

# EVALUATION OF BIOMATERIAL IMPACT RESISTANCE AND DAMAGE DETECTION USING ULTRASOUND C-SCAN METHODS

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**Abstract:** In recent years the use of composite materials in structural components has become increasingly common in a wide range of engineering applications. Composite materials offer numerous advantages over more conventional materials because of their superior specific properties, but a serious obstacle to a more widespread use of these materials is their high sensitivity to localized impact loading. This paper presents an experimental study to assess the impact response of drop weight impact tests on fiber reinforced polymer composites with deferent load and damage identification of composite using Non-destructive testing techniques ultrasonic testing (UT) C scan. In the study includes checking the strength of the specimen, plotting of graphs between the height and the impact energy obtained and tabulating the results after conducting the various functional tests.

**Keywords:** Composites materials; Mechanical property; Structural behavior; Impact test; Drop-weight test; Non-destructive testing; NDT UT C-scan

## INTRODUCTION

### 1.1 Composites

Composites are well known for their excellent weight/strength and weight/stiffness properties and they are the materials of choice for light-weight structures. Fiber Reinforced Plastics (FRP) composites are widely used in aircraft components such as spoilers, wings and in subsystems such as turboprops and turbofans. Composites have now replaced light alloys in aircraft components since they are lighter and have a lower maintenance control surface (cleaning and polishing). Laminated fiber reinforced composite materials are also known for their good environmental resistance and fatigue resistance. Glass Fiber Reinforced Polymer (GFRP), Carbon Fiber Reinforced Polymer (CFRP), Kevlar and hybrid composites are commonly used for aircraft structures and components. However, these materials are at risk of experiencing damage. There are different types of damage possible in an aircraft such as fatigue, corrosion, accidental (impact) damage, and associated repairs; it is reported that at least 13% of 688 repairs to 71 Boeing 747 fuselages were related to impact damage Impact damage is an important type of failure in aircraft structures.

In the last few decades, the use of composite materials in different structures has become increasingly popular since composites are well known for their excellent weight/strength and weight/stiffness properties and this makes them the material of choice for light weight structures. Laminated fiber-reinforced composite materials are also known for their good environmental resistance and fatigue resistance. A composite material is a combination of two or more materials and it creates a new material with a unique combination of properties. Normally, composite material is formed by reinforcing fibers in a matrix resin as shown in Figure 1. The strength and stiffness of the composites is provided by the reinforcing fiber or fabric, while the rigidity and environmental resistance of the composite is provided by the matrix.

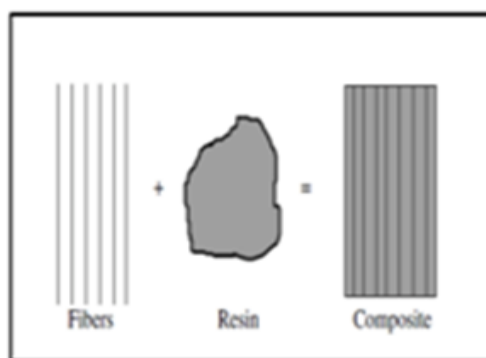


Figure 1: Composite material formed by reinforcing fibers in a matrix resin

Because of high specific strength and modulus, low specific density and corrosion resistance, fiber reinforced plastics are used in vast majority of fields such as aerospace, transportation and building structures. In order to

optimize designing with these materials it is necessary to perform standard tests and find out their mechanical properties. Toughness is an important property of composite materials and shows energy absorption capacity of the specimen. This energy is measured by impact testing. The impact behavior of FRP materials is so diverse and complex and the present knowledge is far from complete. The resulting damage due to impact, often in the form of de-laminations, matrix cracking and fiber failure may severely reduce the structural strength and stability. Therefore, a current and important design requirement in load bearing composite structures is the ability to tolerate the impact damage. In the field of low velocity impact, the most frequently used testing machines are of "Drop Weight" type, as they allow tests to be performed in operating conditions close to the actual ones, and at the same time assure a wide range of impact velocities and energies.

**1.2 Fiberglass**

In general, fiberglass is a low cost material and has good electrical insulation. However, it has a short fatigue life due to the low stiffness of glass reinforcement. In a humid environment, the strength of fiberglass is reduced under sustained loading, as the moisture absorbed onto the surface of the flaw reduces the surface energy. Glass fiber is commonly chosen in impact sensitive applications even though it has a lower elastic modulus and lower resistance to fatigue. It has the higher impact damage tolerance of laminates and a lower raw material cost compared to carbon fibers GFRP laminate has great impact resistance since it has higher energy absorption due to its higher strain to failure ratio compared to a carbon fiber reinforced material Table-1 shows the mechanical properties of C-glass and E-glass. The density, tensile strength and modulus of elasticity of E-glass is higher than that of C-glass.

Table-1. Mechanical properties of C-glass and E-glass

Property	C-glass	E-glass
Density (g/cm <sup>3</sup> )	2.52	2.58
Tensile strength at 23° C (MPa)	3310	3445
Young's modulus at 23° C (GPa)	68.9	72.3
Elongation percentage	4.8	4.8

Source: International Journal of Impact Engineering

**1.3 Drop weight impact testing:**

In this study, a weight is dropped from a known height and allowed to accelerate under the force of gravity. The hammer comes down and strikes the material specimen causing some type of failure, whether it be fracture, cracking, plastic deformation, or purely elastic deformation.

