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TEMPERATURE EFFECT ON IMPACT DAMAGE IN CFRP COMPOSITES LAMINATES

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ABSTRACT
Over the years, there has been major concern over the safety of laminated composites subjected to a low velocity impact. A low velocity impact on laminated composites may encounter various types of damages including delamination, fiber breakage, matrix cracking and fiber matrix interfacial debonding. These types of damages cannot be detected visually and lead to structural failure at loads well below design levels. In this Project the CFRP laminates are zero and cross ply were fabricated with LY556 epoxy resin as a matrix and the specimens were cut according to the ASTM D790 using water jet cutting. By using Fractovis Drop weight impact machine, barely visible damage was introduced to the specimen at a constant velocity of 1.5 meter per sec. To identify the effect of temperature, specimens were subjected to impact at elevated temperature in the environmental chamber. The impacted specimens were further subjected to flexural testing in Tinius Olson 100KU universal testing machine under acoustic emission monitoring to compare the residual strength with the normal specimen. From the flexural results it's observed that the considerable increment in the impact resistance and residual strength in the specimens impacted at elevated temperatures. From the Acoustic emission monitoring results nature and extent of damage can be clearly observed.

INTRODUCTION
Composite materials are widely used now days in aerospace industries where the service temperatures falls in the range of 120°C – 150°C has created a need for the study of its behavior at elevated temperatures. Carbon Fiber Reinforced Plastics (CFRPs) are widely used in aerospace industry, on account of their high stiffness and strength as well as their low density. These materials present specific properties such as stiffness/weight and strength/weight ratios higher than those of metallic materials.

However, mechanical or structural components made of composite materials may suffer large damage extension when subject to impact loads, with the corresponding decrease of their residual strength and the subsequent risk of structural failure under service loads. The possibility of using composite materials for load bearing applications in future supersonic transport aircraft , where the service temperatures are likely to fall in the range 120-150°C, has created a need for data on materials at these elevated temperatures. In particular, the internal delamination being the major mode of damage, it is of vital importance to have a better understanding of the impact characteristics, energy absorption and induced damage of the laminated composite.

Objective Of The Work
a. To estimate the Residual Strength of post impacted CFRP composite laminates at elevated temperatures by subjected to flexural loading.
b. To study the nature and extent of damage due to temperature effect from the Acoustic emission parameters.

Impact Test
To simulate actual impact by a foreign object, the initial kinetic energy of the projectile is an important parameter to be considered, but several other factors also affect the response of the structure. A large mass with low initial velocity may not cause the same amount of damage as a smaller mass with higher velocity, even if the kinetic energy are exactly the same. In one case, the impact might induce an overall response of the structure, while in other the response might be localized in a small region surrounding the point of impact. Therefore, the selection of the appropriate test procedure must be made very carefully to ensure that test conditions are similar to the impact conditions to be experienced by the actual structure.
At the moment, two types of test are used by investigators, although many details of the actual test apparatus may differ. Experimental studies attempt to replicate actual situation under controlled conditions. For example, during

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aircraft take-off and landing, debris flying from the runway can cause damage; this situation, with small high-velocity projectiles, is best simulated using a gas gun. Another concern is the impact of a composite structure by a larger projectile at low velocity, which occurs when tools are accidentally dropped on the structure.

Low velocity impact damage

For impacts at low velocity do not results in complete penetration of the target, experiments indicate that damage consists of delamination, matrix cracking and fiber failures. Delamination is the debonding between adjacent laminas of most concern since they significantly reduce the strength of the laminate. Delamination occurs only at interfaces between plies with different fiber orientation. If the two plies are in same fiber orientation, no delamination will be introduced at the interface between them.

CFRP applications in aerospace

Aircraft structures are mostly made of carbon fiber epoxy composites. These materials are extremely strong and light. They comprise long fine carbon fibers immersed in a so-called matrix of epoxy. In its uncured state, the epoxy is sticky, soft, and pliable. In its cured state, the epoxy is hard and rigid. Curing involves heating the epoxy until a chemical reaction begins. This reaction provides additional heat and converts the epoxy into its final physical and chemical form. The epoxy holds the carbon fibers in place relative to each other and provides some compressive strength while the fibers provide tensile strength. One of the other important advantages of composites is that they can be assembled into large structures by bonding rather than riveting. Airframe cost forms the significant portion in the overall cost of aircraft. Any reduction in the airframe cost will also reduce the overall acquisition cost of the aircraft.

Fig.1.a. Boeing-787 Dreamliner Composite Profile.

The Boeing 787 Dreamliner is pushing envelope with a total composites of 50% by weight, including the integration of an all composite fuselage, wings and applications.

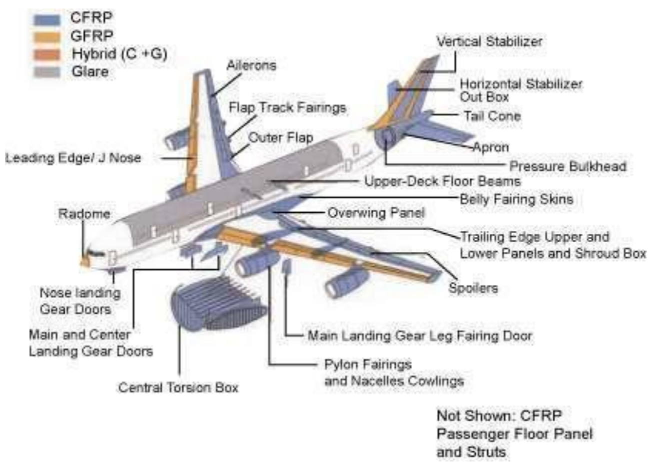

Fig.1.b. Airbus A380 Composite Profile

The Airbus A380 will be 25% by weight composites including 23% carbon fiber-reinforced polymers and 2% GLARE fiber glass reinforced aluminum.

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Acoustic emission overview

Composite materials under stress experience numerous damage mechanisms. For example, these may include fiber failure, debonding of phase etc. These damage mechanisms can occur at numerous locations throughout a composite beginning at very low stress levels. The task of keeping track of all of these damage sites and mechanisms is far more complex than simply monitoring crack growth at a few locations in metallic material. Because the accumulation of damage in a composite is closely tied to the actual strength, life and stiffness of the composite, understanding the development of this damage is very important to those who use composite material for structural applications.

Several methods have been used to monitor the damage occurrences in composites. Among these the techniques of acoustic emission (AE) has been increasingly used. AE is based on monitoring the stress waves that are generated by rapid local distributions of stress which accompany the operation of many damage mechanisms.

