IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Factura '20 - National Conference On Emerging Trends In Manufacturing

NSS College of Engineering, Palakkad, Kerala, India

Vol. 7, Special Issue 1, August 2020

A Comparative Study of Acoustic Emission in Hybrid Composite Under Quasi Static Indentation

Ajith U[1], Aneesh Kumar P [2]

M. Tech Student, Department of Mechanical Engineering, NSS Engineering College, Palakkad, India[1]

Assistant professor, Department of Mechanical Engineering, NSS Engineering College, Palakkad, India[2]

Abstract: Non-destructive testing methods are extensively utilized to improve understanding of damage evolution in laminated composite materials. Acoustic Emission (AE) is a non-destructive testing method and exhibits potential for monitoring damage evolution of composite materials. AE signal is the outcome of transient elastic strain waves generated inside materials as they undergo fracture or deformation. Therefore, this technique is efficient to offer in situ information about damage mechanisms occurring in the time of loading. Composite materials are the lightest, stiffest, and strongest corrosion-resistant materials known today. Any internal invisible damage in FRP composites can be sensed and evaluate only by using non-destructive testing (NDT) methods. Acoustic emission (AE) is a impressive technique in NDT methods and can be used for assessment of the damage in FRP composite materials. In order to design structural components using composite materials a deep knowledge of the material behaviour and its failure mechanisms is mandatory. To create a better knowledge of the initiation, accumulation and interaction of the different types of damages, the monitoring of damage during mechanical loading is crucial. In this aspect, AE is a effective non- destructive technique for real time monitoring of damage development in materials and structures which has been used successfully for the identification of damage mechanisms in composite structures under quasi static and dynamic-cycle loading. In this work the latest advanced composite structure which is the hybridized composite laminates are manufactured for determining the damage characterization using acoustic emission testing. The hybrid composite laminates are manufactured in 16-layer symmetrical cross ply orientation using hand layup technique. The well-known synthetic fibers like glass, Kevlar and carbon fibers are used as reinforcement. The study was conducted on quasi static indentation setup having 100 KN loading with different angle of indentation. For that, different custom made base plate is manufactured. Evaluation of indentation response has been done by measuring peak force and absorbed energy. Significant AE parameters that include amplitude, duration, cumulative counts and peak frequency have been considered for monitoring damage progression during QSI loading. The graphs are plotted and analysed for determining the failure mode. By analysing the frequency content the frequency ranges for different damages are tabulated. It was found to be that by increasing the angle of indentation the fiber breakage was reduced. Matrix cracking and inter laminar shear damage was still active at the higher indentation angles.

Keywords: Acoustic Emission, NDT, Hybrid composite, failure mode, indentation

I. INTRODUCTION

Different Non-Destructive Testing (NDT) methods are used for the characterization of the damage mechanisms in the composite materials. Among the several NDT methods, Acoustic Emission (AE) is an efficient monitoring technique, and differs from most other NDT methods in two key aspects. First, the signal has its origin in the material itself and not in an external source such as light or ultrasonic energy. Second, this technique detects movement of defects, while most other NDT methods detect only the existing geometrical discontinuities. The AE technique is particularly attractive due to the acquisition of real-time data, potential for monitoring damage initiation, progression and accumulation, anticipating failure sites, identifying different damage mechanism, determining damage criticality and its sensitivity to invisible damage such as fabrication defects, impact damage [1]. Hence AE is a powerful NDE for real- time structural health monitoring of composite materials under static and dynamic loading.
Hybridization of different fibres is an approach frequently used to increase the resistance of composite materials against impact damage by introducing two or different types of fiber as matrix reinforcement. The effect of the various configurations of hybrid laminates has been investigated during recent years and impressive results have been reported. However, more research studies are still needed for a more effective investigation of impact damage progression in hybrid composite laminates obtained with different layup configurations and using various materials. The purpose of using layers of different laminates in the same composites, hence obtaining a hybrid, would, in particular, allow behaviour tailored for the service needs to a great extent. For example, adding glass fibers demonstrated increase in the dissipations of nonlinear deformations in carbon fibers composite without leading to
interplay cracking[2]. It is also important to study and characterize the failure modes in the newly fabricated composite materials. Here the acoustic emission technique has a significant role to characterize the damages like matrix cracking, fiber matrix de-bonding, fiber pull out, delamination, fiber breakage mainly by frequency analysis of acoustic emission signals [3]. The multi-layer cracking is the first to be active, followed by matrix cracking, delamination and fiber breakage [4]. A number of studies exist, which are aimed at finding a correlation between AE parameters and damage mechanisms [5]. Woo, S.C. et al. [6]

compared the different amplitude classifications for the damage mechanisms of composites–fiber breakage (i.e., 70 dB–100 dB), fiber/matrix debonding (i.e., 50 dB–70 dB), and matrix cracking (i.e., 30 dB–50 dB), respectively. De Rosa, I.M. et al. [7] summarized previous work to conclude that the AE events of higher energy and frequency can be related to fiber breakages, while events of lower energy and frequency can be related to matrix cracking. In this work, an experimental investigation is conducted to characterize the damage mechanism in composite like matrix cracking, fiber matrix failure, fiber pull out, delamination and fiber breakage using acoustic emission technique. Also, we are trying to study the variation of response of damage formation when the angle of indentation is increased in the quasi static indentation testing. AE is one of the powerful non-destructive techniques for real-time monitoring of damage development, in materials and structures under quasi-static loading conditions [8]. Since hybrid composites are the latest advanced composite, we are doing this experiment in two different hybrid composite and a glass fiber reinforced composite for a reference. The acoustic emission signal is collected during the test using a sensor. The collected signals are processed in software which is given with the acoustic emission testing setup by Physical Acoustic Corporation. The data obtained from the software is categorized in several parameters. The favorable parameters are tabulated and plotted for the analysis and study.