In the case of fiber reinforced composite materials, delamination and/or tearing of fibers can occur as material failures. With the drop weight method, the weight is guided to the target material specimen by sliding through a tube or by sliding down guide rails. Since the mass either stops dead on the specimen or breaks it, the test was essentially pass/fail. However, the energy absorbed by a specimen when it breaks can be estimated:

- i) The mass is dropped from increasing heights until the specimen fractures or breaks.
- ii) Further tests are carried out on other samples to get more accurate value.

Both the mass and the drop height can be varied. The impact energy is the kinetic energy of the mass at impact. The energy absorbed by the test specimen is the impact energy required to just fracture or break the specimen. The impact testing can have a load cell attached to it so that impact force can be determined. And boxes showing the margins and print areas. If you hold it and your printed page up to the light, you can easily check your margins to see if your print area fits within the space allowed.

**1.4 Testing standards**

Depending on the type of material being tested, the method of testing, or the configuration of the material being tested, ASTM International has produced standards governing the method and analysis for many types of impact resistance tests. For the case of drop weight impact testing there are standards plastics and fiber reinforced composites and the standard used is ASTM D5628. This standard governs the configuration of the test sample, the proper type of impact device to use, and the proper configuration of clamp to hold the test specimen.

**1.5 Non Destructive test UT**

Ultrasonic Testing (UT) uses high frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection/evaluation, dimensional measurements, material characterization, and more. To illustrate the general inspection principle, a typical pulse/echo inspection configuration as illustrated below will be used.

A typical UT inspection system consists of several functional units, such as the pulser/receiver, transducer, and display devices. A pulser/receiver is an electronic device that can produce high voltage electrical pulses. Driven by the pulse, the transducer generates high frequency ultrasonic energy. The sound energy is introduced and propagates through the materials in the form of waves. When there is a discontinuity (such as a crack) in the wave path, part of the energy will be reflected back from the flaw surface. The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen. In the applet below, the reflected signal strength is displayed versus the time from signal generation to when an echo was received. Signal travel time can be directly related to the distance that the signal travelled. From the signal, information about the reflector location, size, orientation and other features can sometimes be gained.

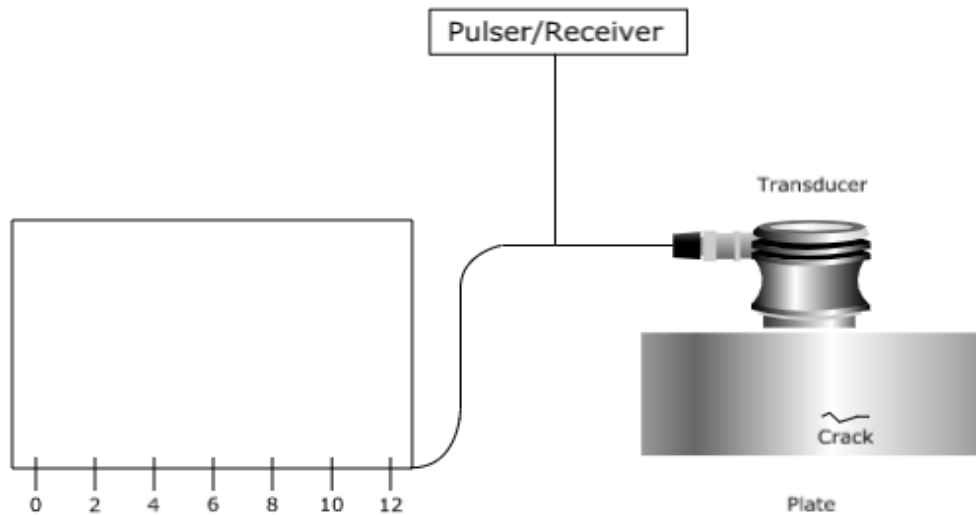


Figure 2: Ultrasonic Testing

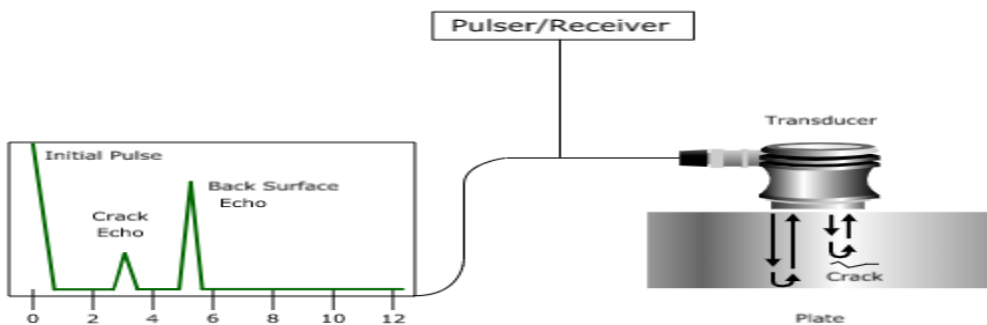


Figure 3: Ultrasonic Testing

Ultrasonic Inspection is a very useful and versatile NDT method. Some of the advantages of ultrasonic inspection that are often cited include:

- It is sensitive to both surface and subsurface discontinuities.
- The depth of penetration for flaw detection or measurement is superior to other NDT methods.
- Only single-sided access is needed when the pulse-echo technique is used.
- It is highly accurate in determining reflector position and estimating size and shape.
- Minimal part preparation is required.
- Electronic equipment provides instantaneous results.
- Detailed images can be produced with automated systems.
- It has other uses, such as thickness measurement, in addition to flaw detection.

