EVALUATION OF MECHANICAL PROPERTIES OF HYBRID ALUMINIUM/FIBER-REINFORCED COMPOSITES

By
SAAD A. MUTASHER

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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Special Dedication

This thesis is dedicated to

My affectionate parents and my beloved wife and son for their patient, love and support

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 : Professor Ir. Barkawi Bin Sahari, PhD

Faculty : Engineering

The purpose of drive shaft is to transmit static and dynamic torques with vibration stability. Extensive researches have been carried out on the fiber-reinforced composite drive shaft for the last two decades. Hybrid shafts made of unidirectional glass fiber or carbon fiber epoxy and steel or aluminum have high fundamental bending natural frequency as well as high torque transmission capability. The fiber increases the fundamental bending natural frequency due to its high specific stiffness and aluminum or steel transmits the required torque. In the present work experimental tests were carried out to study the bending fatigue life, static torsion capacity and power transmission capacity of a hybrid aluminum/ composite drive shaft. The composite used are glass and carbon fiber/epoxy. A tensile test was carried out to find the mechanical properties of composite materials used throughout this work. A hybrid shaft was fabricated using a wet filament winding method by winding glass and carbon fibers onto aluminum tube with different winding angles, θ, numbers of layers and stacking sequence. A filament winding machine was developed to fabricate the hybrid aluminum/ composite drive shaft. A special

mechanism was designed and fabricated for carrying out the static torsion test of the hybrid shaft. In addition, an apparatus was designed and fabricated to investigate the power transmission capacity of the hybrid shaft. Minor modifications were made for the rotating bending fatigue machine to perform the bending fatigue test. Flexural moment fatigue life relationships were obtained and the failure modes of the hybrid shaft were studied under fully reversed bending load, R = -1. The results show that the fatigue life for a winding angle of 45o is larger than that for 90o, for both glass and carbon fibers. The [±45]3 carbon fiber/epoxy laminates enhanced the fatigue life of aluminum tube up to 54% and the hybrid specimen did not fail till 107 cycles at 14.7 N.m applied bending moment. In the hybridized specimens two carbon percentage contained 34% and 51% were examined. The results show that the percentage contained of carbon and glass fibers were significantly affected the fatigue life of the hybrid shaft at high and low levels of bending load. The use of matrix inside the aluminum tube increased the fatigue life by 6.5% and increases the weight of the hybrid specimen by 16%. The results of fatigue test on a macroscopic level indicate that the cracks initiated in the fiber free zones or in the outer skin of resin and increased with increasing number of cycles until failure of specimen. On other hand the micro damage shows that the delamination completely took place between the composite layer and surface of aluminum tube before the catastrophic failure of a hybrid specimen. In addition, the aluminum tube failure was perpendicular to the applied bending load and this phenomenon is the same as that for the aluminum shaft under bending fatigue test. There is no fiber breakage being observed from the rotating bending fatigue test.

The torque-angle-of-twist response under static torsion load was obtained and the failure modes of the hybrid shaft were studied. The results show that the static torque capacity for a winding angle of 45o is larger than that for 90o, for both glass and carbon fibers. The maximum static torsion for aluminum tube wound by [+45/-45]3 laminates are 273.2 N.m and 173.5 N.m for carbon and glass fiber respectively. The percentage difference is approximately 36%. The aluminum tube yielded first at the central region of the shaft, followed by crack propagation in the composite part along the fiber direction, which eventually caused delamination of the composite layers from the aluminum tube. This due to the matrix crack and finally the fibers broke and the catastrophic failure took place. For a hybrid shaft wound with fiber configurations of [90/+45/-45/90] and [+45/- 45/90/90], the torque-angle-of-twist response results were similar and this satisfied the Classical Lamination Theory. In addition, the torque capacity increased by approximately 12 times for the case of an aluminum tube wound with six layers of the carbon fiber at winding angle of 45o compared to the aluminum tube alone. From the power transmission test, it was found out that the difference between the static torque and dynamic torque is approximately 7%-15%. The finite element analysis has been used to analyzed the hybrid shaft under static torsion. ANSYS finite element software was used to perform the numerical analysis for the hybrid shaft. Full scale hybrid specimen was analyzed. Elasto-plastic properties were used for aluminum tube and linear elastic for composite materials.

The predicted results gave good agreement with the experimental results, the percentage differences between the experimental and theoretical results is approximately 3.5%-25%.

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

PENILAIAN SIFAT-SIFAT MEKANIKAL BAGI KOMPOSIT BERTETULANG GENTIAN/ALUMINIUM HIBRID.

