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Experimental Analysis of Flexural Properties of E-Glass/Epoxy Laminate Composite with Artificial Delamination

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Abstract:
A composite materials of Fiber reinforced plastic used in a variety of industrial applications, including aircraft structures, automobile structural parts, and micro-electromechanical systems. The goal of this study was to look at how interlayer delamination affects the mechanical properties of composite materials. Artificial delaminations were used to evaluate the effect of their size on laminate stiffness and strength. The hand lay-up approach was used to create a bi-woven E-glass/epoxy composite with an artificial polytetrafluoroethylene (PTFE) film defect in the centre between the first and second plies and the fifth and sixth plies. PTFE film was round in shape, with diameters of 6 mm, 8 mm, and 10 mm, and square in shape, with side lengths of 6 mm, 8 mm, and 10 mm. Twelve layers of glass fabric composed the composite specimen. The flexural performance of Glass/Epoxy laminates samples with and without artificial defects of distinct geometric shapes (circle and square) and three distinct sizes inserted at different positions has been effectively determined under three-point bending mode. It was established that the presence of the imperfection manifested in a lowering in the flexural modulus. The square fault with either a 10 mm side had the least modulus, and as the defect was transferred to the middle layers, the modulus dropped.

Keywords: *Delamination, polytetrafluoroethylene (PTFE), Glass/Epoxy, Plies, Hand Lay-up*

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I. Introduction

A composite material is a material system made up of two or more distinctly different materials that are insoluble in each other and differ in form or chemical composition. Be a result, any substance with two or more phases is referred to as a composite material. The properties of the constituent materials as well as the properties of the interface determine the properties of the resulting structure. Fiber reinforced plastic composite materials have gradually can be used in a wide range of industrial applications, notably aeronautical and aerospace structures, navy ship hulls, automobile structural elements, micro-electromechanical systems, and civil structures for strengthening concrete members. Some of the factors that have contributed to the advancement and increased use of laminated composites encompass increased strength and stiffness for a given weight, increased toughness, increased mechanical damping, increased chemical and corrosion resistance in comparison to conventional metallic materials, and the potential for structural tailoring. Apart from these variables, the increased use is attributed to the expanding market for constituents for use in reinforced composites. The classification of composite materials based on the reinforcement material is shown in fig.1

1.1 Glass fiber

In FRPs, this is the most often used fibre. Minimal cost, great tensile strength, low chemical resistance, and excellent insulating characteristics are some of its benefits. Low tensile modulus, high specific gravity, high degree of hardness, and tensile strength loss owing to abrasion during handling are some of its drawbacks. They can't handle heavy loads for lengthy periods of time, either.

1.2 Carbon Fiber

They have a unique combination of great strength, stiffness, and light weight. High tensile strength-to-weight ratio, high tensile modulus-to-weight ratio, very low coefficient of thermal expansion, and high fatigue strength are all advantages of these fibres. Their low impact resistance and high electrical conductivity are disadvantages.

1.3 Epoxy Resin

Epoxy resins are primarily employed in high-performance aerospace structures. Epoxy resins are widely used in industry because of (1) their ease of processing, (2) their excellent mechanical properties in composites, and (3) their high hot and wet strength properties. Because of their superior mechanical qualities and resistance to degradation by water and other solvents, epoxies outperform polyester resins.

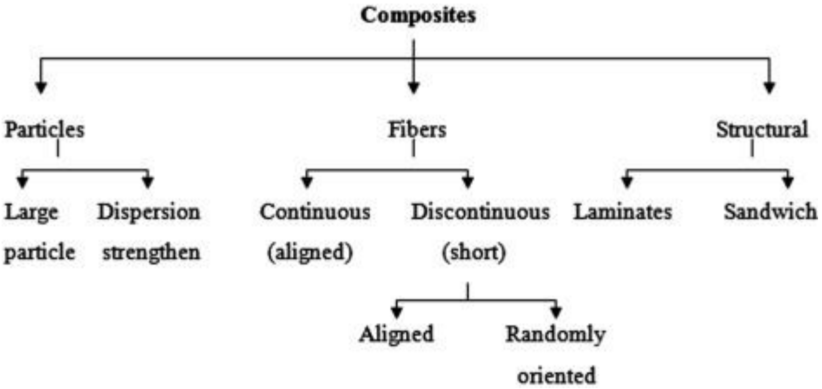

Fig.1: Classification of composite material is based on the reinforcement (Image Courtesy: [8])

