UNIVERSITI PUTRA MALAYSIA

MECHANICAL PROPERTIES OF PULTRUDED KENAF FIBRE REINFORCED VINYL ESTER COMPOSITES

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FK 2016 18

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By

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

June 2016

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

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June 2016

Chairman : Professor Mohd Sapuan Salit, PhD, P.Eng
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Pultrusion is one of the polymer composite fabrication processes employing the combination of pulling and extrusion processes. The composite profiles are obtained by pulling resin impregnated fibres through a series of heated dies. The ability of pultrusion technique that supports high volume of fibre fraction produces the high stiffness of the composite profile. There are many parameters such as filler loading, mold temperature and pulling speed to be considered and controlled during pultrusion process. In the research, the studies on the optimal parameters that influence the mechanical properties of pultruded kenaf composites revealed that the pulling speed has the highest influence in the fabrication process which is 49.3% of the contribution. The combination of the optimal parameters was obtained from Analysis of Variance (ANOVA) are pulling speed 0.4 m/min, gelation temperature 120ºC, curing temperature 180ºC and filler loading 30% of the weight. The investigation of the effect of filler loading on mechanical properties of pultruded kenaf composites shown the highest tensile strength was obtained when the filler loading reached at 50%, flexural strength at 30%, flexural modulus at 50% and compressive strength at 40%. The studies on the effect of gelation and curing temperatures shows the optimum tensile strength of gelation and curing temperatures were at 100ºC and 140ºC respectively, tensile modulus 80ºC and 180ºC respectively, flexural strength 100ºC and 140ºC, flexural modulus 120ºC and 180ºC and compressive strength at 120ºC and 180ºC respectively. The investigation of the effect of pulling speed on the mechanical properties of pultruded kenaf composites shows the optimal pulling speed for tensile strength and compressive strength is 0.3 m/min, tensile modulus 0.1 m/min, flexural strength 0.4, flexural modulus 0.2 m/min. The effect of filler loading, gelation and curing temperatures and pulling speed on tensile properties of composites was observed morphologically in the micrograph images of tensile fractured samples. Fibre wetting, fibre and matrix adhesion, the gaps within the samples and fibre breakages were among the phenomena occurring in the composites.

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

SIFAT MEKANIKAL KEPADA KOMPOSIT BERPULTRUD VINIL ESTER DIPERKUATKAN DENGAN GENTIAN KENAF

Oleh

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Pultrusi adalah salah satu process fabrikasi komposit menggabungkan kaedah penarikan dan penolakan. Profil komposit gentian dihasilkan dengan disaluti resin melalui acuan panas secara bersiri. Keupayaan teknik pultrusi mampu menampung kepadatan gentian yang tinggi menghasilkan profil komposit yang berkeliatan tinggi. Terdapat banyak parameter yang diambil kira dalam penghasilan komposit menggunakan kaedah pultrusi iaitu, muatan pengisi, suhu acuan dan kelajuan penarik. Dalam tesis ini, pengoptimunan parameter komposit pultrusi vinil ester diperkuatkan dengan kenaf telah dijalankan. Dalam penyelidikan ini, kajian kepada parameter-parameter optimum yang mempengaruhi sifat-sifat mekanik komposit kenaf pultrusi mendedahkan bahawa kelajuan penarik mempunyai pengaruh yang paling tinggi dalam proses fabrikasi iaitu 49.3% daripada sumbangan. Gabungan parameter-parameter yang optimum diperoleh daripada Analisis Varians (ANOVA) adalah kelajuan penarik 0.4 m / min, suhu mengejel 120ºC, suhu pengerasan 180ºC dan pembebanan pengisi 30% daripada berat. Siasatan kesan pembebanan pengisi ke atas sifat-sifat mekanikal komposit kenaf berpultrusi menunjukkan kekuatan tegangan tertinggi diperolehi apabila bebanan pengisi mencapai pada 50%, kekuatan lenturan pada 30%, keliatan lenturan pada 50% dan kekuatan mampatan pada 40%. Kajian mengenai kesan suhu mengejel dan mengeras menunjukkan kekuatan tegangan yang optimum bagi suhu mengejel dan mengeras masing-masing berada pada 100ºC dan 140ºC, keliatan tegangan masing-masing pada 80ºC dan 180ºC, kekuatan lenturan masing-masing pada 100ºC dan 140ºC, keliatan lenturan masing-masing pada 120ºC dan 180ºC dan kekuatan mampatan masing-masing pada 120ºC dan 180ºC. Siasatan kepada kesan kelajuan penarik pada sifat-sifat mekanikal komposit kenaf berpultrusi menunjukkan kekuatan tegangan dan kekuatan mampatan yang optimum adalah ketika penarik berada pada kelajuan 0.3m/min, keliatan tegangan pada 0.1m/min, kekuatan lenturan 0.4 m/min, keliatan lenturan 0.2m/min . Kesan bebanan pengisi, suhu mengejel dan mengeras dan kelajuan penarik kepada sifat tegangan komposit diperhatikan morfologi dalam imej mikrograf sampel tegangan patah. Kebasahan gentian, kelekatan antara gentian dan matriks, jurang dalam sampel dan putusnya gentian adalah antara fenomena yang berlaku dalam komposit.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious and the Most Merciful.