II. SPECIMENPREPARATION

A E-glass fiber mat having fiber of diameter GSM 0.3, Kevlar fiber mat having of diameter GSM 0.375, carbon fiber mat having of diameter GSM 0.45 were used as reinforcements for the preparation of the different hybrid composite laminates. Epoxy resin (LY556) i.e., diglycidyl ether of bisphenol-A (DGEBA) with hardener (HY 951) in the ratio of 10:1 was used as the matrix materials. Fiber mats into the epoxy resin in a ratio of 1:1 by weight was selected.

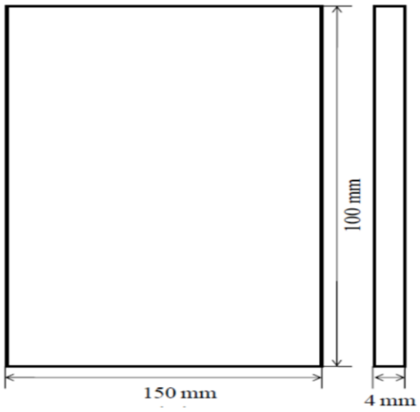


Fig 1 ASTM D6264M standard indentation test specimen

The conventional hand lay-up technique was employed for characterization of failure modes and indentation damage resistance studies to reinforce the fiber mats into the epoxy resin in a ratio of 1:1 by weight. 16 layers cross ply orientation (0, 90, 90, 0) which is a symmetrical cross ply is manufactured. The fibre was placed in the mould and the resin hardener mix was allowed to better impregnating the reinforcement with aid of rollers. The laminates were allowed to cure at room temperature under a pressure of 50kg/cm2 in a 30kN compression moulding machine for 24h.

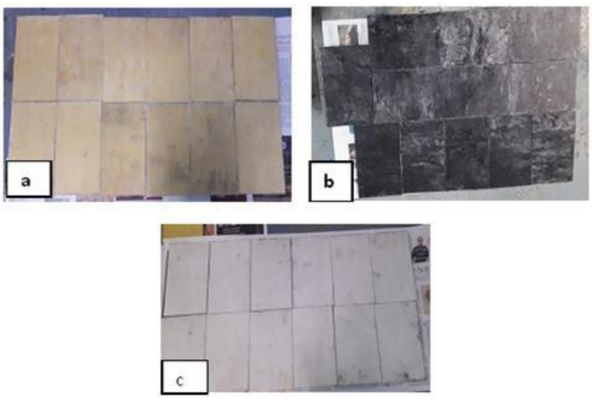


Fig 2 (a) Glass/Kevlar Hybrid specimen (b) Glass/Carbon Hybrid specimen (c) Glass fiber reinforced composite

The standard ASTM D6264M size specimen showed in figure 1 is used for the indentation experiment. The fabricated composite laminates of size are 500mm x 500mm. Then the required size specimen is cut by wood cutter as shown in figure 2.

III. EXPERIMENTALSETUP

3.1 Quasi Static Indentation setup

Fig 3 10 ton Universal Testing Machine for QSI

Quasi-static indentation tests were performed using Tinius-Olsen Universal Testing Machine (UTM) with a maximum load capacity of 100kNshowed in figure 3. The ASTM D6264-98(04) standard indentation fixture employed in this study was composed of a plate-like equipped support (i.e. unlike clamped plate geometry with edge support) with a central rectangular hole cut-out, above which the specimens was mounted. QSI tests were done on the 150mm x 100mm specimens and the four corners of the rectangular specimens were rigidly clamped on the fixtures, then applied indentation test directly above at the center of the laminates as shown in Fig4. A series of indentation tests were performed with the velocity of 1mm/minute up to 4.5mm with the aim of comparing the damage behavior of the indented laminates. Here we are conducting the indentation in 4 different angles that is 0^0, 10^0,15^0, 20^0. The acoustic emission is recorded for each indentation angle. For the indentation process customized structure in four different angles is used

