UNIVERSITI PUTRA MALAYSIA

INTERNAL DEFECT DETECTION AND RECONSTRUCTION FRAMEWORK FOR LAMINATED GLASS FIBRE REINFORCED POLYMER COMPOSITE MATERIALS

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By

NGSOKCHOO

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

May 2013

DEDICATION

TO MY FATHER, MY FAMILY AND CAROL BEH

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

INTERNAL DEFECT DETECTION AND RECONSTRUCTION FRAMEWORK FOR LAMINATED GLASS FIBRE REINFORCED POLYMER COMPOSITE MATERIALS

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Chairman **Professor Datin Napsiah Ismail, PhD**

Faculty **Institute of Advanced Technology**

The detection of internal defects in composite materials with non-destructive techniques (NDT) is crucial for both quality checks during the production phase and in-service health monitoring during maintenance operations in industrial and civil environment. Visual inspection allows only the analysis of surface characteristics of materials. If internal faults occur inside the composite structures, a deeper analysis is required. Ultrasonic testing has been a promising NDT which is based on the detection and the interpretation of the ultrasonic waves reflected by defects. However, ultrasonic data are difficult to interpret since they require the analysis of continuous signals for each point of the material under consideration. Particularly, the non-homogeneous nature of reinforced composite materials induces high dimensionality of analysis space and a very high level of structural noise that greatly complicates the interpretation task. Increasing the ultrasound system frequency can result in detection of smaller defects but the depth of penetration of the wave

decreases. Therefore, an advanced signal processmg technique is necessary to manage large data sets and to extract suitable features for effective internal defect detection. The objective of the research is to design and develop a new cost-effective nondestructive evaluation (NDE) framework to detect and reconstruct the internal defects in high dimensionality environments. The proposed framework consists of four steps: (i) the relationship between the defects and the behaviour of the ultrasound is identified. (ii) Multiresolution signal decomposition technique is then applied to reduce the dimensionality of the data. (iii) The image of the defect region is reconstructed by using the attenuation of the reflected ultrasound signal (iv) Entropy-based fuzzy k-nearest neighbour classification method is used to extract the feature of the defects. Delamination was introduced as the internal defects in the experiments. The proposed framework was tested on glass fibre reinforced polymer (GFRP) composites with different thickness and fiber orientations.

The research finding showed that the position of damage has been the significant control factor to the attenuation of the ultrasound signal. Experimental results showed that the proposed framework successfully reduce the dimensionality of the analysis space. The proposed wavelet-based minimization algorithm has achieved 79.8% and 30.2% improvement of signal-to-noise ratio for the simulated and experimental noisy data respectively. This framework exhibits high accuracy of internal defect localization in high dimensionality environments. It is found out that the proposed entropy-based k-nearest neighbour classification method has shown promising performance with 94.01% accuracy in close-spaced defects detection when minimal k-nearest neighbor is used. Considering all results and the collected information, it can be concluded that the structural noise in ultrasound signals induces low frequency. Therefore, by removmg the low frequency signals, the intemal defect detectability can be improved. Moreover, the classification of an input pattem based on the closest neighbours of the point of interest provides more accurate defect detection in comparison with the classification based on experience data as the defect pattems vary on circumstances in ultrasonic NDE problems.