AE offers a numbers of potential advantages which gives the technique some unique capabilities. Among these are:
High sensitivity
Real time capability
Location of damage regions
Total specimen volume sensitivity
Sensitivity to any mechanism that generates stress waves

Acoustic emissions signals & processing

Acoustic emission (AE) is defined as the range of phenomena associated with structure-borne and fluid-borne propagation waves generated by the rapid release of energy from the localized sources within and/or on the surface of the material. A typical source of acoustic emissions includes plastic deformation, micro fracture, wear, bubble collapse, friction and impacts. When these waves reach the surface of the material they can be detected and measure by acoustic emission sensors. Acoustic emission signals are generally only a few microvolts in amplitude when measured at the sensing element and range from several kHz to a few MHz. At these frequencies, signals are strongly attenuated in air, so a suitable couplant is required between the sensor and material to ensure signal transmission.

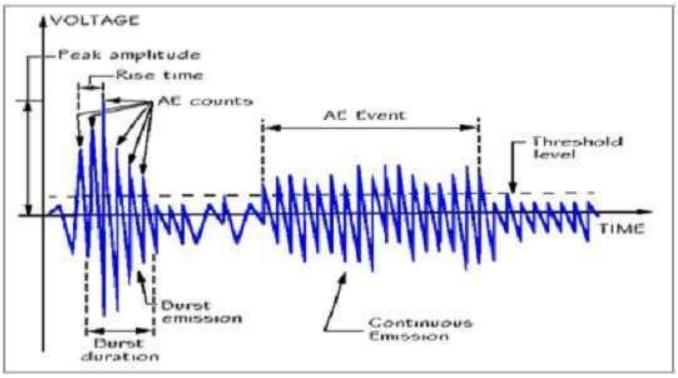

Fig.1.c. AE Signal

AE pre-processing involves amplification and filtering to refine the bandwidth and avoid aliasing. Signals are characterized as continuous, burst or mixed mode. Burst emissions are typically discrete transients with relatively short decay times and even shorter rise rimes. Continuous emissions are bursts that occur too closely together to differentiate between individual events, appearing as an increase in the background signal level. They typically have no distinguishing features other than their amplitude and frequency content. As the name suggests, mixed mode AE contains a number of large individual bursts above a background level of continuous emission. As most AE is broadband, processing is usually done in the time domain.

A distinction is made between two types of emission. One form known as very low energy continuous emission, the amplitude of which increases with the applied load. This emission is generally considered to be associated with

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the dislocation movements in the material. The second form occurs in discrete pulses (bursts) of considerably greater amplitude, which are considered to be linked with the appearance and development of macro faults (cracks, fissures etc.). Bursts of a much lower level are emitted at the moment when the blocking of the dislocation occurs at the material boundaries and when they fade out the surface or with a combination of both effects.

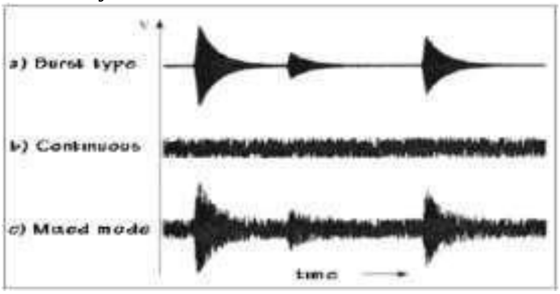


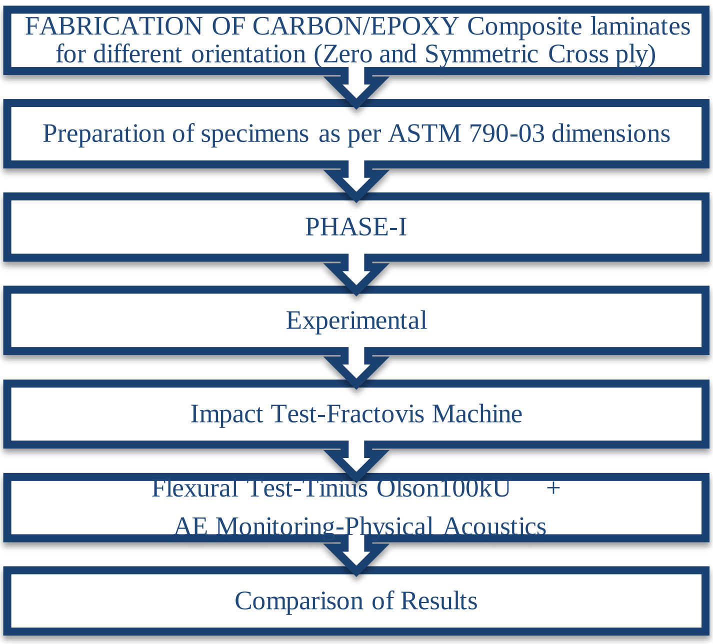
Fig.1.d.Types of AE Signals

Hits and events are important concepts to traditional AE signal analysis. A hit is defined as an AE burst that exceeds a certain voltage threshold. Generally an event occurs when the peak voltage remains above the threshold for consecutive hits. Both hit and event data features are therefore a function of the type and value of the selected threshold. Threshold are referred to as fixed , in which case they are set to an absolute value for the duration of the test above the background level. Fixed thresholds are used for monitoring static equipment while the floating thresholds are necessary for rotating equipment.

Facilities required

a. Dynamic Mechanical Analyzer
b. CEAST Fractovis Drop Impact machine
c. Tinius Olson Universal Testing Machine
d. Acoustic Emission Sensor setup

Flow of work methodology



LITERATURE SURVEY

Introduction

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The temperature effect increases the flexural strength of the specimens. In this chapter the literatures related to the temperature effect on residual strength of the impacted laminates and variations in the acoustic emission parameters has been studied.

Literature review on temperature effect & impact

[1] Kwang-Hee I et al,"Effects of temperature on impact damages in CFRP composite laminates". Composite Part B 2001; 32:669–82. This work focuses on the experimental study of effect of temperature on impact damages in CFRP. The low or high temperature conditions also affect the impact behaviors of composite structures. There are a few studies interested in the impact response of composite materials for various temperature conditions in the literature, especially, the Carbon Fiber Reinforced Plastic (CFRP) composites may be exposed to low or high temperatures, such as air at - 73°C to 80°C or the space at - 140°C to 120°C. the influence of temperature variations (30°C to 120°C) on matrix cracking and interfacial delamination damage of CF/epoxy and CF/PEEK composites subjected to impact loading at low and high temperatures were investigated. It was observed that there is a linear relation between impact energy and delamination area with change of temperature.