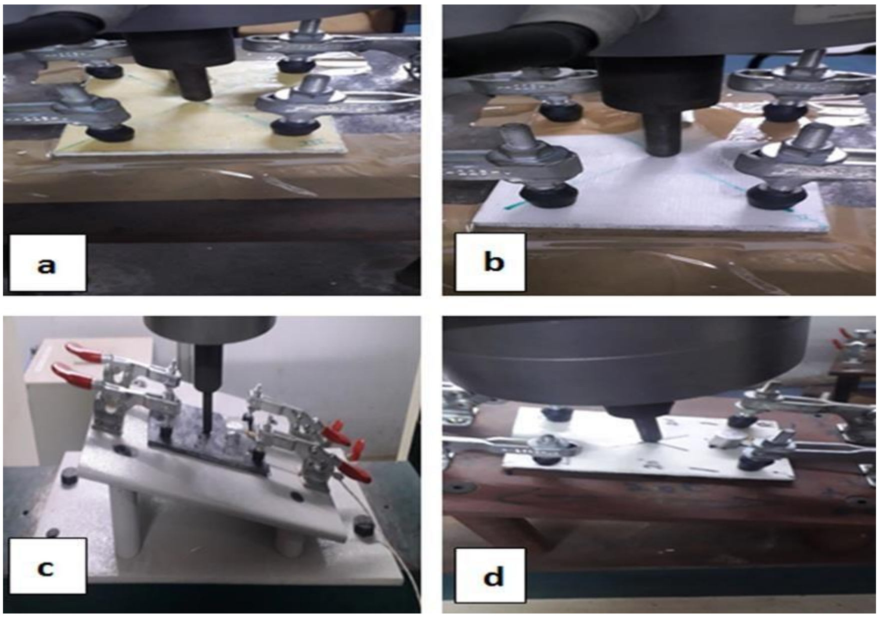


Fig 4 (a) 0 degree indentation angle (b) 10 degree indentation angle
(c) 15 degree indentation angle (d) 20 degree indentation angle

3.2 Acoustic emissionmonitoring

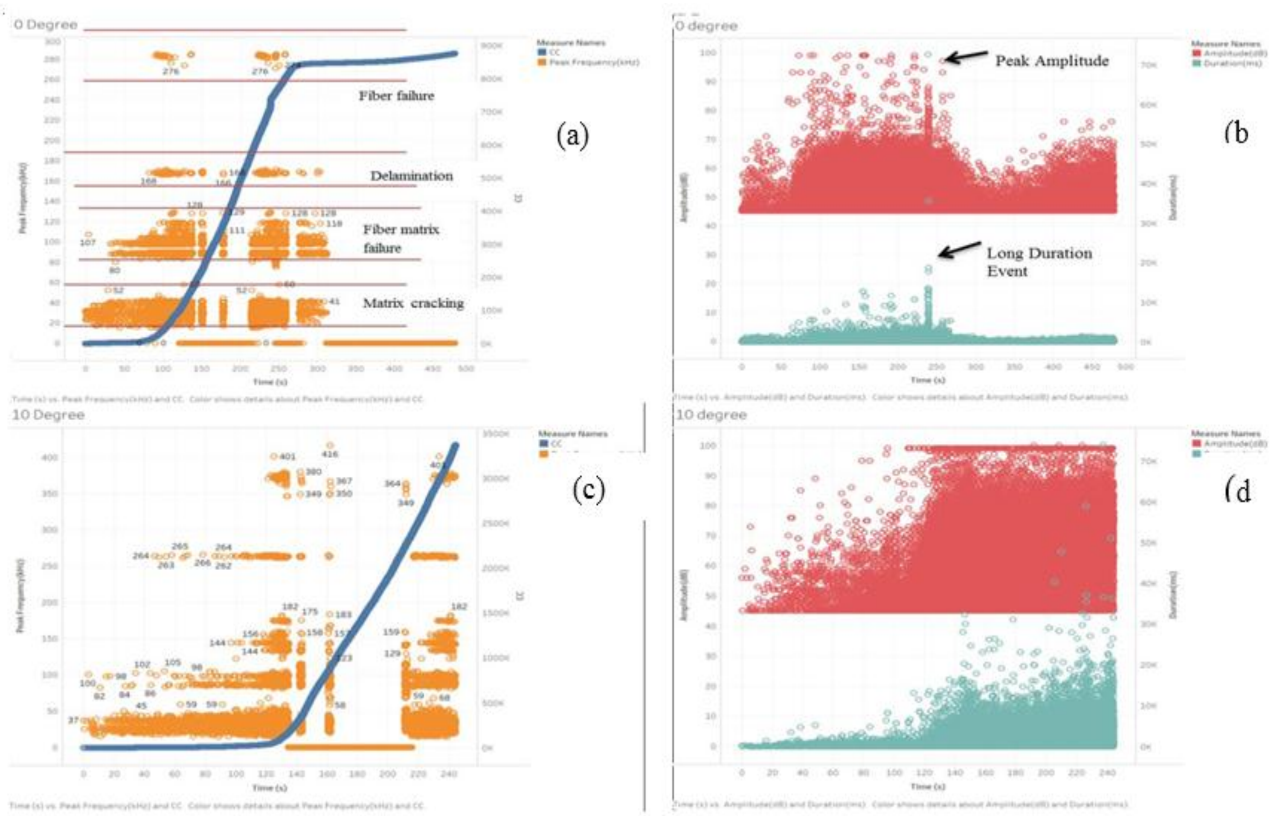
A Physical Acoustics Corporation (PAC) Acoustic Emission (AE) monitoring device was employed to monitor the real-time dynamic changes within the composite laminates during mechanical loading. The AE device was equipped with a single-channel

