UNIVERSITI PUTRA MALAYSIA

ENHANCEMENT OF PHYSICAL PROPERTIES OF SUGAR PALM (ARENGA PINNATA MERR.) FIBRE-REINFORCED UNSATURATED POLYESTER COMPOSITES VIA VACUUM RESIN IMPREGNATION

MOHAMAD RIDZWAN BIN ISHAK

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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 2012

DEDICATION

"Bring me blocks of iron." At length, when he had filled up the space between the two steep mountain-sides, He said, "Blow (with your bellows)" Then, when he had made it (red) as fire, he said: "Bring me, that I may pour over it, molten lead."

Al-Kahfi 18:65

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

ENHANCEMENT OF PHYSICAL PROPERTIES OF SUGAR PALM (*ARENGA PINNATA* MERR.) FIBRE-REINFORCED UNSATURATED POLYESTER COMPOSITES VIA VACUUM RESIN IMPREGNATION

By

MOHAMAD RIDZWAN BIN ISHAK

June 2012

Chairman : Zulkiflle Leman, PhD

Faculty : Faculty of Engineering

This research was carried out to study the enhancement of properties of sugar palm (*Arenga pinnata*) fibre reinforced unsaturated polyester composites. The study was divided into three stages, where the first stage focused on the characterisation of tensile, chemical properties, thermogravimetric analysis (TGA) and fourier transform infrared (FT-IR) spectra of the sugar palm fibres obtained from different heights (1, 3, 5, 7, 9, 11, 13 and 15 m) of a sugar palm tree. It was observed that the fibres obtained from dead palm frond region showed the lowest tensile properties and considered to be biologically degraded. Chemical analysis of the fibres showed that the content of cellulose, hemicelluloses and lignin had a direct relationship to the increase in tensile strength, elongation at break and modulus of the fibre respectively. The second stage of the study investigated the effects vacuum resin impregnation on physical and mechanical properties of the sugar palm fibres. The fibres were impregnated with two different impregnation agents: phenol formaldehyde (PF) and unsaturated polyester (UP) at a constant pressure of 1000 mmHg at different impregnation times (0, 5, 10, 15, 20 and 25 minutes). Both physical and mechanical properties of the fibres showed significant improvement after being impregnated for 5 minutes and no improvement when impregnation time was extended from 10 to 25

minutes. The study further investigated the effects of elevating impregnation pressure (1000, 900, 800, 700, 600 and 500 mmHg) on physical and mechanical properties of sugar palm fibre with PF and UP at constant impregnation time of 5 minutes. It was observed that the moisture content (MC) of the impregnated fibres dropped from 8.19% to 0.75-0.46% for PF and 0.87-0.44% for UP, while the water absorption (WA) was reduced from 116.82% to 61.64-22.52% for PF and 63.49-23.31% for UP. The tensile strength increased from 243.77 MPa to 251.39-297.67 MPa for PF and 287.84-344.71 MPa for UP. The tensile moduli increased from 3.07 GPa to 3.1-3.98 GPa for PF and 3.15-3.98 GPa for UP. The elongation at break decreased from 25.16% to 17.66-6.26% for PF and 24.24-19.05% for UP. Low tensile strength and elongation at break of PF-impregnated fibres showed that the fibres were inferior in toughness (48.51 MJ/m^3 to 33.08-12.29 MJ/m^3) compared to UP-impregnated fibres (48.51 MJ/m^3 to 57.56-45.21 MJ/m^3). The third stage was continued by impregnating the fibres with UP resin at impregnation pressure of 600 mmHg for 5 minutes. The interfacial shear strength (IFSS), TGA and FT-IR spectra of UP-impregnated sugar palm fibre were initially determined before the fibres were used as reinforcement in composites at 10, 20, 30, 40 and 50% fibre loadings. It was observed that the impregnation process increased the fibre-matrix interfacial bonding by 72.46%. The lower moisture uptake of the impregnated fibre than the control was qualitatively proven by TGA and FT-IR spectra. In general, the impregnated composites showed better tensile and flexural properties than the controls where 30% fibre loading gave the highest values. It was also observed that MC, WA, thickness swelling (TS) and linear expansion (LE) of impregnated composites were lower than the controls and the moisture excluding efficiency (MEE) and anti-swelling efficiency (ASE) were also increased.