[2] Semih Benli and Onur Sayman,"The Effects of temperature and thermal stresses on impact damage in laminated composites", Mathematical and Computational Applications, Vol. 16, No. 2, pp. 392-403, 2011.© Association for Scientific Research. This work focuses on the experimental study of the effect of temperature on the impact damages on laminated composites. The results obtained from both thermal stress analyses and impact tests show that the contribution of thermal stresses to impact damage increases with decreasing temperature and therefore, the stresses at low temperatures have a significant effect on the impact damage and impact parameters of unidirectional laminated composites. Besides, it is seen that testing temperature and stacking sequence of the laminated composites have Considerable effects on impact parameters, specific energy values and damage areas.

EXPERIMENTAL PROCEDURE

Fabrication of test specimens

Preparation of CFRP Mat

1. Carbon fibers of dimension 300x300mm are cut from the big roll.
2. 8 such carbon fibers are required for preparing a CFRP laminate.
3. The weight of all the 8 glass fibers is measured using an electronic weighing machine.

Ppreparation of epoxy resin

1. Epoxy resin equal in weight to that of fiber is weighed and taken separately.
2. The 1/10th epoxy weight amount hardener is added to the resin.
3. Then epoxy resin and hardener is mixed thoroughly.

Preparation of unidirectional CFRP laminates

Two types of laminates are prepared:

i. Zero layer laminates [0º]
ii. Symmetric cross ply layer laminates [0º /90º/0º /90º]S

The specimens are prepared as follows:

1. Place the Mylar sheet on the table.
2. Apply a thin layer of resin on the surface of the Mylar sheet.
3. Next place the first layer of carbon fiber laminate and use rollers to squeeze the excess resin.
4. Apply resin over the first layer of carbon and place the second carbon layer and again use the rollers to squeeze the excess resin.
5. Repeat the procedure with alternating layers of carbon fiber and resin mixture until all the 8 layers of carbon fibers are finished.
6. Place the Mylar sheet over it and keep the weight to cure for a period of 24hrs.
7. Then zero and symmetric cross ply laminates will be having a thickness of about 3.4 mm.

As per the ASTM standard D 790-03 for flexural testing (3-point loading), span to depth ratio can be 32:1.

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Preparation of CFRP specimens

Depth	-	3.3 mm
Span (32 times of depth)	-	110 mm
Width (0.25 times of depth)	-	27 mm
Over hanging at each end (10%span)	-	20.4 mm

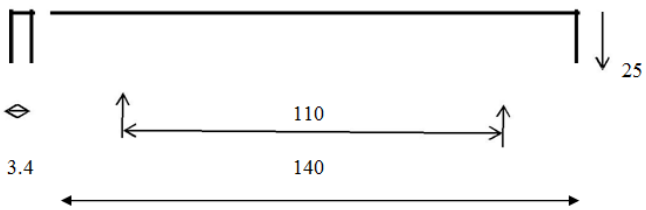

Fig.3.c. Flexural Specimen (All dimensions are in mm)

So the Required flexural specimen dimension calculated as 140 x 25 x 3.4 mm as per the ASTM standard. After the 300*300 mm laminates preparation, specimens are cut by water jet cutting as per the dimensions.

Dynamic mechanical analysis- T_g identification
Dynamic Mechanical Analysis (DMA) measures the mechanical properties of materials as function of temperature, frequency and time and also it is a thermal analytical method by which the mechanical response of a sample subjected to a specific temperature program is investigated under periodic stress.

At temperature below the glass transition temperature, a composite behaves like a glassy material. At high temperatures, the composite behaves like a viscoelastic material. The glass transition is often used to identify the temperature range of the glass to viscoelastic transition.

DMA 50N 01dB Metravib:

High force : 50N

Frequency: 1E-5 to 200Hz

Temperature: -150°C to 600°C

Specimen preparation

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To identify the Maximum range of operating temperature for the Impact testing, a small specimen of dimension 15x3x3.3 mm is cut from the prepared plate and T_g test is carried out by using the Dynamic Mechanical Analyzer.

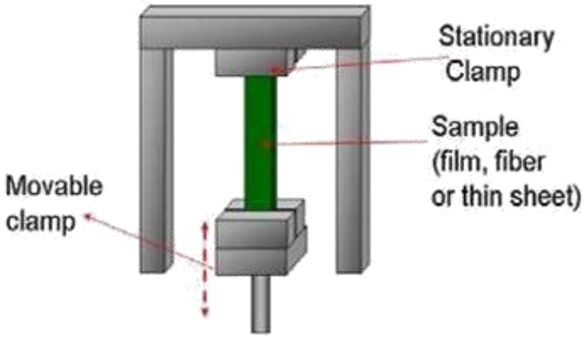

Fig.3.e. Tension clamp for DMA

The material was heated from 30ºC to 160ºC with the heating rate of 5ºC/min for epoxy-carbon fiber composites. The applied constant frequency was 0.5 Hz and the material were tested using tensile clamp.

Impact testing on specimens

Fig.3.f. Striker view ***Fig.3.g. Specimen holder***

Specimens of dimensions 140*25*3.4mm (ASTM D 790-03) are subjected to impact damage which is done by following procedure:

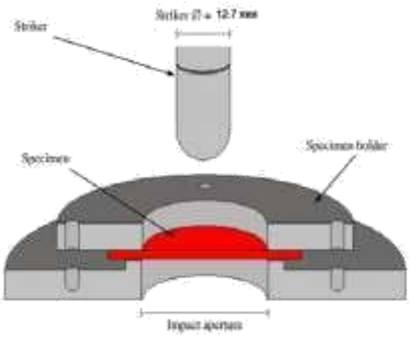

Fig.3.h. Impact loading view

1. Barely visible damage has been created on the test specimens by using a CEAST Fractovis Drop Impact tower.

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2. A striker of mass 1.926Kg is used.
3. The diameter of the impactor used is 15mm.
4. The impactor is dropped at a constant velocity of 1.5 m/sec.
5. Clamp force is 500N
6. Operating Temperature: ambient 30ºC, 55 ºC,75 ºC and 90 ºC

Flexural testing of specimens

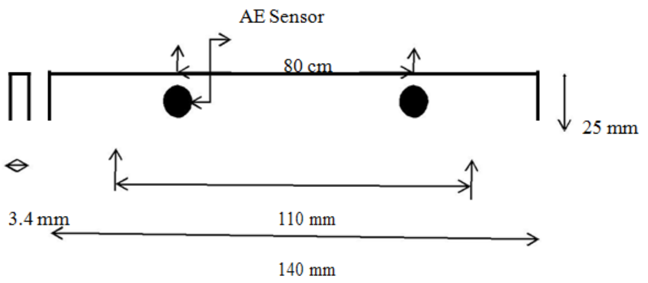

Fig.3.i. Flexural Specimen with sensor position

Fig.3.j. Flexural Testing with AE Sensor position

In order to study the effect of temperature on the residual strength in normal and post impacted specimens the following procedure is followed:

The Specimens are mounted on the TINIUS OLSEN 100kU Universal Testing Machine.

