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OFFLINE AND ONLINE INVESTIGATION OF DROP IMPACT DAMAGE ON GFRP COMPOSITE USING NON-DESTRUCTIVE DATA BY ARTIFICIAL NEURAL NETWORK[*]

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Abstract– The objective of this experimental work was to assess the drop impact damage on Woven Glass Fibre Reinforced Polymer composite laminate through online method and offline method. Online monitoring of drop impact damage was carried out by Acoustic Emission (AE) technique and AE signals during the drop impact test were captured. From the analysis of AE signals, it was observed that as the impact energy increases the AE parameters such as counts, counts to peak, signal strength and root mean square (RMS) values also increase. Offline assessment of impact damage on composite laminate was also observed by ultrasonic technique and it was inferred that ultrasonic parameters, namely amplitude and attenuation ratio were decreased with increase in impact energy of test. But attenuation coefficient had an indirect relationship with impact energy. During online/offline monitoring of composite laminate the AE/UT parameters which were obtained from real time monitoring are used to predict Impact Damage Tolerance (IDT) using a separate trained artificial neural network model. Based on the IDT value of composite, the component should be continued in-service or replaced.

Keywords– Acoustic emission technique, drop impact damage, ultrasonic technique, GFRP composite laminate

1. INTRODUCTION

Composite materials are widely used in many industrial applications like automotive, aviation and construction. Fibre breakage had occurred prior to the major damage during impact testing of laminate. The threshold effect of force and energy of major damage require further study [1]. Fibre breakage, matrix cracking, delamination, intra-ply cracking and translaminar fracture are the common damage modes induced by impact loading [2]. Low velocity impact causes three principal types of damage modes in laminated polymer composites namely, matrix cracking, delaminations and fibre breakage, which together can seriously degrade the laminate monotonic compressive strength [3]. The materials with the tougher resins experience less impact damage which results in better strength than other composite systems.

The impact velocity had insignificant effect and the impact energy appreciably affects the impact performance of the panels [4]. Woven laminate was found to offer the maximum residual strength under all the impact energies [5]. Neural Network was used in detection of the embedded delamination size, shape and location in an FRP composite laminated structure from simulated data. The actual efficiency of ANN model will be better when the network is modelled with real life data [6]. Back Propagation Neural Network was able to determine the failure load of tensile specimens with 1.22% error tolerance. Amplitude had better efficiency than absolute energy in predicting the failure strength [7].

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Bayesian probabilistic neural network was used for the detection, location and extent of the damage of composite materials with data from vibration or thermography by observation [8]. AET has good potential as an online NDE tool for monitoring fatigue damage in composites [9]. Ultrasonic method supplies a detailed analysis of damage [10]. AE monitoring system can be used to detect the first failure sign of Glass Reinforced Plastic (GRP) material [11]. AE yielded very accurate information about the extent and location of damage in various constituents of composite [12].

2. EXPERIMENTAL WORK

WGFRP composite laminate was selected for the experimental work. Epoxy resin of dobeekot 520F and hardener of HY758 mix were used as matrix material. Fibre cloths of oven bake glass with fibre weight of 250 gram per square meter were used as reinforcement material. The composite laminates with a size of 200mmX200mm were prepared with the matrix and fibre weight percentage of 50:50.

The acoustic emission system (Physical Acoustic Corporation- PAC18-bit, 1 kHz - 3MHz PCI-2) is comprised of signal detection, data acquisition and analysis of AE signal. This system contains built-in, real time AE feature extraction and independent direct memory access transfer for each AE channel and it provides high speed transient data analysis at high hit rates. This AE system also has AE-Win post software to perform the analysis. The composite laminate was fixed on a support frame and clamped. The AE sensor was firmly fixed on the WGFRP composite laminate at a distance of 40mm away from the point of impact as shown in Fig. 2. The required AE parameters were selected and set in AE software. Hemispherical impactor was dropped on the composite laminate and AE signals were captured during the drop impact test.

AE parameters obtained at impact energy of 10J were used to set the filter for AE setting to eliminate noise due to drop weight. After setting the filter, drop impact tests were carried out on WGFRP composite laminates at different energy level and the corresponding AE signals were captured.

