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

1S. GHLIZADEH, 2Z. LEMAN, 3BTHT. BAHRUDIN, 4O. INNAYATULLAH

1, 2, 3Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
4School of Engineering and Technology (Mechanical Engineering), University College of Technology Sarawak (UCTS), Sarawak, Malaysia
E-mail: 1vsoo_gh@yahoo.com, 2zleman@upm.edu.my, 3hangtuh@upm.edu.my, 4drothman@ucts.edu.my

Abstract- This paper presents acoustic emission (AE) technique for detecting onset damage of composite materials damage and validate this technique using actual AE data from fatigue crack growth. AE piezoelectric transducer was attached to glass fibre reinforced polyester composite specimen during the fatigue cyclic test. For data collection, AE parameters, i.e., duration, amplitude, and energy near fracture zone were obtained and were correlated to fatigue life. AE signals were obtained at four different applied loads (60.97MPa, 67.75MPa, 74.52MPa, and 81.30 MPa) which were 45% to 60% of ultimate tensile strength (UTS) of material. The results show correlation between AE parameters and the number of cycles to failure. These correlations show that AE can be used to predict the fatigue life and can be tool for detecting damages in composite materials.

Index terms- Acoustic Emission, Glass fibre reinforced composite, Fatigue, failure mode, damage assessment

I. INTRODUCTION

Acoustic emission, a non-destructive testing that was developed over three decades, is used to detect active microscopic events in a material, such as crack initiation and propagation. 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 testing technique. A major strength of AE is its ability to be used as a “global” monitoring tool 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[1].

The definition of AE as given by ASTM E1316 (2014) "is a category of phenomenon in which transient elastic waves are produced by the quick release of energy from localized sources though a material". Piezoelectric transducers are usually used to detect the propagation of these waves via structures, and which are then processed using several methods to yield a range of parameters. AE has the potential to not only analyze these resulting electrical signals for locating and defining structure defects but can also be used for monitoring the integrity of structures during service and proof-testing [2].

Most studies that investigated about damage mechanism in composite materials used pattern recognition as a multivariable technique for AE event classification [3-8]. B. Bhat [8]conducted a research with the purpose of usage of the acoustic emission technique (AE) to classify the mechanism of damage in multi-layered glass fibers reinforced plastic (GFRP). The signals of AE were developed through a polyvinylidene fluoride (PVDF) film sensor as of composite laminates of three dissimilar sets stacking sequences during monotonically increasing tensile load. Bhat et al. [7] used artificial neural networks (ANN) for finding noise suppression in acoustic emission data and with the long-term objective of in-flight monitoring. Few writers have described damage modes in the usage of AE distributions in glass fibre reinforced composite. Huguet et al., [3] conducted a research of the AE signal parameters to identify the various real-time damage in applied stress to glass fibre reinforced polymer composite. Gostautas et al.,[10] studied structural performance of glass fibre-reinforced composites bridge decks to characterize damage where specimen were subjected to static loading (three point bending) and repaired ones compared with the originals. Felicity Ratio (FR) was used to check the Kaiser effect and the Felicity effect and also intensity analysis was used.

Using AE waveform multiparameter for improving the identification of damage modes in composite materials as a tool to detect onset of damage should be necessary. This study was done to apply AE technique for detecting onset of composite materials damage and validate this technique using actual AE data from fatigue growth. The current study aimed at evaluating AE as a structural health monitoring technique to detect deformation, fracture and fatigue cracks in composite materials.

II. EXPERIMENTAL PROCEDURE

Woven glass fibres reinforced were cut in dimension of 30 × 30 cm to fabricate glass fibre reinforced composites. For fabrication, 40wt% glass fibre,
60wt% matrix (GP 268 BQT-W) and 2wt% hardener were used. The specimens were cut from a six-layered unidirectional glass fibre reinforced polyester plates for testing in the laboratory to evaluate properties of the materials under different loading conditions. A set of 19 specimens with dimension of 5 mm thick, 250 mm length and 25 mm width (Figure 1) were cut according to ASTM D3039 and 3 samples were run by tensile test before doing the cyclic fatigue test following ASTM D3479.