PCI-8 board with a sampling frequency of 4 MHz to simultaneously perform operations such as AE signal acquisition, AE signal processing and high-speed transfer of AE data. In order to boost the strength of weak acoustic signals for further processing and to reduce the consequence of interference due to external sources, the pre- amplifier gain was set to 40 dB. Wide-band differential AE sensors of operating frequency range 100-1000 kHz were used to acquire the stress wave signals generated during fracturing of the specimens under mechanical loading. The amplitude threshold was fixed to 40 dB, which prevents the acquisition of unwanted ambient noise signals during damage monitoring process. High sealant vacuum grease (silicon grease) was used as the coupling agent between the AE sensor and the specimens to improve acoustic coupling between them. The wave velocities and signal definition times were mean values estimated as per the standard ASTM E976-10 pencil break test method. The AE events that were recorded by the sensors were utilized for the data processing. The acoustic activities and signal parameters were monitored in real-time using AE Win software supplied by PAC

IV. RESULT AND DISCUSSION

4.1 Frequency Analysis of AE Signals

To discriminate the failure modes involved in quasi static indentation testing of composite laminates, frequency analysis is one of the promising techniques. Figure 5, 6, 7 shows the variation of peak frequency with time for the three different type specimen subjected to quasi static indentation test with AE monitoring. The pure glass peak frequency showed mainly 5 clusters of reading that indicates different damages. In fig 5a frequency range of 20-55 kHz may associate with matrix cracking was recorded as the first cluster. The frequency range of 80-98 kHz may indicate the fiber matrix failure. The frequency range of 100-130 kHz may relate to fiber pull out. The delamination or inter laminar failure have a good importance in this study because the increase in the indentation angle is shifting the damage to delamination. Here the frequency range 160-170 kHz may be indicating the delamination. The last frequency cluster is indicating the fiber breakage or failure. it is in rage of 270-282 kHz



ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Factura '20 - National Conference On Emerging Trends In Manufacturing

NSS College of Engineering, Palakkad, Kerala, India

Vol. 7, Special Issue 1, August 2020

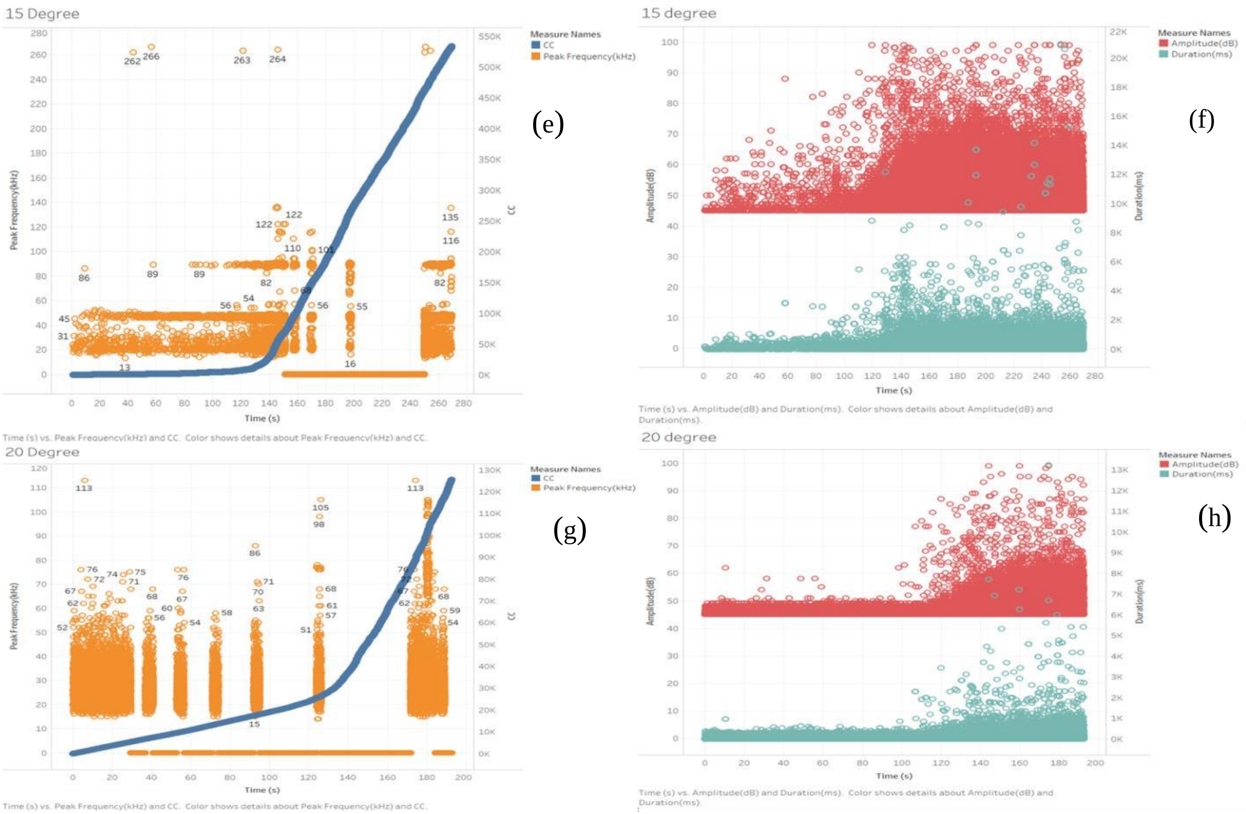
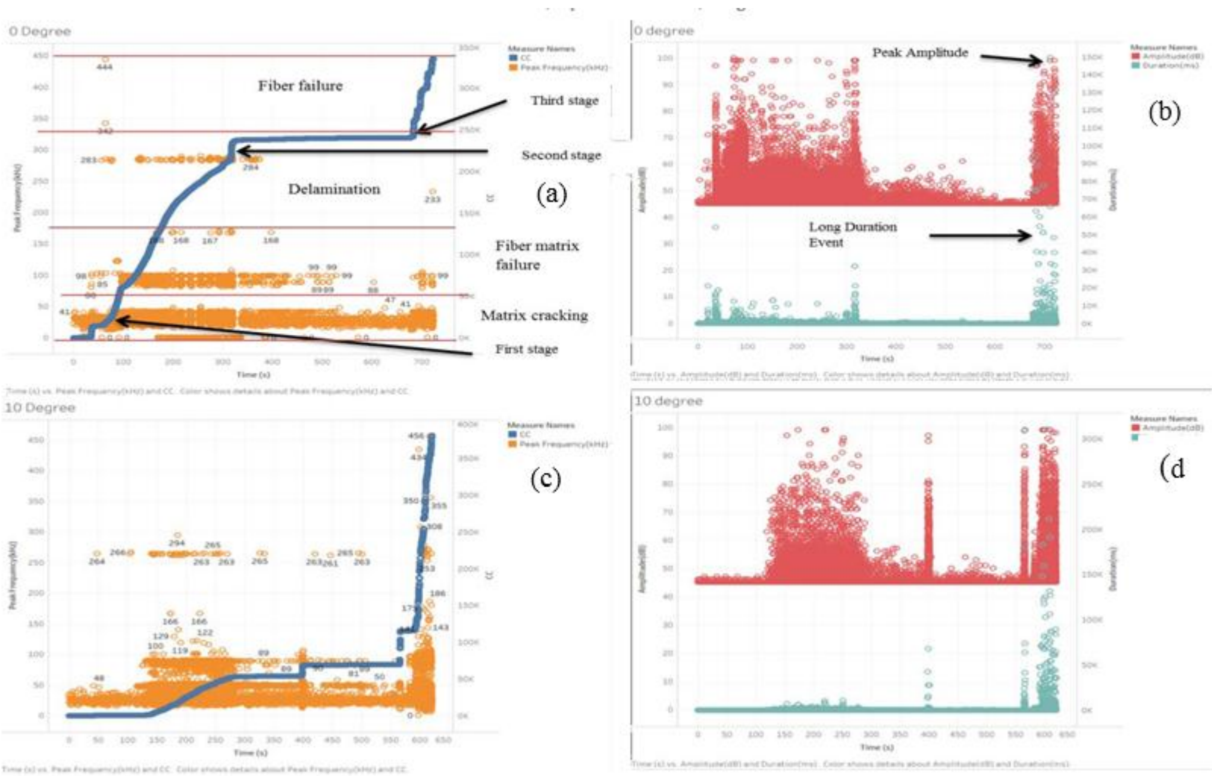


