. In addition, pure glass and kenaf composites were fabricated for comparison purposes. All composites had an approximate fiber volume fraction of 35-40%. Tensile, compression, and flexural tests were performed. Finally, the fourth stage, based on the ultimate static strength determined, uniaxial cyclic fatigue tests were conducted under three different stress ratios (R) of 0.1 (Tension-Tension), -1 (Tension-Compression), and 2.5 (Compression-Compression). Stress levels ranged from 30% to 70% of their ultimate static strength were used with R = 0.1 and -1, and from 40% to 90% of ultimate static strength with R = 2.5. Wohler S-N curves were generated for each stress ratio for all composites, which were used to construct a constant life diagrams for each composite. In conclusion, hybridization of glass fiber with kenaf fiber showed unique and improved influence on monotonic as well as fatigue properties.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SIFAT BEREKANADA DAN KELESUAN KOMPOSIT HIBRID BERTETULANG GENTIAN KENAF/KACA

Oleh

MOHAIMAN JAFFAR KASHKOL

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Penglibatan komposit gentian semulajadi dalam bidang rekabentuk kejuruteraan masih terhad disebabkan kurang kefahaman tentang sifat jangka panjang bahan tersebut, khususnya dalam bebanan kitaran lesu. Tujuan utama penyelidikan ini adalah untuk mengkaji sifat monotonik dan kelakuan jangka hayat lesu komposit poliester tak tepu diperkuat anyaman kenaf, serta kesan hibridasi fabrik E-kaca terhadap sifat-sifat tersebut melalui peringkat hibridasi dan peringkat tegasan yang berbeza. Kajian ini dibahagikan kepada lima peringkat untuk mencapai objektif yang ditetapkan. Peringkat pertama adalah untuk mengkaji sifat mekanikal selapis anyaman komposit poliester tak tapu diperkuat gentian kenaf yang direka menggunakan infusi vakum dan teknik penekanan tanpa haba. Keputusan menunjukkan peningkatan secara keseluruhan dalam kekuatan tegangan dan lenturan, serta modulus bagi komposit yang dihasilkan secara tekanan tanpa haba. Oleh itu, kaedah tekanan tanpa haba digunakan untuk menghasilkan komposit hibrid dalam peringkat seterusnyai. Peringkat kedua memfokus kepada perbandingan kesan penjajaran gentian kenaf terhadap sifat mekanik dan kelesuan komposit hibrid kenaf/kaca berkonfigurasi selang seli bersimetri dengan petala kaca dan teras kenaf. Tiga jenis gentian kenaf digunakan iaitu alas rawak tanpa tenunan, benang pintal ekaarah dan kenaf tenunan biasa dengan nisbah berat kenaf/kaca sebanyak 30/70% serta pecahan isipadu pada 35%. Ujian tegangan, mampatan, lenturan, dan kelesuan berbalik penuh turut dijalankan. Alas tanpa tenunan hibrid kenaf diasingkan daripada perbandingan akibat kelemahan sifat dalam semua jenis ujian. Penghibridan dengan gentian kenaf berjaya meningkatkan pekali degradasi kelesuan bagi komposit terakhir, masing-masing kepada 6.6% dan 6.8% bagi kenaf tenunan dan ekaarah, dibandingkan dengan 8.4% bagi kenaf tanpa tenunan. Peringkat ketiga diteruskan dengan penggantian separa gentian kaca dengan kain kenaf tenunan diperkuat poliester tak tepu. Penggantian ini dicapai melalui tiga nisbah berat iaitu 70/30 (H1), 55/45 (H2) dan 30/70 (H3) untuk menghasilkan komposit hibrid. Selain itu, komposit kaca dan kenaf tulen turut dihasilkan untuk tujuan perbandingan. Kesemua komposit mempunyai anggaran pecahan isipadu gentian pada kadar 35-40%. Ujian tegangan, mampatan, dan