1.4 Delamination

Delamination between plies is one of the most common failure types in composite structures. A fissure that occurs between neighbouring plies is known as delamination. The fiber orientations of the plies on either side of the delamination can be varied. As a result, a delamination can be thought of as a crack at the interface of two anisotropic materials. Material and structural discontinuities that cause interlaminar stresses are the most typical causes of delamination. The classification of the main delamination onset causes are shown in fig.2

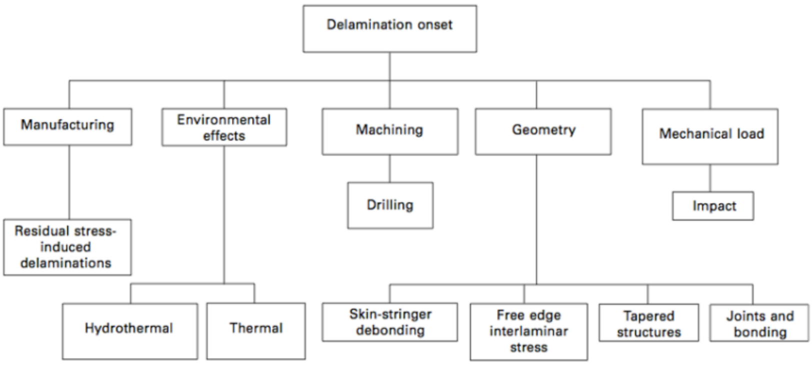

Fig.2: Classification of the main delamination onset causes (Image Courtesy: [10])

1.5 Effect of delamination:

Strong interlaminar stresses resulting from a variety of causes cause delamination, which can impact the laminate's strength and stiffness, and hence it’s structural performance. In general, delamination has little effect on a laminate's tensile behavior, but it can have a substantial impact on compressive behavior. Effect of delamination due to low velocity impact on thick and thin ply are shown in fig.3

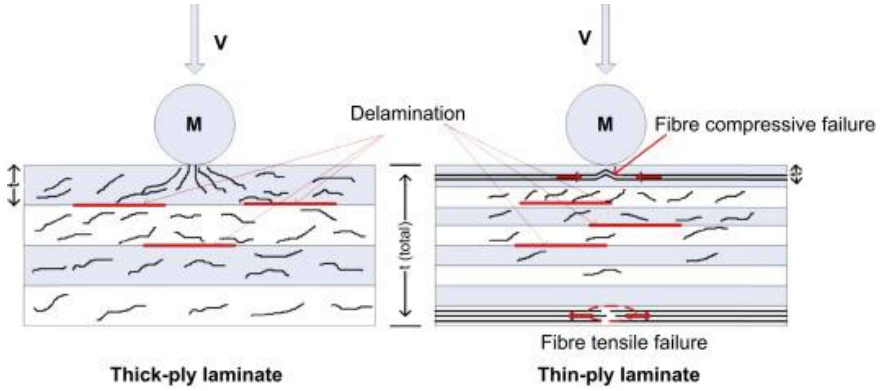

Fig.3: Delamination due to low velocity impact on thick and thin ply

1.6 Objective of the present work:

The hand lay-up method will be used to create a bi-woven E-glass/epoxy composite with an artificial flaw of polytetrafluoroethylene (PTFE) film situated in the centre position between the first and second plies and the fifth and sixth plies. PTFE film is round in shape, with diameters of 6 mm, 8 mm, and 10 mm, and square in shape, with side lengths of 6 mm, 8 mm, and 10 mm. Twelve layers of glass fabric will make up the composite specimen. To determine the behavior of laminate, experiments will be conducted in flexure with a three-point bending test. The results will be compared against laminates that do not have an artificial flaw.

