TECHNICAL NOTE

NOVEL REPAIR SCHEME FOR THE EDGE DELAMINATED COMPOSITES

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Abstract

Edge delamination refers to those delaminations, which arise at the free edge of a laminate. Although edge delamination in advanced laminated composites is a well-documented phenomenon, the repair of edge delamination is still a gray area.

This paper presents an effective novel repair approach to repair edge delamination. Special repair tools have been designed and fabricated for this purpose. It also highlights the fabrication of artificially edge delaminated Carbon Fiber Reinforced (CFRP) specimens. Repair strengths have been evaluated by compression tests and Ultrasonic C-scan is used for validation of the repair scheme. From the tests it has been observed that the repair scheme has no bearing on the location of edge delamination and stacking sequence.

Nomenclature

A	= area in mm^2
G	= specimen cut from good region
M_1, M_2, M_3	= CFRP laminates with edge delamination a mid plane
MQ	= CFRP laminates with quasi-isotropic lay-up sequence $(0/45/90/-45)_{2s}$ and delamination at mid plane
P	= failure load in kg
Q_1, Q_2, Q_3	= CFRP laminates with edge delamination at quarter plane
QQ	= CFRP laminates with edge delamination and quasi-isotropic lay-up sequence
R	= specimens cut from repaired region
σ_c	= compressive strength in N/mm^2

Introduction

In composite aircraft structures, edge delamination is a common phenomenon. This can happen during fabrication and also in service.

During demoulding of the part, with the help of hand tools like chisel, spatula etc, can lead to the edge delamination on the component. In service, this happens because of excessive loading or an external hit from a foreign body.

The prime objective of this paper is to evolve a special repair scheme and to develop sophisticated fixtures to repair edge delamination.

The entire work has been reported in the following sub-heads:

- Fabrication of edge delaminated specimens
- Development of vacuum valve and test chambers for the repair
- Edge delamination repair by Resin Injection- an overview
- Repair procedure
- Testing and validation of the repair

Fabrication of Edge Delaminated Laminates

In order to study repair of edge delaminated structures, we have taken CFRP laminates. These laminates have been made from Hexply 914C-TS-6K-6-34%, UD carbon prepreg. The lay-up sequence and laminate dimensions have been depicted in Fig.1.

The edge delaminated laminates have been fabricated by Autoclave moulding process. The artificial delamination have been created by placing a thin copper foil

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Item No.	Layer No.	Orientation in Degrees	Remarks
1	1	90	Material used ; Hexply 914C-TS-6K-6-34% Carbon UD Prepreg
2	2	0	
3	3	90	
4	4	0	
5	5	90	
6	6	0	
7	7	90	
8	8	0	
9	9	0	
10	10	90	
11	11	0	
12	12	90	
13	13	0	
14	14	90	
15	15	0	
16	16	90	

Fig.1 Lay-up Sequence of CFRP Panel

(0.10mm thick) at the half and quarter thickness of the panel. Fig.2 represents typical edge delamination in the CFRP panel.

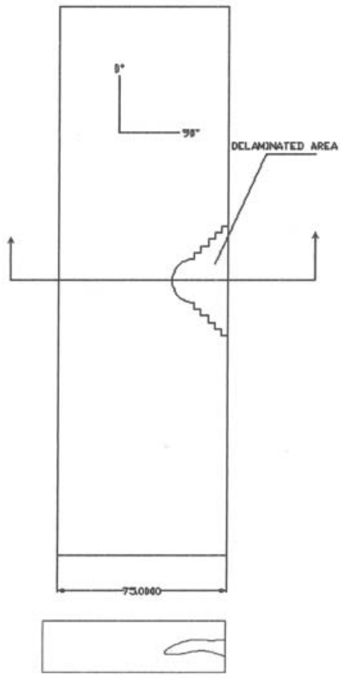

Fig.2 Typical Edge Delaminated CFRP Panels

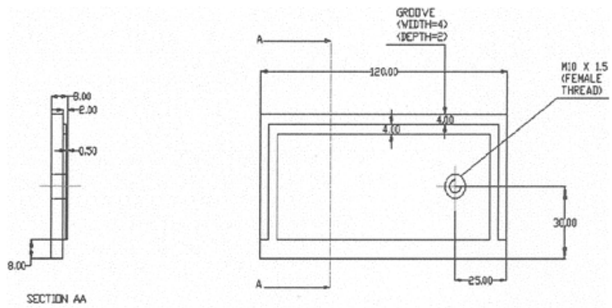

Fig.3 Vacuum Chamber for Resin Injection (Top)

Development of Vacuum Valve and Vacuum Chambers

To facilitate good vacuum over the delaminated area, special vacuum valve and chambers have been fabricated. The vacuum chamber has been fabricated with M.S. and dimensions are depicted in Fig.3 and Fig.4. The top chamber has a threaded hole wherein the vacuum valve can be connected.

To facilitate the scheme, a special vacuum valve has been fabricated using SS304@ the dimensions and shape of the valve is shown in Fig.5.

