Fracture behavior characterization of unidirectional composite laminates with hole defects under tensile load

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Abstract

Composites components are used in reticular structures, however their structural performance related to its damage tolerance has not been studied extensively. The present research is concerned with mechanical strength of composite laminates containing hole defects. Experiments involved fabrication of epoxy/glass unidirectional laminates with at least 60% volume fibre at different orientations using vacuum bagging method. Specimens were induced with different hole defect sizes to characterize crack propagation before instability conditions. Mechanical behaviour was observed in tension tests, loading specimens to failure. Fracture sequence and mechanism were established by fractographic examination.

1. Introduction

Glass Fibre reinforced composites (GFRC) offer exceptional properties in structural applications that require high strength to density ratios, so their employment in aeronautics has been rising in recent years. The employment of GFRC has been expanded to numerous aircraft laminated components, however their structural perfomance related to damage tolerance has been studied a few [2][3][4], specially when they contain stress concentrators, such as pin holes, large drills or notches.

Due to the imminent risk of a crack presence in laminates, the understanding of crack sequence and propagation mechanism is essential to calculated residual strength based on defect size – maximum load ratio in order to design damage tolerant components and establish crack size limits used for inspection on service [1].

Recently, some researches [5][6][7] published investigations considering circular defects as stress concentrators which causes strength weakness as function of non-uniform crack propagation. However they don't establish physical parameters to define residual strength in composites elements [9][10][11].

The present research is focused to the characterization of fracture behaviour of epoxy/glass unidirectional laminates with hole defects. Optimization of the vacuum bagging was necessary to obtain high fibre volume fraction and low porosity.

Mechanical characterization was realized by tensile tests loading specimens to failure.

Laminates strength was related to hole defect size for predicting maximum load available in the structural components. Fracture surfaces formed were analyzed in order to establish rupture sequence and mechanism.

2. Materials and laminates manufacturing

The composite used in this work consists of unidirectional E-glass (800 gr/m^2) and EPOLAM 2015 resin. All laminates were manufactured using vacuum bagging process.

Laminates physical characterization was done according to the hydrostatic method established in ASTM D2584 [15] to determinate composite density. Volume fiber fraction was evaluated using the burn-off method, obtaining typical values of 63% fiber fraction and 4% void content.

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3. Mechanical laminates response and fractographic examination

The laminate mechanical properties were measured using 250 mm X 25 mm X 1.5 mm samples and cut for three different orientations (0°, 45°, 90°) and one ply sequence [0º/90º/+45º/-45º].

Specimens without defects were loaded to failure according to ASTM D3039. To obtain strength and stiffness values, composite samples were instrumented with polyimide strain gages. Gages were connected to a strain indicator to record data during loading; information were stored with proper software.
To improve data acquisition during test, displacement rate of testing machine was adapted; laminates of 0°, 45° and 90° were broken at 2 mm/min, 1 mm/min and 0.1 mm/min respectively. Strain – stress curves for each laminate orientation were drawn to estimate mechanical properties.

Then the rest of specimens were induced with different hole defects using drilling tool to represent stress concentrators in structural components. Hole sizes were 1.5, 2.5, y 3 mm of diameter, located in the center of samples.
Maximum strength of all specimens was recorded to calculate average strength for each orientation using Weibull statistical method [14]. The effect of hole defects presence in mechanical response of laminates was analyzed drawing the residual strength curve.

After the test fractographic examination was done to identify the failure path. For macroscopic observation, photographs of the stress concentrator were taken to preserve visual evidence of fracture plane, fracture angle and crack path, as shown in Fig. 4.
Then, for microscopic evaluation a nanometric graphite film was deposited in laminates surface to enable samples observation by Scanning Electron Microscopy (SEM). Micrographies were acquired to find indications of cracking mechanism related with loading experimental conditions.

4. Results and discussion

The laminates oriented at 0° show the maximum strenght, followed by the ply sequence and finally samples with aligned fibres at 45° and 90°. A considerable diminish of specimens strength is observed meanwhile hole defect increases its size. The biggest defect evaluated (3 mm) decreases laminate mechanical strength at least 30%.
Stress concentrators aids crack nucleation at circumference limits causing fibre/resin separation. The interlaminar fracture exhibit poor adhesion at matrix-reinforcement interface but shows damage tolerance properties. Interlaminar fracture mode gives stable crack propagation until the amount of energy provided by mechanical load is bigger than that necessary to form new fracture surfaces. However completely fragment separation of specimen does not occur, so composite failure does not occur in sudden way.

Conclusions

Presence of defects aids crack nucleation at hole surroundings causing fibre/resin fracture.
Laminates mechanical response suffered a significant decrement related to hole defect size.
Laminates residual strength provide maximum strength knowing defect size and critical hole size for an specific application.
Fractographic evaluation revealed interlaminar fracture by matrix-reinforcement decohesion.
E/2015 composite shows damage tolerance, with stable crack propagation and no sudden fragmentation.