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Fractographical Investigation of the Delamination under Fatigue Using Laser Confocal Electron Microscope

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Abstract: In this paper fracture surface of the fatigue delamination have been investigated. Fatigue delamination tests were performed on the crabon/epoxy under different stress ratios. Samples were cut from the DCB specimens and analyzed in Laser Confocal Scanning Microscope. The analysis was used to measure the roughness values. Different fractographic features observed in the study are discussed.

Key words: Composite materials; Fractography; DCB specimens; Fatigue Delamination

1. Introduction

The use of fiber reinforced composites in structural applications is tremendously increased in past few decades. However; threat of delamination is a major hurdle to its use in load critical components. Delamination causes a reduction of strength, stiffness, redistribution of stresses, further delamination and ultimately structure failure.

Fractography is a common tool for the study of the delamination mechanism. Large number of researchers has performed fractography in the past decades.

Purslow [1] described the origin and development of fractographic features found in the matrix of carbon fibre-reinforced epoxy composites and their significance in the analysis of the failure of structures fabricated from composite material. The purpose of his paper was to examine in detail the origins of the various matrix features observed in static failures of carbon fibre-reinforced epoxy (carbon/epoxy) composites using scanning electron micrography and to apply accurately descriptive terminology.

Greenhalgh et al. [2] provided an overview of fractographic observations from the detailed examination of delamination fracture surfaces. The influence of migration on delamination growth from embedded defects in laminates under compression was presented, and these results were extended to demonstrate how migration influences damage growth in structures.

Richards-Frandsen and Yngve Naerheim [3] microscopically examined the delamination failure planes of graphite/epoxy composites that failed in three point bending fatigue to identify and relate fracture surface morphology to the composite microstructure and the applied loading conditions. The failure surfaces were also examined for indications of crack initiation and propagation from manufacturing induced defects in the microstructure. The dominant failure surface features were found to be matrix cleavage, hackle formation, and wear regions.

Laser confocal electron microscopy is a relatively new kind tool for the study of surface topology. In this type of microscopy the surface topology is modeled from the images taken from the surface. The objective of the current paper is to investigate the surface topography of the fracture surfaces created due to fatigue delamination growth. Carbon/epoxy specimens were tested under mode I fatigue. After fatigue tests, samples were taken from the specimens and analyzed in laser confocal microscope.

2. Experimental program

2.1. Test specimens

The specimens were made of carbon/epoxy prepreg, M30SC/DT120. The composite laminate was made by stacking 28 plies of the prepreg in a unidirectional layup. A Teflon insert of 12.7 µm thickness and 40 mm width was placed at the edge of the panel between the 14^{th} and 15^{th} ply during layup to act as a starter delamination. The curing of the laminate was performed in an autoclave at a pressure of 6 bars and temperature of 120ºC for 90 minutes.

Double cantilever beam (DCB) specimens were cut from the laminate plate. The length of each specimen was 150 and mm width was 20 mm and the thickness was 4.62 mm.

2.2. Fatigue Test Procedure

The DCB specimens were clamped in the machine with the help of hinge assembly as shown in figure 1. Fatigue delamination tests were performed in a 10 kN MTS machine. Tests were conducted at room temperature. The cyclic frequency was 3 Hz. The maximum and minimum cyclic displacements were constant during tests.

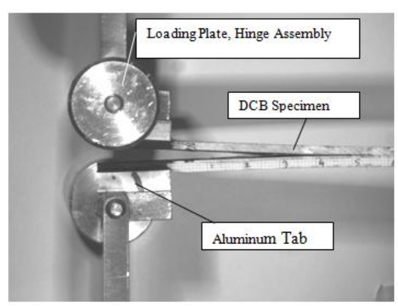

Figure 1: DCB specimens in the machine grips

2.3. Fractography in the laser LCSM

Samples were cut out from the DCB specimens after fatigue tests. The size of sample was approximately 15 mm X 15 mm. The sample was attached to the LCSM table by gum. The lens of the microscope was fixed at the specimens. One edge of the specimen was taken as the reference. Images of the fracture surface were taken at appropriate locations of the sample.

3. Results and discussion

LCSM was used for taking images of the fracture surface. At same time the roughness values of the fracture surfaces were also calculated by the software in the computer system attached to the LCSM. The fracture surface was formed of fiber imprints, matrix failure between adjacent fibers and fiber breaks as shown in figure 2.

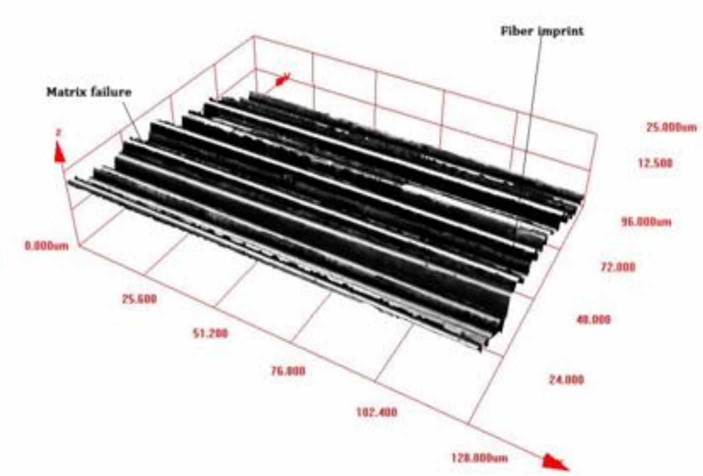

Figure 2: LCSM image of the fracture surface showing fiber imprints and matrix failure

The presence of local matrix debris was observed as shown in figure 3. Such debris may be the result of local void or air traps during lay up. The voids act as accumulation places for the liquid matrix during curing process. Delamination growth under fatigue may be affected by these local debris.