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

PENAMBAHBAIKAN SIFAT FIZIKAL KOMPOSIT POLIESTER TAK TEPU DIPERKUAT GENTIAN IJUK (*ARENGA PINNATA* MERR.) MELALUI VAKUM RESIN IMPREGNASI

Oleh

MOHAMAD RIDZWAN BIN ISHAK

Jun 2012

Pengerusi : Zulkiflle Leman, PhD

Fakulti : Fakulti Kejuruteraan

Penyelidikan ini dijalankan bagi mengkaji penambahbaikan sifat-sifat komposit poliester tak tepu diperkuat gentian ijuk (*Arenga pinnata*). Penyelidikan ini dibahagikan kepada 3 peringkat kajian di mana peringkat pertama adalah pencirian sifat tegangan, komposisi kimia, analisis gravimetrik haba (TGA) dan spektroskopi (FT-IR) gentian ijuk yang diperolehi daripada ketinggian yang berbeza (1, 3, 5, 7, 9, 11, 13 and 15 m) dari sebatang pokok enau. Didapati bahawa gentian yang diperolehi dari bahagian pelepah reput mempunyai sifat tegangan yang paling rendah dan dianggap terdegridasi secara biologi. Analisis kimia ke atas gentian menunjukkan bahawa kandungan selulosa, hemiselulosa dan lignin mempunyai hubungan langsung terhadap peningkatan kekuatan tegangan, pemanjangan pada takat putus dan kekakuan tegangan. Peringkat kedua kajian adalah mengkaji terhadap kesan vakum impregnasi resin terhadap sifat-sifat fizikal dan mekanikal gentian ijuk. Gentian telah diimpregnasi dengan menggunakan dua agen impregnasi; fenol formaldehyde (PF) and poliester tak tepu (UP) pada tekanan seragam 1000 mmHg dengan masa impregnasi yang berbeza (0, 5, 10, 15, 20 and 25 min). Kedua-dua sifat fizikal dan mekanikal gentian menunjukkan peningkatan yang signifikan selepas diimpregnasi selama 5 minit dan tiada peningkatan yang signifikan selepas masa impregnasi

ditambah dari 10 hingga 25 minit. Kajian selanjutnya mengkaji kesan penambahan tekanan impregnasi (1000, 900, 800, 700, 600 and 500 mmHg) terhadap sifat-sifat fizikal dan mekanikal gentian ijuk pada masa impregnasi yang seragam selama 5 minit. Didapati bahawa kandungan lembapan (MC) gentian terimpregnasi berkurang dari 8.19% kepada 0.75-0.46% bagi gentian yang telah diimpregnasi dengan PF dan 0.87-0.44% bagi UP, manakala penyerapan air (WA) telah berkurang dari 116.82% kepada 61.64-22.52% bagi PF dan 63.49-23.31% bagi UP. Kekuatan tegangan meningkat dari 243.77 MPa kepada 251.39-297.67 MPa bagi gentian yang diimpregnasi dengan PF dan 287.84-344.71 MPa bagi UP. Kekakuan tegangan meningkat daripada 3.07 GPa kepada 3.1-3.98 GPa bagi gentian yang diimpregnasi dengan PF dan 3.15-3.98 GPa bagi UP, manakala pemanjangan pada takat putus bagi gentian yang diimpregnasi dengan PF menurun dari 25.16% kepada 17.66-6.26% dan kepada 24.24-19.05% untuk UP. Kekuatan tegangan dan pemanjangan pada takat putus gentian yang rendah bagi gentian yang diimpregnasi dengan PF telah menyebabkan keliatan gentiannya menjadi jauh lebih rendah (dari 48.51 MJ/m^3 kepada 33.08-12.29 MJ/m^3) berbanding dengan gentian yang diimpregnasi dengan UP (48.51 MJ/m^3 kepada 57.56-45.21 MJ/m^3). Peringkat ketiga kajian diteruskan dengan mengimpregnasi gentian dengan resin UP pada tekanan impregnasi 600 mmHg selama 5 minit. Kekuatan ricihan antara muka (IFSS), TGA dan FT-IR gentian telah diperolehi sebelum gentian tersebut digunakan untuk penguatan komposit dengan kandungan gentian 10, 20, 30, 40 dan 50%. Didapati bahawa proses impregnasi telah meningkatkan ikatan antara muka gentian-matrik sebanyak 72.46%. Serapan lembapan yang rendah bagi gentian terimpregnasi berbanding tak diimpregnasi telah dibuktikan secara kualitatif melalui TGA dan spektrum FT-IR. Secara keseluruhannya, komposit diperkuat gentian terimpegnasi menunjukkan sifat

tegangan dan kelenturan yang lebih baik berbanding tak diimpregnasi dan komposit-komposit dengan kandungan gentian 30% menunjukkan nilai yang maksimum. Diperhatikan juga bahawa MC, WA, pengembangan ketebalan (TS) dan kadar pengembangan arah bertentangan (LE) komposit diperkuat gentian terimpregnasi lebih rendah berbanding dengan tak diimpregnasi dan keupayaan menentang penyerapan lembapan (MEE) dan keupayaan menentang pengembangan (ASE) meningkat.

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I certify that a Thesis Examination Committee has met on 12 June 2012 to conduct the final examination of Mohamad Ridzwan Bin Ishak on his thesis entitled "Enhancement of physical properties of sugar palm (*Arenga pinnata* Merr.) fibre-reinforced unsaturated polyester composites via vacuum resin impregnation" 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 degree of Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

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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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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

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MOHAMAD RIDZWAN BIN ISHAK

Date: 12 June 2012

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