Indian J.Sci.Res. 17(2): 278-282, 2017 ISSN: 0976-2876 (Print)
ISSN: 2250-0138(Online)

FABRICATION AND DAMAGE ANALYSIS OF CFRP USING FOUR POINT BENDING TEST

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Abstract- Composite materials usage has been increased in design of aeronautics and astronautics applications which requires lightweight and robust structures. Thickness dimensions of these structures are less as compared with the in plane dimensions which offers low strength under bending. In the current study curved beam specimens are fabricated as per the ASTM D6415 standard to evaluate the interlaminar tensile strength. The curved beam consists of two straight legs connected with a 90 degrees bend with inner radius of 6.4 mm. The V-shaped mould is fabricated by bending a SS (stainless steel) plate to 90 degrees. The V-shaped CFRP composite specimens of required dimensions were fabricated using V-shaped SS mould. Knurled rollers were used as testing fixtures. To evaluate bending strength of the specimens, 4-point bending test is used. Optical Images of the cross-section of the specimen were used to check quality of the specimen. DIC (Digital Image Correlation) technique was used to evaluate the deformations during the testing. Acoustic Emission (AE) testing was performed simultaneously to quantitatively observe the damage occurred in the specimen. It is observed that manufacturing defects like wrinkles, effect the strength of the specimens and hence causing failure. Moreover, to study the effect of these manufacturing defects, curved beam specimens are fabricated by including wrinkles at the bend (curved) part with controlled size and location and tested

Keywords—Composite, CFRP, four point bending test, damage analysis, carbon fibre

I. Introduction

The use of composite materials in aerospace applications have increased due to a number of factors, including lightweight, fuel efficiency, and improvements in manufacturing techniques. In the last few decades, the application of fibre reinforced polymer composites as structural materials has been dramatically increasing in aviation, transportation, construction and many other related applications due to their remarkable structural and functional advantage over traditional metals. As an example specific to the aviation industry, in the 1990's, the Boeing 777 aircraft only used 12% by weight of composites. By 2010, this figure increased to as high as 50% in the latest 787 Dreamliner. In line with this, the traditional design and manufacturing techniques, which were specifically suited for metals, have been replaced by new methodologies that are appropriate for composites. However, composite processing technology is a relatively new area of research and it does not benefit from the well-established design guidelines and manufacturing techniques that are utilized for metals. As a result of centuries of research devoted to characterise their mechanical behaviour.

Weight saving is the primary reason for choosing composite materials as components along with its higher relative stiffness and strength. As an example, carbon-fibre reinforced composite can be five times stronger than 1020 grade steel while having only one fifth of the weight. Aluminium (6061 grade) having comparable weight to carbon-fibre composite, though still somewhat heavier, however, the composite can have twice the modulus and up to seven times the strength. In composites generally the reinforcing phase provides the strength and stiffness as mostly the reinforcement is harder, stronger, and stiffer than the matrix. The reinforcement is usually a fibre or a particulate. Particulate composites have dimensions that are approximately equal in all directions, the shape may be spherical, platelets, or any other regular or irregular geometry. Generally particulate composites tend to be much weaker and less stiff than continuous fibre composites, however particulate composites are less expensive. Particulate reinforced composites usually consist of less reinforcement (up to 40 to 50 volume percent) due to processing difficulties and brittleness. Fibre's length is generally much greater than its diameter. The length-to-diameter (l/d) ratio is known as the aspect ratio, which, can vary greatly. Continuous fibres have long aspect ratios, while discontinuous fibres have short aspect ratios. The term 'defects' with reference to composites can be defined as an unintentional local variation in the physical state or mechanical properties of a material or structure that may adversely affect the structural behaviour of the component. In the current study composites have been prepared using epoxy and carbon fibres by vacuum consolidation method. The test specimens have been prepared in V – shape and then tested using four point bending test.

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II. Materials and Methods

Fabrication of CFRP Specimen

The composite is fabricated with epoxy and carbon fibre mat using V – shaped tool, in which the curvature part is designed to hold the specific load and taken as per desired thickness and width [1-3, 6].The Dimensions for the fabrication of the specimen are, length 140 mm, inner radius 6.5 mm, width 25 mm, thickness 4 mm(Figure 1).