II. Literature Review

Dipen Kumar Rajak et.al [3], Composite materials, which were first emerged in the 20th century, are currently one of the most frequently researched areas in modern technology. Their promising qualities make them perfect for a broad range of applications, including aviation, auto, architecture, sports, medical, and many others. These materials possess exceptional structural and mechanical properties, such as a high strength-to-weight ratio, chemical, fire, corrosion, and wear resistance, while being expense to manufacture.

Naheed Saba et.al [8], Epoxy resins have been widely employed in modern industries for several decades, ranging from adhesives to microelectronic materials to matrices for sophisticated fiber reinforced composites. Epoxy has a number of advantages, but it also has some drawbacks that limit its advanced and high-performance uses. This review will also discuss new developments in epoxy-based polymer hybrid nano composites and their applications.

Luis F. Sánchez-Heres et.al [5], This paper comprises a number of exceedingly study at cutting the cost of purchasing marine composite structures and optimizing their benefits by creating better the use composite materials (in other words, weight reduction of the composite structure). Material safety factors, material characterization, and numerical optimization of massive composite structures are being studied as potential areas for doing so.

Moniruddoza Ashir et al. [7], The research effort described in this article looked at whether the loss of mechanical qualities like tensile, flexural, and impact strengths is affected by the position of defined local flaws in the thickness direction of FRPs, such as polytetrafluorethylene (PTFE) in this case. Before infusion, PTFE was inserted in several layers of unidirectional non-crimp fabric (UD-NCF) reinforcing fabric to achieve this goal. PTFE. The tensile, flexural, and impact strengths of both types of CFRPs were reduced exponentially by increasing the distance of PTFE from the top surface.

Aslan Zuleyha et al. [2], The goal of this study is to investigate the effect of multiple delaminations on the compressive, tensile and flexural strength of E-glass/epoxy composites and to evaluate their effects on the first critical buckling and re-buckling loads. Artificial delaminations of different sizes were inserted into four interlayer's-oriented E-glass/epoxy composite using a hand lay-up method and a hot press. The effects of through-the-width strip, circular and peanut shaped delaminations and triangle and inverted triangle patterned delaminations through the thickness direction were investigated experimentally. According to the results, the presence of multiple large delaminations influences the compressive and flexural strength and critical buckling load significantly. However, tensile strength is less affected by multiple delamination.

Riming Tan et al. [9], In this paper the relationship between matrix cracking and delamination was studied using cross-ply laminates. Several methods, including micrograph, C-scan, and visual inspection, were adopted to characterize the damage after Low Velocity Impact experiments. From the experiments it was revealed that the matrix crack in the bottom ply not only promoted the outward propagation of delamination but also contributed to the narrow delamination beneath the impact location. Multiple matrix cracks occurred in the middle ply. The ones close to the plate center initiated the delamination and prevented large-scale delamination beneath the impact location. For the cracks that were far away, no significant effect on delamination was found. In their study, the C-scan and micrograph of the internal damage revealed that delamination only existed at the lower interface. The typical delamination detected by C-scan from the lower surface was in a “peanut shape”. The main delaminated region (MDR) consisted of two lobes. A narrow-delaminated region (NDR) beneath the impact location connected these two lobes. Each lobe was sharp at the tip and shrank near the impact location.

A.Wagih et al. [1], The residual flexural strength of a pre-impacted Carbon-Aramid hybrid composites is analyzed using three-point bending. A hybrid composite with Carbon-Aramid carbon/epoxy fibers is designed to have the Aramid layers in between the two carbon/epoxy sheets The impact results show that, within the range of impact energies examined, the carbon fiber plies at the lower surface of the laminate do not show any damage and the damage is localized only under the impactor. It was important to notice that after the impact test and three-point bending test, the carbon fibers in the lower plies of the laminate remain undamaged. This undamaged region at the lower part of the laminate increases the capability of the laminate to sustain loads. As a result, the residual strength is high when compared to non-hybrid CFRP, GFRP and CFRP with aluminium core laminates.

