UNIVERSITI PUTRA MALAYSIA

AGLASS FIBER-REINFORCED POLYESTER COMPOSITE FATIGUE CRACK MONITORING USING ACOUSTIC EMISSION

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GLASS FIBER-REINFORCED POLYESTER COMPOSITE FATIGUE CRACK MONITORING USING ACOUSTIC EMISSION

By

SAMIRA GHOLIZADEH

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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

GLASS FIBER-REINFORCED POLYESTER COMPOSITE FATIGUE CRACK MONITORING USING ACOUSTIC EMISSION

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October, 2015

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Acoustic Emission (AE) is an elastic stress wave which is produced by a quick release of the energy through a material. There are many reasons that result in AE such as deformation of the material, crack initiation and growth of cracks. Only a little study has investigated about damage assessment in glass fiber reinforced polyester composite, and some other studies considered about one or two AE signal parameters with pattern recognition. AE basic parameters have not been widely used to detect the onset of damage in composite materials. This study was done to apply AE technique by using basic parameters for detecting onset of glass fiber reinforced polyester composite materials damage and validate this technique using actual AE data from fatigue growth. Tensile test was done on 3 specimens of glass fiber reinforced polyester composite to find out the percentage of applied stress. 15 specimens were used for the fatigue test with 40%, 45%, 50%, 55%, and 60% of ultimate tensile strength (UTS) as a stress level. A cyclic tension-tension loading was applied to the samples, during the test, AE sensor was attached to the center of the specimens and AE signal parameters were generated from the specimens during the test. The discussion showed when crack propagated in materials; AE signal parameters such as energy, amplitude, number of hits, as well as correlation of two basic parameter such as amplitude versus duration was were analyzed to find out crack growth behavior in different stage of testing in early time of testing, middle and near fracture zone. Therefore from the trend of the AE signal parameters, failure of material such as matrix cracking between 40 dB - 60 dB of amplitude, fiber debonding 60 dB - 65 dB, fiber pull out between 65 dB - 85 dB and fiber breakage between 85 dB - 100 dB were observed. The high degree correlation between AE signal parameters such as energy and number of hits, between number of cycles to failure as well as applied stress with R^2 = 91% and R^2 = 92% in the composite material presented that AE basic parameter can be used for detecting the onset of damage as it can record from initial cracks and also crack propagation at different time of service at different stress level.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGAWASAN RETAK-LESU KOMPOSIT POLIESTER DIPERKUAT GENTIAN KACA MENGGUNAKAN EMISI AKUSTIK

Oleh

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Emisi akustik (AE) adalah gelombang tegasan anjal yang dihasilkan oleh pelepasan tenaga yang cepat melalui bahan. Terdapat banyak sebab-sebab yang menyebabkan AE seperti ubah bentuk bahan, permulaan retak dan pertumbuhan retak. Hanya satu kajian kecil telah menyiasat tentang penilaian kerosakan dengan serat kaca bertetulang poliester komposit, dan beberapa kajian lain yang dianggap kira-kira satu atau dua parameter AE isyarat dengan pengiktirafan corak. AE parameter asas belum digunakan secara meluas untuk mengesan bermulanya kerosakan dalam bahan komposit. Kajian ini dijalankan untuk memohon teknik AE dengan menggunakan parameter asas untuk mengesan bermulanya bertetulang gentian kaca kerosakan bahan poliester komposit dan mengesahkan teknik ini menggunakan data AE sebenar daripada pertumbuhan keletihan. Ujian tegangan telah dilakukan ke atas 3 spesimen kaca bertetulang gentian poliester komposit untuk mengetahui peratusan tekanan gunaan. 15 spesimen telah digunakan untuk ujian keletihan dengan 40%, 45%, 50%, 55%, dan 60% daripada kekuatan tegangan muktamad (SUA) kerana tahap tekanan yang. Satu kitaran ketegangan-ketegangan loading telah digunakan untuk sampel, semasa ujian, sensor AE bertugas di pusat spesimen dan parameter isyarat AE dijana dari spesimen semasa ujian. Perbincangan menunjukkan apabila retak disebarkan dalam bahan-bahan; Parameter isyarat AE seperti tenaga, amplitud, beberapa hits, serta hubungan dua parameter asas seperti amplitud berbanding tempoh telah dianalisis untuk mengetahui tingkah laku pertumbuhan retak dalam peringkat ujian yang berbeza dalam masa awal ujian, tengah dan berhampiran patah zon. Oleh itu dari trend parameter isyarat AE, kegagalan bahan seperti matriks retak antara 40 dB - 60 dB amplitud, serat nyahikatan 60 dB - 65 dB, serat menarik keluar antara 65 dB - 85 dB dan serat kerosakan antara 85 dB -100 dB diperhatikan. Korelasi ijazah tinggi di antara parameter isyarat AE seperti tenaga dan beberapa hits, antara bilangan kitaran kegagalan serta tekanan gunaan dengan R2 = 91% dan R2 = 92% dalam bahan komposit dikemukakan bahawa parameter asas AE boleh digunakan untuk mengesan bermulanya kerosakan kerana ia boleh merakam dari retak awal dan juga perambatan retak pada masa perkhidmatan yang berbeza pada tahap tekanan yang berbeza.