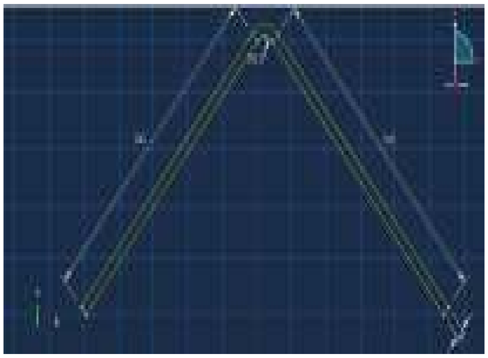

Fig. 1. Schematic reprentation of specimen showing length, angle and shape of the specimen

To make composite in desired V –shape, a tool made up of stainless Steel plate (Figure 2) of dimensions 300*200*6 (in mm) was bent to 90 degrees using a hydraulic press machine to get the final V-shaped tool of required inner radius 6.5 mm (Figure 3). The carbon fibre reinforcement mat for composites was cut in desired length and bread, about 20 carbon fibres in single stack of mat having dimensions 280*150 (in mm) were cut unidirectionally (Orientation angle is zero degrees). Each layer has a thickness of 0.2 mm and thus (20*0.2 = 4 mm) was the total expected thickness of the composite. To fabricate composite a 10:1, epoxy: hardener ratio mixture was prepared by mixing 100 gm of Lapox L-12 resin & 10gms of K-6 hardener. It was thoroughly stirred so that hardener properly mixes in Resin. Hand Lay-up method was used to make composite followed by curing (Vacuum Bagging Process).

Fig. 2. Stainless steel plate used as raw material for making V - shaped tool

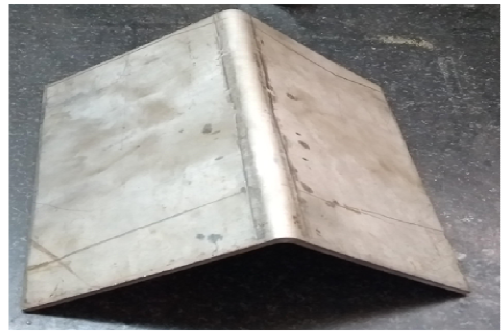

Fig. 3. V- Shaped stainless steel tool

Vacuum Bagging Process

It is a simple modification of Hand lay-up, in which the composite prepared after lay-up completion is placed inside a bag made of flexible film and all edges are sealed (Figure 4).

Fig. 4. Setup of vacuum bagging process

Also, excess resin is sucked by breather so the composite is of much more improved quality. The bag is then evacuated, (using a Vacuum Pump) so that the pressure eliminates voids in the laminate, forcing excess air and resin from the mould. Vacuum consolidation method produces high-quality moulding with complete exclusion of air bubbles. Vacuum Pump Pressure was set to around -70 KPa and it was left to curing for 24 hrs. After the complete curing, V shaped specimen was ready as shown in Figure 5. This entire composite was cut into four specimens as shown in Figure 6, with dimensions as mentioned in the ASTM standard D6415 [5].

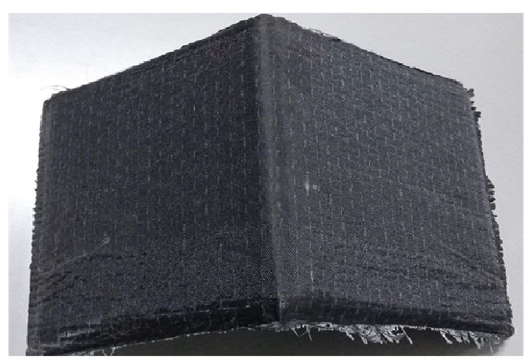

Fig. 5. Composite specimen after curing

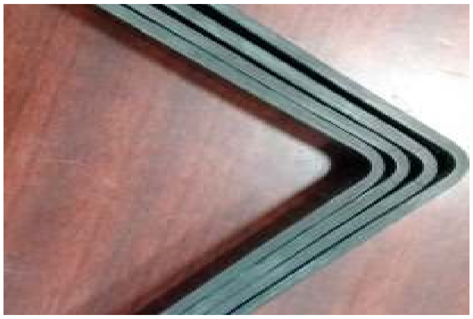

Fig. 6. Specimen after cutting and ready to be tested

Fig. 7. SS rod; raw material for rollers

Manufacturing of Fixtures

Suitable fixtures and knurled rollers were used for testing the specimen. The knurled rollers were fabricated from stainless steel (SS) rod as shown in Figure 7. A SS rod of 300 mm length and 30 mm was diameter was used who's diameter was reduced to 25 mm using turning process in Lathe machine. The entire 25 mm diameter rod was knurled on Lathe Machine. The Knurled rod was cut into 4 equal pieces (rollers) (Figure 8).

Fig. 8. Knurled rollers for four point bending test

The surface of the rollers was finished and drilling was done on both of cross-section parts of the rollers. The length and diameter of each roller was taken as 72 mm and 25 mm respectively as per ASTM standard.

Optical Characterization

The Optical Images of the cross-section of the curved part of the specimen were taken using an Optical Microscope (Figure 9). Among 5X, 10X & 50X lenses 10X lens was used. Around 200 Images were taken for each specimen and then combined together to create a Panorama using Image Composite Editor Software. From this image (Figure 10) we can easily differentiate between the excess resin regions. Further these stitched Images were processed in MATLAB to clearly differentiate between the excess resin region and the plies (Figure 11).

