Evaluation of patch repaired composite panel under tensile loads

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Abstract — In the past few decades, the use of composite structures has significantly increased due to the great advantage of the high strength-to-weight ratio of composites. This increase in demand has become the major reason behind the need to develop an effective technology to repair composite structures whenever exposed to damage while in service. Bonded patch repair of composite structures is a relatively new and attractive technology. The objectives of the present study are to evaluate the tensile strength of repaired laminated composite panel and to investigate the performance of the undamaged panel, panel with centered hole and a repaired panel under tensile loading conditions. All the three configurations namely the undamaged, damaged and the repaired are analyzed for their strength in order to examine the effect of damage on the strength reduction in the damaged specimen and to assess the performance of the repaired panels in regaining the strength of the undamaged panel.

Index Terms— composite material; repaired panel; strength; damaged panel.

I. INTRODUCTION

The use of composite materials in aircraft structural components has increased in the past few decades as a result of the many advantages they offer compared to metals. The causes of the defects depend on many factors such as human error, environmental degradation, imperfect design, there are possibilities of accidental damages like tool drop, bird impact, foreign object damage which may lead to predominant mode of failure in composite structures. Hence, repairs or reinforcing the damaged parts of structures to restore the structural efficiency. The scientific approach to designing and assessing repairs has probably started in the early 1970s. After many years of study, various repair techniques have been successfully applied.

The finite element formulation on the basis of the layer wise linear displacement theory to study the first-ply failure of moderately thick laminated composite plates was observed by T.Y. Kam [2]. The finite element is used to determine the first-ply failure loads of a number of laminated composite plates on the basis of several phenomenological failure criteria. The capabilities of the failure criteria in predicting first-ply failure loads are investigated by comparing the finite element first-ply failure loads with the experimental ones. It has been found that the failure criteria can yield reasonably good results for the cases considered.

The both experimental tests and numerical study are carried out to investigate different repair parameters effects on the ultimate strength and failure mechanism of adhesively bonded repaired structures by Liu and Wang [3]. Hamoush [4] evaluate the residual strength of a scarfed repaired solid composite panel, to evaluate the response of the patch to tension static loading conditions, and to investigated the performance of defectively repaired panels under a unidirectional tensile load.

The review summarizes the previous effort of many researchers whose contributions were made on composite repair. It was therefore felt that a better understanding on the scarf repair under tensile loading conditions is required. Hence the present work attempts for the strength prediction of undamaged, damaged and repaired composite panels under tensile loads. Also investigates the amount of strength regain of scarf repaired composite panel with the undamaged composite panel.

II. GEOMETRICAL MODEL

In the present study, three different types of carbon fibre composite panels i.e; a pristine, damaged and a scarf repaired were considered and their geometrical details are shown in the figure 1. All dimensions are in mm. The selected configuration allows a reasonable panel thickness for repair and provides a reasonable overall panel size that can be tested.

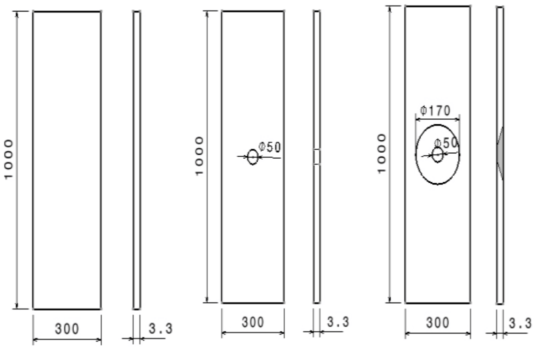

Figure 1: Geometrical details of the pristine, damaged and a scarf repaired CFC panels

III. COMPOSITE LAMINATE PROPERTIES

Composite laminate is made up of 16 layers of CFRP AS4/914, lamina of thickness 0.2 mm following stacking sequence $[+45/-45/0/0/90/45/0/0]_S$. The properties are tabulated in the Table 1.