Acoustic emission measurements are more sensitive to damage accumulation in any material. Damage modes in composite material such as delamination, fibre breakage and matrix crack emit strong acoustic emission during loading of material [13]. One of the AE activities, AE count, is strictly related to residual tensile strength after impact test [14]. This suggests that AE activities, are derivatives of damage induced during loading of composite materials. The higher the AE activities the lower the residual strength left in the material. The extracted AE features clearly indicate that AE is sensitive for micro-structural damage during loading of composite material. AE activities, namely counts, counts to peak, signal strength and RMS were used to characterise the drop impact damage.

Ultrasonic technique is a well known non destructive technique (NDT) that can be used for many industrial applications for offline assessment of damage. All sound waves, whether audible or ultrasonic are mechanical vibrations involving movement of the medium in which they are travelling. A sound wave may be transmitted through any material which behaves in elastic manner and is used for flaw characterisation.

The schematic experimental diagram used for offline assessment of drop impact damage is shown in Fig. 1. The composite laminates were scanned using Ultrasonic Flaw Detector (UFD) (Olympus- EPOCH XT) in A-scan mode before and after the impact test. A 10 MHz probe with an ultrasound velocity of 2750 m/s was used for observation of the WGFRP specimens. Silicon grease was used as a couplant between probe and composite laminate. The quality of fabricated composite materials was inspected through ultrasonic inspection and no major defect was found. This examination helps to confirm the uniform and defect free nature of the composite laminates. The drop impact tests were conducted to find threshold energy of impact damage by increasing impact energy from 2 Joules to 15 Joules. The above impact tested composite laminates were examined ultrasonically in A-scan mode. A-scan signals which were obtained up to 10J energy of the impact test were similar to that of the A-scan signal obtained for good WGFRP composite laminates. But after increase in the impact energy of more than10J, there is a variation in the A-scan signal. Ultrasonic signals obtained during inspection were analysed. Ultrasonic parameters such as amplitude, attenuation co-efficient and attenuation ratio were used for characterisation of drop impact damage.

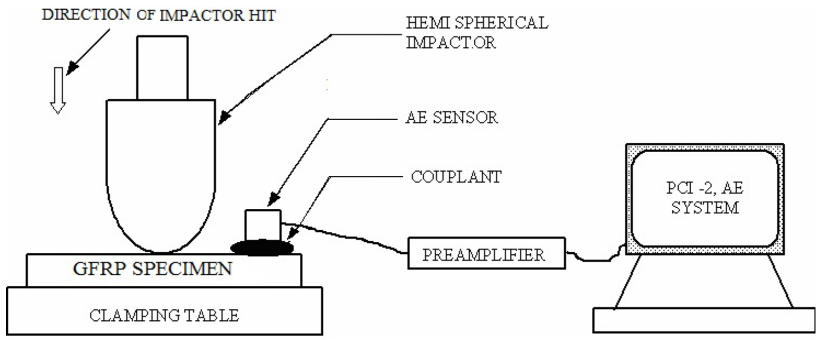

Fig. 1. Schematic experimental diagram for acoustic emission set up

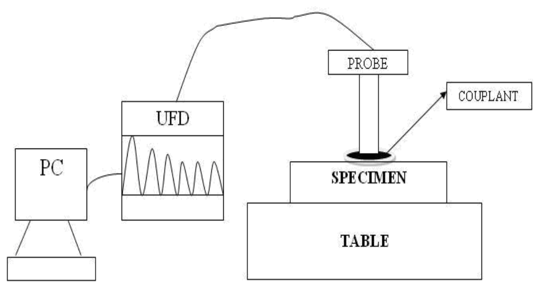

Fig. 2. Schematic experimental diagram for ultrasonic set up

3. RESULT AND DISCUSSION

a) Impact energy and acoustic emission parameters

Experimental results plotted in Figs. 3-5 show the variations in which, as the impact energy increases, sensitive AE parameters namely, signal strength, counts, counts to peak and RMS values also increase. It is found from Fig. 3 that AE counts and counts to peak are increasing with increase in impact energy. For the same impact energy, the number of counts is slightly greater than the counts to peak. It is observed that as the impact energy increases there is an increase in RMS with respect to impact energy. From Fig. 5, it is observed that as impact energy increases there is an increase in AE signal strength.