- **Tensile Testing techniques**
  In this study the goal of the tensile tests was to determine the ultimate tensile strength (UTS) of materials. Three specimens were used for tensile testing which were carried out on a universal machine testing system type INSTRON 3382 with 100 kN capacity. An average UTS of 135.5 MPa was obtained from the tensile test and this amount of UTS were the basis of subsequent experiments.

- **Fatigue testing with acoustic emission sensor attachment**
  The specimen was installed into the test rig under one point test set up (AE sensor) as shown in Figure 2. The specimen was loaded using a 100 kN hydraulic MTS test machine. Load was applied sinusoidal waveform. AE sensor was attached on the surface and its position is displayed in Figure 3.

The MTS 647 Hydraulic Wedge Grip testing machine with maximum load of 100 kN and maximum pressure of 21 MPa or 3000 psi was used to apply the load to the specimens until specimens separation. A set of 16 specimens were loaded under tension-tension cyclic loading at frequency of 8 Hz with 45% to 60% of UTS, maximum load of 10.07 kN and minimum load of 7.33 kN at stress ratio R = 0.1 with 3.5 MPa pressure. Load data from testing machine was fed to parametric channel of AE data acquisition system. This load data was recorded simultaneously with the transient AE signals detected during fatigue test and both data were used for AE source mechanism characterization by correlating AE parameters with the load value.

- **Acoustic emission (AE)**
  The MISTRAS AE system from Physical Acoustic Corporation [9] Two-Channel, was used to acquire AE signals released from fatigue crack growth throughout this work. One wideband (W5u) AE transducers with frequency range of 100 to 1000 kHz were used to detect AE signals from fatigue test at the center of the specimen. This sensor was attached to specimen and connected to AE data acquisition system through coaxial cable. The 40 dB threshold level has been used for AE data acquisition and detected events were amplified by 40 dB amplifier and 26 dB pre-amplifier. In order to avoid any unnecessary AE signals that would be affected by the environmental noise, a threshold value of 40 dB has been selected as all the noise signals were below this value. All recorded signals were stored on the computer for further analysis. The software for data acquisition and signal processing is AE Win™. AE Win for MISTRAS was used to replay and display store AE data throughout this study. To run proper AE monitoring, certain parameters of the data acquisition systems need to be set according to the testing material and the existing noise level. Peak Definition Time (PDT), Hit Definition Time (HDT) and Hit Lock out Time (HLT) are timing parameters of the signal acquisition process and contain material specific values (Table 1).
III. RESULT AND DISCUSSION

Time Domain Trends. The number of incoming signals is the most basic parameter of an AE monitoring. This number is a criterion for characterization of structural integrities in many cases of standardized monitoring. Usually some of AE parameters such as, amplitude, energy, duration increase with load increment, because the crack propagation increases when the load increases. The signal patterns of AE duration vs amplitude, which were measured near the fracture zone at different applied stress of 45%, 50%, 55%, and 60% of UTS with amount of 60.97MPa, 67.75MPa, 74.52MPa, and 81.30 MPa, respectively, are shown in Figure 5.

One parameter which can be considerable among AE signal parameter is duration. Duration is related to the time of signal crossing threshold until end of crossing. It affects the breakage in composite material. Events with higher amplitude and longer duration generally signify the breakage of the fibers while short to medium duration and low to medium amplitude events tend to signify matrix cracking within the material [10].

