Journal of Engineering Science and Technology
Vol. 13, No. 8 (2018) 2495 - 2503

MECHANICAL CHARACTERIZATION OF INTRA-PLY HYBRID COMPOSITE LAMINATES USING ACOUSTIC EMISSION

SALEEM M.*, GOPI E., RAJAGURUNATHAN M., VISHNU V.

Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology
*Corresponding Author: strokesaleem1@gmail.com,saleemm@veltech.edu.in

Abstract

A recent year, in the replacement of heavy weight components into a lightweight components and parts. The main advantage of this type of material increment is the low-cost fabrication and development in the biodegradability. This paper deals with the failure behaviour of homogenous and hybrid composite laminates reinforced by carbon-glass intra-ply fabrics using A.E. technique. Fiber Reinforced composite materials have been widely used in aircraft, spacecraft, automotive and electronic industries. There are several methods used to detect damage mechanism of composite materials and acoustic emission (AE) technique is an important method of non-destructive testing. The main advantage of AE is that it is a dynamic method capable of continuously testing the structures. The characterization of the damage mechanism in composite materials under AE monitoring is still a major concern to differentiate the failure. To overcome this issue of identifying the failure modes, successfully correlating the AE signal and mechanical properties of the different composite materials subjected to tensile testing. AE data recorded during the tensile testing of a single layer specimen are used to identify failure modes such as matrix cracking and fiber failure, while delamination is characterized using a single-layer specimen. The specimens are prepared and tensile test is carried out using 100 kN Tinious Olsen universal testing machine with AE monitoring. Parametric studies using AE peak frequency is very powerful tool to describe the damage mechanism of the different stacking sequence of GFRP (Carbon Fiber Reinforced Polymer) and CFRP (Glass Fiber Reinforced Polymer) composite laminates. The individual failure mode of Glass/epoxy, Carbon/epoxy, Hybrid /epoxy laminates was investigated.

Keywords: Acoustic emission, Delamination, Hybrid composites, Frequency, Failures.

1. Introduction

Fiber Reinforced polymer composite (FRP) materials have been widely used in aircraft, spacecraft, automotive and electronic industries because of their superior properties like strength to weight ratio, stiffness to weight ratio, non-corrosive properties, high fatigue life etc.,. However, a potential disadvantage is damage evolution such as matrix cracking, delamination, fiber breakage and debonding, that appear before final fracture. There are several methods used to detect damage mechanism of composite materials. Acoustic emission (AE) technique is an important method of non-destructive testing [1]. The main advantage of AE is that it is a dynamic method capable of continuously testing the structures. Materials during loading, the strain-energy release due to microstructural changes results in stress-wave propagation [2, 3].

AE signals are not only generated by structural changes, it can also come from other sources, such as the testing machine, electrical disturbances [4], friction due to rubbing of parts [5-8] Friction generated AE can provide important information about the condition of composite. Most studies involving parametric based approach have been performed using AE parameters such as energy, counts, amplitude, duration and rise time. The damage Characterization in polymer based Composite laminates clearly reported that Matrix cracking has low to medium amplitude and short to moderate duration, Fiber breakage has medium to high amplitude and short duration. Debonding as well as delamination covers the whole range of amplitudes and long duration [9]. Effect of fiber orientation in unidirectional carbon fiber using amplitude [10-12] as the key parameter is investigated with help of AE. The failure mode was correlated with help of Kohonenself organising map [13, 14].

Frequency analysis is a promising technique to discriminate the failure modes occurring in composite structures. Therefore each AE waveform has a unique feature, in the sense that its amplitude, duration and frequency content are related to the damage mechanisms [15].The different failure mechanisms, matrix cracking, debonding, pull-out and fiber failure generate specific, distinguishable frequencies Mikael Johnson investigate the possibility to utilize numerically calculated AE signals in order to classify damage mode in composite laminates was observed that fiber failures generate more AE events than other failure in composites. Natural fibres [16-17] are gaining more interest are reinforcing materials due to their environmental and economical.