Fig 5 parametric plots for pure glass fiber reinforced composite under quasi static indentation in 4 different angles



IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Factura '20 - National Conference On Emerging Trends In Manufacturing

NSS College of Engineering, Palakkad, Kerala, India

Vol. 7, Special Issue 1, August 2020

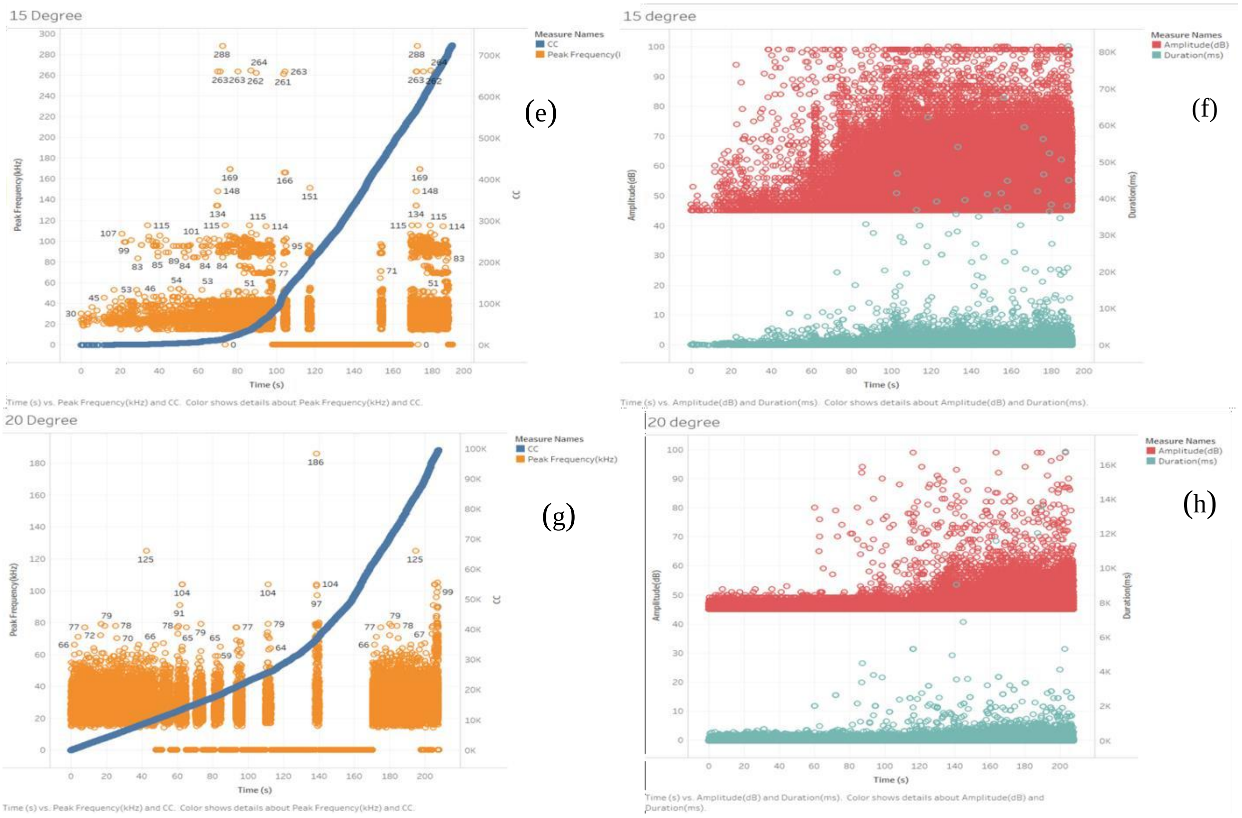
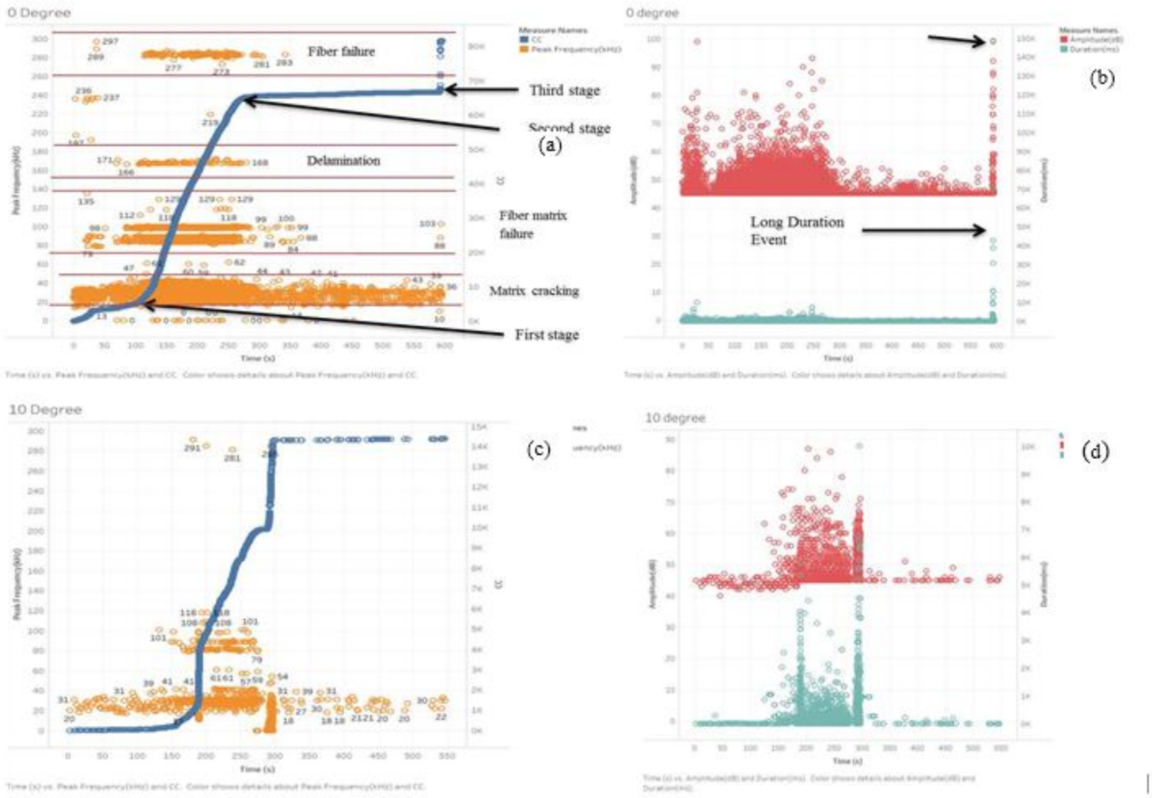


Fig 6 parametric plots for Glass/Carbon Hybrid composite specimen under quasi static indentation in 4 different angles



IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Factura '20 - National Conference On Emerging Trends In Manufacturing