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I certify that a Thesis Examination Committee has met on 20 October 2015 to conduct the final examination of Samira Gholizadeh on her thesis entitled "Glass Fiber-Reinforced Polyester Composite Fatigue Crack Monitoring Using Acoustic Emission" in accordance with the Universities and University Colleges Act 1971 and the Constitution of 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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LIST OF ABBREVIATIONS

Term	Definition
AC signal	Alternative Current signal
AE	Acoustic Emission
ANN	Artificial Neural Network
ASTM	American Society for Testing and Materials
CFRP	Carbon Fiber–Reinforced Polymer
FFT	Fast Fourier Transform
FR	Felicity Ratio
GFRP	Glass Fibers Reinforced Plastic
HDT	Hit Definition Time
HLT	Hit Lockout Time
NDE	Non-Destructive Evaluation
NDT	None-Destructive Testing
PAC	Physical Acoustic Corporation
PDT	Peak Definition Time
RMS	Root Mean Square
SHM	Structural Health Monitoring
ST-FFT	Short-Time Fast Fourier Transform
SW	Stress Wave
UTS	Ultimate Tensile Strength
Wt	Weight

CHAPTER 1

INTRODUCTION

1.1 Background

Recently, after producers and in-service in aircraft industry, non-destructive testing (NDT) of composite materials has been a significant issue regarding. A necessary factor which takes into account the total cost especially costs arising from component fault or error, is spending enough time for inspection and checkup. The non-destructive testing of composite materials has become more crucial and demanding. This is due to the fact that composite tools are mostly used in critical-safety applications for example in aircraft primary constructions.

When the use of composite materials increases dramatically in safety-critical applications, such as aircraft primary structures the non-destructive evaluation of composite materials becomes significantly important and more demanding. Conventional non-destructive evaluation (NDE) of composite tools by acoustic emission (AE) techniques can be utilized for the evaluation of the damage in the brittle materials (Ren et al., 2013). Currently, one advantage of conventional non-destructive evaluation is the recording of damage process during the entire load history without any disturbance to the specimen. In addition, these techniques have been used to analyze the dynamic damage and fracture information of materials (Landis, 1999; Ren et al., 2013).

Acoustic Emission (AE) is considered as a passive NDT technique because AE detects emitted elastic waves within structure during deformation while most other traditional NDT methods such as radiography, ultrasound and eddy currents require a source input and are therefore defined as active NDT technique. A major strength of AE is its ability to be used as a "global" monitoring tool (Holford. & Carter., 1999) i.e. it can provide inspection on a wider area compared with other NDT techniques. AE offers the opportunity to monitor the fatigue damage continuously and cracks can be identified at early initiation stage of formation without interference on the test.

A composite material is a mixture of more than one material that still possesses their unique individual features while acting together. This mixture of different materials generally yields different features and properties than those of the original materials.
Among the constituting materials is a matrix that develops into a continuous phase while the other major constituents reinforce into particulates or fibers. This reinforcement produces a discontinuity which helps improve the properties of the matrix, which can either be a ceramic, metal or polymer.

The type of material of the matrix usually determines the name of the composite materials such as metal matrix composite or polymer matrix composite. Also the type of matrix used determines the type of major effect the reinforcement will have on the composite. For instance, fibers used to reinforce polymer matrix have greater effect in terms of strength and modulus than polymers (Karam, 1991).