Table 1: Material properties of AS4/914

E_1 (MPa)	$130*10^3$
E_2 (MPa)	$10*10^3$
E_3 (MPa)	$10*10^3$
G_{12} (MPa)	$5*10^3$
G_{13} (MPa)	$5*10^3$
G_{23} (MPa)	$5*10^3$
ν_{12}	0.34
ν_{23}	0.33
ν_{13}	0.33
X_t (Mpa)	1300
X_c (Mpa)	1000
Y_t (Mpa)	98
Y_c (Mpa)	215
S (Mpa)	65

IV. FINITE ELEMENT MODEL

In the present work, the finite element model, boundary conditions and material properties is generated using pre-processor MSC Patran. A linear static analysis using MSC Nastran is carried out, to determine the strength of the undamaged panel, panel with centered hole and a repaired panel. The FE model of undamaged panel was constructed using two dimensional CQUAD4 shell elements which are suitable for analyzing thin to moderately-thick shell structures. The element size of 5 mm is maintained throughout the panel. The 12000 shell elements were used to model the undamaged panel.

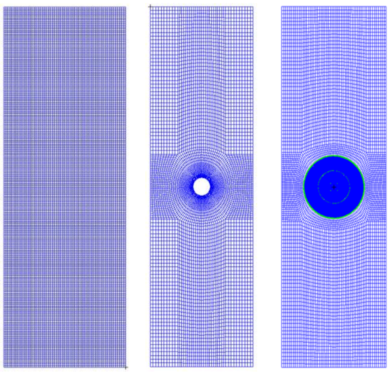

Figure 2: FE model of the pristine panel, damaged panel, repaired panel.

The damaged panel meshing is carried with the element size of 1 mm is used around the cutout and rest is maintained with the element size 10 mm. The 6880 shell elements were used to model the damaged panel. The repaired panel meshing is carried out by using CQUAD4 and CTRIA3 shell elements. Finer mesh is required only at critical regions of the panel. The total number of elements in the model is 37980. In that 36120 quad shell elements and 1860 tria shell elements were used. The scarf angle 3^0 was maintained at the patch region. Local coordinate is created with x-axis along length, y-axis along width and z-axis along the thickness of laminate. The FE models of three CFC panels i.e; a pristine, damaged and a scarf repaired as shown in Figure 2.

V. EXPERIMENTAL STUDY

In the present study, sixteen-ply (1000x300 mm) quasi-isotropic (45/-45/0/0/90/45/0/0)s pristine, damaged and repaired laminates were considered. AS4 carbon fibres and high-strength damage-resistant epoxy matrix (914) were used in the prepreg (thickness 0.2 mm) form to fabricate all panels. The repairing process started with drilling 50 mm diameter circle at the center of the panel to simulate the damage. The damaged area was then scarfed (scarf angle 3^0) in accordance with the manufacturer's structural repair manual specifications.

Panels were fabricated using carbon UD prepreg to the specified dimensions. Curing and post curing was carried out as per standard curing cycle of 914 resin system. A cutout of 50 mm in diameter was made to simulate the prepared area to carry out repair for a damage that is encompassed within a circle of 50 mm diameter in the panel. However, as these repairs were carried out on freshly fabricated panels, the bonding operations were carried out immediately after the removal of peel-ply without any extensive surface preparation as carried out during the repair on painted surfaces. Scarfing was performed on one side of the panel and the adhesive Redux 319A is used to bond the scarf patch to parent panel. Finally, the patching kit was applied onto the scarfed area starting with the filler ply to enhance the lateral strength of the adhesive film filling the 50 mm diameter hole. The patch was cured in the oven at 350^{o}F to produce a good repair panel.

VI. TENSILE TESTS

Tensile test was carried out in Servo hydraulic computer controlled Instron Universal Testing Machine (UTM) of capacity 1000 kN.