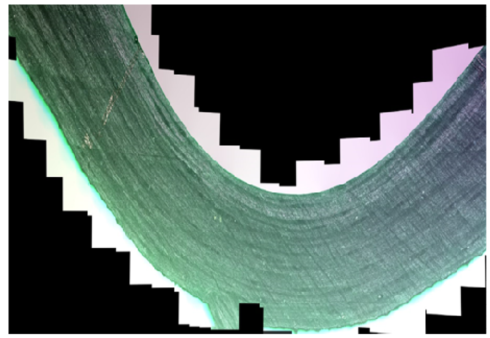

Fig. 9. Microscopic image of the composite specimen

Canny Edge Detection Method was used to differentiate cohesive region and the composite region. While applying the Edge Detection Algorithm, it worked fine for the individual images taken in Optical Microscope, but for the entire stitched Image, it doesn't worked properly due to the large size of the stitched Image. The black colored region is the resin-rich region whereas the while color denotes the composite. This color contrast is helpful in modeling the specimen with CZM elements by inserting delamination between the plies.

Fig. 10. Optical image of the composite specimen

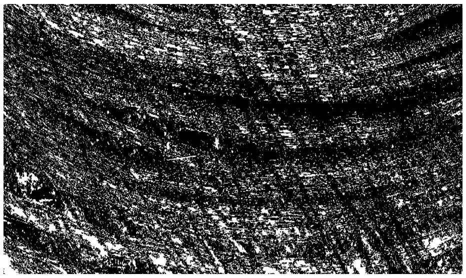

Fig. 11. MATLAB processed image

Mechanical Testing of the Specimen

The V- shaped curved specimens were subjected to four point bending test (Figure 12) in MTS machine, and the test was performed according to ASTM D6415. Digital Image Correlation (DIC) and Acoustic Emission Testing (AE) experimental techniques were used simultaneously to understand the damage & failure of the specimen [4]. In four point bending test a constant displacement load was applied to the specimen with the upper rollers fixed while lower roller were moving. The distance between upper and lower rollers was kept 75 mm and 100 mm respectively. Displacement/strain Rate for four point bending test was taken as 0.5mm/min.

DIC (Digital Image Correlation)

DIC is a highly advanced technique which can determine Displacement & strain of an object under load in 3-D. It saves complication by avoiding contact of sensors with the sample. Since, DIC compares random patterns of surface of a sample, so we need to spray our sample with the speckle pattern which will be tracked by the DIC technique. In DIC, 4pps (pictures per second) was used as image grabbing rate, with front and back camera distance of 0.6 and 0.9 m, and camera aperture of 4 and 5.6 respectively.

Fig. 12. Four point bending test of the composite specimen

Acoustic Emission Testing

AE testing was used which detects the energy released inside the object when a material undergoes some changes in its internal structure such as formation of crack. Due to structural changes, elastic waves are generated and thus the accumulate energy released is detected by AE sensors. In this, two WD (Wide Band) sensors were used with frequency range of 100 KHz to 1MHz. Distance of AE sensors were kept at a distance of 20 mm each from the bottom of the specimen.

III. Results and Discussion

The first delamination for each of the specimens was observed with a “Tickk” sound at around 0.7 to 0.8kN. Then another sound came which confirmed the initiation of second delamination. Then for some time these two delamination were propagating in the specimen. Then some more delamination were initiated and then they propagated in the specimen and so on till the crushing of the specimen (Figure 13). From the Load vs Displacement graph (Figure 14) for each of the specimens, it can be observed the exact value of the load at which the delamination was initiated. The load drop in the graph indicates the initiation of the delamination. The increase in load with displacement in the graph shows the initiation of the crack while propagation of crack can be observed when load is decreasing with displacement. It can be observed from the graph that, in the first specimen two delaminations initiated before their propagation starts. For the second and third specimen, there is only one delamination before propagation starts. After two or three propagations of the crack, specimens finally crushed.

Fig. 13. Delamination of CFRP composite specimen

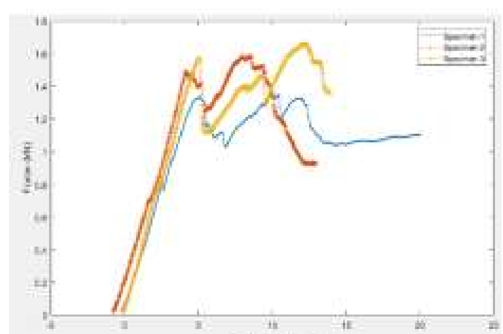

Fig. 14. Displacement vs load delamination Results

IV. Conclusion

Static tests performed on the curved specimen for calculating the interlaminar strength of the composite shows that failure of specimen occurs with the multiple delamination and their propagations. Delamination were observed by the drop in the load. The AE and DIC results matched with the corresponding strain/displacements vs. load confirmed delamination and propagation phenomena which extends from each other.

Acknowledgment

The authors acknowledge the Indian Institute of Technology, Hyderabad for support and opportunity it had created to carry out this work.

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