lenturan dijalankan sekali lagi. Pada peringkat keempat, berdasarkan kekuatan statik muktamad yang diperoleh pada peringkat ketiga, ujian kelesuan kitaran ekapaksi dijalankan berdasarkan tiga nisbah tegasan (R) yang berbeza iaitu pada 0.1 (Tegangan-Tegangan), -1 (Tegangan-Mampatan), dan 2.5 (Mampatan-Mampatan). Tahap tegasan di antara 30% hingga 70% daripada kekuatan statik muktamad digunakan dengan R = 0.1 dan -1. Tahap tegasan di antara 40% hingga 90% daripada kekuatan statik muktamad dengan R = 2.5 turut digunakan. Keluk Wohler S-N dijana bagi setiap nisbah tegasan untuk semua komposit yang digunakan untuk membina gambar rajah hayat tetap untuk setiap komposit. Kesimpulannya, proses hibridasi gentian kaca dengan gentian kenaf telah menunjukkan keunikan dan pengaruh penambahbaikan terhadap sifat monotonik dan kelesuan.

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I certify that a Thesis Examination Committee has met on 29 November 2016 to conduct the final examination of Mohaiman Jaffar Kashkol on his thesis entitled "Monotonic and Fatigue Properties of Kenaf/Glass Fiber-Reinforced Hybrid Composites" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
CO_2	Carbon dioxide
C-C	Compression-Compression
HLU	Hand Lay-Up
HCFS	High Cyclic Fatigue Strength
HE	Hybridization Effect
ISO	International Organization for Standardization
IRT	Infrared Radiation Thermography
NDE	Non-Destructive Examination
NWK	Non- Woven Kenaf mat
SEM	Scanning Electron Microscopy
S-N	Stress-Number of Cycles
T-T	Tension-Tension
T-C	Tension-Compression
UDK	Unidirectional Kenaf
UP	Unsaturated Polyester
UCS	Ultimate Compressive Strength
UTS	Ultimate Tensile Strength
VI	Vacuum Infusion
WK	Woven Kenaf

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Polymer composites reinforcement fibers can commonly classify into two types: synthetic fibers such as glass, carbon, etc., and natural fibers including kenaf, flax, hemp, sisal, etc (Mohanty *et al.*, 2000). Although the glass fiber reinforced plastic composites meet structural and durability demands, they have shortcomings such as in their relatively high fiber density, difficulty to the machine, small recycling properties, and the potential health hazards posed by glass fiber particulates (Holbery *et al.*, 2006). Natural fibers are environmentally friendly and sustainable materials, which can be used to replace synthetic fibers in the composite industry (Faruk *et al.*, 2014). Despite this attractiveness of natural fiber reinforcement, several disadvantages were noticed, such as poor wettability, inconsistence physical and mechanical properties, and low moisture resistance makes it insufficient for advanced applications (Abedin *et al.*, 2006). Therefore, hybrid fibers composite is the best solution to overcome these disadvantages and create a balance in the advantages of individual ones (Faruk *et al.*, 2014).

In the last decade natural/ synthetic hybrid fiber composites have an increased interest due to the environmental awareness of consumers and as a realistic alternatives to replace or reduce synthetic fibers usage (Swolfs *et al.*, 2014). This applied in many sectors for application consumer's goods and low cost housing (Ratna and Rao 2011), structural (Atiqah *et al.*, 2014), automotive components (Davoodi *et al.*, 2010), military and ballistic (Yahaya *et al.*, 2014a, 2014c), and biomedical applications like orthopedic medicine and socket prosthesis (Bagheri *et al.*, 2013; Bharath *et al.*; Me *et al.*, 2012; Ramakrishna *et al.*, 2001; Scholz *et al.*, 2011). Figure 1.1 and Figure 1.2 show some of the potential applications developed using natural/synthetic hybrid composites. Recently, the use of hybrid composites have found increased applications in bridges and building construction sectors (Faruk *et al.*, 2014).

Figure 1.1: Medical applications fabricated from fiber composites (Ramakrishna *et al.*, 2001; Scholz *et al.*, 2011).