The observed rises in duration versus amplitude plot occurred because of the increased applying load and subsequent stress concentrations, that they increases amplitude and duration of recorded events during testing procedures (Figure 5). These features of the waveform indicates that, “zones” can be utilized to determine the different types of damage characteristics, such as fiber breakage, matrix cracking, and debonding or false events (for example,
mechanical rubbing) which were developed by [10] and [11]. Regarding to Gogtautas et al., (2005) about different damage characteristics division, in all applied stress level, mechanical rubbing and matrix cracking as well as crack growth are obvious which are occurred between 40dB to 45dB, 45dB to 65 and 60dB to 70dB at different duration from 1 to 1000µs. As can be seen the extensive amplitude between 60 dB to 80 dB in Figure 5(d) shows the much more matrix cracking, debonding, crack growth and delamination in material because of load increment which lead to fibre breakage compare with other stress level. The details of aggregation propagation and breakage can be observed. The highly matrix cracking as well as crack growth is clear and material started to fibre breakage from 60 dB with high amount of cracking because of load increasing and subsequence crack propagation.

Figure 6: Energy and amplitude at different applied stress level (a) 45%, (b) 50%, (c) 55%, (d) 60% of UTS
At 55% of UTS with 74.52MPa stress level, according to material behavior in previous all level of stress, it was predicted to break faster, therefore every 30s was recorded to find out and more details about material behavior. The AE energy and amplitude compare with previous level was decreased. According to Figure 5 and 6, because of short time recording and also because AE activity is related to fracture events and crack behavior; and a high load pertain to shorter failure time, acoustic activity experienced by the specimens is not as strong compare with lower loads [12]. In addition, cracking rate is faster and consequently fracture events occur gradually more rapid emitting the corresponding signals with hundreds/s rate [13]. Therefore, AE parameters decreased compare to previous levels. However, at the time of delamination and fibre breakage, high level of energy and amplitude as well as duration at this level of applied stress is clear. It is obvious that at the time of breaking, material released high amount of energy around 100,000 and 100 dB of amplitude. Fibre breakage starts from 60 dB of amplitude with 10,000 µs duration to 100 dB of amplitude.

The final level of testing which was 60% of UTS with amount of 81.30 MPa stress has been shown in Figure 8. At this level of testing, all of time of testing from starting until breakage was recorded; according to material behavior in previous level it was predicted that at this level specimens should break faster. Although AE parameters compare to previous level was increased, is lower than other applied stress level. An extensive amplitude and crack propagation is clear at this level compare with others, it is reasonable because when the load increases, other than that the matrix cracking becomes larger; numerous delaminations take place while it was not active at the previous loading steps. Micro-cracking started to develop initially, after strength of material was obtained, a macroscopic crack was created, then large amount of cracking was suddenly observed; and therefore high level of energy was recorded. The extensive of amplitude between 60 dB to 80 dB shows the much more matrix cracking, debonding, crack growth and delamination in material because of load increment which lead to fibre breakage compare with other stress level.

The correlations between the selected AE parameters and fatigue life were then established to predict the specimen fatigue life. The correlation coefficient R2 of linear relationship between AE parameters, duration, energy and the number of cycles to failure are shown is Figure 7 and 8 respectively. All graphs of AE parameters fit the linear regression line to the number of cycles to failure. The number of cycles to failure clearly increased when all parameters value decreased. The correlation coefficient \( R^2 = 91.13\% \) and \( R^2 = 91.06\% \) indicates a good correlation for prediction of specimen life.

Common AE parameters for damage assessment in glass fibre reinforced polyester composite material was discussed in this study. Three AE parameters, such as amplitude, energy and duration were analyzed to determine the behavior of fatigue cracks during cyclic fatigue test. It was found that in higher applied stress because of faster failure the AE parameters can be decreased in the time of onset damage in specimen. Based on linear correlation between AE parameters and number of cycles to failure with 91.13% and 91.06% correlation coefficient, all AE parameters increased when stress value increased and number of cycles decreased. The correlation coefficient shows a good R2 coefficient for predicting fatigue life.

REFERENCES

Glass Fiber-Reinforced Polyester Composite Fatigue Crack Monitoring Using Acoustic Emission


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