I. Papa et al. [4], Composite laminates with different stacking sequences of woven carbon and glass fiber layers in hybrid configurations were manufactured by vacuum resin infusion. The specimens were tested at bending and low-velocity impact at different energies. The bending tests showed that the stacking sequence does not affect the flexural modulus, but it mainly affects the flexural strength and the failure mode. The maximum value of the flexural strength was reached when the glass layers were placed on the compression side and in this case the failure mode occurred for shear inside the glass layers. Instead, the worst flexural behaviour was shown when the carbon layers were placed on the compression side. Regarding the impact behaviour, it was pointed out that hybrid laminates showed competitive results in terms of maximum load and absorbed energy.

M.S El-Wazery et al. [6], In this research work, an E-glass fiber with random oriented reinforced polymer composite was developed by hand lay-up technique with varying fiber percentages (15%, 30%, 45%, and 60% by weight percentage). The influence of glass fiber percentage on the mechanical properties such as tensile strength, bending strength and impact strength was investigated. The results showed remarkable improvement in the mechanical properties of the fabricated composite with an increasing in the glass fiber contents. The best mechanical properties were obtained at 60 wt.% of glass fiber of fabricated composites.

III. Methodology, Fabrication And Testing Of Laminate

Plain weave of 7 Mil E-glass cloth shown in fig.4. In this current work it was employed because of its good strength-to-weight ratio. Mechanical properties of E-Glass fiber/ Epoxy resin is as shown in Table 1. The fibre is inexpensive and comes in a number of shapes. The tensile modulus and flexural modulus of this fabric are bidirectional because it is woven in two mutually perpendicular directions. Furthermore, this fabric can be used for hand lay-up moulding.

Table 1: Mechanical Properties of E-Glass fiber / Epoxy

Material	Density (Kg/m^3)	Tensile Strength GPa)	Youngs Modulus (GPa)
E-Glass fiber	2550	1750e3	70
Epoxy Resin	1300	125e3	4.0

Fig.4: 7-Mil E-Glass fabric

3.1 Laminate Preparation

The laminates were prepared using a compression matched die mould hand layup process. The following is the procedure for making Glass/Epoxy laminates. Demarcations and cutting of fiber cloth is shown in fig.5

- Marking and cutting
- Cleaning and applying wax to mould
- Weighing of GRPF material
- Mixing of epoxy resin and hardener
- Stacking of layers
- Compression of laminate
- Machining process and finishing

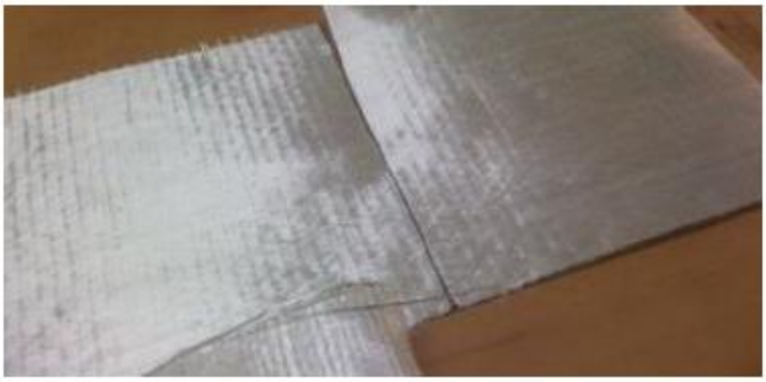

Fig.5: Demarcations and cutting of fiber cloth

3.2 Stacking of Laminates

Each layer of glass fibre was gently placed on the mould and the resin-hardener mixture was poured on top of each layer of fibre as shown in fig.6. A roller was utilized to ensure appropriate resin soaking of the fibers as well as the removal of any air bubbles, ensuring optimal adhesion with neighboring layers. The laminate was made up of 12 plies totaling 2.1mm in thickness. During hand layup, the PTFE film was inserted in the centre of the specimen on the contact plane of two sites to act as an artificial defect for producing delamination as indicated in figure 7. The PTFE film was put between the first and second (red in colour in figure 7) and fifth and sixth (yellow in colour in figure 7) layers of the specimen in two locations. Polytetrafluoroethylene (PTFE) films come in a variety of configurations, including circular with diameters of 6 mm, 8 mm, and 10 mm, and square with sides of 6 mm, 8 mm, and 10 mm. The PTFE film has an 80 micron thickness. The different types of specimens after machining are shown in fig.8

