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VOLUMETRIC COMPOSITION AND HYBRIDIZATION EFFECTS ON MECHANICAL PROPERTIES OF THE PULTRUDED HYBRID KENAF/GLASS FIBER COMPOSITES

SEYED FARIBORZ HASHEMI DIZAJI

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By

SEYED FARIBORZ HASHEMI DIZAJI

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

November 2015

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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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November 2015

Chairman: Professor. Paridah Md.Tahir, PhD

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The properties of fiber reinforced composite materials strongly depend on the volumetric composition of the composite (i.e.,volume of fiber, matrix, and void). Natural fibers have lower packing ability than synthetic fibers. Thus, fiber volume fraction of natural fibers is less than that of synthetic fibers. This characteristic is very crucial particularly for controlling and designing the volumetric composition of the hybrid natural/synthetic fiber reinforced composites. Based on the constant local fiber volume fraction criteria, an equation was derived for calculation of the required number of yarn/roving for fabrication of pultruded hybrid kenaf/glass composites. Six types of pultruded composite (two non-hybrids and four hybrids) with different fiber mixing ratios were manufactured. The volumetric composition of the composites was determined gravimetrically. Optical microscopy was employed to determine the location of voids. Three types of voids were identified, namely lumen voids, interface voids and impregnation voids. It was found that there was a linear relationship (R^2= 0.96) between the kenaf fiber and void volume fraction. Impregnation voids constituted the highest amount of the voids which appeared to be caused by the moisture content of the kenaf fibers. It was found that the volume fraction of the fiber is directly related to the selected number of rovings, and not affected by the void volume fraction of the composites. The experimental volumetric composition of the composites showed the very good agreement with the volumetric composition model. The hybridization effect was studied on interlaminar shear strength, compression, flexural, dynamic flexural vibration and damping properties of the composites. The failure modes under static loading condition were studied. It was found that the mechanical properties of the composites are decreased as the kenaf and void volume fraction is increased. The regression analysis showed that there is a good agreement between the static and dynamic flexural modulus.

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PENILAIAN KOMPOSISI ISIPADU DAN KESAN PENGHIBRIDAN TENTANG SIFAT-SIFAT MEKANIKAL KE ATAS KOMPOSIT HASIL PULTRUSI HIBRID GENTIAN KENAF DAN GENTIAN KACA

Oleh

SEYED FARIBORZ HASHEMI DIZAJI

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I certify that a Thesis Examination Committee has met on 24 November 2015 to conduct the final examination of Seyedfariborz Hashemidizaji on his thesis entitled "Volumetric Composition and Hybridization Effects on Mechanical Properties of the Pultruded Hybrid Kenaf/Glass Fiber 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

wt%	Weight percentage
V_f	Fiber volume fraction
v_f	Absolute fiber volume
v_c	Absolute composite volume
A_f	Fiber cross section area
A_c	Composite cross section area
T_r	Linear density of the fiber
ρ_f	Density of the fiber
V_{cf}	Composite volume fraction of fiber
v_{cf}	Absolute composite volume of fiber
v_{cf}	Absolute composite volume of fiber
v_m	Matrix absolute volume
V_f^*	Local fiber volume fraction
v_m^*	Local matrix volume
V_f^0	Non-hybrid fiber volume fraction
n_r	Number of yarns
n_r^0	Number of yarns for non-hybrid composites
β	Hybrid fiber weight mixing ratio
m_f	Mass of the fiber
γ	Hybrid fiber volume mixing ratio
W_f	Fiber weight fraction
T_c	Linear density of the composite
m_m	Mass of the matrix
m_c	Mass of the composites
ASTM	American Society for Testing and Materials
V_m	Matrix volume fraction
V_v	Void volume fraction
ILSS	Interlaminar shear strength
S	Interlaminar shear strength
P	Breaking load
d	Diameter of the specimen
ANOVA	Analysis of variance
σ	Stress
ε	Strain
L	Length of the sample
ΔL	Displacement
E_F	Modulus of elasticity
ρ	Density
I_{GZ}	Moment of inertia
v	Transversal displacement
G_{XY}	Shear modulus
A	Cross section area of the beam
t	Time
f_n	Resonance frequency of the order n
P_n	Coefficient associated with the solution of Bernoulli
$s(x,t)$	Temporal signal
A_n	Amplitude

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ω_n	Angular frequency
α_n	Temporal damping of the nth component
δ	Logarithmic decrement
x_0	First amplitude
x_n	Final amplitude
$tg\delta$	Damping (internal friction)
F	Load
L	Span length of the beam
r	Radius of the beam
δ	Displacement
R	Diameter of the beam sample
SPSS	Statistical Package for the Social Sciences

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CHAPTER 1

INTRODUCTION

1.1 General Background

The composite material is manufactured by mixing, at least, two different materials to form a new material with superior properties. Composites contribute us to achieve the preferred properties by combining various materials in a proper form (Nunna et al., 2012). The main factors for composites usage are low weight, corrosion resistance, and high specific stiffness and strength. Other advantageous of composites include electromagnetic transparency, wear resistant, improved fatigue life, thermal and acoustical isolation, small thermal expansion, suitable thermal conductivity, etc (Barbero, 2011). The higher specific modulus (modulus per unit weight) and specific strength (strength per unit weight) of composite materials are two very important factors particularly in transport components where weight reduction cause better efficiency and energy saving (Hull and Clyne, 1996).