The crosshead speed was maintained at a rate of 0.25 mm/min

Then the specimens are subjected to flexural loading under acoustic emission monitoring using a 8-channel Acoustic Emission setup supplied by Physical Acoustics Corporation.

Acoustic emission monitoring
AE parameters and their description
Acoustic Emission: Elastic waves generated by the rapid release of energy from sources within a material.
Event: A local material change giving rise to acoustic emission.
Hit Data Set: The set of numbers representing signal features and other information, stored as a result of hit.
Event Data Set: The set of numbers used to describe an event pursuant
Rise Time: The time from an AE signal's first threshold crossing to its peak.
Counts: The number of times the AE signal crosses the detection threshold. Also known as "ring down counts" or "threshold crossing counts".
Energy: The total elastic energy (in the wave) released by an acoustic emission event.

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Duration: The time for which an AE signal crosses the threshold first time and for the last time.
Amplitude: The largest voltage peak in the AE signal waveform; customarily expressed in decibels relative to 1 microvolt at the preamplifier input.
Peak Definition Time: The function of peak definition time is to enable determination of the time of true peak of the AE waveform.
PDT = Distance between the sensor Wave Velocity
Hit Definition Time: The function of Hit Definition Time is to enable the system to determine the end of the hit, close out the measurement processes and store the measured attributes of the signal.
Hit Lockout Time: The function of Hit Lockout time is to inhibit the measurement of reflections and late arriving parts of the AE signal.

WAVE VELOCITY STUDY

1. Velocity study involves finding out the velocity with which the wave travels in the test structure.
2. Initially the sensors are fixed at two locations in the specimen.
3. High vacuum grease is applied on the sensor and then fixed using tape.
4. The distances between the two sensors are measured.
5. Velocity study is done using Hsu-Nielson source (pencil lead break).
6. The test is performed at various locations within the sensors.
7. Then the velocity is calculated using the formula,

$$\text{Velocity} = \frac{\text{Distance between the sensors}}{\text{Time interval at which signal is detected}}$$

From the calculations, it has been observed that the wave velocity for the used material is ≈ 6000 mm/s.

DATA ACQUISITION

1. Monitoring of AE signals generated from flexural test is done by an acquisition system.
2. The signals were detected using two R15 D piezoelectric transducers, which are attached to the specimen surface using high vacuum grease as a couplant and fastened by tape.
3. The signals from the transducer passed through PAC 2/4/6 G/A pre-amplifier before reaching the main unit.

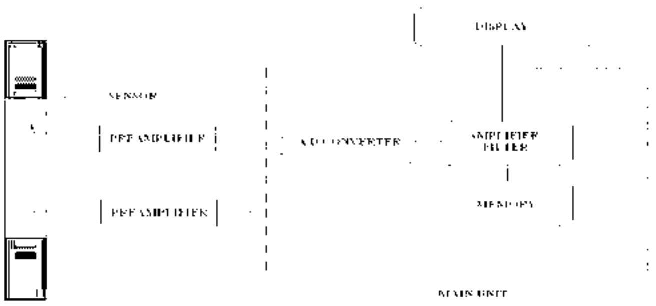

Fig.3.k. Data Acquisition setup

AE HARDWARE SETTINGS	
SAMPLING RATE	3 MSPS
PRE-AMPLIFIER GAIN	40DB
THRESHOLD DETECTION	45DB
TYPE OF SENSOR	R 15 D PAC
COUPLANT	HIGH VACCUMM GREASE
PEAK DEFINITION TIME	13µs
HIT DEFINITION TIME	134µs
HIT LOCK OUT TIME	300µs

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Table.1 Typical Settings of Data Acquisition System during AE Monitoring

4. Wave velocity test is performed on the specimen and wave velocity is calculated. The wave velocity of UD CFRP composite is found to be approximately 6000 m/s.
5. Next the sensors are connected to the 8-channel AE data acquisition system.
6. UTM is switched ON and the flexural load is applied.
7. Various AE parameters such as Amplitude, Counts, Energy, Rise, and Duration are recorded during the test.
8. Then the data's are proceed for wave analysis.

RESULTS & DISCUSSIONS

Introduction

To study the effect of temperature on the specimens, the post impacted specimens were subjected to the flexural testing and Acoustic emission monitoring. The results were discussed as follows.

DMA results

The CFRP specimen is subjected to the dynamic mechanical analysis, to identify the glass transition temperature. Glass transition temperature is the temperature value at which the sudden drop in the stiffness of the specimen occurs. This was useful in identifying the range of temperature need to be gone for impact.

From the results it is observed that the stiffness of the specimen drops nearly 95 °C and it can be considered as a glass transition temperature for the specimen. The impact test was being carried out below the obtained value.

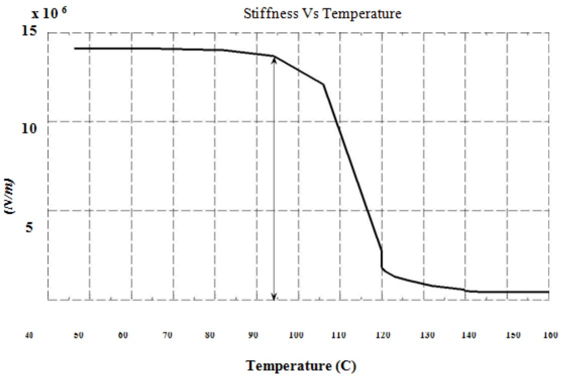

Fig.4.2.a. Temperature vs. Stiffness

From the results it is observed that the stiffness of the specimen drops nearly 95 °C and it can be considered as a glass transition temperature for the specimen. The impact test was being carried out below the obtained value.

Impact test results

Impact test was carried out for zero and symmetric cross ply specimens at the elevated temperatures (30 ˚C, 55 ˚C, 75 ˚C and 90 ˚C) using Fractovis impact machine. The Parameters like Peak force, Total Energy, Deformation, and Velocity with respect to time were noted down.