Hybridization effective results have been found out to motive use of such as materials. However, there are no universal [18] classification boundaries between tensile and shear signals mainly due to geometric effects, material properties, as well as sensor location and response function. In order to highlight this problem and discuss the possibility of a solution, the study occupies not only with the evaluation of the damage mode based on AE parameters but in addition uses multiple sensors to investigate the effect of the wave propagation distance. This is crucial in thin cementitious laminates since damping, scattering, reflections and plate wave dispersion seriously distort the signal having a strong effect on the classification result. It is seen that the classification boundaries between tensile and shear fracture should incorporate the information of propagation distance

An efficient processing of the large data sets that can be generated via MAE, during the composite structures health monitoring, is a challenging topic. This study concerns the development of an algorithmic tool for resolving the problem of memory saturation, which can be encountered when working with such large data sets. It is a first step towards Big Data based solutions, launched recently by the authors' team. A case of study is discussed, showing the robustness of the already implemented algorithmic tool. The damage induced by impact consisted of fiber breakage, matrix cracking and delaminations. Recent advancement in processing techniques like vacuum assisted resin infusion or Resin Transfer molding has caught the attention of industry to adopt woven fabric composites for manufacturing primary structural components [18].

Analysed many structural components made with composite laminates, such windmill blades, robot arms, transmission axes, etc., can be considered as beams subjected to out-of-plane loads that cause mainly bending moments and also shear forces. These loads can be dynamic, as these structures can, for example, be subjected to impact during assembly and maintenance operations, or during service life. Composite laminates are especially sensitive to low-velocity impacts since even minor damage can cause considerable reduction in structural integrity. Described the actual experimental techniques that are used on low and intermediate energy impact testing on laminated composite materials. They conducted experiments on carbon fibres in epoxy resin and four different stacking sequences were used.

A wide range of impact energies have been applied to specimens according to the proposed standards testing using an instrumented drop weight-testing machine. Modified compression after impact testing equipment, similar to that proposed on the referenced standards, was used for the determination of the residual strength of the specimens. This allowed a better understanding of the buckling behaviour of the specimen associated with the delamination areas. Prakash et al. [19] and Juliyana et al. [20] concluded that the delaminated area due to impact loading is a function of the absorbed energy and relatively independent of the stacking sequences used in this study but is highly dependent on the number of interfaces. They also observed unstable damage growth was obtained by compression after impact due to a buckling mechanism in the delaminated area and two main buckling failure mechanisms were identified

2. Experimental Details

The experimental work was carried out on Bidirectional Glass, Carbon and Hybrid Epoxy composite materials. In this experiment, three types of specimens were prepared by Hand layup technique. Hand layup technique is easiest and low cost open moulding method and its required least tools and equipment. Fibres are placed by hand in a mould and wetted by resin. Brushes or rollers are used to distribute the resin. Rollers used to work air bubbles out. Lay-up should be continuous no break of more than 24 hours for polyester resin. Extended breaks may necessitate cleaning and/or roughening the surface before continuing and removing entrapped air. Those are pure glass, pure carbon, hybrid layer specimens to identify the matrix cracking, fibre failure and other failure modes (delamination, debonding) respectively. ASTM D638 Standard tensile specimens of size 150×25 mm^2 were cut from the fabricated laminate. Figure 1 shows the carbon and glass fibers mat were used to prepared the test specimens which fabricated by hand layup method [17, 18]. The properties of the materials used are shown in Table 1.

Fig. 1. Carbon and glass fibre.

Table 1. Materials used for test.

Parameters	Value
Glass fiber (bi dirctional) mat	300 gsm
Density of glass fiber mat	2.5 gm/cc
The carbon fiber of bidirectional mat	300 gsm
Density of carbon fiber	1.78 gm/cc

Test specimen Preparation

Case 1 : 100 % carbon,100 % glass fiber

Case 2 : 50% carbon ,50 % glass fiber

The weight of the fraction of fibres and epoxy matrix materials were determined by considering the density, specific gravity and mass. Initially, the fabrication of the composite was done at room temperature by hand layup technique. The required ingredients of resin and hardener were mixed thoroughly in a basin and mixture is frequently stirred constantly.

The glass and carbon fibers reinforced epoxy composites slabs were taken out from the mold and the specimens of suitable dimensions were prepared from the composite slabs for different mechanical tests according to ASTM standards. The test specimen was cut by slabs using diamond tipped cutter and different tools in the shop. Tensile test specimen was prepared According to ASTM D638.

3. Tensile Specimens

In addition to the ASTM specifications suitable fixture designed to facilitate the holding of the test piece on its length grip between the fixed and moveable jaws of an UTM can handle even still lesser dimensions and the load calibration of the dial gauge has also limitation on softer materials / specimens. Properties that directly measured with tensile test. Tensile strength and maximum elongation and reduction in area were measured from the tensile specimens.