Edge Delamination Repair

Resin injection is widely employed to repair delamination in composites. We have also taken up the repair of edge delaminated specimens by the above method.

In resin injection technique, the usual practice is to drill holes on the delaminated area, inject resin from one hole and fill the cavity by applying vacuum and cure under vacuum.

The main disadvantage of this process is that while applying vacuum, the delaminated space is forced to close, thereby offering resistance to the flow of resin. Further after removal of vacuum, the delaminations will have a tendency to open. Hence the resin injection method may not be effective for edge delamination repair, if this is done in a normal way. In the normal method of vacuum application, the atmospheric pressure acts on the laminate and forces the laminate to move close to the other pall of the laminate. This will offer resistance for the resin to move.

To overcome this concern, a novel method of resin injection was proposed. In this method, two vacuum chambers were fabricated and a new vacuum valve was developed to implement the scheme. These chambers prevent the delaminated portion of the laminate to move close to the other counter part. As a result the original configuration of the delaminations is maintained.

The advantage of this technique was that here the vacuum is not applied directly on the delaminated area. Special vacuum chambers were used with rubber gaskets, so that the chamber rests on the laminate and provides easy access for resin injection.

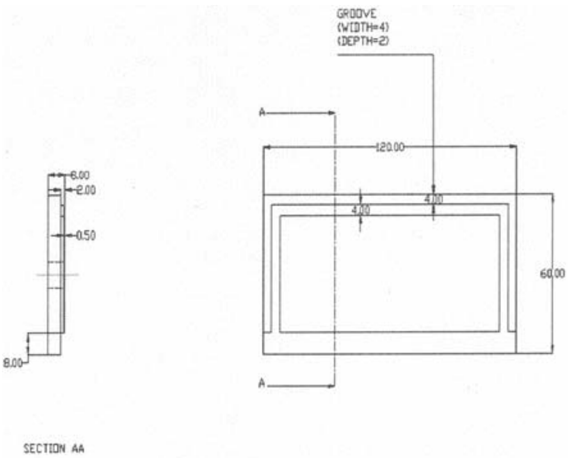

Fig.4 Vacuum Chamber for Resin Injection (Bottom)

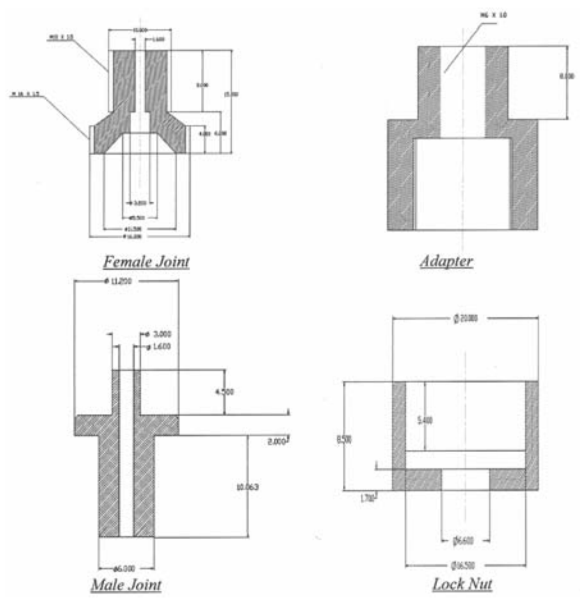

Fig.5 Vacuum Valve

Vacuum was applied only at time of injection and the chamber was removed as soon as the injection was over. During the time of curing of injected resin, no force was applied on the laminate; as a result the laminate was not strained and was kept in its natural state.

Repair Procedure

Vacuum assisted resin injection technique was employed to repair edge delaminated CFRP specimens. The epoxy paste adhesive (Araldite 403) was used for the repair.

As a first step, the extent of delamination was evaluated on the test specimens by ultrasonic C-scan. Holes of diameter 1.5 mm were drilled down to the delamination on the delaminated specimens with spacing of 1.0mm.

Position vacuum chambers, vacuum valve and injection syringe properly so that the chamber does not rests on the delaminated area. Fig.6 shows the resin injection arrangement. Apply vacuum during injection. After 3 min of injection of Araldite 403, remove vacuum and allow curing of the specimen in its natural state. After 16 hrs of RT cure, post cure the specimens at 70° C in an oven for 4 hrs.

Tests and Validation of the Repair

In order to study the extent of delamination, all the specimens were ultrasonically C scanned. Fig.7 shows the C-scan image of the delaminated area in 'J' specimens.

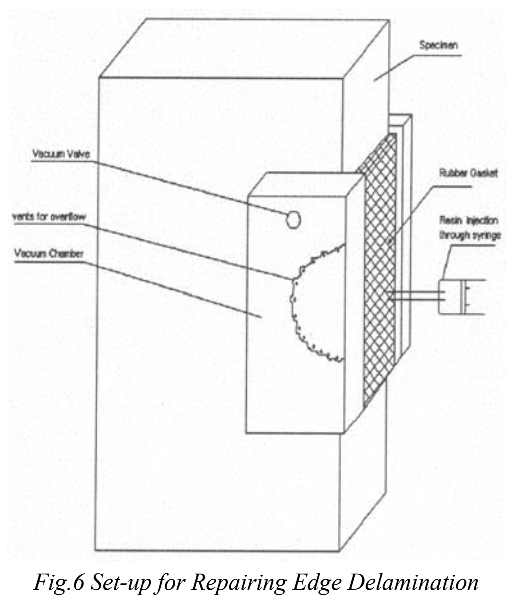

Fig.6 Set-up for Repairing Edge Delamination

After the repair, the specimens were C-scanned to evaluate the quality of the repair. Fig.8 in appendices an image of the repaired specimens.