Alhamdulillah, all praise to Allah for the strengths and His blessing in completing this thesis. First and foremost, I wish to express my special appreciation and thanks to Prof. Ir. Dr. Mohd Sapuan Salit, Chairman of the Supervisory Committee for his dedications and overwhelming guidance throughout the completion of the research. I am also very thankful to the members of the Supervisory Committee: Assoc. Prof. Dr. Edi Syams Zainudin and Dr. Che Nor Aiza Jaafar for your most valuable contributions and assistances in this research. I also wish to extend my deepest gratitude to Kementerian Pendidikan Malaysia for providing the opportunity and supports especially through the financial scholarship (MyPhD) in pursuing my doctoral study.

Last but not least, I wish to dedicate my heartiest thanks to my beloved mother: Zainab bt Daud, family members and dearest friends for your precious encouragements and endless supports given throughout the entire course of my study. To my beloved wife Nur Marliana Mohamad and my precious children Muhammad Muaz and Muhammad Ziyad: Thank you for everything and this is for all of you.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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CHAPTER 1

INTRODUCTION

1.1 Research background

Recently, there is great awareness within the society on the issues of sustainability and environmental friendliness. As far as composite technology is concerned, these issues are addressed partly by introducing natural fibres in polymer matrices. Natural fibres offer many features that are not found in conventional fibres (glass and carbon fibres) such as recyclability, biodegradability, abundance, low cost, and low processing energy consumption (Sapuan *et al.*, 2003; Sastra *et al.*, 2006; Rashdi *et al.*, 2009;). Earlier past research works have shown that there are many natural fibres such as coir, hemp, jute, kenaf, sugar palm, pineapple leaf, and banana stem demonstrated the ability to replace the conventional fibres. Natural fibres have been developed as reinforcements or fillers in biocomposites. Studies on chemical, physical, mechanical and thermal properties of the natural fibres show very encouraging results, which made them suitable for reinforcements and fillers in polymer composites.

Kenaf fibre is one of natural fibres that have been spotted to be the replacement for conventional fibres such as aramid, glass and carbon fibres. Kenaf plants can be grown in short period, and can be found in abundance in countries such as India, Pakistan, Indonesia, Japan, China, Thailand, Vietnam and Malaysia (Ashori et al., 2006). These plants can be harvested twice a year.

Kenaf fibre composites had been developed and investigated over two decades by many researchers (El-Shekeil *et al.*, 2012; Hamma *et al.*, 2014; Intan *et al.*, 2014; Saba *et al.*, 2015; Yahya *et al.*, 2016) and the fibres can be made into various forms such as woven and non-woven mats, short fibres, particles and twisted yarns (see Figure 1.1). Kenaf fibre composites have been widely commercialized and used in various industries capitalizing various fabrication processes such as compression moulding, extrusion, pultrusion and injection moulding.

One of the established composite manufacturing technologies is pultrusion process. This process combines pulling and extrusion method to form continuous pultruded composite profiles. Pultrusion process is currently dominated by glass fibre composites and they can be found in various applications such as in civil structures, marines, sporting goods, and oil and gas industries. The fibre fraction of pultruded composites can be as high as up to 70% (Nosbi *et al.*, 2010) and this produced high stiffness profile and reduced total material cost. In pultrusion process high pressure is normally applied to the composite parts and this ensures better impregnation and fibre wetting, thus producing high quality pultruded composite profiles compared other composite fabrication methods.