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

RANGKA KERJA PENGESANAN DAN PEMBINAAN SEMULA KECACATAN DALAMAN BAHAN KOMPOSIT KACA BERTETULANG GENTIAN POLIMER BERLAMINA

Oleh

NGSOKCHOO

Mei2013

Pengerusi **Profesor Datin Napsiah Ismail, PhD**

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Pengesanan kecacatan dalaman dalam bahan komposit dengan teknik bukan pemusnah (NDT) adalah penting bagi kedua-dua semakan kualiti dalam fasa pengeluaran dan pemantauan kesihatan dalam layanan semasa operasl penyelenggaraan dalam bidang industri dan pembinaan awam. Pemeriksaan visual hanya membolehkan analisis ciri-ciri pemlukaan bahan. Jika kesilapan dalaman berlaku di dalam struktur komposit, analisis secara mendalam diperlukan. Ujian ultrasonik adalah NDT yang baik di mana kaedah ini berasaskan daripada pengesanan dan tafsiran gelombang ultrabunyi yang digambarkan oleh kecacatan. Walau bagaimanapun, data ultrasonik adalah sukar ditafsir kerana ia memerlukan analisis isyarat berterusan bagi setiap titik dalam bahan yang dipertimbangkan. Terutama sekali, sifat bukan homogen bahan komposit bertetulang menyebabkan ruang dimensi analisis yang tinggi dan tahap yang sangat tinggi bagi bunyi struktur yang amat merumitkan tugas tafsiran. Meningkatkan kekerapan sistem ultrabunyi

membolehkan pengesanan keeaeatan yang keeil tetapi penembusan gelombang akan berkurangan. Oleh itu, teknik pemprosesan isyarat yang eanggih adalah diperlukan untuk menguruskan set data yang besar dan untuk mengekstrak eiri-eiri yang sesuai bagi pengesanan keeaeatan dalaman yang berkesan. Objektifkajian ini adalah untuk merekabentuk dan membangunkan satu rangka kerja penilaian tanpan musnah yang kos efektif dan barn untuk mengesan dan membina semula keeaeatan dalaman dalam persekitaran dimensi tinggi. Teknik yang dieadangkan terdiri daripada empat langkah: (i) hubungan antara keeaeatan dan tingkah laku ultrabunyi dikenalpasti. (ii) teknik penguraian isyarat seeara pelbagai resolusi kemudimmya digunakan untuk mengurangkan dimensi data. (iii) imej rantau keeaeatan dibina semula dengan menggunakan pelemahan isyarat ultrabunyi yang terlantun. (iv) kaedah klasifikasi kabur k-jiran terdekat berasaskan entropi digunakan lmtuk mengekstrak eiri keeaeatan. Nyahikatan diperkenalkan sebagai keeaeatan dalaman dalam eksperimen. Rangka kerja yang dieadangkan telah diuji atas komposit kaea bertetulang gentian polimer (GFRP) dengan ketebalan dan orientasi gentian yang berbeza.

Dapatan kajian menunjukkan bahawa kedudukan kerosakan telah menjadi faktor pengawal penting kepada pengeeilan isyarat ultrabunyi. Keputusan eksperimen menunjukkan bahawa rangka kerja yang dieadangkan berjaya mengurangkan dimensi rnang analisis. Algoritrna eadangan merninimumkan yang berasaskan wavelet telah meneapai peningkatan sebanyak 79.8% dan 30.2% masing-masing pada nisbah isyarat-kepada-bunyi bagi data bising simulasi dan eksperimen. Rangka kerja ini mempamerkan ketepatan yang tinggi bagi penyetempatan keeaeatan dalaman dalam persekitaran dimensi tinggi. 1a adalah didapati bahawa kaedah klasifikasi kabur k-jiran terdekat berasaskan entropi telah menunjukkan prestasi yang cemerlang dengan ketepatan 94.01% dalam pengesanan kecacatan dekat jarak apabila k-jiran terdekat minimum digunakan. Memandangkan semua keputusan dan maklumat yang dikumpul, ia boleh membuat kesimpulan bahawa bunyi struktur dalam isyarat ultrabunyi mendorong kekerapan rendah. Olell itu, dengan mengeluarkan isyarat frekuensi rendah, pengesanan kecacatan dalaman boleh diperbaiki. Selain itu, pengkelasan corak input berdasarkan jiran terdekat titik kepentingan memberi pengesanan kecacatan yang lebih tepat dalam perbandingan dengan klasifikasi berdasarkan data pengalaman sebagai corak input kerana corak kecacatan berbeza kepada keadaan dalam masalah NDE ultrasouik.

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Ng Sok Choo

May 2013

I certify that a Thesis Examination Committee has met on **9 May 2013** to conduct the final examination of **NG SOK CHOO** on her thesis entitled" Internal defect detection and reconstruction framework for laminated glass fibre reinforced polymer composite materials" 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 Tecommends that the student be awarded the degree of Doctor of Philosophy.

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

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DECLARATION

I hereby 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 or concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.

NGSOKCHOO

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