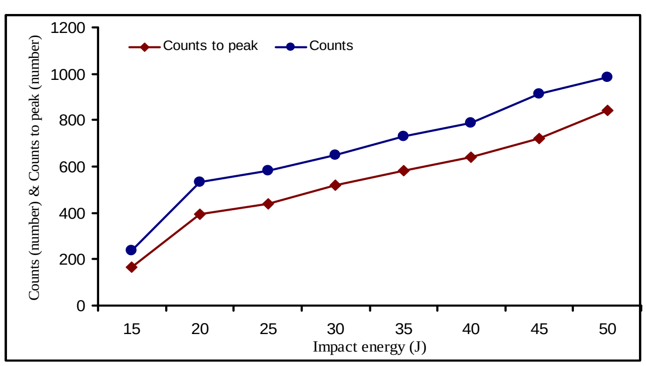

Fig. 3. Impact energy vs counts, counts to peak

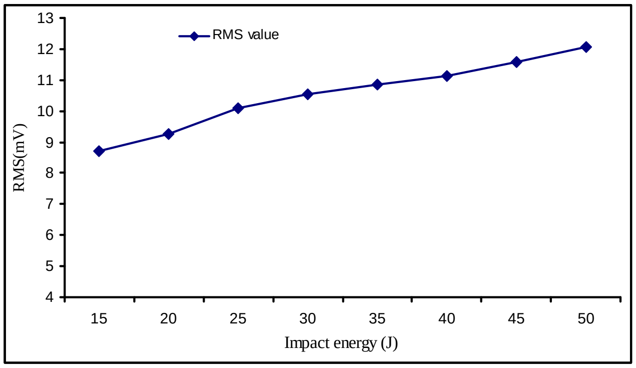

Fig. 4. Impact energy vs RMS value

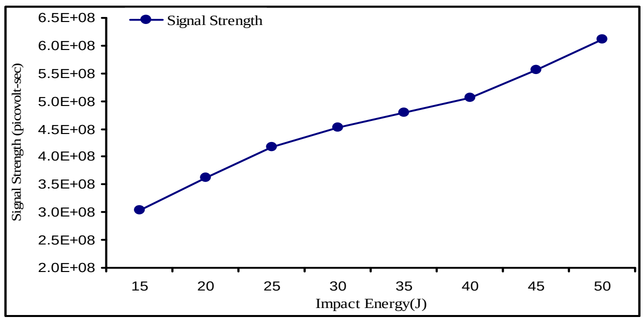

Fig. 5. Impact energy vs AE signal strength

b) Acoustic emission parameters and impact damage tolerance

The residual strength of impact damaged composite laminate was measured by impact damage tolerance. Impact damage tolerance is the measure of residual compressive strength left in the impact tested composite specimens. The relationship with AE parameters and the percentage of impact damage tolerance are shown in Figs. 6-8.