As with all NDT methods, ultrasonic inspection also has its limitations, which include:

- Surface must be accessible to transmit ultrasound.
- Skill and training is more extensive than with some other methods.
- It normally requires a coupling medium to promote the transfer of sound energy into the test specimen.
- Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect.
- Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.
- Linear defects oriented parallel to the sound beam may go undetected.
- Reference standards are required for both equipment calibration and the characterization of flaws.

The above introduction provides a simplified introduction to the NDT method of ultrasonic testing. However, to effectively perform an inspection using ultrasonic, much more about the method needs to be known. The following pages present information on the science involved in ultrasonic inspection, the equipment that is commonly used, some of the measurement techniques used, as well as other information.

## II. METHODOLOGY

The testing of the specimens was done in the impact testing machine developed. The specimen was clamped to the base of the machine before testing. The crushing force of the specimen during the impact was sensed by using the load cell which was placed between the specimen and the steel base. An impactor was elevated and then released at a certain height above the specimen. The impactor would hit the specimen with an impact speed that depends on the dropping height. The kinetic energy of the impactor was then absorbed by the progressive folding of the specimen, which reduced the kinetic energy of the impactor until it finally stopped. The crushing force data was later used in the numerical analysis.

From the design principle and requirements, the drop weight impact testing was designed. The impact testing machine can be divided into 4 subsystems namely the frame that consists of guide columns; base plate; impactor assembly that consists of weighing masses, impactor head and clamp and the load cell with display. Damage evaluation of composite sample using Non Destructive test UT immersion ultrasonic testing system. The objective of the study is to find dimension of damage using immersion UT system. Choosing the inspection method depends up on the various factors like nature of defects to be identified, sample thickness.

### 2.1 Preparations of specimen

The composite materials chosen are Owen roving fabric 0/90 bi bidirectional Glass Fiber Reinforced Polymer (GFRP) type E-glass ,Epoxy 400 g/m<sup>2</sup> were laminated with resin to increase their impact strength. The materials were fabricated using a vacuum infusion process technique.

Table 2 - Laminate thickness for type E-glass/Epoxy 400 g/m<sup>2</sup>

Type of fiber glass	Number of plies	Thickness (mm)
E-glass/Epoxy 400 g/m <sup>2</sup>	12	4

There are numerous methods for fabricating composite components. Some methods have been borrowed but many were developed to meet specific design or manufacturing challenges. Selection of a method for a particular part, therefore, will depend on the materials, the part design and end-use or application. Composite fabrication processes involve some form of molding, to shape the resin and reinforcement. A mold tool is required to give the unformed resin /fiber combination its shape prior to and during cure. For an overview of mold types and materials and methods used to make mold tools.

### 2.2. Composite Manufacturing Processes

#### Thermoset composites

1. Short fiber reinforced
- 2 .Continuous fiber reinforced
  - A) Prepreg
  - B) Resin transfer

#### Thermoplastic composites

1. Commingle
- 2 . Impregnated

### 2.3 Composite Manufacturing Processes

- Hand Lay-up
- Pre-preg forming

- Pressure molding
- Vacuum bagging
- Filament winding
- Pultrusion
- Spray method
- Sheet molding
- Bulk molding
- Vacuum Assisted Resin Transfer Molding

#### 2.4 Vacuum bagging

The vacuum bagging molding process utilizes a flexible and transparent film in order to fully enclose and compacting the wet laminate by using atmospheric pressure. This process is also called vacuum bagging for short as it uses a vacuum and pump to extract the air from inside the vacuum bag and compress the part under atmospheric pressure in order for the compacting and hardening process to take place. Vacuum bagging is an upgrade of the wet lay-up process and is widely spread in the composite industry because of its clear benefits over this method. You will most often see the use of fiberglass, carbon fiber and resin materials being laminated together using the vacuum bag technique. The outer atmospheric pressure caused through the vacuum within the closed system will compress the laminate and excess resin is sucked out of the wet laminate into the bleeder cloth and resin catch pot.

##### Advantages of Vacuum bagging:

1. simple design
2. any fiber/matrix combination
3. cheap mold material
4. better quality for the cost

##### Disadvantages of Vacuum bagging:

1. Cannot be heated up too much
2. Breeder clothe has to be replaced frequently
3. Low pressure (760 mm Hg the most)
4. Inconsistency