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Particular		Specimens Orientation			
Temperature	Parameters	Zero 1	Zero 2	Cross 1	Cross 2
30°C	Peak Force (N)	1520.418	1436.882	1504.255	1469.956
	Energy (J)	1.51	1.32	1.509	1.125
	Deformation (mm)	1.781	1.211	1.778	1.006
55°C	Peak Force (N)	1480.368	1448.2	1498.13	1471.493
	Energy (J)	1.326	1.223	1.424	1.339
	Deformation (mm)	1.306	1.197	1.523	1.36
75°C	Peak Force (N)	1481.593	1445.45	1384.209	1533.654
	Energy (J)	1.186	1.207	1.208	1.287
	Deformation (mm)	1.159	1.196	1.15	1.204
90°C	Peak Force (N)	1220.064	1196.789	1240.088	1312.548
	Energy (J)	1.639	1.725	1.78	1.659
	Deformation (mm)	1.774	1.859	1.821	1.795

Table.2 Impact test Results

Total Energy Vs Time

The total energy absorbed by the specimen over a period of time has been recorded and the plot has been made.

1. As the temperature increases the energy absorbed by the specimens decreases in both the zero and cross ply specimens.
2. This is due to ductility nature of the matrix increasing over the temperature.
3. But when the temperature reaches near the glass transition temperature, the specimens absorb higher energy.

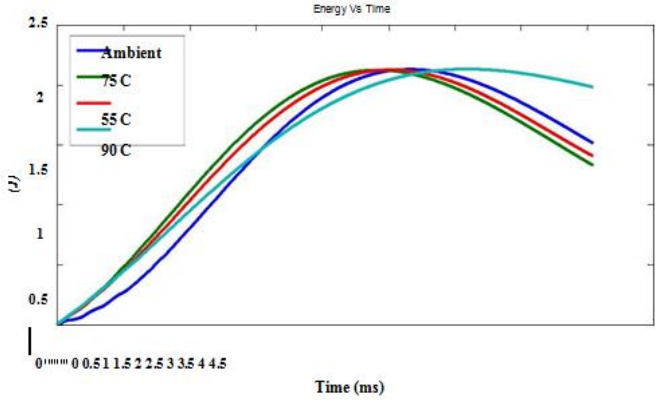

Fig.4.3.a. Total Energy vs. time for Zero plies specimens

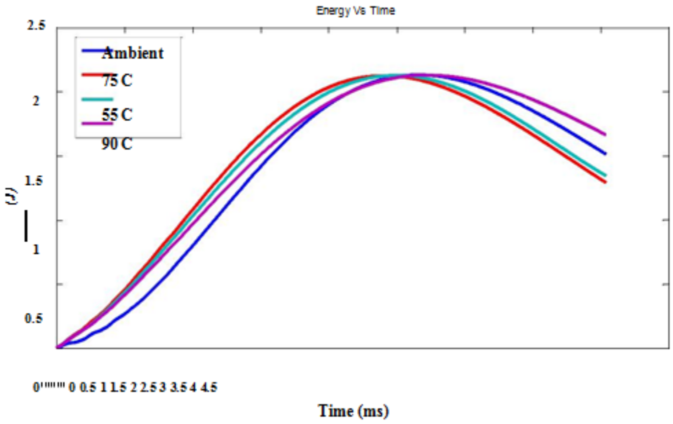

Fig.4.3.b. Total Energy vs. time for Cross ply specimens

Deformation Vs Time

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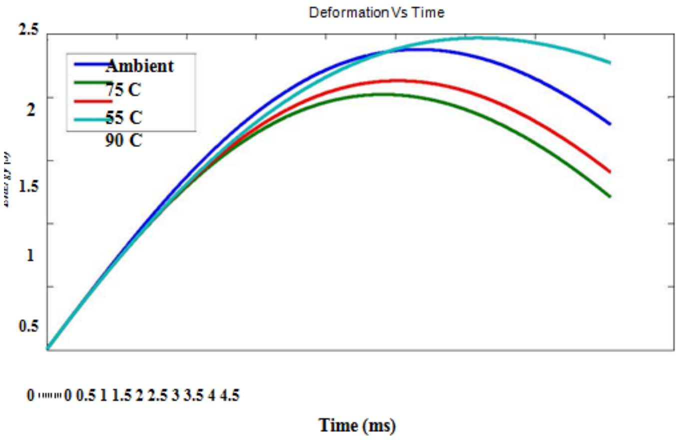

Fig.4.3.c. Deformation vs. time for Zero ply specimens

1. As the temperature increases the deformation of the specimen's increases in both the zero and cross ply specimens.
2. But when the temperature reaches near the glass transition temperature, the specimens deform higher.

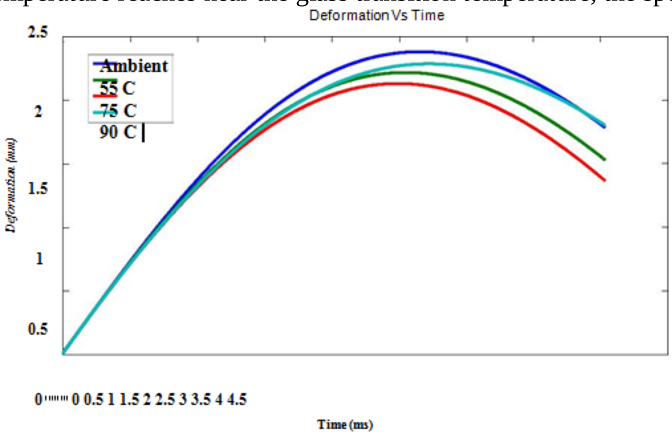

Fig.4.3.d. Deformation vs. time for Cross ply specimens

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PARTICULAR	SPECIMENS ORIENTATION		
Temperature	Parameters	Zero ply	Cross ply
Normal Specimen	Flexural Modulus (MPa)	42400	40600
	Ultimate Force (N)	1159.95	1113.13
	Ultimate stress (MPa)	662.26	635.52
Impacted at 30°C Ambient	Flexural Modulus (MPa)	41400	39000
	Ultimate Force (N)	1062.35	932.28
	Ultimate stress (MPa)	606.53	532.27
Impacted at 55°C	Flexural Modulus (MPa)	41000	38900
	Ultimate Force (N)	1099.62	958.84
	Ultimate stress (MPa)	627.81	547.44
Impacted at 75°C	Flexural Modulus (MPa)	42400	39600
	Ultimate Force (N)	1105.73	1056.48
	Ultimate stress (MPa)	631.3	603.18
Impacted at 90 C	Flexural Modulus (MPa)	40900	37700
	Ultimate Force (N)	966.54	909.63
	Ultimate stress (MPa)	551.83	519.34

Table.3. Flexural Results

1. Flexural strength increases as the temperature of the impacted specimen increases.
2. This trend observed in both the zero ply and cross ply specimens impacted at elevated temperature (30°C, 55°C & 75°C).
3. For the specimen impacted at 90 C has very low residual strength due to the temperature been near to the glass transition temperature.