Oleh

SAAD A. MUTASHER

April 2006

Pengerusi : Profesor Ir. Barkawi Bin Sahari, PhD

Fakulti : Kejuruteraan

Peranan aci pacu adalah untuk menghantar tork statik dan dinamik dengan kestabilan getraran. Kerja penyelidikan mendalam telah dijalankan ke atas aci pacu komposit bertetulang gentian sepanjang dua dekad yang lalu. Aci hibrid yang dibuat daripada komposit bertetutang gentian eka-arah dan logam mempunyai frekuensi tabii asas yang tinggi serta keupayaan penghantaran tark yang tinggi. Komposit meningkatkan frekuensi tabii lenturan asas disebabkan kekukuhan specifik yang tinggi dan logam seperti aluminium atau keluli menghantar tork yang diperlukan. Dalam kajian ini eksperimen telah dijalan bagi mengkaji hayat lesu lenturan, keupayaan kilasan statik dan keupayaan penghantaran kuasa bagi aci paca aluminium/kopmposit hibrid. Satu ujian tegangan telah dijalankan bagi mendapatkan sifat-sifat mekanikal bagi bahan komposit yang digunakan sepanjang kajian ini. Sebuah aci hibrid telah dibikin menggunakan kaedah belitan filamen basah dengan melilit gentian kaca dan karbon ke atas tiub aluminium dengan sudut belitan, bilangan lapisan dan turutan tindanan yang berbeza. Sebuah mesin belitan filamen telah dibangunkan bagi membikin aci pacu aluminium/komposit hibrid. Sebuah mekanisme khusus telah direka bentuk dan

dibikin bagi menjalankan ujian kilasan statik bagi aci hibrid. Sebagai tambahan satu radas telah direka bentuk dan dibikin bagi mengkaji keupayaan penghantaran kuasa bagi aci hibrid. Pengubahsuaian kecil dibuat bagi mesin lesu lenturan berputar bagi menjalankan ujian lesu lenturan.

Hubungan hayat lesu momen lenturan telah di dapati dan rangam kegagalan bagi aci hybrid telah dikaji di bawa beban lenturan terbalik sepenuhnya, R = -1. Keputusan menunjukkan bahawa hayat lesu bagi sudut belitan 45o adalah lebih besar daripada 90o bagi gentian kaca dan karbon. Laminat gentian karbon/epoksi [±45]3 telah meningkatkan kekuatan lesu bagi tiub aluminium sehingga 54% dan sampel hybrid tidak gagal sehingga 107 kitaran pada 14.7 N.m momen lenturan yang dikenakana.

Dalam sampel terhibrid nisbah karbon/kaca telah memberikan kesan yang besar hayat lesu bagi aci hybrid pada tegasan tahap tinggi dan rendah. Penggunaan matriks di dalam tiub aluminium meningkatkan hayat lesu sebanyak 6.5% dan menambah berat sample hibrid sebanyak 16%. Keputusan ujian lesu ke atas tahap makroskop menunjukkan rekahan bermula di zon yang bebas daripada gentian atau di kulit luar dammar dan bertambah dengan pertambahan bilangan kitaran sehingga kegagalan sampel sebaliknya kerosakan mikro menunjukkan bahawa nyahikatan berlaku sepenuhnya antara lapisan komposit dan permukaan tiub aluminium sebelum kegagalan bencana sampel hibrid. Sebagai tambahan, kegagalan tiub aluminium adalah berserenjang dengan beban lenturan yang dikenakan dan fenomena ini adalah sama dengan aci aluminium di bawah ujian lesu lenturan. Tiada terdapat gentian patah diperhatikan daripada ujian lesu lenturan berputar. Tindak balas tork-sudut-piuh telah didapati dan ragam kegajalan bagi aci hibrid telah dikaji. Keputusan menunjukkan keupayaan tork statik bagi sudut belitan 45o adalah lebih besar

daripada 90o bagi gentian kaca dan karbon. Bagi laminat [±45]3, kilasan statik maksimum bagi gentian karbon adalah kira-kira 36% lebih tinggi bagi gentian kaca. Tiub aluminium menghasilkan mula-mulanya pada kawasan tengah bagi aci, diikuti dengan perambatan rekahan dalam aci komposit sepanjang arah gentian, yang akhirnya menyebabkan nyahikatan bagi lapisan komposit daripada tiub aluminium. Kemudian, kawasan putih telah dilihat dalam lapisan komposit dan akhirnya gentian patah dan kegagalan bencana telah berlaku. Bagi aci hibrid dililit dengan tatarajah gentian [90/+45/-45/90] dan [+45/-45/90/90], keputusan tindak balas tork-sudut-piuh adalah serupa dan ini memenuhi Teori Penglaminatan Klasik. Sebagai tambahan, keupayaan tork telah bertambah sebanyak kira-kira 14 kali ganda bagi kes tiub aluminium dililit dengan enam lapisan gentian karbon pada sudut belitan 45o berbanding dengan hanya tiub aluminium. Analysis unsur tertingga telah digunakan bagi menganalisis aci hibrid di bawah kilasan statik. Perisian unsur terhingga ANSYS telah digunakan bagi menjalankan analisis berangka bagi aci hibrid. Sampel hibrid bersaiz penuh dianalisis. Sifat-sifat anjal-plastik telah digunakan bagi tiub aluminium dan anjal lelurus bagi bahan komposit. Keputusan yang diramal memberikan persetujuan yang baik dengan keputusan eksperimen. Daripada bahawa peratusan antara tork statik dan tork dinamik ialah kira-kira 7%-15%.

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Finally, I would like to thank my family for all of their love and support through the years. You have always encouraged me to challenge myself, and I enjoy sharing my accomplishments with you.

I certify that an Examination Committee has met on **10th April 2006** to conduct the final examination of Saad A. Mutasher on his Doctor of Philosophy thesis entitled "*Evaluation of Mechanical Properties of Hybrid Aluminium/Fiber-Reinforced Composites*" in accordance with Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy.
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DECLARATION

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

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SAAD A. MUTASHER

Date:

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