NSS College of Engineering, Palakkad, Kerala, India

Vol. 7, Special Issue 1, August 2020

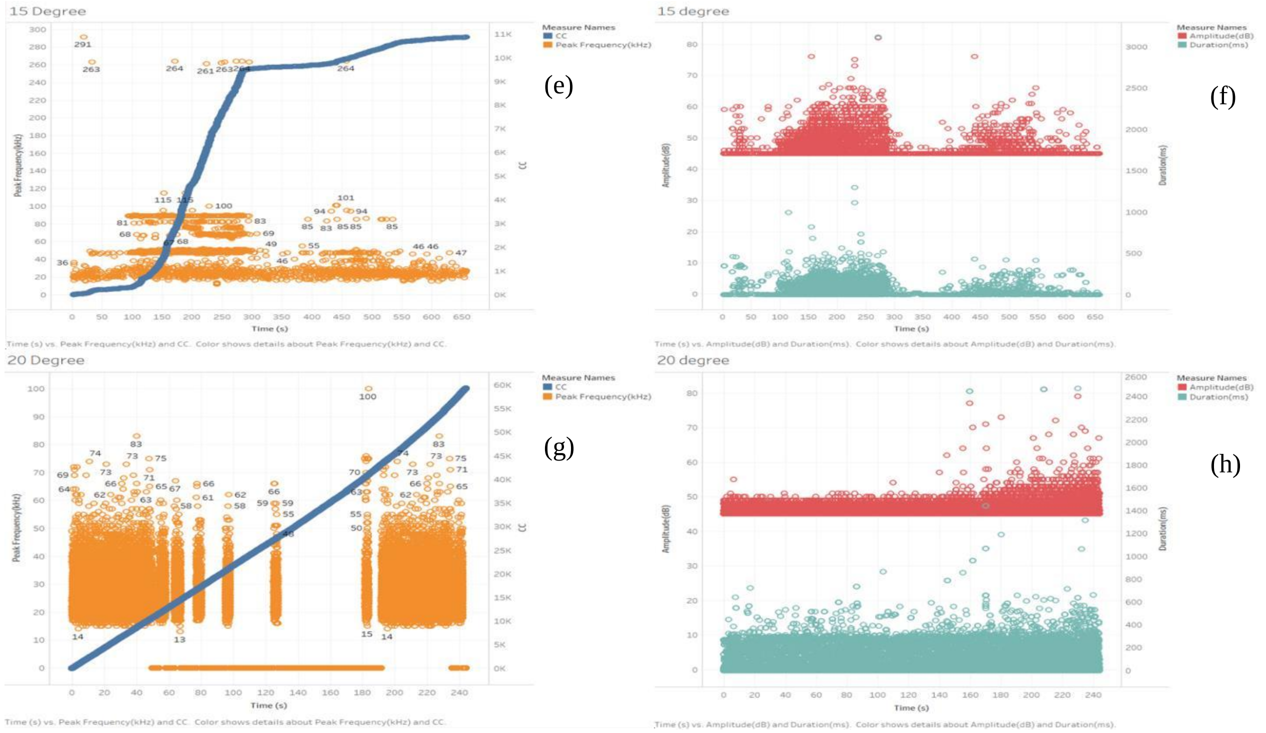


Fig 7 parametric plots for Glass/Kevlar Hybrid composite specimen under quasi static indentation in 4 different angles

Peak frequency cluster plot of G/K hybrid for different angle of indentation is shown in fig 7. In fig 7a the frequency range related to matrix cracking was 20-50 kHz which is most common. The frequency range 79-88 kHz may associate with fiber matrix failure. The fiber pull out was marked in range of 100-129 kHz. The inter laminar failure or delamination was plotted in frequency range of 166-171 kHz. The frequency range 273-297 kHz may relate to fiber breakage was plotted. In fig 7b that is corresponding to 10-degree indentation showed fiber breakage in frequency range 281-291 kHz. The peak frequencies marked are showed in figure8.

4.2 *Identification of matrix cracking*

The frequency range of 20-55 kHz was observed in fig 5a, 6a and 7a associate with matrix in the three cases. The amplitude plots showing the growth of matrix cracking in each indentation angle which is showed in the fig 5b. while increasing the angle the amplitude was observed like a scattering plot rather than sudden peak and voids.

4.3 *Identification of Fibre Pull-out Failure Mode and Debonding*

The frequency ranges of 80-98 kHz were observed for pure glass specimen which indicate the fiber matrix failure. They are of low to moderate amplitude and low duration; this failure mechanism is identified as fiber pullout failure mode [9]. The frequency range of 100-130 kHz relates to fiber pull out was also observed in case of pure glass specimen showed in fig 5a. In the case of Glass/Carbon Hybrid specimen the frequency range for fiber matrix failure was marked between 90-103 kHz. The figure 6a shows fiber pull out frequency range recorded between 155-170 kHz. The last case is the Glass/Kevlar Hybrid specimen showed the frequency range 79-88 kHz may associate with fiber matrix failure. The fiber pull out was marked in range of 100-129 kHz. Increases in the indentation angle don't have a great change in this category damage that showed in figure 5g, 6g and7g.

4.4 *Identification of Delamination FailureModes*

The pure glass specimen showed frequency range 160-170 kHz in plots indicating the delamination. The Glass/Carbon Hybrid specimen showed frequency range for delamination in range of 270-300 kHz. The inter laminar failure or delamination of Glass/Kevlar Hybrid specimen was plotted in frequency range of 166-171 kHz

4.5 *Identification of Fiber FailureMode*

The failure mode in this peak frequency range is of high frequency and can be related to a micro event known as fiber failure. Generally, the fibre failure mechanism corresponds to high frequency. Fiber breakage is normally associated with moderate amplitude and long duration with high frequency content [10,11]. It occurs only after the fiber pulls out and fibre bridging phenomenon is observed between the fractured surfaces. Fig 5a ,6a and 7a which is related to 0-degree indentation shows typical plots of peak frequency versus cumulative count versus time. The last frequency content is indicating the fiber breakage or failure was found to in the rage of 270-282 kHz for pure glass specimen. Figure 6a shows fiber failure of G/C Hybrid specimen in the range of 350-444 kHz. The frequency range 273-297 kHz was observed in G/K Hybrid specimen for the fiberbreakage.