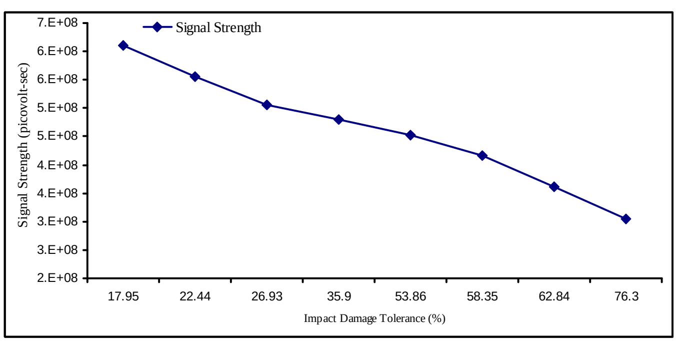

Fig. 6. Impact damage tolerance vs signal strength

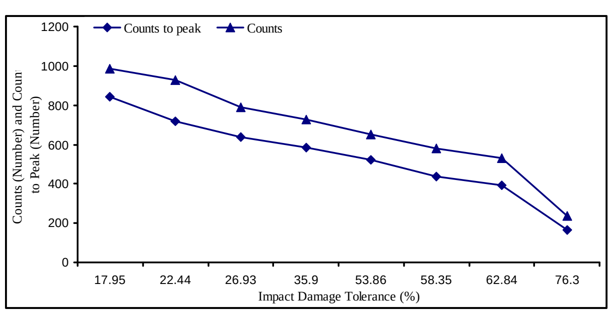

Fig. 7. Impact damage tolerance vs counts, counts to peak

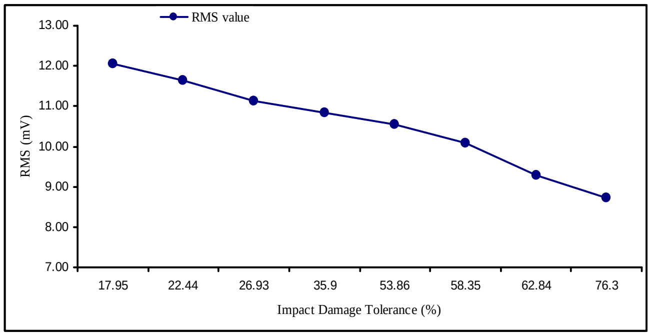

Fig. 8. Impact damage tolerance vs RMS value

It is found that as the signal strength increases, the percentage of impact damage tolerance for the impacted specimen gradually decreases (Fig. 6). Higher signal strength is due to more damage induced in the material and more damage results in lower impact damage tolerance. It is inferred from Fig. 7 that when counts and counts to peak increase the percentage of impact damage tolerance for impacted specimen gradually decreases and from Fig. 8, as RMS value increase, the percentage of impact damage tolerance for impacted specimen gradually decreases.

c) Impact energy and ultrasonic parameters

Ultrasonic parameters namely amplitude, attenuation ratio and attenuation coefficients were determined for A-scan ultrasonic signals obtained from the impact tested GFRP composite laminate. It was found that as the impact energy of the test increases the amplitude of reflected ultrasonic signals were decreased as shown in Fig. 9. The attenuation coefficient increases from 0.0715.04 nepers/mm to 15.04 nepers/mm for the impact energy, which ranges from 15 J to 50 J as shown in Fig. 10. The specimen damaged by 50 J of impact energy has the attenuation coefficient of 15.04 nepers/mm where the composite specimen failed.

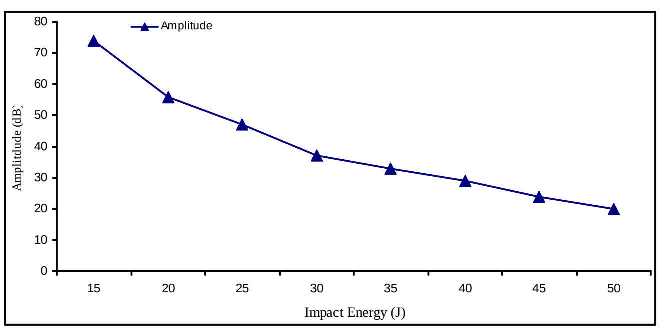

Fig. 9. Impact energy vs amplitude

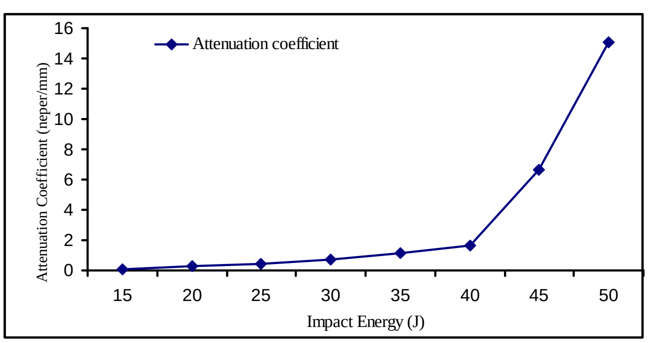

Fig. 10. Impact energy vs. attenuation coefficient

Attenuation ratio is defined as the ratio of amplitude of the impacted specimens to the amplitude of unimpacted specimens. The attenuation ratio decreases with increase in impact energy as shown in Fig. 11. The increase in impact energy of test induces higher damage in the composite material.