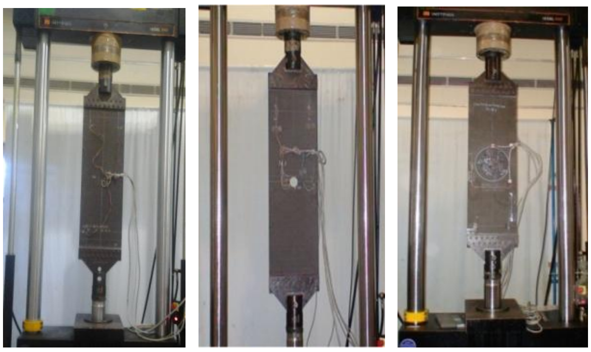

Figure 3: Undamaged, damaged and repaired panel mounted on UTM for tensile test.

The strain gauged CFC panel assembled to the loading fixtures was mounted on testing machine. All strain gauge wires were connected to the data acquisition system to record the strains during the experiment. All tensile tests described were carried out at room temperature. The panels were loaded under tensile loading rate of 0.5 mm/minute. The tensile strength of tested panel was measured at the moment of rupture. Fig 3. shows the pristine, damaged and repaired panel mounted on the testing machine for tensile load test.

VII. RESULTS AND DISCUSSION

7.1. Strength prediction of CFC panel by FEA

A linear static analysis was carried out using a commercially available FEA package MSC Nastran. Tsai-Wu failure theory was used to predict the failure load. The analysis was carried out initially for an applied load of 50kN and the failure indices at each ply were observed and were found to be in smaller magnitudes. Further the analysis was continued with an increase in the load step of 50kN. Failure Index (FI) for different angle lamina for three panels are tabulated in Table 2.

Table 2: Failure Index (FI) for panels by FEA

Lamina orientation	FI of Undamaged panel	FI of Damaged panel	FI of Repaired panel
45	0.984	1.01	1.01
-45	1.02	0.991	0.928
0	0.563	0.765	0.607
90	0.834	0.885	0.663

It is observed that in the undamaged panel -45^0 lamina showed a critical failure index than the 45^0, 90^0 and 0^0 lamina. From this, it is concluded that pristine panel fails at 630 kN. In the damaged panel is observed that $+45^0$ lamina showed a critical failure index than the -45^0, 90^0 and 0^0 lamina. From this, it is concluded that damaged panel fails at 182 kN. And in the repaired panel is observed that $+45^0$ lamina showed a critical failure index than the -45^0, 90^0 and 0^0 lamina. Hence it can concluded that $+45^0$ lamina will fail first (first ply failure) at load magnitude of 365 kN.

7.2. Comparison of FEA and experimental strength prediction

Comparison of failure loads between finite element method and experimental method is tabulated in Table 3. The FEA failure loads were obtained based on first ply failure theory, using Tsai-Wu failure criteria. On comparison of these values with experimental failure loads, it is observed that failure load obtained by FEA were in very good agreement with experimental results.

Table 3: Comparison of FEA and Experimental failure loads.

Type of panel	Failure loads (kN) (FEA)	Failure loads (kN) (Experimental)
Undamaged	630	750
Damaged	182	287
Repaired	365	400

VIII. CONCLUSIONS

The performance of composite repair panel under static tensile loading condition was evaluated. Three types of composite panels were considered for analysis i.e; pristine, damaged and repaired. All these panels were first analyzed using FE codes. These composite panels were fabricated and tested. Both FEA and experimental results were compared. Based on the results following conclusions are drawn.

- The effect of damage (circular hole) has resulted in the strength reduction of more than 62% in the damaged panel compared to the pristine one, due to the stress concentration created at the hole.

- Strength regain in the scarf repaired panel compared to the undamaged panel was studied. The scarf repaired panel has restored up to 53% of the tensile strength.

ACKNOWLEDGEMENT

The authors would like to express the voice of gratitude and respect to all who had directly or indirectly supported for carrying out this study. The authors would like to thank and acknowledge the Director, CSIR-National Aerospace Laboratories, Bangalore for providing an opportunity to carry out the study. Also sincere thanks are acknowledged to The Principal, Acharya Institute of Technology, Bangalore for the support. Special thanks are acknowledged to The Head of the Department, Department of Mechanical Engineering, Acharya Institute of Technology, for his support and encouragement.

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