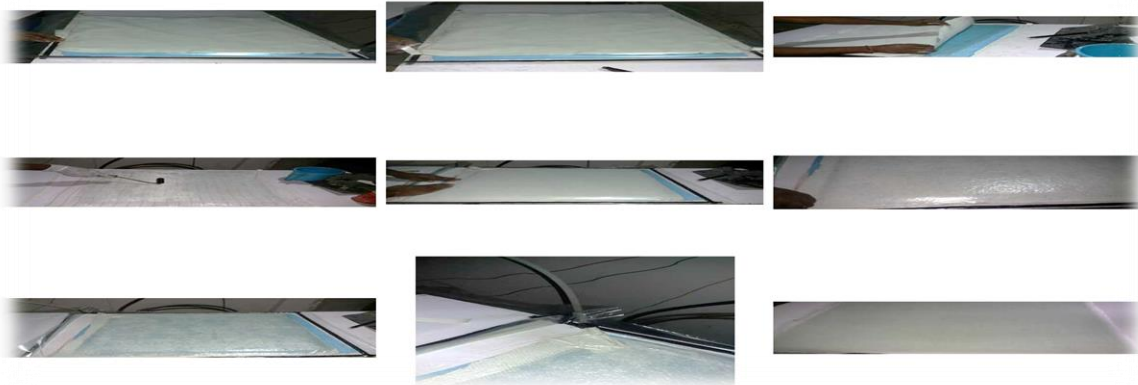


Figure 4: Preparations of specimen

#### 2.4 Preparations of specimen vacuum infusion process:

##### Steps:

1. Mould preparation
2. Applying wax (release agent) on mould surface ,wait for 20 to 30 minutes after applied release agent
3. Make lamination layer one by one
4. Use peel ply after finishing he lamination
5. Use release film
6. Use breather cloth
7. Vacuum bagging-close the bag by using sealant tape
8. Start the vacuum pump-running time min 3hrs
9. Release the product

### III. FORMULAE

Using Equation (1)

$$\text{Impact energy (E)} = m \times g \times h \text{ (Joule)} \quad (1)$$

Where,

$m$  = Drop mass (kg)

$h$  = Drop height (m)

$g$  = Acceleration due to gravity (m/s)

### 3.1 Impact Test Procedure

A drop-weight impact test is performed using a balanced, laminated plate. Damage is imparted through out-of-plane, concentrated impact using a drop weight. The damage response is a function of the test configuration; the damage resistance is quantified in term of size and type of damage in the specimen.



Figure 5: Drop weight impact test

This method cover the damage resistance of fiber glass E-glass laminated plates subjected to a drop-weight impact event. The composite material forms are limited to continuous-fiber reinforced laminate plates, with range of acceptable test laminates and thickness. The potential energy of the Drop-weight, as define by the mass and drop height of the impactor is specified prior to test. Equipment and procedure are provided for optional measurement of contact force during impact event. The damage resistance properties generated by this test method are highly dependent upon several factors, which include specimen geometry, lay-up, impactor geometry, impactor mass, impact force, impact energy, and boundary conditions.

#### Specimen and testing details:

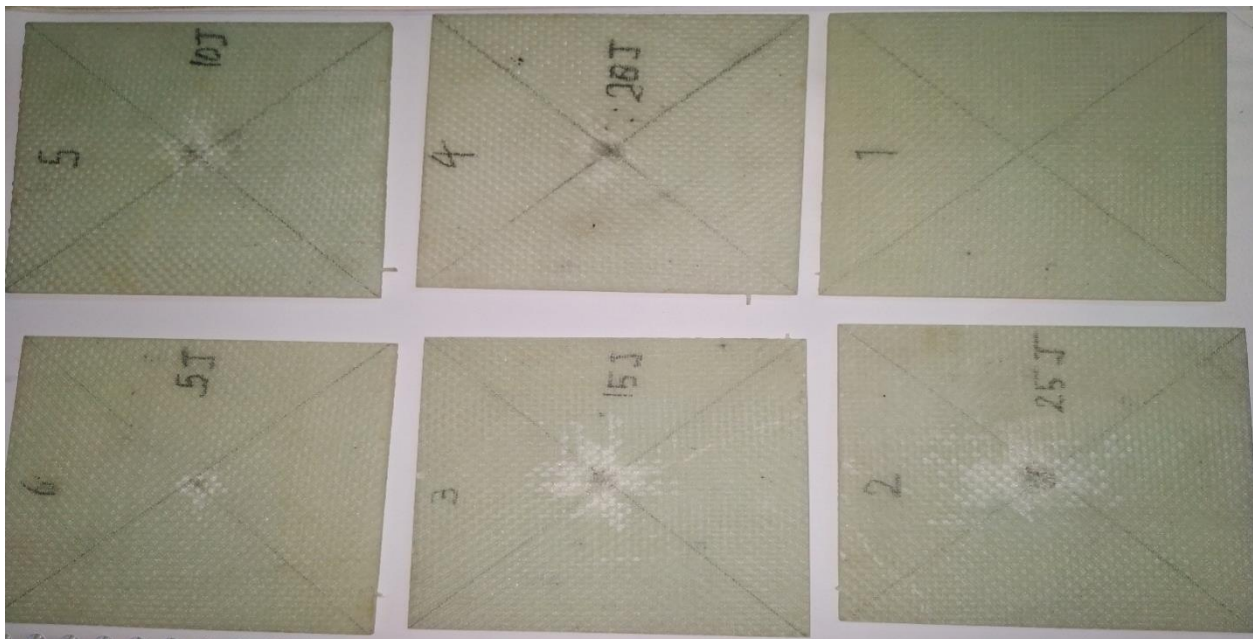


Figure 5: composite glass fiber on drop test

Composite materials offer numerous advantages over more conventional materials because of their superior specific properties, but a serious obstacle to a more widespread use of these materials is their high sensitivity to localized impact loading. The impact response of drop weight impact tests on fiber reinforced polymer composites with deferent load. The composite materials chosen are Owen roving fabric 0/90 bi bidirectional Glass Fiber Reinforced Polymer (GFRP) type E-glass ,Epoxy 400 g/m<sup>2</sup> were laminated with resin to increase their impact strength. The materials were fabricated using a vacuum infusion process technique.