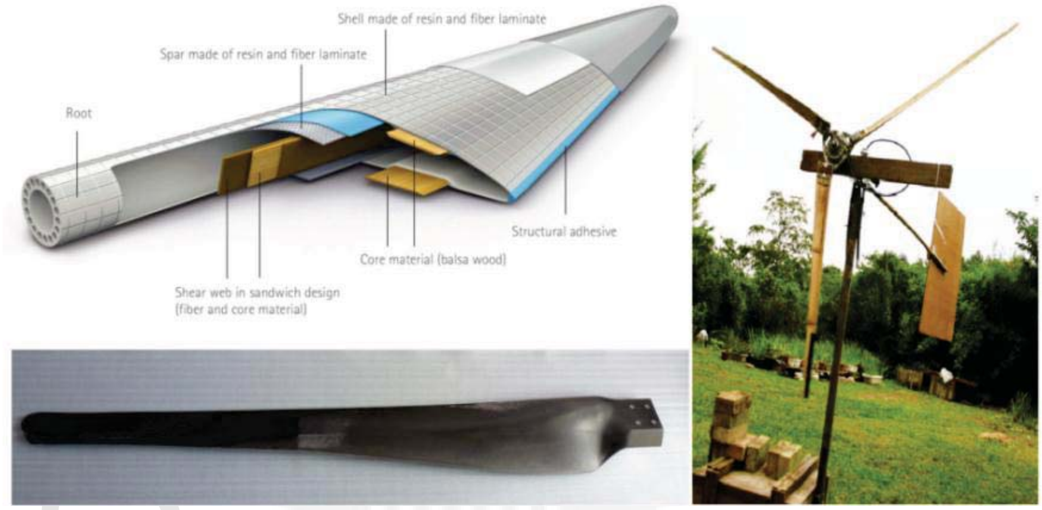

Figure 1.2: Wind turbine blade materials specifications and prototypes fabricated from natural fiber composites (Shah *et al.*, 2013)

Hybrid composites offer three key benefits over single reinforcement composites for many reasons. Firstly, they offer engineers with new choices of tailoring composites to attain required properties (Swolfs *et al.*, 2014). Secondly, a more cost-effective use of highly cost and nonrenewable fibers as glass could be achieved by changing them partially with cheaper and eco-friendly fibers such as kenaf (Mansor *et al.*, 2013). Finally, a balanced mixture of properties for instant, strength, ductility, and stiffness can be achieved by hybrid composites (Jawaid *et al.*, 2011). The glass fiber is more prevalent, as it offers greater improvements in most mechanical properties. Precisely, kenaf bast fiber which has been proven using analytical hierarchy process to be the best choice for hybridization with synthetic fibers for different structural applications (Mansor *et al.*, 2013; Yahaya *et al.*, 2014).

Fatigue has been recognized as a unique and independent failure process (Swolfs *et al.*, 2014). Widespread studies of fatigue failures have led to the conclusion that fatigue causes as many as 90% (Abo-Elkhier *et al.*, 2012) or 80% (Gassan *et al.*, 2003) of all material failures. Although the usage of natural fibers is on the rise, around 95% of plant fibers are used for non-structural automotive components sectors (Shah *et al.*, 2013; Swolfs *et al.*, 2014). The fatigue performance of natural fiber composites suggests that they are suitable for use in dynamically loaded structures and may be utilized as a substitute for glass fiber reinforced composites in fatigue (Jawaid *et al.*, 2011; Shah *et al.*, 2013; Towo *et al.*, 2008b).

However many authors assessed the fatigue life of natural fibers reinforced composites in tension–tension mode (Abdullah *et al.*, 2015; Belaadi *et al.*, 2013), used different fiber structure (Shah *et al.*, 2013). A few studies were reported on the uniaxial fatigue life of hybrid (Bagheri *et al.*, 2014; Shahzad *et al.*, 2011; Thwe *et al.*, 2003) which was limited to the tensile fatigue performance or for fixed fiber ratio. There are many aspects not covered yet and for an instance, the effects of the natural fiber structure of hybrid composites, the gradual replacement of synthetic fiber with natural fiber, and the fatigue stress ratio on the fatigue sensitivity and fatigue life of hybrid composites.

