Experiments were carried out for the assessment of drop impact damage, using the Ultrasonic Technique and Acoustic Emission Technique, on a Glass Fibre Reinforced Polymer composite laminate. From the studies, it is found that the Ultrasonic Technique (UT) can be used as an offline inspection method for the assessment of drop impact damage. UT can be applied during scheduled and preventive maintenance of the composite structure. Experiments using the Acoustic Emission Technique (AET) reveal that the AET can be used for online monitoring of drop impact damage during real time problems.

13.1 ASSESSMENT OF DROP IMPACT DAMAGE USING THE ULTRASONIC TECHNIQUE

The impact damage assessment of GFRP composite laminates was studied, using Ultrasonic Technique. The usage of UT for the assessment of drop impact damage is presented, and its feasibility for practical implementation is also reported.

The inferences drawn from the experimental work are as follows,

- The impact energy is directly proportional to the area of impact damage. The area of impact damage increases from
102 mm$^2$ to 742 mm$^2$ for the impact energy, which ranges from 15 J to 50 J.

- The Amplitude of the reflected ultrasonic signal and attenuation ratio are inversely proportional to the area of impact damage. The range of amplitude is 73% to 21% and the range of attenuation ratio is 0.9 to 0.15 for the measured area of impact damage which ranges from 102 mm$^2$ to 742 mm$^2$.

- The areas of impact damage and attenuation coefficients have better relation with impact damage. The larger the area of impact damage, the larger will be the attenuation coefficient. This is because of the complex nature of the damage induced in the GFRP composite laminate. The range of attenuation coefficients is from 0.07 nepers/mm to 15.04 nepers/mm for measured the area of impact damage, which ranges from 102 mm$^2$ to 742 mm$^2$.

- Impact Damage Tolerance (IDT) is inversely proportional to the area of impact damage. It is found that there is a lower value of IDT for samples damaged with a larger area of damage, and a larger value of IDT for a lower area of impact damage induced in the GFRP laminated composite. The range of IDT is 76% to 18% for measured the area of impact damage, which ranges from 102 mm$^2$ to 742 mm$^2$.

- It is found that both the amplitude of the reflected ultrasonic signals and the attenuation ratio are directly proportional to the IDT.

- The relationship between the IDT and attenuation coefficient states that both are inversely proportional to each other. The
IDT varies from 76 MPa to 20 MPa for the attenuation coefficient range of 0.07 nepers/mm to 15.04 nepers/mm.

- It is found that the amplitude and attenuation ratio of ultrasonic signals increases with a decrease in the percentage of reduction of IDT for the impact damaged samples. It is also noted, that the attenuation coefficient is directly proportional to the percentage of reduction of IDT for the impact damaged samples.

- Artificial Neural Network modelling is developed for the prediction of the Impact Damage Tolerance of the impact damaged samples. ANN modelling considers the ultrasonic parameters, namely, amplitude, attenuation ratio and attenuation coefficients. For the complex nature of the drop impact damage, ANN can be used for modelling rather than the statistical or analytical model, with a minimum error of 2.77%.

Based on the experimental and predicted impact damage tolerance by the ANN model, decisions can be taken about the damage state of the composite component.

13.2 ASSESSMENT OF DROP IMPACT DAMAGE USING THE ACOUSTIC EMISSION TECHNIQUE

The online impact damage assessment of GFRP composite laminates was investigated using the Acoustic Emission Technique (AET). The application of AET for the online assessment of drop impact damage is presented, and its feasibility study for practical implementation is also reported.
The findings of the experimental work are as follows:

- The experimental results show that as the impact energy increases, the area of impact damage also increases in the GFRP laminated composite, which is obvious.

- Acoustic Emission (AE) parameters, namely, signal strength, counts, counts to peak and RMS values, are directly proportional to the area of impact damage. The range of signal strength is $304 \times 10^6$ picovolt-sec to $611 \times 10^6$ picovolt-sec, and the range of RMS is 8.71 mV to 12.06 mV for the measured area of impact damage, which ranges from 102 mm$^2$ to 742 mm$^2$.

- The range increase of the counts is from 238 to 987 and the range of the counts to peak is 164 to 842 for the measured area of impact damage, which ranges from 102 mm$^2$ to 742 mm$^2$.

- The AE parameters are inversely proportional to Impact Damage Tolerance and have an indirect relationship with each other. Lower values of the AE parameters are obtained for higher values of IDT. This indicates that the lower the damage induced in the composite material, the lower are the values of the AE parameters.

- The range increase of signal strength is $304 \times 10^6$ picovolt-sec to $611 \times 10^6$ picovolt-sec and the range of RMS is 8.71 mV to 12.06 mV for the decrease of IDT which range from 76% to 18%.
The range increase of the counts is from 238 to 987 and the range of the counts to peak is 164 to 842 for the decrease of IDT, which ranges from 76% to 18%.

It is observed that as the signal strength increases, the percentage of reduction in the IDT for the impacted specimen, also gradually increases. The higher signal strength is due to the higher damage induced in the material, and in turn, due to more damage, which results in more percentage of reduction in the IDT.

It is inferred, that when the counts, RMS values and counts to peak increase, the percentage of reduction in the IDT for the impact damaged specimen gradually increases.

ANN modelling was developed for the prediction of IDT, during the online monitoring of the drop impact damage using AE parameters, such as the signal strength, counts, counts to peak and RMS values. The experimental and predicted IDT values for the drop impact damage during ANN training are determined, with an average error of 1.49%. From the validation of the ANN model, the average error for the IDT prediction is 2.49%.

ANN modelling can be used for the prediction of the IDT values of the impact damaged GFRP laminated composite. Based on the critical value of IDT for specific applications, an alarm can be set for real time applications to indicate damaged damage status.

13.3 SIGNIFICANCE OF THE PRESENT WORK

The Ultrasonic Technique (UT) can be used as an offline inspection method for the assessment of the drop impact damage in small and medium
scale industries. UT can be applied during scheduled and preventive maintenance of composite structures in aerospace and marine applications.

The Acoustic Emission Technique (AET) can be used as an online monitoring inspection method for the assessment of the drop impact damage in critical applications, namely, aerospace and marine applications. The AET can also indicate major accidents that may happen in real time monitoring.

13.4 SUGGESTIONS FOR FUTURE WORK

1. The presented ultrasonic damage monitoring of drop impact damage can be extended as an online damage monitoring system for real time applications.

2. The cumulative effect of the damage modes, namely, matrix crack, fibre breakage and delamination constructively investigated by the impact damage tolerance method. This study can be extended to relate individual effects of each of the impact damage modes.

3. The study can be further extended to various types of loads, like fatigue, shear and bending etc. to study the effect of the UT parameters.

4. The thickness of the composite specimen was kept constant for the present experimental work. This work may be further extended to specimens with different thicknesses and different stacking sequences.