Table 3: specimen

Impact energy	height
5	0.1484
10	0.29676
15	0.44514
20	0.59352
25	0.7419

### 3.1 UT and Scan parameters

Ultrasonic parameters

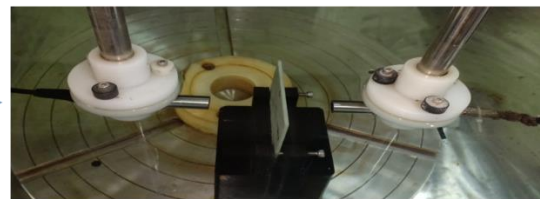
- Method : Through Transmission
- Transducer frequency : 2.25 MHz
- Transducer focal distance in water : 2 inch
- Pulser voltage : 200 V;
- Gain :18 dB;

Scan parameter

- Index resolution : 0.3 mm
- Scan resolution : 0.3 mm



Immersion Ultrasonic Testing System



Through Transmission setup with sample placement

Figure 6: Sample placement

### Through Transmission Method

- Through transmission testing is used to evaluate defect information in the sample.
- Two separate probes are used for transmitting and receiving the ultrasonic energy. The probes are placed opposite side of the sample at equal distance.
- The signal from the good region is taken as a reference and gain is adjusted such way that the signal will not get saturated.
- At the damaged regions, the sound waves get scattered and sound energy reaching the receiver transducer will be less compared with good region.
- This technique shows abnormality in a material.

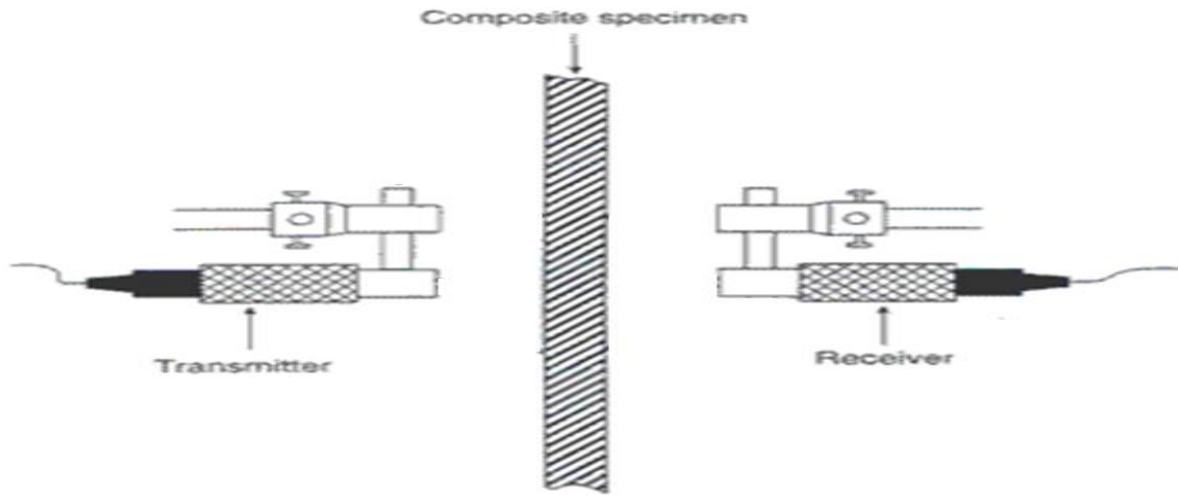
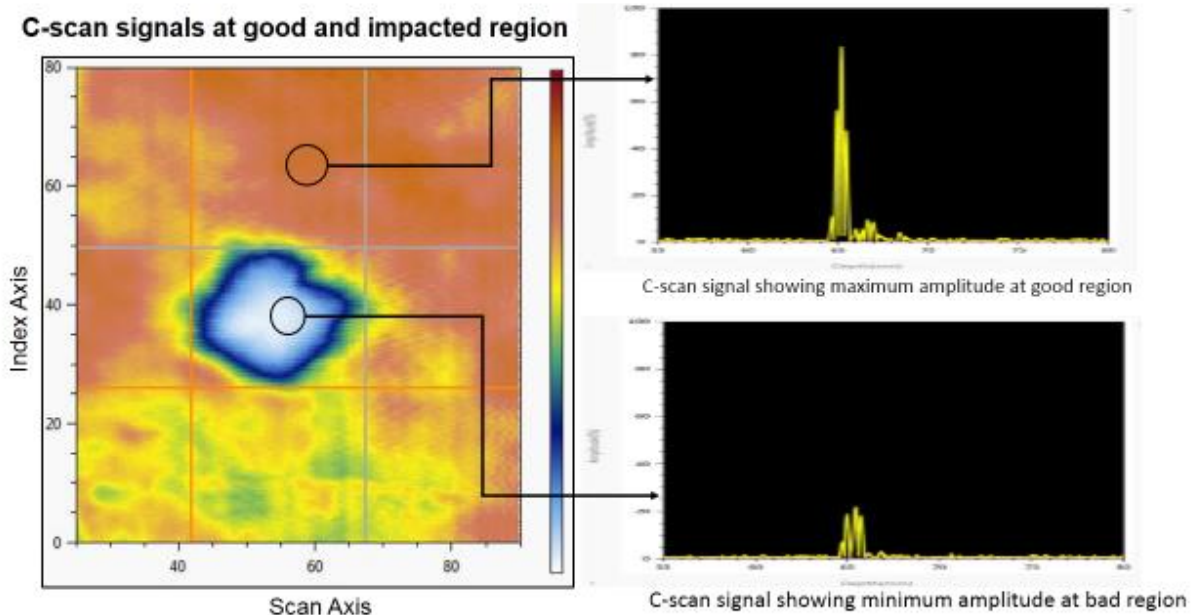