STRESS VS STRAIN

From the flexural results stress vs. strain values has been plotted for the various elevated temperature impacted specimens.

For Zero ply Specimens:

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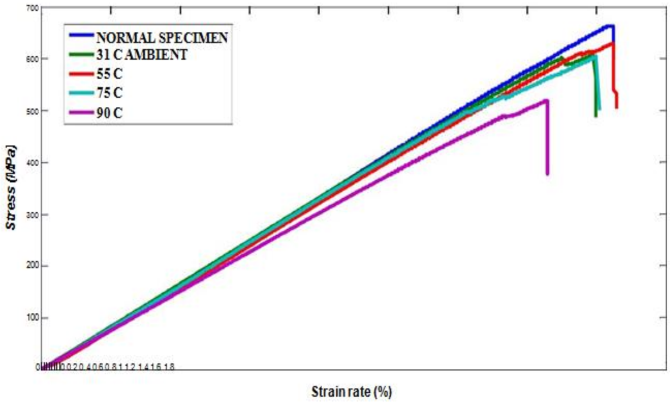

Fig.4.4.a. Stress Vs Strain for Zero ply specimens

For Cross ply Specimens:

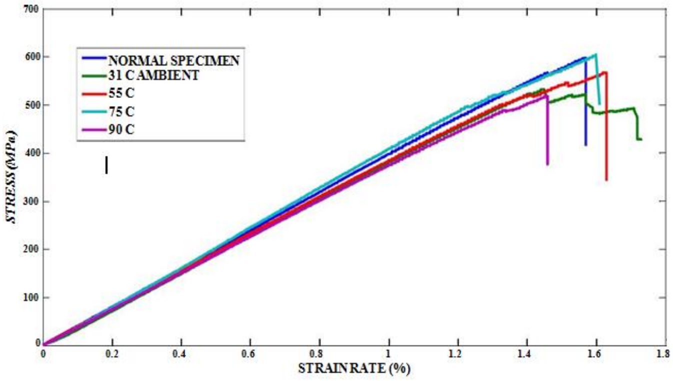

Fig.4.4.b. Stress Vs Strain for Cross ply specimens

1. Flexural strength increases as the temperature of the impacted specimen increases.
2. This trend observed in both the zero ply and cross ply specimens impacted at elevated temperature.
3. For the specimen impacted at 90 C has very low residual strength due to the temperature been near to the glass transition temperature.

FLEXURAL MODULUS VS TEMPERATURE

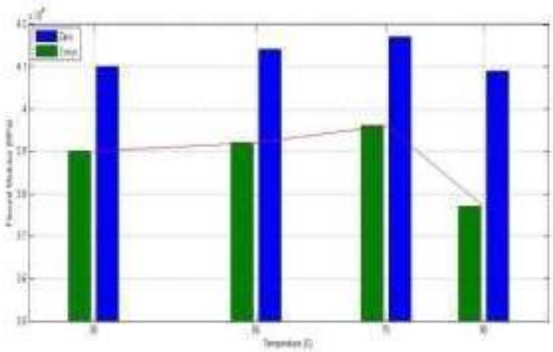

Fig.4.4.c. Flexural Modulus Vs Temperature

Flexural modulus increases as the temperature increases and drops for the 90 C for both the zero and cross ply specimens.

FLEXURAL STRENGTH VS TEMPERATURE

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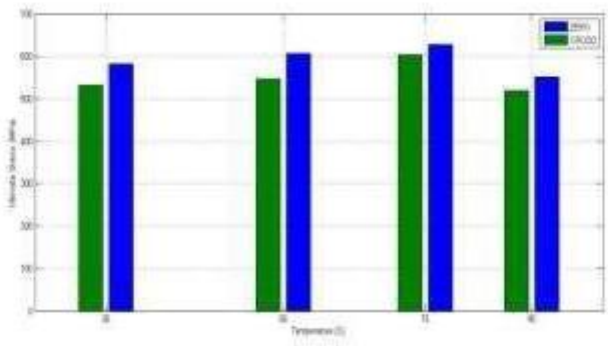

Fig.4.4.e. Ultimate force Vs Temperature

Ultimate force increases as the temperature increases and drops for the 90 C for both the zero and cross ply specimens.

ACOUSTIC EMISSION RESULTS

DURATION, AMPLIUDE VS TIME

From the AE data acquired during three point flexural test, Time vs. Amplitude and Duration were plotted for all specimens.

1. Short duration and high amplitude (> 90 dB) could be matched to fiber failure.
2. Medium to long duration and medium to high amplitude (60 to 90 dB) corresponds to delamination
3. Short duration and low amplitude (40 to 60 dB) could be correlated with matrix failure.

CUMULATIVE COUNT, PEAK FREQUENCY VS TIME

From the AE data acquired during three point flexural test, Time vs. Peak frequency and cumulative counts were plotted for all the specimens.

1. Three ranges of frequency have been observed from the plot as 60 kHz to 120 kHz, 120 kHz to 180 and above 200 kHz.
2. 60 kHz to 120 kHz range corresponds to Matrix failure.
3. The frequency range from 120 kHz to 180 kHz range corresponds to Delamination.
4. The frequency range above 200 kHz corresponds to fiber breakage.

AE PLOTS

The plots of Amplitude, duration vs. Time & Peak Frequency, Cumulative Counts vs. Time have been compared between the normal and temperature impacted specimens.