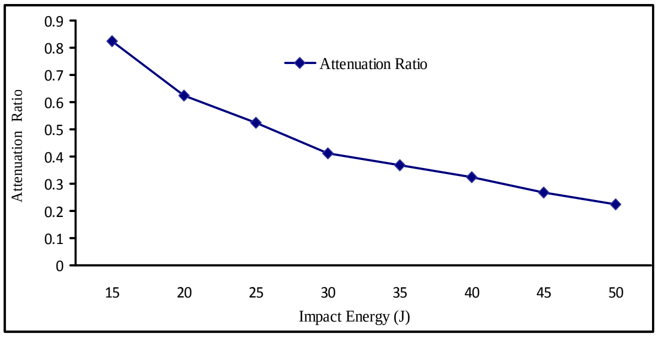

Fig. 11. Impact energy vs attenuation ratio

d) Ultrasonic parameters and impact damage tolerance

Amplitude of reflected UT signal increased with increase in IDT value as shown in Fig. 12. It was found that the attenuation coefficient increases with decrease in Impact Damage Tolerance as shown in Fig. 13. The decrease in compression strength after impact test from 74MPa to 17MPa was observed for the increase of attenuation coefficient which increases from 0.07 to 15.04 nepers/mm. The attenuation ratio increases as the Impact Damage Tolerance increases as shown in Fig. 14. This result is due to the high resistance to ultrasonic signal due to high damage induced in the composite material that decreases the impact damage tolerance.

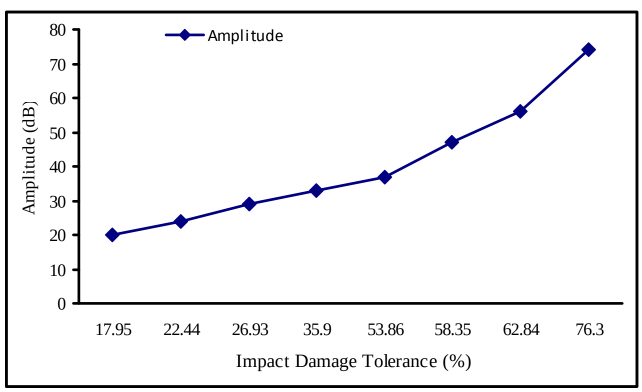

Fig. 12. Impact damage tolerance vs amplitude

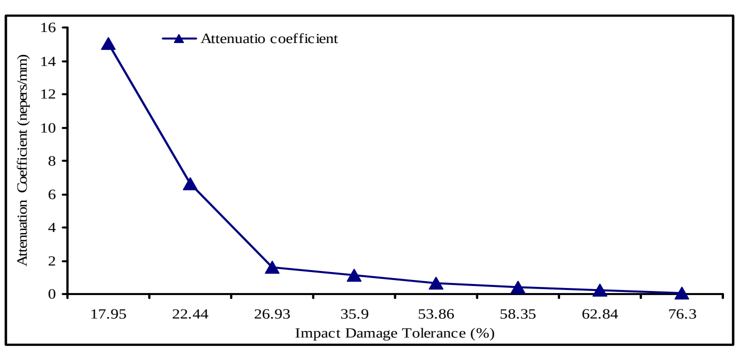

Fig. 13. Impact damage tolerance vs attenuation coefficient

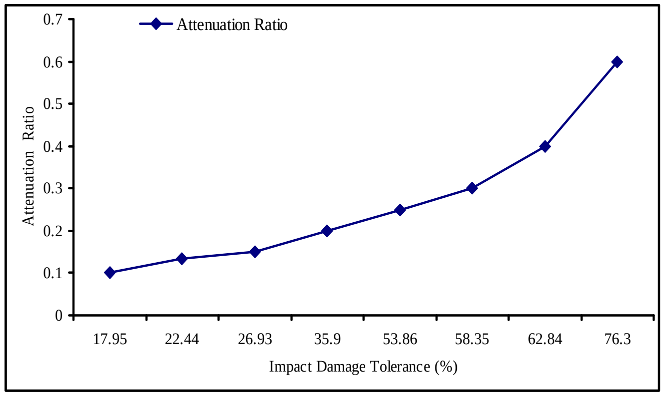

Fig.14. Impact damage tolerance vs attenuation ratio

4. ARTIFICIAL NEURAL NETWORK

a) ANN modelling using AE parameters

ANN models were developed to predict the impact damage tolerance using acoustic emission data and ultrasonic data. AE parameters namely signal strength, counts, counts to peak and RMS values used as input and impact damage tolerance as output. The average training error is 1.49%. Error during validation of ANN model using AE parameters was shown in Fig. 15.