Fig.6: Stacking of layers

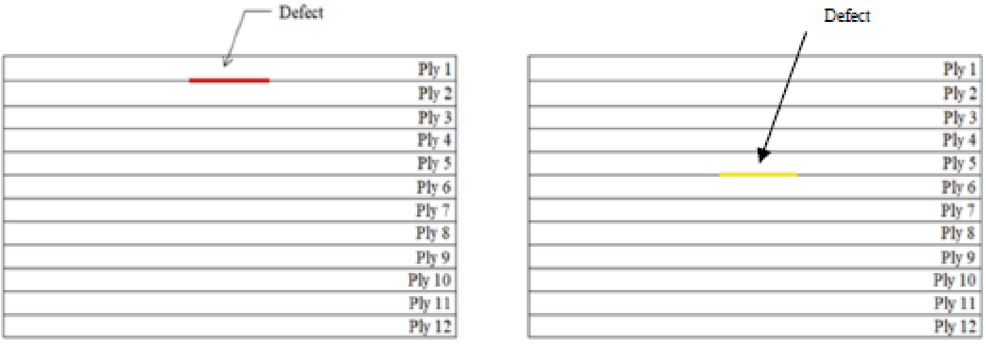

Fig.7: Location of defects between different layers

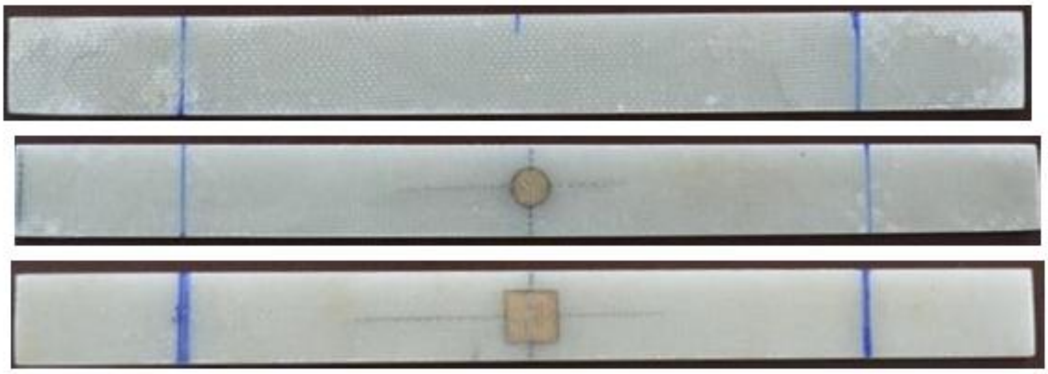

Fig.8: Different types of specimens after machining

3.3 Testing of specimen / procedure

The testing procedure is as follows

- The length, width and thickness of test piece were measured by micrometer.
- The bending fixture (shown in fig.9)was placed on the lower cross head of testing machine
- The test piece was placed on the rollers of the bending fixture
- The machine was started and the readings were recorded by the computer
- The specimen after testing shown in fig.10 and deflected until the outer surface ruptures.

Fig.9: Three point bending fixture

Fig.10: Specimen after testing

IV. Results And Discussion

Graphs of load-deflection curves were generated by the testing machine software. The magnitudes of maximum flexural load and deflection were obtained from this test. With the help of these values and dimensions, maximum stress and maximum strain in the outermost layer of each specimen is calculated and recorded. The slopes of the load- deflection curves were obtained from the linear region of graphs as shown in fig. 11 to 14 for each specimen. Finally, the flexural moduli were calculated and are compared in fig.15 for the different shapes, sizes and positions of delamination.

