UNIVERSITI PUTRA MALAYSIA

EXPERIMENTAL AND THEORETICAL EVALUATION OF THE TENSILE PROPERTIES OF CARBON NANOTUBE-COATED CARBON FIBRE HYBRID COMPOSITES

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MASTER OF SCIENCE
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DEDICATION

To my belated parents,
with memories…

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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By

SHAZED MD. AZIZ

February 2013

Chair : Associate Professor Suraya binti Abdul Rashid, PhD

Faculty : Engineering

Hierarchically structured hybrid composites are ideal engineered materials to carry loads and stresses due to their unconventional in-plane specific mechanical properties such as tensile modulus, strength, and stiffness. Growing carbon nanotubes (CNT) on the surface of high performance carbon fibres (CF) provides a means to tailor the mechanical properties of the fibre-matrix interface of a composite. The growth of CNT onto the surface of CF was conducted via floating catalyst chemical vapor deposition (CVD) technique. The mechanical properties of the resultant fibres, CNT density and alignment morphology were shown to depend on the CNT growth temperature, growth time, carrier gas flow rate, catalyst amount, and atmospheric conditions within the CVD chamber. The evidence of intensive CNT-coating on CF was shown at a CVD temperature of 700 °C and 30 minutes reaction time by using Scanning electron microscope (SEM). Single fibre/Epoxy composite coupons were fabricated by using both neat and CNT-coated CF to conduct single fibre fragmentation test (SFFT). For neat-CF/Epoxy composite coupons, IFSS was found to be 12.52 MPa. A CNT-coated CF demonstrated approximately 45% increase in calculated IFSS when treated at 700 °C and 30 minutes reaction

environment over that of the untreated fibre from which it was processed. Carbon nanotube coated short carbon fibre reinforced polypropylene (CNT-CF/PP) composites were fabricated. The resulting hybrid composite samples were characterized using the tensile testing method. For neat-CF/PP composite, Young's modulus and tensile strength were found to be 1.72 GPa and 20.5 MPa respectively. In contrast with the neat CF/PP composite, CNT-CF/PP composite has shown enhanced Young's modulus by approximately 104% and tensile strength increased to approximately 64%. The fibre-matrix adhesion was analyzed by using SEM on cryogenically fractured surface of both types of composites. The proper justification of fibre-matrix interfacial adhesion featuring the composite tensile properties was explained through interfacial shear strength (IFSS). Composites with high IFSS was found to show a high Young's modulus and tensile strength. Theoretical prediction of hybrid CNT-CF/PP composite tensile properties was accomplished by using a hierarchical model which comprises Halpin–Tsai equations, Combined Voigt-Reuss model, simple rule-of-mixtures (RoM) and Krenchel approach. When the internal geometry of composite was a key factor RoM was utilized to study the fibre orientation distribution in the composite. A comprehensive fractographic investigation was carried out with scanning electron microscope (SEM) to analyze the fibre orientation distribution on the CNT-CF/PP composite fracture surfaces. Then, a thorough analysis was done on the SEM images using Bersoft and Geozebra image analyzing software packages to evaluate the fibre orientation distribution factor (η_0). In the context of this approach, when the fibre orientation effect is ignored a noteworthy deviation in tensile modulus with 51% was notified rather than experimental result of 1.72 GPa. When η_0 is considered a more acceptable validation with the experimental results of tensile modulus was obtained which shows a

moderate deviation with 30% to the predicted value of 4.57 GPa. Finally, the discrepancies between the predicted and experimental values were explained in terms of stress-strain behavior.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Sarjana Sains