Many materials are stronger and stiffer in the form of the fiber than in bulk form thus making fiber reinforcement very effective (Gibson, 1994a). However, strong fibers cannot be applied alone because fibers cannot endure transverse or compression loads. For this reason, a binder or matrix is required for holding the fibers together and protect them against the environmental and external destructions. Matrix materials keep the fibers together by generating the continuous and consistently formed material to endure the load that is being transferred between fiber and matrix Matrix materials are divided into three broad categories, metal, ceramic and polymers. Polymers are most common matrix materials in modern composites.

In recent years, because of ecological and environmental concerns, the composite industries have shifted to using the natural fibers as partial replacement of petroleum-based products (Jawaid and Abdul Khalil, 2011a). Reviewed work on composite using cellulosic natural fibers such as sisal, coir, jute, ramie, kenaf and pineapple leaf, concluded that these renewable resources have the potential to be used alternatively with glass or other synthetic reinforcement materials.

The earlier studies have shown the advantages of combining different fiber types in a single matrix for hybrid composite fabrication (Bunsell and Harris, 1974; Arrington and Harris, 1978; Fischer and Marom, 1987; Peijs et al., 1990). This approach is used in the hybridization of natural/synthetic fibers. Natural fiber has some advantageous, for example, they are low-density, low-cost, available from renewable sources and non-abrasive, and disadvantageous such as hydrophilic characteristic and moderate mechanical properties (Amico et al., 2010). The hybridization of the natural and synthetic fiber creates a hybrid composite with moderate properties. Also, it creates a balancing effect in performance, environmental advantageous and cost effectiveness in composite material. (Arbelaiz et al., 2005; AlMaadeed et al., 2012; Atiqah et al., 2014).

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Natural fiber, in contrary to the synthetic fibers, have not a uniform structure and, therefore, the fiber alignment controlling and orientation are crucial to assure the effective mechanical properties and maximum fiber content (Madsen et al., 2007b). The applied natural fibers for reinforcing in polymer composites are relatively short. For example, flax and hemp fibers are no longer than 5-8 cm of length. Therefore, for positioning and processing of the fibers, traditionally they are spun into yarns from using the ring-spinning technique where the parallel bundle fibers are twisted into a spiral configuration (Rask and Madsen, 2011).

Recently the plant fiber composites have been used mainly in non-structural material applications in non-load bearing components using the random fiber orientation in automotive and building industries (Parikh et al., 2002; Karus et al., 2003). With the advent of the aligned plant fibers as reinforcement for fabrication of composite materials, the processes such as filament winding and pultrusion gained much attention for application of the aligned plant fiber composites. The using of the aligned plant fiber composites have a significant advantageous. The aligned fibers provide the feasibility of fabrication of the composite with high fiber volume fraction and high tensile properties of the composites. Thus, the potential of natural fibers in composites for structural elements can be studied by employing plant fiber textile yarns for composite reinforcement (Madsen et al., 2007a).

One of the potential usages of aligned natural fiber is in pultrusion process for fabrication of composites in comparison with other fabrication techniques. Pultrusion is a proper procedure for fabrication of the aligned fiber composites for load-bearing structural components. For aligned composites such as pultruded, the theoretical maximum fiber volume fraction for hexagonal and square packing of fibers is 90.7 % and 78.5 % respectively. However, due to the non-regular packing of the fiber, the practical maximum fiber volume fraction is 70 % (Hull and Clyne, 1996; Irfan, 2013). This high fiber content makes up pultrusion a remarkable process for fabrication of the hybrid and non-hybrid natural fiber based composites (Lackey et al., 2007b; Peng et al., 2011; Zamri et al., 2011a; Akil et al., 2014; Zamri et al., 2014).

1.2 Problem Statement

The mechanical properties of the composites materials depend on some crucial factors such as mechanical properties of the fiber and matrix, volumetric composition of the composite (i.e.,volume fraction of the fiber, matrix and voids), the, arrangement of the fibers, and interface features of the fiber and matrix. In this study our focus is on the volumetric composition of the pultruded plant fiber composites.