The availability of kenaf fibres in the form of twisted yarn provides the advantage for the materials to be used in pultrusion process. In the past, investigation on the pultrusion process using natural fibre composites had been carried out by Akil et al., 2009a; Zamri et al., 2014; Mazuki et al., 2011; Nosbi et al., 2011; Omar et al., 2010; Safiee et al., 2011; Affzan et al., 2011 and the works offer promising findings.

Figure 1.1: Various forms of kenaf fibre (Dan-mallam *et al.*, 2014)

1.2 Problem statements

Composite fabrication using pultrusion technique needs a proper preparation to produce a high quality product. The defected or uncured pultruded composite profiles occurred during the pultrusion process can be eliminated through proper temperature setting and correct pulling speed. However, it is a challenging task to determine the optimal parameter levels due to different types of fibres and matrices that have been used in the fabrication of composites using the pultrusion process.

The success in the pultrusion process requires a knowledge of the polymerization of the matrix (Sarrionandia *et al*., 2002). Hence, the optimum level of parameters in pultrusion process need to be defined and investigated in order to produce quality products. The analysis of the variance is a tool used to predict the optimum level of parameters and to determine the best combination of the parameters in pultruded composites. The parameters that have been spotted to be very important during the pultrusion process are filler loading, fibre loading, gelation and curing temperatures, and pulling speed. Earlier research works on the determination of optimum level of parameters in pultruded composite process had been carried out by Chen and Ma et al., (1994); Liu and Hillier, (1999); Liu *et al*., (2000); Coelho and Calado, (2002); Lam *et al*., *(*2003). The results of the optimization show there are correlation between the parameter and properties of the pultruded composites. The most of the contribution parameter is the thermal behaviour which is effect the gelation and curing temperatures. The pulling speed also been studied to analysis the effect of the pulling rate on the pressure behaviour of the pultruded composites.

Since the previous works were still lacking in one aspect or another, the current work is proposed this research focusing mainly on the optimization of parameters, the effect of various parameters such as filler loading, gelation and curing temperatures and pulling speed of the pultruded kenaf reinforced vinyl ester composites. The effect of exposure to outdoor on mechanical properties of pultruded kenaf fibre reinforced vinyl ester composites also been propose to determine the degradation behavior of the pultruded kenaf composites.

1.3 Research aim and objectives

The aim of this research is to determine the effect of various parameters on the mechanical performance of pultruded kenaf reinforced vinyl ester composites. The specific objectives of this research are:

1. To determine the optimal parameter level of pultruded kenaf fibre reinforced vinyl ester composites.
2. To investigate the effect of filler loading on mechanical properties of pultruded kenaf fibre reinforced vinyl ester composites.
3. To investigate the effect of gelation and curing temperatures on mechanical properties of pultruded kenaf reinforced vinyl ester composites.
4. To investigate the effect of pulling speed on mechanical properties of pultruded kenaf fibre reinforced vinyl ester composites.

1.4 Structure of the thesis

A literature reviews of research work in various areas relevant to this research is presented in Chapter 2. The review started with polymer composites used in engineering products. The reviews also cover the natural fibre and kenaf, their composites and past research on pultruded natural fibre composites. The method of the composite fabrication using the pultrusion process is presented along with review of level of parameters during processing. Mechanical properties of pultruded composites have also been presented. The methodology of the research is presented in Chapter 3. The optimization of pultruded kenaf fibre reinforced vinyl ester composites is described in Chapter 4. The effect of filler loading on mechanical properties of pultruded kenaf reinforced vinyl ester composites is described in Chapter 5. The effect of gelation and curing temperatures on mechanical properties of pultruded kenaf reinforced vinyl ester composites is described in Chapter 6. The effect of pulling speed on mechanical properties of pultruded kenaf reinforced vinyl ester composites is described in Chapter 7. The discussion related to objective paper are presented in Chapter 8. Conclusions and recommendations for future work are presented in Chapter 9.

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