Figure 7: Schematic of the Immersion UT system for through transmission method

#### IV. CALCULATIONS

In this study testing of composite on drop-weight impact testing were performed on GFRP type E-glass/Epoxy 400 g/m<sup>2</sup> with specimens thicknesses 4mm according to number of plies fabricated, and by varying the impact energy from the result obtained, the impact force, the energy absorbed, with increase of impact energy displacement increase the damage area it can be concluded that GFRP type E-glass/Epoxy 400 g/m<sup>2</sup> with specimens thicknesses 4mm specimen with low force had a less damage compare to specimen with applied more force specimen more impact resistant, the highest impact strength obtained for the fiber glass with respect to the height and impact energy from 5(J) to 25(J) in five specimen.



The results could be analysed through C-scan UT presentation as receive pulse amplitude displacement along one axis (y-axis) and the travel time of the ultrasonic pulse is represented as a displacement along the other axis (x-axis). It was possible to obtain indication of an echo from the defects in laminate specimens, detected by the peak rise in signal amplitude analyses are ultrasonic C-scan from fiber glass /E-glass which show high percentage depth of internal delamination. Through transmission testing is used to evaluate defect information in the sample. Two separate probes are used for transmitting and receiving the ultrasonic energy. The probes are placed opposite side of the sample at equal distance. The signal from the good region is taken as a reference and gain is adjusted such way

that the signal will not get saturated. At the damaged regions, the sound waves get scattered and sound energy reaching the receiver transducer will be less compared with good region. This technique shows abnormality in a material.

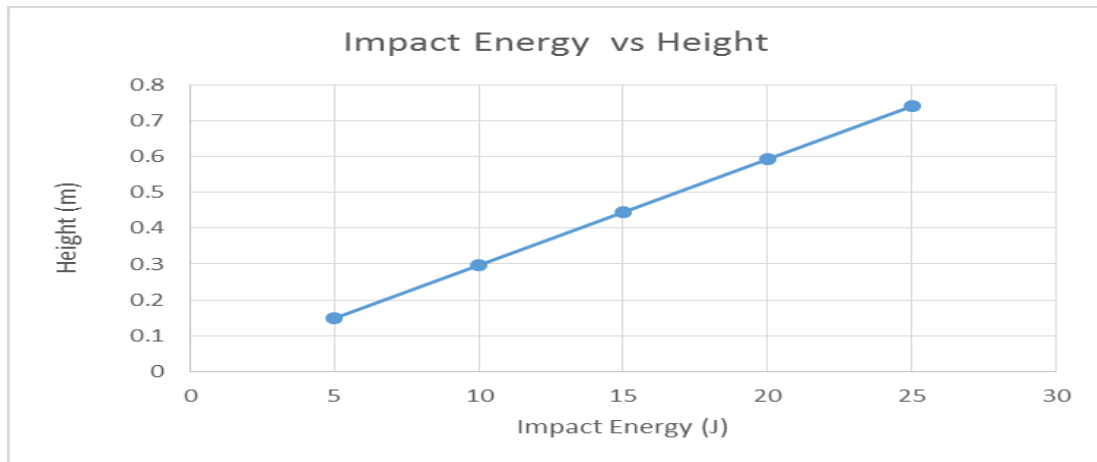


Figure 8: Specimen's E v/s H

The specimens E-glass are impacted at five different load. Since the study is on testing of composite on drop-weight impact testing and damage identification of composite using Non-destructive Testing Techniques UT - C Scan. The damage mechanisms observed for specimens due to impact loading strongly influenced by, impactor energy, the deformation in specimens increase the energy increases. The overall delamination area increased by the increasing impact load, as the impact energy also increases.

As the load increases the damage also increases. Susceptibility to damage from concentrated out-of-plane impact force is one of the major design concerns of structures made of advanced composite laminates. Knowledge of damage resistance properties of a laminated composite plate is use full for product development and material selection. To establish quantitatively the effects of stacking sequence, fiber surface treatment, variation in fiber volume fraction and processing and environmental variables on the Damage resistance of a particular composite laminate to concentrated drop-weight impact force and energy. The properties obtained using this test method can provide guidance in required to anticipated damage resistance structure of material, thickness, Stacking sequence. However it must be understood that damage resistance of a composite structure is highly dependent upon several factor including geometry thickness, stiffness, mass, support condition.