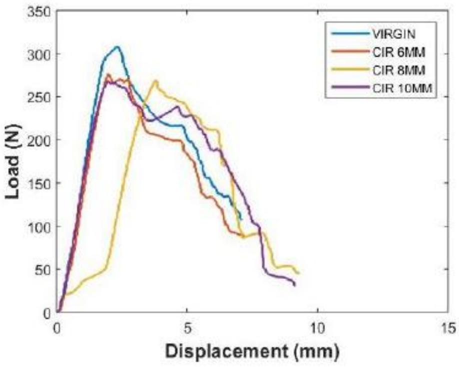

Fig.11: Load Displacement curve of circular defect at 1-2 layers

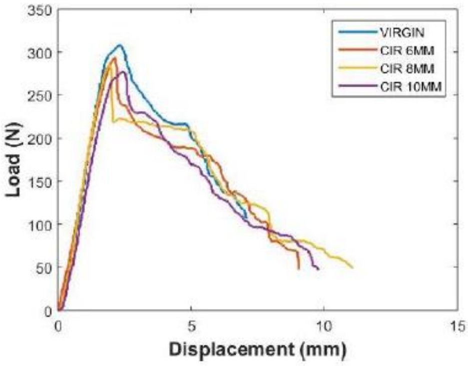

Fig.12: Load Displacement curve of circular defect 5-6 layer

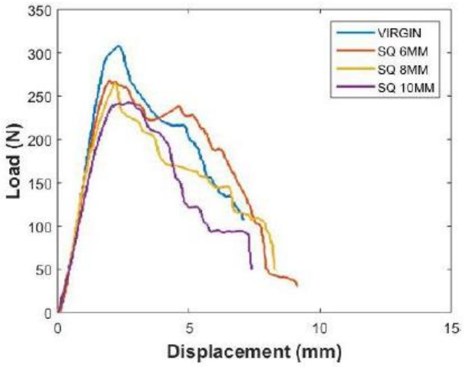

Fig.13: Load Displacement curve of square defects at 1-2 layer

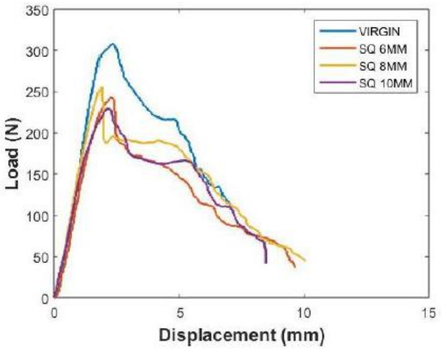

Fig.14: Load Displacement curve of square defects at 5-6 layer

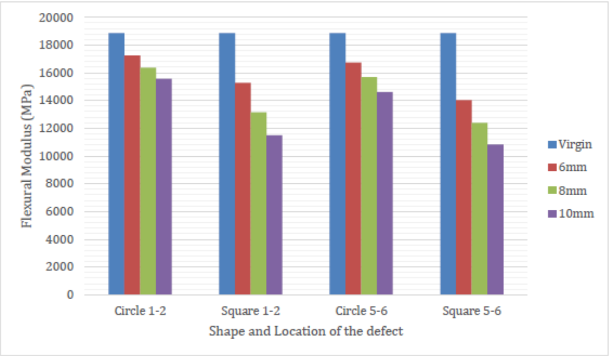

Fig.15: Variation in flexural modulus with change in position and shape of the defect

V. Conclusions

The flexural behavior under three-point bending mode for the Glass/Epoxy laminates samples with and without artificial defects of different geometric shapes (circle and square) and with three different sizes (6mm,8mm,10mm) placed at different locations was effectively determined and the following conclusions were drawn:

- The flexural properties of the laminate give a critical response to the presence of the defect, area of the defect and its position in the laminate.
- A linear behavior to a peak followed by a nonlinear trend in the load deflection graph was observed for the samples with and without defect.
- A maximum drop by **42.5%** in the flexural modulus was observed in the specimen with square defect of side 10 mm at 5-6 layer When compared to the virgin specimen.
- A decrease in modulus from **5–8%** is observed when the position of the defect is shifted from the layers 1-2 to 5-6.
- Shape and the position of delamination is critical when the member is subjected to flexural loading and their presence should be considered in the design stage.

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