NORMAL ZERO PLY SPECIMEN

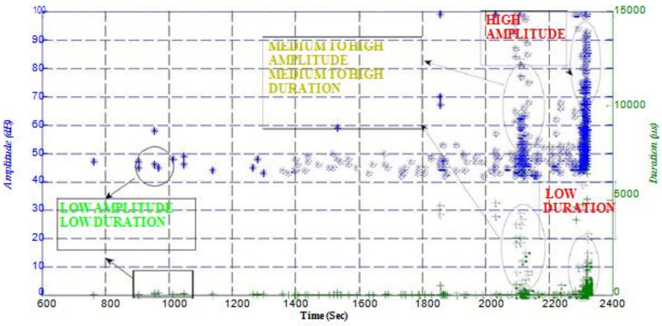

Fig.4.5.a.Time vs. Amplitude & Duration-Zero ply specimen

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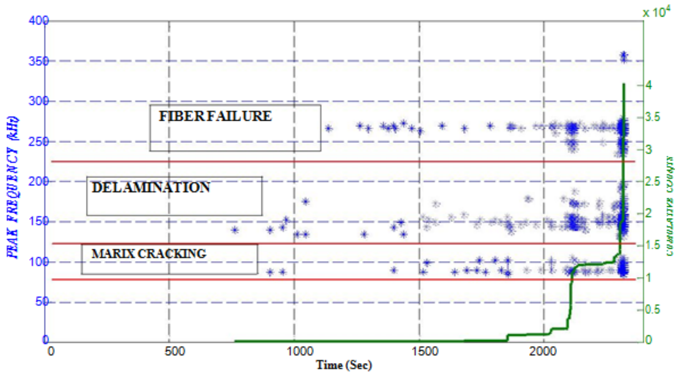

Fig.4.5.b.Time vs. Peak frequency & cumulative counts-Zero Ply specimen

Fig.4.5.a &b, plot clearly shows short duration, and low amplitude signals predominant in the initial time of test up to 1800 seconds corresponds to the matrix failure. Medium duration and medium amplitude signals observed during 1800-2100 seconds represents the delamination.

From the 2100 seconds up to failure, a mixed of signals corresponds to delamination and fiber failure observed.
NORMAL CROSS PLY SPECIMEN

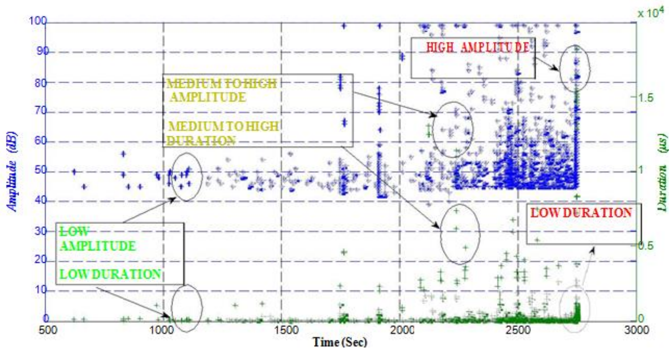

Fig.4.5.c.Time vs. Amplitude & Duration-Cross ply specimen

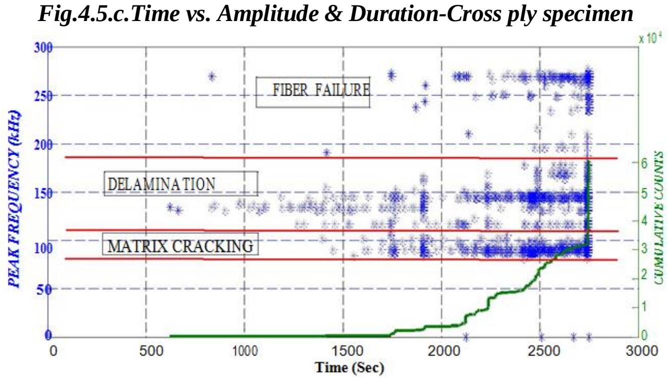

Fig.4.5.d.Time vs. Peak Frequency & Cumulative Counts -Cross ply specimen

Fig.4.5.c&d.plot clearly shows that medium duration and medium amplitude signals observed from the beginning of the testing, since the cross ply specimens susceptible to the delamination due to its 90o oriented layers.
FOR AMBIENT IMPACTED ZERO PLY SPECIMEN

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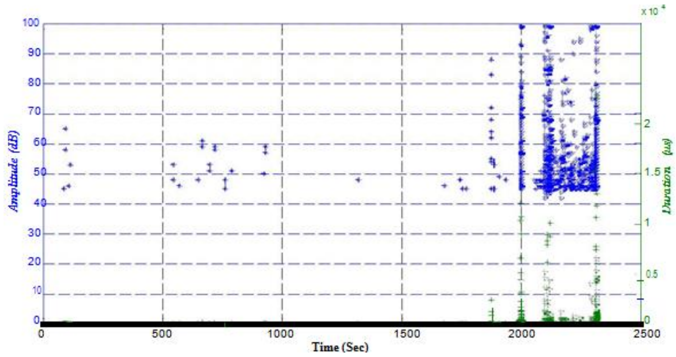

Fig.4.5.e.Time vs. Amplitude & Duration-Zero ply specimen

Fig.4.5.e &f, plot clearly shows that, at 200 seconds a few matrix cracking signals observed which were raised from the impacted area. From 500 to 1800 seconds very few signals correspond to delamination observed.

