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Experimetnal Investigation on Delamination of Nanocomposite Laminates

G.Narendar, E. Arjun
Associate Professor University College of Engineering Osmania University, Hyderabad
PG Scholar University College of Engineering Osmania University, Hyderabad
Corresponding auther: G.Narendar

ABSTRACT
The principal mode of failure of layered composites is the separation along the interfaces of the layers, viz. delamination. This type of failure is induced by interlaminar tension and shear that developed due to variety of factors such as: Free edge effects, structural discontinuities, localized disturbances during manufacture and in working condition, such as impact of falling objects, drilling during lab applications, moisture and temperature variations and internal failure mechanisms such as matrix cracking, etc.
Engineering layered composites involves complex definitions that include numerous layers, materials, thicknesses and orientations. The engineering challenge is to predict how well the finished product will perform under real-world working conditions. Simulation is ideal for this when considering stresses and deformations as well as a range of failure criteria.
Experimental investigation is carried out on the composite laminates for delamination analysis

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I. INTRODUCTION

A material having two or more distinct constituent material or phase may be considered a composite material. Most composites consist of fibers of one material tightly bound with another material called a matrix. The matrix binds the fibers together, and makes them more resistant towards the external damage, whereas the fiber makes the matrix stronger and stiffer and helps it resist cracks and fracture.

1.1 Mechanical Behavior of Composite Materials

Composite materials are both inhomogeneous and orthotropic. The orthotropic materials are those where the material properties are different in three mutually perpendicular directions at a point in body, and have three mutually perpendicular planes of symmetry. Thus, the properties are functions of orientation at a point in the body.

1.2 Defects of composites

Defects can inadvertently be produced in composite materials, either during the manufacturing process or during the normal service life of the component. The manufacturing process has the potential for causing a wide range of defects, the most common of which is “porosity,” the presence of small voids in the matrix. Porosity can be caused by incorrect, or non-optimal, cure parameters such as duration, temperature, pressure, or vacuum bleeding of resin. Porosity levels can be critical, as they will affect mechanical performance parameters, such as inter-laminar shear stress.

Elisa Borowski et al. [1] observed improvements in the interlaminar fracture toughness with Micro structural investigations using Fourier transform infrared (FTIR) spectroscopy and X-ray photoelectron spectroscopy (XPS) verify that chemical reactions took place between the COOH–MWCNTs and the epoxy resin. Experimental investigations and numerical modeling were performed to determine the effects of using MWCNTs in CFRP laminates. The experimental results show a 25%, 20%, and 17% increase in the maximum interlaminar fracture toughness of the CFRP composites with the addition of 0.5, 1.0, and 1.5 wt. % MWCNTs, respectively.

Djebbara Benzerga et al. [2] developed a delamination model that can predict delamination growth in the new woven hybrid composite used in tibiae prosthesis. Delamination initiation and propagation are numerically predicted of a new laminated composite reinforced with natural organic load. This new composite is obtained from a laminated composite woven by incorporating a natural non-polluting organic load (granulates of date cores) which becomes hybrid composite.

Shivani Pande et al. [3] investigated various types of application of loads on the plate. The pre-peg model was developed on Ansys to check the effect of Delamination region due to uni-Axial load with different number of plies, and to check the resistance to Delamination. The problem of crack opening due to load parallel to the crack face can be overcome by changing the fiber orientation.

Antonio T. Marques et al. [4] compared four different drills in terms of thrust force during drilling and delamination caused by this machining operation. In order to evaluate delamination damage, enhanced radiography is applied.

R. A. Smith [5] carriedout a comprehensive analysis on various types of composite defects and there detection. The most significant defects in monolithic structures are porosity, caused by incorrect manufacture, and impact damage during in-service use. Low-frequency vibration methods are utilized for in-service inspection of sandwich structures with honeycomb cores where ultrasound is not sensitive to all the types of defect.

Wei Ding [6] conducted a combined theoretical and experimental study delamination of fiber reinforced polymeric composites. A fracture criterion, based on the size of the crack tip plastic zone, was incorporated into these beam models so that the mode 1 and mode II critical strain energy release rates of composites can be predicted using the corresponding resin and fiber properties as well as composite structural parameters.

Literature study has been carried out on composite laminate defects, it is found that there are some research gaps in the delamination property of composite materials. Limited Literature is available on the research of nanocomposite with carbon composite materials and also delamination effect of hybrid composites.

II. METHODOLOGY

Experimental work is carried out on the composite laminates in the laboratory, preparation of the specimen according to ASTM D3171-06 for the delamination test has be carried out on Universal testing machine with the help of additional fixtures and development of 3D delamination model for simulation analysis; the dimension of the test specimen is shown in figure. The results obtained from both the process are tabulated and compared to understand the force required for the laminate to deform.

2.1 Materials used in the preparation of laminates are

1. Epoxy Resin 566
2. Epoxy Hardener HY951
3. Carbon Fiber (Plain Weave)
4. Kevlar Fiber (Plain Weave)
5. Carbon-Kevlar Hybrid Fiber (2x2 Dual Twill)
6. Alumina Nanopowder APS: 20-30nm

2.2 Preparation of Composites

The moulds are first cleaned with the acetone and then wax is applied so that after the laminate is cured it can be removed easily from the mould. The fiber weave of required dimension are cut from the sheet which would fill the moulds. Epoxy Hardener is added to the Epoxy Resin in the ratio of 1:10 by weight. First epoxy resin is poured into the mould and then fiber weave is placed, again resin is poured, next layer of fiber is placed over it, on the top the resin in poured. Separation film (Teflon film) is placed between the layers to width of 6cm from the leading edge. On the top of the mould a separation film is placed and closed. Pressure is applied on the mould with help of weights that squeeze out excess epoxy from the mould. For the nanocomposite laminate the nano powder of 1% of the total weight of resin is added to epoxy resin and then heated with the help of water bath and mixed with mechanical strirrer and Probe Sonicator. After curing for one day, the moulds are placed in a closed box with a heat source for 12 hours so that final hot curing is done. Finally the composite laminates are removed from the moulds and required specimens are cut from the laminates and used for tests.