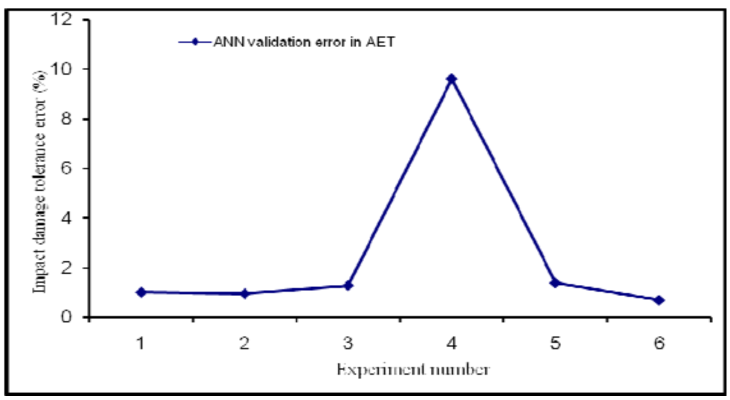

Fig. 15. Validation error of ANN model

Impact damage tolerance from validation of ANN model and experimental value is shown in Fig. 16. There is closer prediction between experimental and ANN output values. The real time impact damages are caused due to bird strike, hail stones falling during hailstorm and falling of heavy luggage on aircraft parts made of GFRP composites. Initiation of drop impact due to above real time impact damage causes will be online monitored through Acoustic Emission Technique. AE signal was analysed and AE parameters were fed to trained ANN model. Impact damage tolerance were obtained from trained ANN model. Threshold value in the proposed method will be set by the design engineer with respect to application of components. The threshold value of impact damage tolerance for accept /repair of composite part may not be fixed as constant value for all the structural elements. It mainly depends on the place where the component is put in use. Therefore, critical value of impact damage is decided from the design stage calculation.

The correlations developed from these experiments may be used for real time monitoring of drop impact damage on WGFRP composite laminate by measuring the impact damage tolerance. Hence this proposed ANN model can be used for the prediction of impact damage tolerance in real time applications as shown in Fig. 17. Based on impact damage tolerance, the decision to remove or repair the composite components may be made.

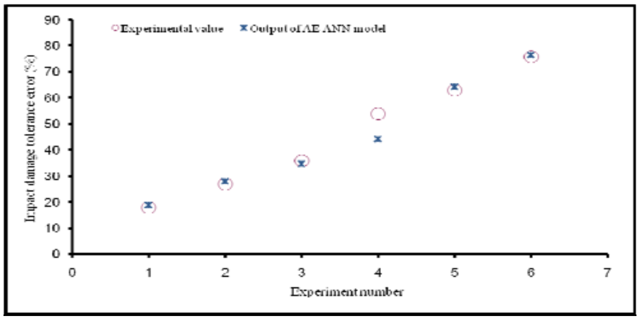

Fig. 16. Experimental and ANN output for ANN validation

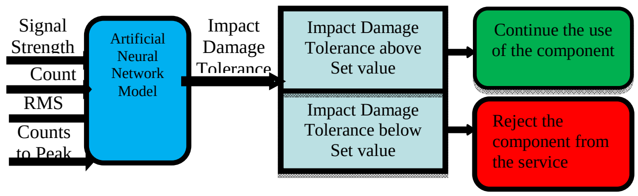

Fig. 17. Decision making algorithm for assessment drop impact damage by online technique

b) ANN modelling using UT parameters

The training error for ANN model using parameter is 2.47%. Validation of ANN model using UT parameters was shown in Fig. 18. This indicates that IDT values from ANN modelling and experimental have smaller error. This error is due to the composite effect of sensor error, error during experiment, signal amplification error. Therefore ANN model can be applied to predict impact damage tolerance in real time applications.