#### 4.1 Through Transmission results

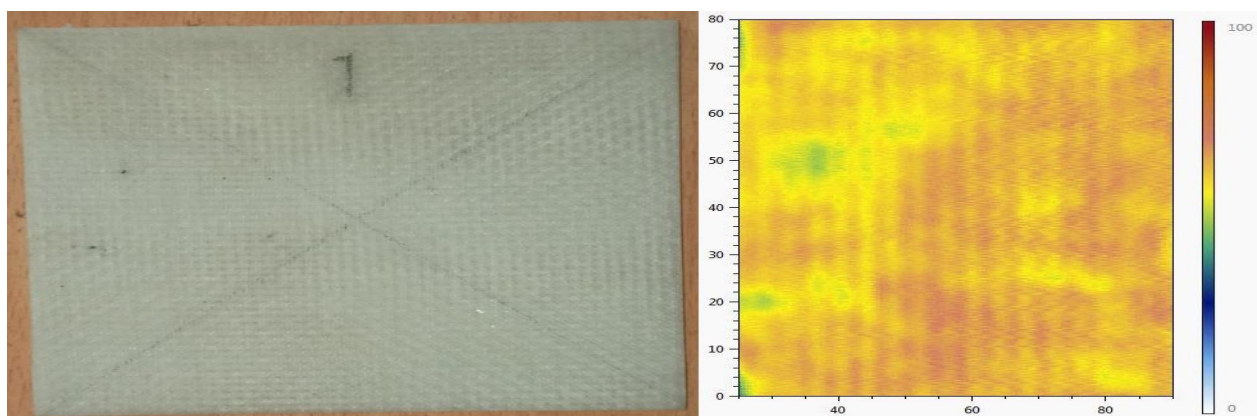


Figure 9: sample 1

- Transducer frequency : 2.25 MHz
- Transducer focal distance in water : 2 inch
- Pulser voltage : 200 V;
- Gain :18 dB;

- Index resolution : 0.3 mm
- Scan resolution : 0.3 mm

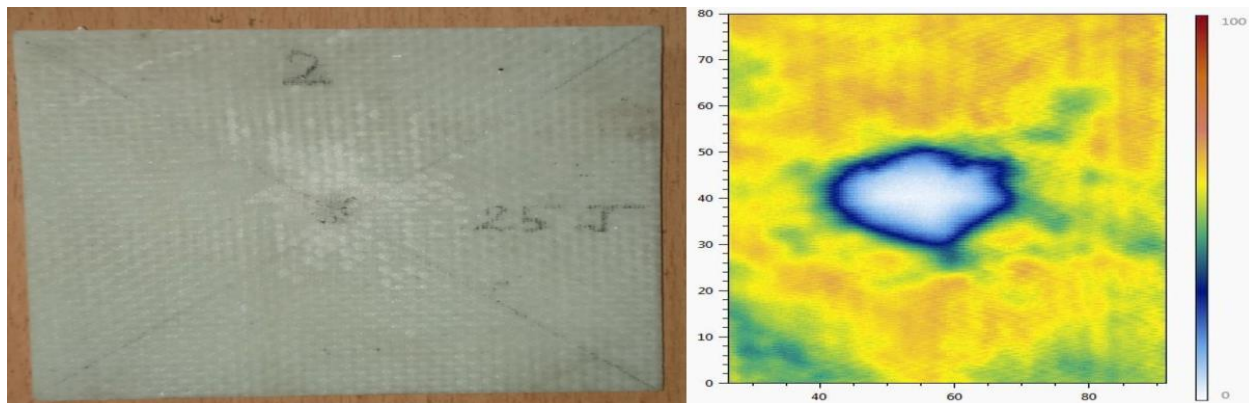


Figure 10: sample 2

**Damage dimensions:**

- In scan axis: 26.53 mm;
- In Index axis : 21.06mm;