Delamination samples made from epoxy resin, in the early stage, a laminate is prepared with epoxy resin and hardener mixture to analyze with specimen dimension and overall process.

The plain epoxy sample was too brittle which lead to the crack at the separation zone and it helped us in analyzing the use of composite fibers in the laminates so that they would stretch with epoxy.

Figure 1: Composite fibers placed in moulds

Figure 2: Mechanical Stirrer, Probe Sonicator used to mix Nano particles with the epoxy resin.

Sonication is the act of applying sound energy to agitate particles in a sample, for various purposes. Ultrasonic frequencies (>20 kHz) are usually used, leading to the process also being known as ultrasonication or ultra-sonication.

1% Alumina Nano powder has been added to Epoxy mixture and mixed for one of the laminate with the help of stirrer and probe sonicator.

The laminates are cured with the help a 200w bulb and a closed box for a period of 12 hours, once cooled they are removed from the moulds and cut for the dimensions needed.

2.3 Delamination Testing Procedure

The delamination test is conducted on the specimens with the help of Universal Testing Machine and fixtures. Load has been applied gradually at a speed of 10mm/min. A hole has been drilled at one side of the laminate so that Galvanised Iron wire can be used in delaminating of the composite. The results obtained from the Universal Testing Machine directly transfers to the computer for precise values.

Figure 3: Specimens after delamination (Straight View and Side View)

III. RESULTS

It is found that there is a linear increase of deformation with applied force. The deformation values are found to be highest for carbon laminates, and are lowest for Carbon-kevlar hybrid laminates. It is found that among carbon and nano-carbon composite laminates, nano-carbon composite is found to have more strength. Among all the four composite laminates, carbon-kevlar hybrid laminate is found to have more strength, interlaminar bonding. This might be attributed to have combined properties of kevlar and carbon.
Average values of the results are presented below. ‘Extension is total linear separation in Y direction i.e., perpendicular to the surface of the laminate’, ‘Elongation’ is separation of laminate layers in X direction along the length of the specimen’.

The property values are found to be highest for Carbon-Kevlar Hybrid laminates, and are lowest for Carbon laminates. It is found that among carbon and nano-carbon composite laminates, nano-carbon composite is found to have more strength. Among all the four composite laminates, carbon-kevlar hybrid laminate is found to have more strength, interlaminar bonding. This might be attributed to have combined properties of kevlar and carbon. Extension value for kevlar was only done for the average of 3 specimens due to lack of results.

IV. CONCLUSIONS

Different types of composite laminates (Carbon, Kevlar, Carbon-Kevlar Hybrid, nano-carbon) are prepared and delamination analysis is carried out. From the numerical and experimental investigation, the following conclusions are drawn:

1. The composite test specimens of Carbon Woven fiber, Kevlar Woven Fiber, Carbon-Kevlar Hybrid Fiber, and Nano-Carbon composites are prepared.
2. From the delamination test the results are found to be highest for Carbon-Kevlar Hybrid laminates (Yield force-58.16 N, Yield elongation-68.90 mm, Tensile strength at yield-0.73 N/mm^2, Extension-19.63 mm, Elongation-71.14 mm) and are lowest for Carbon laminates (Yield force-17.42 N, Yield elongation-28.18 mm, Tensile strength at yield-0.22 N/mm^2, Extension-17.805 mm, Elongation-31.24 mm)
3. Epoxy Carbon with Nano powder Laminate (Yield force-27.362 N, Yield elongation-48.66 mm, Tensile strength at yield-0.34 N/mm^2, Extension-19.456mm, Elongation-58.82 mm) got better results when compared to Epoxy Carbon Laminate (Yield force-17.42 N, Yield elongation-28.18 mm, Tensile strength at yield-0.22 N/mm^2, Extension-17.805 mm, Elongation-31.24 mm). This might be attributed to the combined effects of Nanopowder and Carbon fibers.
4. Among all the four composite laminates, Carbon-Kevlar Hybrid laminate is found to have more strength. This might be attributed to the combined contribution of Kevlar and Carbon fibers.

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Table 1: Test results of various composites

Sr. No.	Property	Carbon composite	Carbon with nano particles composite	Kevlar composite	Carbon-Kevlar Hybrid composite
1	Cross-Sectional Area, mm²	80.00	80.00	80.00	80.00
2	Yield force, N	17.42	27.362	38.338	58.16
3	Yield elongation, mm	28.18	48.66	45.73	68.90
4	Break force, N	17.5	28.08	38.36	59.8
5	Break elongation, mm	31.24	58.82	56.24	71.14
6	Tensile strength at yield, N/mm²	0.22	0.34	0.478	0.73
7	Tensile strength at break, N/mm²	0.22	0.352	0.478	0.746
8	Extension, mm	17.805	19.456	25.13	19.63
9	Max force, N	18.64	29.004	40.05	61.09
10	Maximum elongation, mm	31.24	58.82	56.24	71.14

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