There are several attractive features of composites. These features include: excellent damping characteristics, light weight, resistant to corrosion destruction and stress-free attainment of complex forms. These features make composites to be used as essential

materials in aerospace and automotive. Composites are more effective in their performance compared to metals because of its intrinsic characteristics. Composites have desirable stiffness-to-weight and strength-to-weight ratios which makes them widely used.

Acoustic emissions can be used to identify composite material properties. The major difference between AE and most other NDT techniques is that it detects microscopic movements, not geometric discontinuities. AE is unique in that it can identify damage in real time, i.e. when damage initiates or as it propagates. Furthermore, AE equipment does not introduce energy into the test piece like ultrasound does. It is therefore a passive NDT method. There is no procedure which is similar to acoustic emission and many of NDT methods cannot determine mechanical properties of material. Proper identification of materials properties helps to predict problems that are associated with their features such as crack resistance and strength. These features are very essential in analysis of composites.

Accumulation and interaction of different types of disturbed damage cause fatigue failure in composites, which is a very complex phenomenon, dependent on a large number of material and test parameters. Three main failure modes of matrix cracking, interface debonding and fiber failure play major roles in a sequential order at different stages of damage progression. An accurate approach is required to analyze the AE data obtained from fatigue tests, which should consider nature and quantity of the data.

The acoustic energy is emitted by fatigue crack growth. The AE testing is able to locate this defect through array of sensors located at a certain distance from the source. The implementation of the AE inspection method might be costly, but decreasing the follow up test period can reduce the cost because the damage source and downtime associated with plant shut down are localized. Further cost can also be saved if the defects are sized and located.

1.2 Problem statement

Most studies that investigated about damage mechanism in composite materials used only one or two of AE signal parameter with pattern recognition as a multivariable technique for AE event classification (Bar et al., 2004; Bhat et al., 2003; Godin, et al., 2004; Huguet et al., 2002; Philippidis et al., 1998; Philippidis et al., 1999); Furthermore a little literature has reported about acoustic emission analysis in glass fiber reinforced polyester composite (Barre & Benzeggagh, 1994; Gostautas et al., 2005; Huguet et al., 2002). In this study multiparameter of AE signals which were known as basic parameters are only used to investigate damage modes in glass fiber reinforced polyester composite to show AE itself can be a useful tool to identify onset damage in composite materials and the relationship between AE signal parameters and fatigue cracks was investigated.

1.3 Objective of study

The objective of study is:

1. To evaluate current methods for investigating the onset fatigue crack growth in composite materials and validate these techniques using actual AE data from fatigue crack growth.

1.4 Scope of study

This research was conducted by experimental work. The basic AE signal parameters were collected during the process to assess damage modes in composite specimens in order to find out the relation between acoustic emission signal parameters and fatigue cracks in composite materials. In this study, glass fiber reinforced polyester composites with 40% weight of glass fiber (40wt%) and 60% weight of polyester (60wt%) have been fabricated in the laboratory. Tensile test was done on 3 specimens of glass fiber reinforced polyester composites to find out the percentage of stress levels during fatigue test. 15 specimens were subjected to fatigue test under cyclic tension-tension loading and AE signal parameters were recorded during the test. Data were analyzed based on time domain waveform of acoustic emission at 40%, 45%, 50%, 55% and 60% of ultimate tensile strength (UTS) of 135.5 MPa at different time of service.

1.5 Significance of study

AE testing of material properties allows the companies a chance to know more about their material characteristics which can help them to identify the problems and predict of any kind of problem such as fracture, fatigue life. Using AE in critical components and equipment in companies can identify the crack resistance of materials. Collecting data provides an opportunity to analyze properties of composite component which can point to a critical condition when component is near to fracture or its fatigue life, and to improve material properties by predicting problems.

1.6 Hypothesis of study

The Hypothesis of this study is that the onset damage caused by fatigue loading in composite materials is related to AE signal outputs.

1.7 Thesis layout

This thesis contains the following chapters:
Chapter 1 includes the background of study and statement problems and objectives. Chapter 2 presents literature review which involves all relevant topics related to the acoustic emission that will be discussed. Chapter 3 provides a methodology using acoustic emission method, applied in conducting experiment and the way to collect the AE signals. Chapter 4 consists of results and discussion of the AE signal results and trend of fatigue during test by AE. Chapter 5 contains conclusion of identifying damage assessment using AE signals analysis implementation from the results and discussion.

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