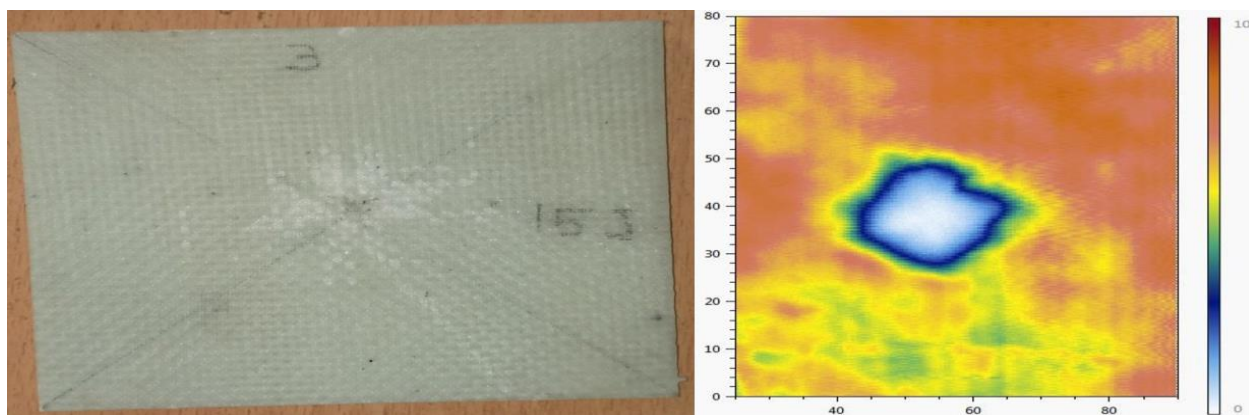


Figure11: Sample 3

**Damage dimensions:**

- In scan axis: 21.3 mm;
- In Index axis :21.1 mm

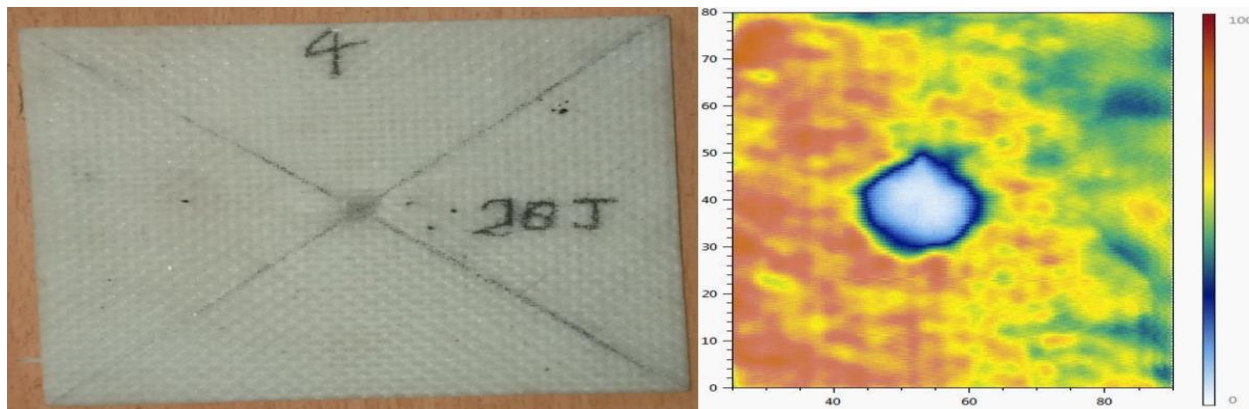


Figure 12: Sample 4

**Damage dimensions:**

- In scan axis: 18 mm;
- In Index axis : 20.3 mm;

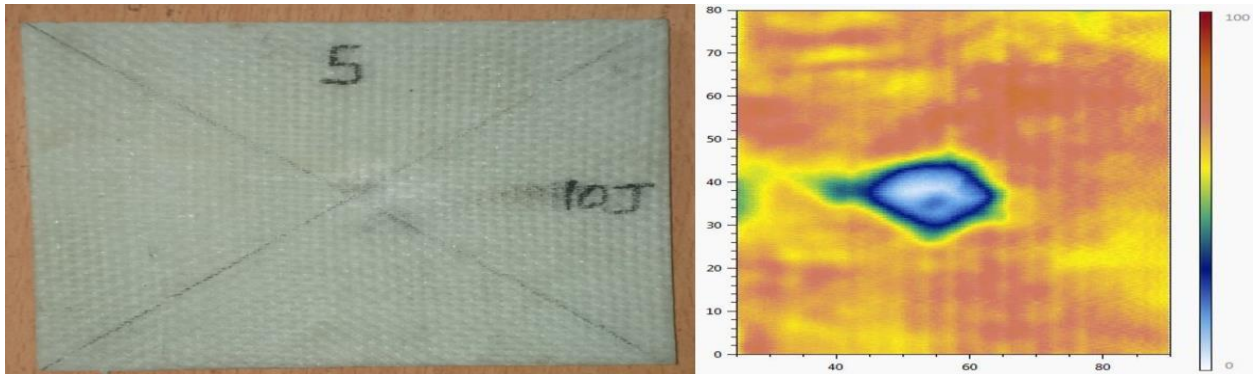


Figure13: Sample 5

**Damage dimensions:**

- In scan axis: 18.6 mm;
- In Index axis : 15.5 mm;

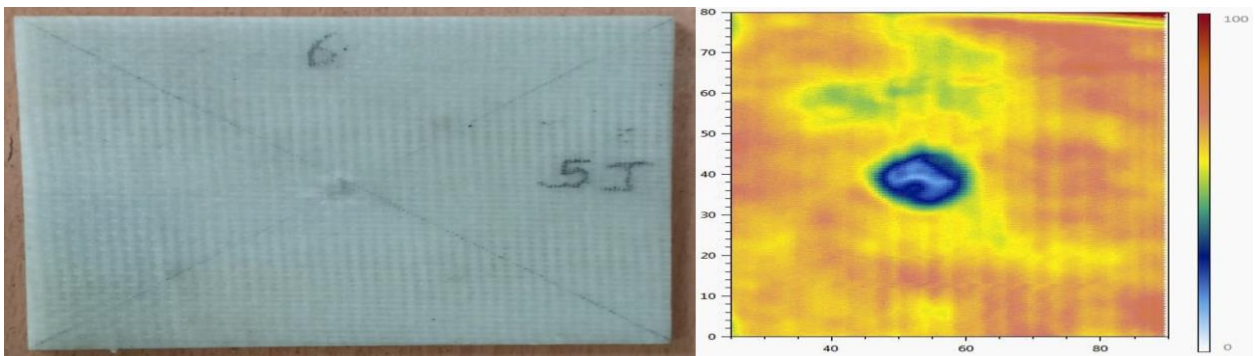


Figure 14: Sample 6

**Damage dimensions:**

- In scan axis: 12 mm;
- In Index axis : 12.1 mm;

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