The volumetric composition is one of the main factors that effects on the macro-mechanical behavior of the fiber reinforced composites (Shah, 2013). Knowledge of the volumetric composition of composites is vital for reliable predictions of the model for mechanical, physical, and thermal property of composites (Madsen et al., 2007b).

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In numerous investigations on mechanical characteristics of plant fiber composite, the volumetric composition of the composites is not well-evaluated (Madsen et al., 2009). Whereas most researchers provide estimations of fiber weight fraction and some state the fiber volume fraction considering no voids (Shah et al., 2012d). It is known that the fiber volume fraction has a direct effect on mechanical properties of the composites. The fiber volume fraction is an important factor for adjusting the composite mechanical performance (Nishino et al., 2003; Aslan et al., 2013; Shah, 2013). Thus, understanding of the volumetric composition of composites is crucial for reliable predictions of the model for mechanical, physical, and thermal characteristic of composites (Madsen et al., 2007b).

The structure comparison of the natural fibers and synthetic fibers showed that, unlike synthetic fibers, the natural fibers are not uniform, they are discontinuous (Madsen et al., 2007a; Stevens and Müssig, 2010; Shah et al., 2013). Such properties give rise to lower packing ability of the natural fibers, consequently affects the volumetric proportions between natural and synthetic fibers. The non-equality of the fiber volume fraction value of both fibers requires a more detail calculation when used to make the hybrid natural/synthetic fiber reinforced composites.

It was demonstrated that the maximum achievable fiber volume fraction in plant fiber composites is lower than the one in synthetic fiber composites (Madsen and Lilholt, 2002; Madsen, 2004a; Goutianos et al., 2006; Stevens and Müssig, 2010; Shah et al., 2013; Durai Prabhakaran et al., 2014a). In a detailed study by Shah et al. (2012d), the theoretical maximum fiber volume fraction for aligned plant fiber composite were found to be 58.9 % which is in a good agreement with experimental data as well.

Pultrusion process is known as a suitable method for producing of composites with high fiber content to about 70% by volume. For fabrication of the pultruded non-hybrid natural fiber and hybrid natural/synthetic fiber composites, the low packing ability of the natural fibers in relative to synthetic fibers must be taken into account for controlling of the natural and synthetic fiber volume fraction and calculation of the actual required number of yarns.

A number of studies can be found on the topic of pultruded hybrid natural/synthetic fiber composites (Mazuki et al., 2011; Safiee et al., 2011; Zamri et al., 2011b; Akil et al., 2014; Zamri et al., 2014). However, these studies appear not to have considered the low packing ability and low fiber volume fraction of the plant fibers, and none had mentioned about how to control fiber volume fraction . It is important to note that the accurate measurement and designing of the volumetric composition is crucial for reliable mechanical and physical characterization of the composite.

1.2.1 Hypothesis of the Study

One of the important factors that influence the volumetric composition of the natural fiber composites is void content. Such voids are formed due to the existence of lumen in the woody cells, as a result of the lack of the matrix penetration into the lumen. The incompatibility of the chemical composition of

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the natural fibers (hydrophilic) and polymeric matrix (hydrophobic) will cause the formation of voids between the fibers and matrix. In addition, the heterogeneous dimension structure of the natural fibers restricts the matrix impregnation, and it will cause the creation of the voids during the processing of the composites (Madsen et al., 2007b; Aslan et al., 2013). Based on the detailed study by Madsen et al. (2007b), the voids part in natural fiber composites usually makes a considerable participation to the volume fraction of the fiber and volume of the composite and should be taken into account.

However, in pultrusion process due to the constant cross section of the die, the volume of the final composite is constant. It is assumed that the void volume fraction has no effect on both volume fraction of the fibers and volume of the final composite. Therefore, the hypothesis used in this study was;

> The volume fraction of the fibers is directly related to the applied number of yarn/ rovings, and the voids volume fraction has no effect on fiber volume fraction and composite volume.

In this study, this hypothesis was examined by fabrication of the pultruded composites with various numbers of yarn and rovings, to evaluate the volumetric composition of the pultruded composites.

The relationship between volumetric composition in pultruded hybrid and non-hybrid natural fiber composites are still not known. The fundamental aspect of these relationships needs to be investigated for fabrication of the high quality pultruded composite. In this study, these fundamental characteristics were addressed before characterisation of the composite properties.

1.3 Objectives

1- To derive the formula for calculating the number of yarns/ rovings, and controlling the volumetric composition in pultruded hybrid natural/synthetic fiber composites.
2- To evaluate the effect of number of yarns/rovings on the volumetric composition of pultruded hybrid kenaf/glass fiber composites.
3- To determine the hybridization effect on mechanical properties of the composites.

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