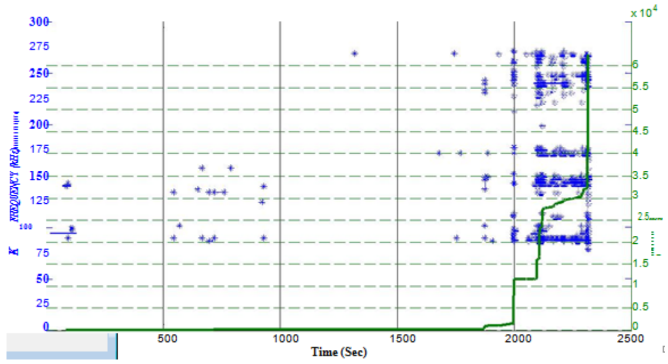

Fig.4.5.f.Time vs. Peak frequency and cumulative counts-Zero Ply specimen

FOR AMBIENT IMPACTED CROSS PLY SPECIMEN

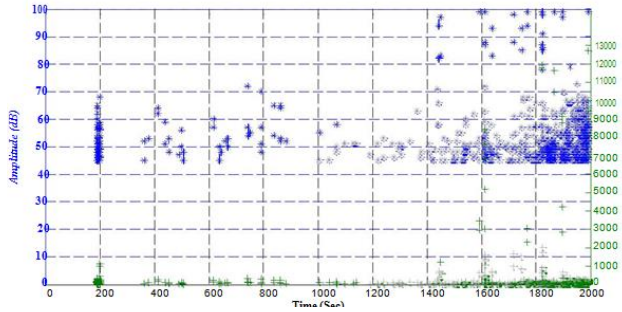

Fig.4.5.g.Time vs. Amplitude & Duration-Cross ply specimen

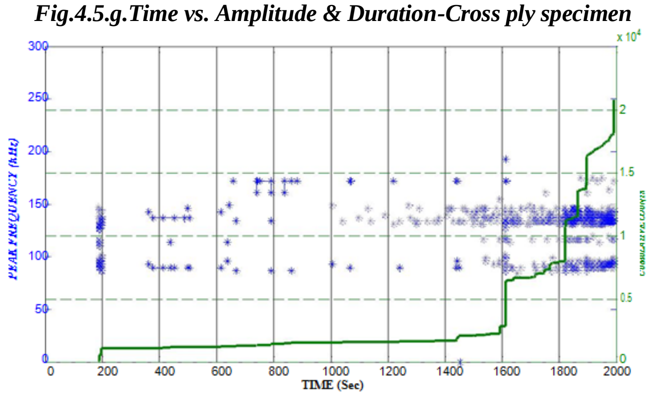

Fig.4.5.h.Time vs. Peak frequency and cumulative counts-Cross Ply specimen

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Fig.4.5.g & h, plot clearly shows that, at 200 seconds a considerable matrix cracking & delamination signals observed which were raised from the impacted area.

75 ˚C IMPACTED ZERO PLY SPECIMENS

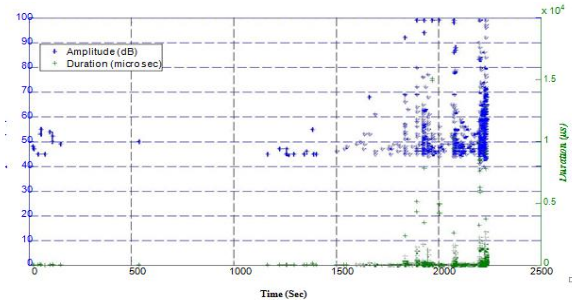

Fig.4.5.i.Time vs. Amplitude & Duration-Zero ply specimen

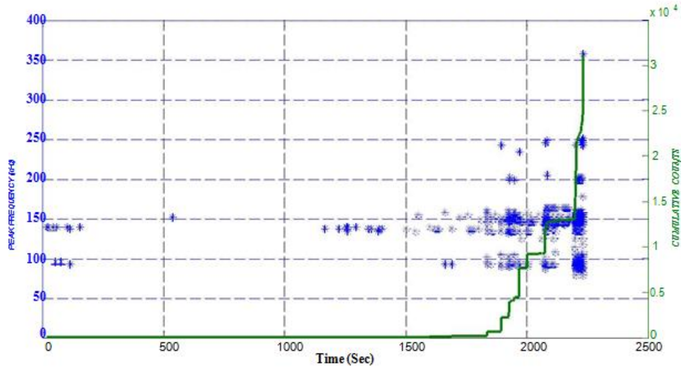

Fig.4.5.j.Time vs. Peak frequency and cumulative counts-Zero Ply specimen

Fig.4.5.i & j, plot clearly shows that, at 200 seconds a few matrix cracking signals observed which were raised from the impacted area less than ambient impacted specimen. From 400 to 1700 seconds very few signals correspond to delamination observed. From 1700 seconds up to failure, a mixed of delamination and fiber failure signals observed.

FOR 90˚C IMPACTED ZERO PLY SPECIMEN

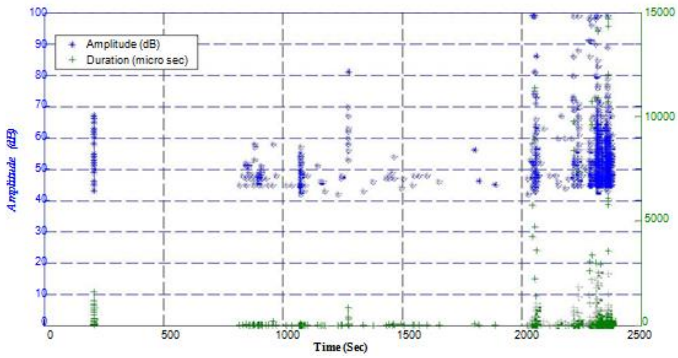

Fig.4.5.m.Time vs. Amplitude & Duration-Zero ply specimen

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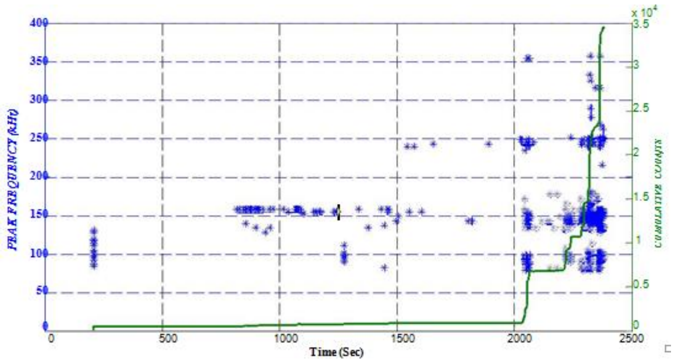

Fig.4.5.n.Time vs. Peak frequency and cumulative counts-Zero Ply specimen

Fig.4.5.m & n, plot clearly shows that, at 200 seconds a considerable delamination signals observed which were raised from the impacted area.

Since at 90C specimen absorbs much energy during impact. A similar like ambient zero impacted trend has been observed.

SUMMARY

1. As the temperature of the impact increases, the energy absorption decreases and the deformation increases in both the zero and cross ply specimens.
2. The residual strength of the elevated temperature impacted specimens higher than the ambient impacted specimen for both zero and cross ply specimens. The trend of increasing in strength of the specimens as impact temperature increases observed.
3. But when the impact temperature reaches near the glass transition temperature, the specimens absorb higher energy even though it deforms higher. And the drop in residual strength also observed. A further investigation has to do at the near glass transition temperature effect in the next phase of the project.
4. Three ranges of frequencies have been observed from the Acoustic Emission results.
5. A further investigation is required to characterize the effect of temperature in AE parameters and the Frequency range.

FUTURE WORK

1. Conduct the test on single and two layer CFRP laminates, to identify the exact range of failure frequencies.
2. Conduct the impact at further different range of temperatures and flexural testing.
3. Investigate the temperature effect at near glass transition temperature.
4. Conduct Ultrasonic C scan over the impacted specimens, to identify the damage propagation due to impact at elevated temperature.
5. Simulate the flexural after impact using software packages (Abacus & LS-Dyna).

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