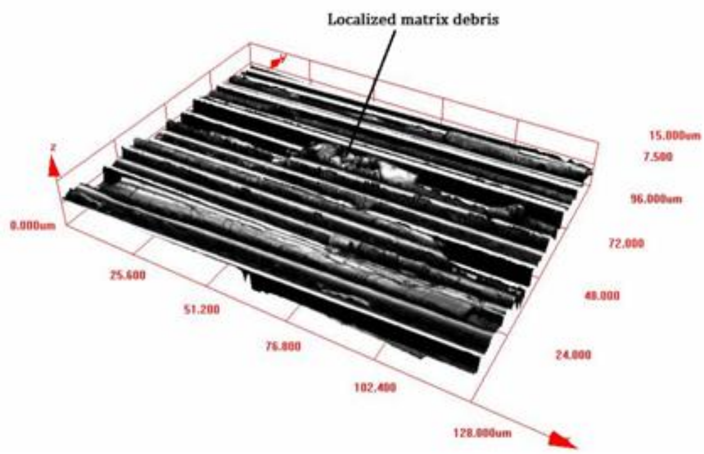

Figure 3: Localized matrix debris

Loose fibers were observed on the fracture surfaces as shown in figure 4. These fibers results from the breakage of bridging fibers. Loose fibers enhance crack closure and acts like wedges during fatigue loading and reduce the delamination growth.

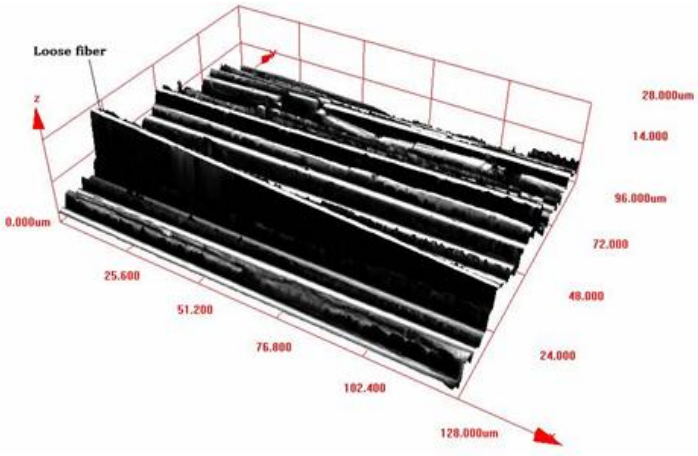

Figure 4: Loose fiber on the fracture surface

Surface topology is highly non-uniform at some places as shown in figure 5. This reflects the uneven delamination growth across the specimens. The crack closure due to roughness will be also different at different locations

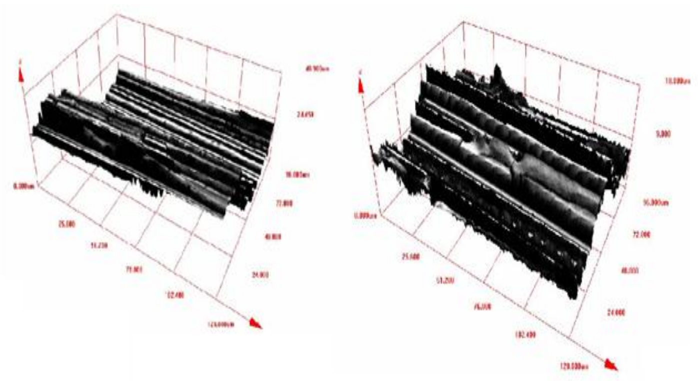

Figure 5: Images showing high degree of non-uniformity of roughness distribution

Average roughness values for different specimens across sample size are shown in figure 6. The mean roughness value is around 2.5 um. Maximum roughness value occurs in few observations and it was equal to 6.9 um.

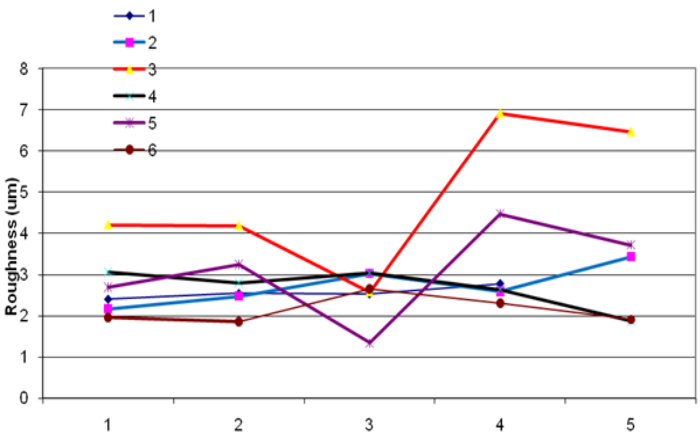

Figure 6: Average roughness values across sample size

4. Conclusions

In this paper the fracture surface produced due to fatigue delamination growth were studied using LCSM. From the results following conclusions are drawn.

1. Fracture surfaces consists of fiber imprints, matrix breaking adjacent fibers and loose fibers.
2. Matrix debris results from the accumulation of liquid matrix in the voids/air traps during curing.
3. Loose fibers results from the breakage of bridging fibers.
4. Loose fibers acts as wedges and produce roughness induced crack closure.
5. Fracture surface topology is highly non-uniform at certain locations.
6. The value of surface roughness remained in sharp range.

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