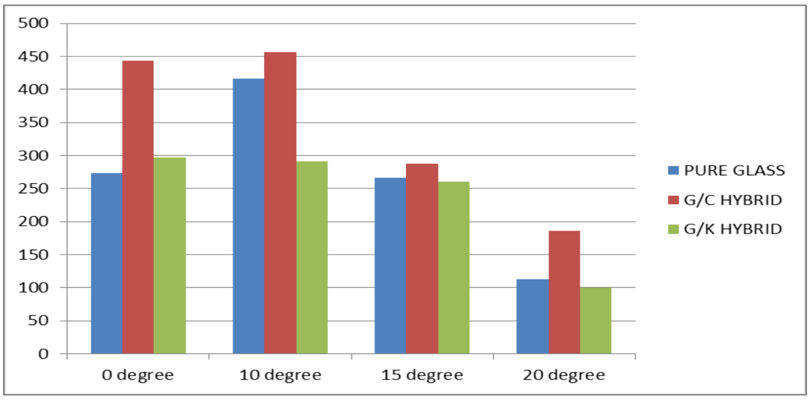


Fig 8 peak frequency (kHz) comparison of 3 different composites

V. CONCLUSION

This study focuses on frequency analysis with the parameters like amplitude, cumulative count and duration as a tool for identifying the different failure modes of hybrid composite laminates subjected to quasi static indentation testing with AE monitoring. The effect of angle indentation on damage in composite laminates was also investigated. The increase in the angle of indentation shows decrease in duration, amplitude and peak frequency. The cumulative count is changing the profile to linear damage were the sudden damages were absent. By comparing the three specimens the G/C hybrid composite showed better property in all aspect. The G/K hybrid composite was not having significant difference in range of frequency but the clarity in damage characterization was found to be better. This difference is considered as advantage of hybridization. . The matrix cracking is found to be low, medium and high amplitude with moderate duration and low frequency. The fiber matrix deboning was found to be low to medium amplitude with moderate duration and medium frequency. The fiber pull out was found to be low to moderate frequency with low duration and moderate frequency. The delamination was found to be moderate to high amplitude with comparatively long duration and moderate frequency. The fiber breakage was found to be high amplitude with high duration and high frequency events.

REFERENCES

[1] A. Bussibaa,*, M. Kupieca (Accepted 11 January 2008) Fracture characterization of C/C composites under various stress modes by monitoring both mechanical and acoustic responses, doi:10.1016/j.carbon.2008.01.020 edn., CA R B O N 4 6 (2 0 0 8) 6 1 8 –6 3 0:Elsevier.
[2] Bascom, W.D.: Fractography of Composite Delamination. NASA Contractor Report 181965(1990)
[3] A. ENFEDAQUE,1 J. M. MOLINA-ALDAREGUI´A,2 (2010) Effect of Glass Fiber Hybridization on the Behavior Under Impact of Woven Carbon Fiber/Epoxy Laminates, Vol. 44, No. 25/2010,DOI: 10.1177/0021998310369602 edn., Journal of COMPOSITEMATERIALS
[4] Bussiba, A., Piat, R., Kupiec, M., Carmi, R., Alon, I., and Bohlke, T, "Threshold parameters and Damage accumulation profile in C/C composites monitored by Acoustic Emission Response: Progress in Acoustic Emission XIV, the Japanese society for NDI,"2008.
[5] Godin, N.; Huguet, S.; Gaertner, R.: Integration of the Kohonen'sself organizing map and K-means algorithms for the segmentation of the AE data collected during tensile tests on cross ply composites. NDT & E Int. 38, 299–309(2005)
[6] Woo, S.C.; Kim, T.W. High strain-rate failure in carbon/Kevlar hybrid woven composites via a novel SHPB-AE coupled test. Compos. Part B 2016, 97,317–328
[7] De Rosa, I.M.; Santulli, C.; Sarasini, F. Acoustic emission for monitoring the mechanical behaviour of natural fibre composites: A literature review. Compos. Part A2009.
[8] Pappas, Y.Z., Kostopoulos, V.: Toughness characterization and acoustic emission monitoring of a 2D carbon/carbon composites. Eng. Fract. Mech. 68(114), 1557–1573(2001)
[9] Yan, Y.J., Yam, L.H.: Online detection of crack damage in composite plates using embedded piezoelectric actuators/sensors and wavelet analysis. Compos. Struct. 58, 29–38(2002)
[10] Ramirez-Jimenez, C.R., Papadakis, N., Reynolds, N., Gan, T.H., Purnell, P.M.: Identification of failure modes in glass/polypropylene composites by means of the primary frequency content of the acoustic emission event. Compos. Sci. Technol. 64, 1819–1827(2004)
[11] Berthelot, J.M., Rhazi, J.: Acoustic emission in carbon fibre composites. Compos. Sci. Technol. 37(4), 411–428(1990)