PENILAIAN UJIKAJI DAN TEORI MENGENAI SIFAT TEGANGAN KARBON NANOTUBE BERSALUT-GENTIAN KARBON HIBRID RENCAM

Oleh

SHAZED MD. AZIZ

Februari 2013

Pengerusi : Profesor Madya Suraya Binti Abdul Rashid, PhD

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Struktur hierarki komposit hibrid adalah ideal kejuruteraan bahan-bahan untuk membawa beban dan menekankan kerana tidak konvensional mereka dalam-satah sifat-sifat tertentu mekanikal seperti modulus tegangan, kekuatan, dan kekakuan. Berkembang nanotube karbon (CNT) pada permukaan gentian karbon berprestasi tinggi (CF) menyediakan satu cara untuk menyesuaikan sifat mekanikal antara muka gentian-matriks komposit. Pertumbuhan CNT ke permukaan CF telah dijalankan melalui terapung pemangkin teknik pemendapan wap kimia (CVD). Sifat-sifat mekanikal gentian yang terhasil, ketumpatan CNT dan morfologi penjajaran ditunjukkan bergantung kepada suhu pertumbuhan CNT, masa pertumbuhan, kadar aliran gas pembawa, jumlah mangkin, dan keadaan atmosfera dalam kebuk CVD. Keterangan intensif CNT-salutan pada CF telah ditunjukkan pada suhu CVD 700 ° C dan 30 minit masa tindak balas dengan menggunakan Mengimbas mikroskop elektron (SEM). Single fiber/Epoxy kupon komposit telah direka dengan menggunakan kedua-dua CF kemas dan bersalut CNT untuk menjalankan serat ujian pemecahan tunggal (SFFT). Untuk neat-CF/Epoxy kupon komposit, IFSS didapati menjadi 12,52 MPa. A CF CNT bersalut menunjukkan peningkatan kira-kira 45%

dalam IFSS dikira apabila dirawat pada 700 °C dan 30 minit tindak balas persekitaran yang lebih serat yang tidak dirawat dari mana ia telah diproses. Karbon nanotube bersalut karbon pendek bertetulang gentian polipropilena (CNT-CF/PP) komposit telah direka. Yang terhasil sampel komposit hibrid telah dicirikan menggunakan kaedah ujian tegangan. Untuk neat-CF/PP komposit, Young's modulus dan kekuatan tegangan telah didapati menjadi 1.72 GPa dan 20.5 MPa masing-masing. Berbeza dengan komposit neat-CF/PP, CNT-CF/PP komposit telah ditunjukkan meningkatkan modulus Young oleh kira-kira 104% dan kekuatan tegangan meningkat kepada kira-kira 64%. Rekatan gentian-matriks telah dianalisis dengan menggunakan SEM pada permukaan cryogenically patah kedua-dua jenis komposit. Justifikasi yang betul melekat gentian-matriks memaparkan sifat tegangan komposit telah dijelaskan melalui kekuatan ricih antara muka (IFSS). Composites with high IFSS was found to show a high Young's modulus and tensile strength. Ramalan teori sifat tegangan CNT-CF/PP hibrid komposit telah dicapai dengan menggunakan model hierarki yang terdiri daripada persamaan Halpin-Tsai, Gabungan Voigt-Reuss model, mudah rule-of-mixture (RoM) dan pendekatan Krenchel. Apabila geometri dalaman komposit adalah RoM faktor utama telah digunakan untuk mengkaji pengagihan orientasi gentian dalam komposit. Satu siasatan fractographic yang komprehensif telah dijalankan dengan mikroskop imbasan elektron (SEM) untuk menganalisis taburan orientasi gentian patah CNT-CF/PP permukaan komposit. Kemudian, analisis yang teliti telah dilakukan ke atas imej SEM menggunakan Bersoft dan imej Geozebra menganalisis pakej perisian untuk menilai faktor pengagihan orientasi gentian (η_0). Dalam konteks pendekatan ini, apabila kesan orientasi gentian diabaikan sisihan yang patut diberi perhatian dalam modulus tegangan dengan 51% telah dimaklumkan bukannya hasil

eksperimen 1,72 GPa. Apabila dianggap pengesahan yang lebih diterima dengan keputusan ujikaji modulus tegangan diperolehi yang menunjukkan sisihan sederhana dengan 30% kepada nilai yang diramalkan 4,57 GPa. Akhirnya, perbezaan di antara nilai-nilai yang diramalkan dan eksperimen telah dijelaskan dalam segi kelakuan tegasan-terikan.

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I certify that a Thesis Examination Committee has met on 20 February 2013 to conduct the final examination of Shazed Md. Aziz on his thesis entitled "**Experimental And Theoretical Evaluation of the Tensile Properties of Carbon Nanotube-Coated Carbon Fibre 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 Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. 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 institution.

SHAZED MD. AZIZ

Date: 20 February 2013

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