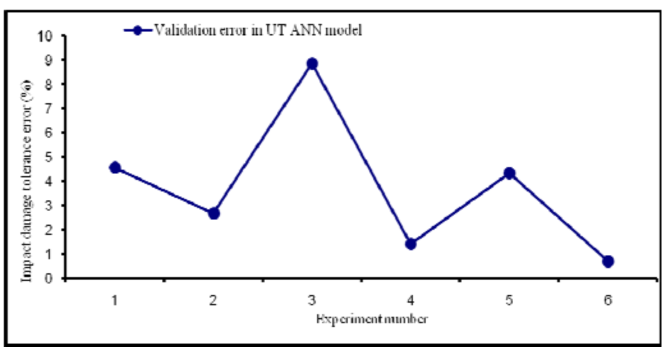

Fig. 18. Validation error of ANN model using UT parameters

The predicted impact damage tolerance and experimental values are very close to each other. UT parameters such as amplitude, attenuation ratio, attenuation coefficient are given as input to network and impact damage tolerance as output for ANN modeling, Fig. 19.

Ultrasonic technique can be applied for the assessment of drop impact damage as offline technique for the measurement of damage characteristics. Ultrasonic technique requires the composite material being inspected should be removed from the service condition and inspected to see the severity of any damage caused due to impact or other loads. By analysing the ultrasonic signals, the ultrasonic parameters were studied and were fed to the ANN model developed using ultrasonic parameters. The outputs from ANN model were compared with the threshold value of IDT and the required decision will be taken to continue the use of the component being inspected or removed from the service as shown in Fig. 20.

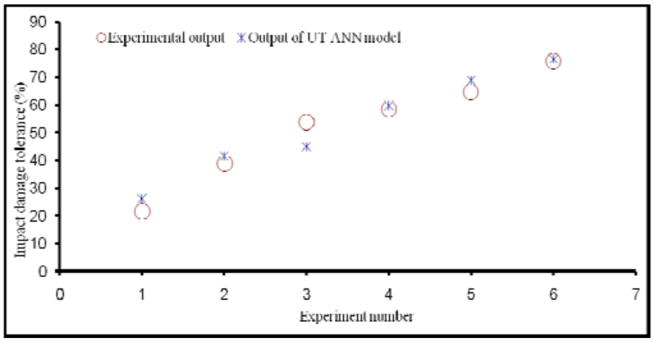

Fig. 19. Experimental and ANN output for validation of ANN model using UT parameters

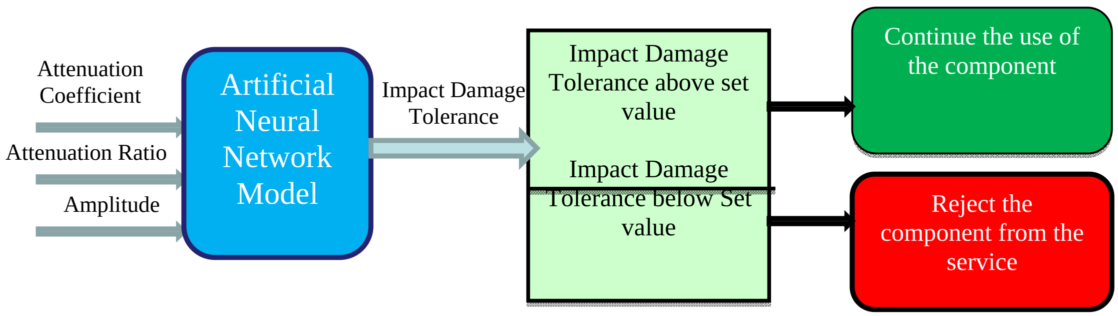

Fig. 20. Decision making algorithm for the assessment of drop impact damage by offline

5. CONCLUSION

The following conclusions were made from the assessment of drop impact damage by online method and offline method through artificial neural network.

Online assessment of drop impact damage finds application during the real time application of composite parts. AE parameters such as signal strength, Counts, Counts to peak and RMS values have direct relationship with impact energy. This result is due to the increased damage in composite materials. Impact Damage Tolerance (IDT) has an indirect trend with AE parameters. As the IDT decreases, it results in increase in AE parameters. This indicates lower IDT due to high density of impact damage induced, which results in greater value of AE parameters.

Offline assessment of drop impact damage using ultrasonic technique will be applied during scheduled and routine maintenance of composite parts. Amplitude and attenuation ratio decreases with increase in the impact energy. Attenuation coefficient increases with increase in the impact energy. Amplitude and attenuation ratio are directly proportional to IDT. But attenuation ratio is indirectly proportional to IDT.

Prediction of IDT is possible with minimum error through ANN model using AE/UT parameters. Effect of damage modes on IDT may be investigated as further work.

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