Tensile specimen (Fig. 2) clearly fabricated with pure carbon and glass fibres and half composition mixed with both combination. The fibre architecture made by this combination and tested under tension loading and well as acoustic emission tests.

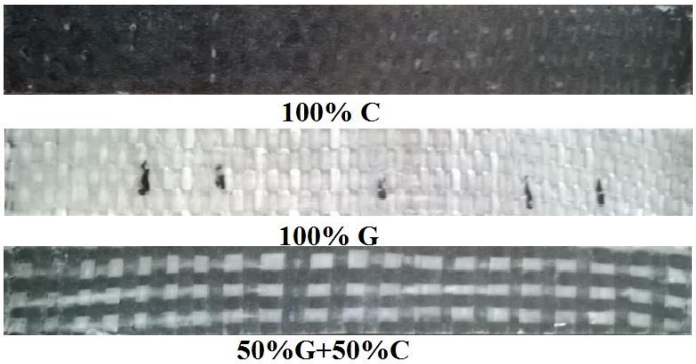

Fig. 2. Tensile specimens.

4. Acoustic Emission Monitoring

AE based NDE and monitoring techniques present the unique advantage over other NDE methodologies of allowing for the “live” sensing of failure processes occurring in a material under loading. This peculiarity of AE testing makes “on-line” decision on damage development and real-time corrective action possible. An 8 channel AE system supplied by Physical Acoustics Corporation (PAC) is used for this study. The sampling rate and pre-amplification are kept as 1 MSPS and 40 dB respectively. Preamplifiers having a bandwidth of 10 kHz to 2 MHz are used. AE activities were sensed using wide band WD piezoelectric sensor, filtering out frequencies exceeding 900 kHz and using a threshold of 45 dB High vacuum silicon grease was used as a couplant. After mounting two transducers on the sample at a mutual distance of 150 mm between them, so that they were both at the same distance from the center of the specimen length, a pencil lead break procedure was used to generate repeatable AE signals for the calibration of each sensor.

5. Results and Discussion

Acoustic emission technique was employed to characterize the damage accumulation on the specimen during testing till failure in terms of AE count rate and cumulative counts. The failure mechanisms in unidirectional GFRP, CFRP and Hybrid (combination of both GFRP and CFRP) Laminates during the tensile testing with AE monitoring were studied. The various failure mechanisms can be identified from AE energy, which is obtained from the amount of strain energy released from damaged material. Therefore AE waveform corresponding to the failure modes such as matrix cracking, fiber pull-out, debonding, delamination and fiber failure are investigated using the AE parameters such as Rise angle, Count, amplitude, duration, energy and peak frequency. Conduct of quasi-static tensile test specimen on intra-ply hybrid composite laminates and investigation of failure behaviour in glass-carbon intra-ply hybrid composite laminates.

The load -displacement curve is shown in Fig. 3. The ultimate strength of carbon composites are better than hybrid and graphite composites and shown in Fig. 4. The deformation of carbon composites are lesser than hybrid and graphite composites and shown in Fig. 5. The stiffness strength of carbon composites are better than hybrid and graphite composites and shown in Fig. 6.

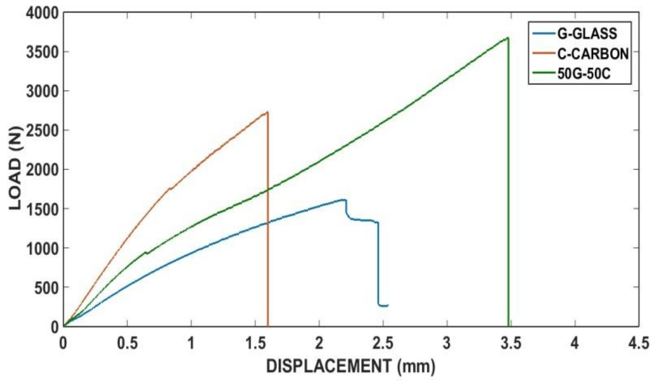

Fig. 3. Load - displacement curve.