1.2 Problem Statement

Fiber-reinforced composites are drawing more concern for these weight-sensitive applications due to their superior strength and stiffness is linked with low-density fibers (Swolfs *et al.*, 2014). Extensive studies have reported tensile, flexural, low, and high-velocity impact strength of hybrid composites (Swolfs *et al.*, 2014). The positive conclusion of these studies indicates natural fibers are good candidates to replace glass fiber composites (Ochi, 2008). However, the range of applications involving natural fiber composites in engineering design is still limited due to a lack of understanding of the long-term behavior of these materials, especially under cyclic fatigue loading. Like all composites, this can be attributed to the complex nature of how these materials fail (Fotouh *et al.*, 2014). Also for natural fiber based composites, there has been lots of work focused on determining monotonic properties, but very limited studies related to fatigue life was observed (Fotouh *et al.*, 2014; Shah *et al.*, 2013).

Fatigue resistance is an essential property for many composite applications such as aircraft or wind turbine blades (Mohammed *et al.*, 2015). The ductile fibers as natural fibers can act as crack stoppers for the broken brittle fibers as glass fiber in a hybrid composite (Swolfs *et al.*, 2014; Hancox, 1981). Also, it is proven that natural fiber composites possess lower fatigue sensitivity than glass fiber reinforced composites (Shah *et al.*, 2013). It could be expected to extend the fatigue life of hybrid composites compared to that of single fiber composites.

However, the usage of natural fiber is increased, many aspects of their behavior are still ineffectively investigated (Fotouh *et al.*, 2014). Lack of researches regarding the fatigue behavior of kenaf or kenaf–synthetic hybrid composite, the constant life diagram is not studied yet. Hybridization influence under more complicated loading conditions such as fatigue test are not well identified. Therefore, more research is required in this area to define the essential mechanisms and to simplify the conclusions.

1.3 Research Objectives

The primary objective of this study to experimentally determine the monotonic properties and fatigue life behavior of woven kenaf fabric reinforced unsaturated polyester composites, also, the effects of hybridization of E-glass fabric on these properties through three stages of hybridization and different states of stress. The specific objectives of this work are:

1. To characterize the physical and the monotonic properties of woven kenaf fiber using vacuum infusion and hand lay-up methods.
2. To determine the effect of kenaf fiber orientation on the monotonic properties and fatigue life of kenaf/glass-reinforced hybrid composites.
3. To investigate the effects of partial replacement of glass by woven kenaf on monotonic and fatigue properties of kenaf/glass-reinforced hybrid composites.
4. To determine the fatigue life of hybrid composites at different fatigue stress ratios and predicting the fatigue life cycle by generating a full constant life diagram.

1.4 Scope of Study

This study focuses on using woven textile kenaf fiber as a primary candidate, which was utilized as received without any chemical treatment. The fabrication method is an important and efficient parameter on the mechanical properties of composites. Therefore, two fabrication methods were used to fabricate a single kenaf layer reinforced unsaturated polyester fabricated using hand Lay-Up (HLU) and vacuum infusion (VI). Woven kenaf fiber was selected to gain the maximum performance of kenaf fiber and to replace glass fiber in hybrid composites. Hybridization was achieved via two stages. First, by fixing kenaf/glass fiber ratio and using different kenaf pattern, while the other one by changing kenaf to glass fiber ratio within the hybrid composite. The resulted hybrid composites were tested under different monotonic and fatigue loading conditions to assess the trend of; static behavior, fatigue life performance, fatigue sensitivity, failure mechanisms, and fatigue constant life diagram through hybridization process.

1.5 Thesis Outline

This research consists of five chapters including:

Chapter 1: presents a brief background to the field of hybrid composite materials with focusing on the noticeable lack of mechanical behavior and highlight the research problems also, describing the objectives of research, finally defines the boundaries of this work.

Chapter 2: contains reviews of the available literature on natural fibers composites and factors influencing monotonic properties, cyclic fatigue loading of natural/synthetic fiber reinforced hybrid composite will be discussed in this chapter.

Chapter 3: in this chapter will show the materials specifications, mechanical tests details, equipment, and standards followed. Finally, the adopted methodology to attain the research objectives will be explained in details in this chapter.

Chapter 4: discussion on the results and findings of the study will be presented in this chapter.

Chapter 5: conclusions on the findings of the research will be drawn. Finally, the recommendations for future research will be suggested in this chapter.

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