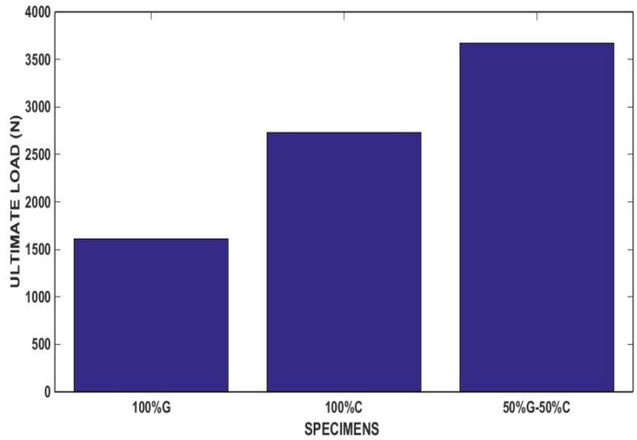

Fig. 4. Ultimate strength graph.

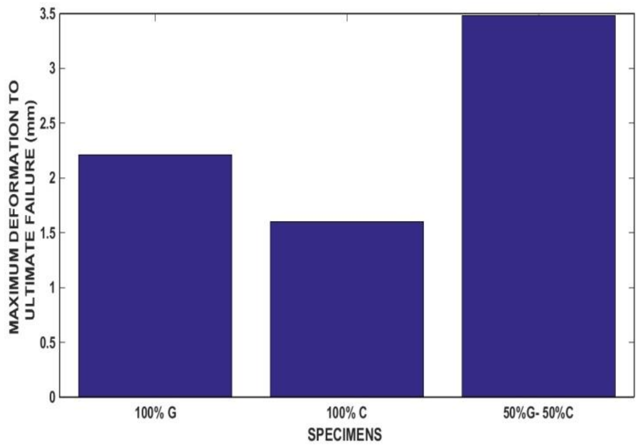

Fig. 5. Deformation graph.

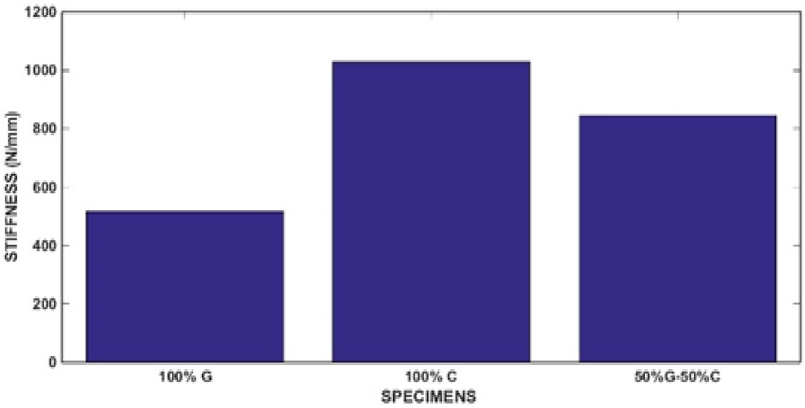

Fig 6. Stiffness strength graph.

6. Conclusions

This comparative work between carbon and glass fiber reinforced laminates showed that materials have a similar damage and impact residual properties determined the failure cases under reasons ahead. Future studies will involve to prepare the composition of hybrid composites or laminates. The tensile properties have been studied and breaking load has been measured. The inclusion of carbon fiber composites rightly enhanced the ultimate tensile strength and peak load of the laminates.50 % glass- 50 % carbon intraply hybrid composites laminates has found to have significant effects on the tensile with acoustic emission behaviour.

Test results showed that 100 % carbon and 100 % glass laminates present the highest and the least stiffness respectively

Abbreviations

AE	Acoustic Emission
CFRP	Carbon Fiber Reinforced Polymer
GFRP	Glass Fiber Reinforced Polymer
NDE	Non-destructive Examination

References

1. Kawamura, Y.; and Yamasaki, M. (2007). Formation and mechanical properties of Mg97Zn1RE alloys with long-period stacking ordered structure. *Materials Transactions*, 48(11), 2986-2992.
2. Hagihara, K.; Fukusumi, Y.; Yamasaki, M.; Nakano, T.; and Kawamura, Y. (2013). Non-basal slip systems operative in Mg12ZnY long-period stacking ordered (LPSO) phase with 18R and 14H structures. *Materials Transactions*, 54(5), 693-697.
3. Bashkov, O.V.; Protsenko, A.E,; and Bryanskii, R.V.; and Romashko. R.V. (207). Diagnostics of polymer composite materials and analysis of their production technology by using the method of acoustic emission. *Mechanics of Composite Materials*, 53(4), 533-540.

4. Máthis, K.; Beran, P.; Čapek, J.; and Lukáš, P. (2012). In-situ neutron diffraction and acoustic emission investigation of twinning activity in magnesium. *Journal of Physics: Conference Series*, 340, 1-6.
5. Gharghouri, M.A.; Weatherly, G.C.; Embury, J.D.; and Root, J. (1999). Study of the mechanical properties of Mg-7.7at.% Al by in-situ neutron diffraction. *Philosophical Magazine*. *Part A*, 79, 1671-1695.
6. Čapek, J.; Máthis, K.; Clausen, B.; Straska, J.; Beran, P.; and Lukáš, P. (2014). Study of the loading mode dependence of the twinning in random textured cast magnesium by acoustic emission and neutron diffraction methods. *Materials Science and Engineering: A*, 602, 25-32.
7. Pomponi, E.; and Vinogradov, A. (2013). A real-time approach to acoustic emission clustering. *Mechanical Systems and Signal Processing*, 40(2), 791-804.
8. Vinogradov, A.; Lazarev, A.; Linderov, M.; Weidner, A.; and Biermann, H. (2013). Kinetics of deformation processes in high-alloyed cast transformation-induced plasticity/twinning-induced plasticity steels determined by acoustic emission and scanning electron microscopy: Influence of austenite stability on deformation mechanisms. *Acta Materialia*, 61(7), 2434-2449.
9. Vinogradov, A.; Orlov, D.; Danyuk, A.; and Estrin, Y. (2013). Effect of grain size on the mechanisms of plastic deformation in wrought Mg-Zn-Zr alloy revealed by acoustic emission measurements. *Acta Materialia*, 61(6), 2044-2056.
10. Farkas, G.; Choe, H.; Máthis, K.; Száraz, Z.; Noh, Y.; Trojanová, Z.; and Minarik, P. (2015). In *situ* investigation of deformation mechanisms in magnesium-based metal matrix composites. *Metals and Materials International*, 21(4), 652-658.
11. Park, J.-H.; Gu, J.-U.; and Cho; N.-S. (2017). Acoustic emission characteristics of methacrylate-based composite and silorane-based composite during dental restoration according to a variety of C-factor. Journal of Dental Research, 31(9), 4067-4072.
12. Ma, B.T.; Schadler, L.S.; Laird, C.; and Figueroa.; J.C. (1990). Acoustic emission in single filament carbon/polycarbonate and Kevlar/ Polycarbonate composites under tensile deformation. *Polymer Composites*, 11(4), 211-216.
13. Ravishankar, S.R.; and Murthy, C.R.L. (2000). Characteristics of AE signals obtained during drilling composite laminates. *NDT & E International*, 33(5), 341-348.
14. Saleem, M.; Gopi, E.; Rajagurunathan; Vishnu, V.; and Juliyana, S.J. (2017). Design and fabrication of natural ramie/epoxy composite bicycle frame with experimental and FEA-abaqus analysis. *International Journal of Mechanical Engineering & Technology*, 8(6), 575-586.
15. Aggelis, D.G.; ElKadi, M.; Tysmans, T.; and Blom, J.; (2017). Effect of propagation distance on acoustic emission fracture mode classification in textile reinforced cement. *Construction and Building Materials*, 152, 872-879.
16. Yaacoubi, F.; Dahmene, A.; Bouzenad, M.; El Mountassir, M.; and Aouini, M. (2018). Modal acoustic emission for composite structures health monitoring. *Composite Structures*, 183, 338-346.
17. Guild, F.J.; Walton.D.; Adams, R.D.; and Short, D. (1976). The application of acoustic emission to fibre-reinforced composite materials. *Composites*, 7(3), 173-179.

18. Prakash, J.U.; and Moorthy, T.V. (2013). Adhesive wear behaviour of aluminium alloy/fly ash composites. *Advanced Materials Research*, 622-623, 1290-1294.
19. Prakash, J.U.; Moorthy, T.V.; and Ananth, S. (2014). Fabrication and sliding wear behaviour of metal matrix composites. *Applied Mechanics and Materials*, 612, 157-162.
20. Juliyana, J.S.; Prakash, J.U.; Karthik, K.; Pallavi, P.; and Saleem, M. (2017). Design and analysis of NACA4420 wind turbine aerofoil using CFD. *International Journal of Mechanical Engineering and Technology*, 8(6), 403-410.