From the ultrasonic inspection report it was found that the vacuum assisted resin injection technique is suitable for edge delamination repair.

For the validation of the repair, compressive tests were performed on the repaired and the parent CFRP laminates. The compressive tests was done in accordance with ASTM test standard D-3410 at Room Temperature (RT) and the compressive strength is found using Equation (1).

$$\sigma_c = P/A \quad (1)$$

For the compressive test, specimens were cut from the repaired area and the good area (2 nos. each). The test was performed in an Instron Universal testing machine at a crosshead speed of 1 mm/ min.

Fig.7 Ultrasonic C-Scan Image of Delaminated CFRP Laminates

Fig.8 Ultrasonic C-Scan Image of Repair CFRP Laminates After Test

Tables-1 and 2 for the test results on midplane delaminated and that for specimen with delamination at one-fourth thickness respectively.

It has been observed that the compressive strength of repaired specimen is over 70% of parent strength. On comparison, the ratio of failure load of the repaired specimen to that of parent specimen was found to be 1:0.8. The variation in compressive strength is due to the variation in specimen dimensions.

Further, specimens with delamination at quarter thickness have shown almost the same compressive strength as that of mid plane delaminated specimen.

The results indicate that the repair method can be effectively applied to delaminations located any where in the thickness.

The compressive test results show that only around 70% of the original compressive strength is recovered

Table-1 : Compression Testing of CFRP Specimens (at RT)

Laminates No.	Sl. No.	Width (mm)	Thickness (mm)	Failure Load (Kg)	Compressive Strength (MPa)
M1	G	9.98	2.29	1860	798
	R	9.81	2.30	1510	656
	G	9.92	2.26	1890	827
	R	9.81	2.28	1526	669
M2	G	9.93	2.34	2025	854
	R	9.98	2.35	1670	699
	G	9.98	2.37	2032	842
	R	10.01	2.38	1700	700
M3	G	10.04	2.30	1750	743
	R	10.06	2.30	1520	644
	G	10.03	2.29	1790	764
	R	10.04	2.30	1565	664
MQ	G	9.90	2.28	1690	734
	R	10.02	2.38	1290	531
	G	9.93	2.34	2025	855
	R	10.00	2.38	1640	676

Table-2 : Compression Testing of CFRP Specimens (at RT)

Laminates No.	Sl. No.	Width (mm)	Thickness (mm)	Failure Load (Kg)	Compressive Strength (MPa)
Q1	G	9.95	2.32	1630	692
	R	10.02	2.36	1380	572
	G	9.95	2.28	1640	709
	R	9.97	2.30	1350	577
Q2	G	9.94	2.30	1720	738
	R	10.02	2.38	1490	613
	G	9.96	2.32	1770	751
	R	10.06	2.40	1540	625
Q3	G	10.06	2.29	1810	770
	R	9.70	2.30	1465	644
	G	9.96	2.28	1790	773
	R	9.82	2.35	1580	672
QQ	G	9.94	2.34	2010	847
	R	10.02	2.38	1490	613
	G	10.06	2.21	1940	856
	R	9.72	2.36	1580	675

through this repair scheme. The authors feel that not recovering 100% compressive strength is not the limitation of the repair method, but it is the limitation from the resin used for repair. By selecting proper resin system, one can restore the complete strength. This is possible only in cases, where the delamination has occurred because of mechanical damage. If the delamination is because of some contamination of the layers during lay-up, unless that is thoroughly cleaned, it is not possible to restore 100% strength, whatever may be the resin system used in the repair.

Conclusion

The vacuum assisted resin injection method is best suited for the repair of edge delaminated specimens. The quality of the repair depends on the alignment of vacuum chambers and injection needle.

Further edge delamination repair is independent of depth where it had occurred. It is observed that quasi-isotropic stacking sequence had low compressive strength than that of an edge delaminated specimen with all $(0/90/0/90)_{2s}$ degree plies. The percentage of reduction in compressive strength in quasi-isotropic laminate is found to be less than 5%. The prime advantage of this repair technique is that it can be extended for the repair of actual edge delaminated aircraft parts.

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References

1. Baker, A.A. and Jones, R., "Bonded Repair of Aircraft Structures", Martinus Nijhoff Publishers, 1998.

2. "Composite Repair of Military Aircraft Structures", AGARD-CP-550, 1995.

3. Miller, S.H. and Labor, J.D., "Repair of Advanced Composite Structures", J. Aircraft, 1998.

4. Daniess-iez, D. and Frantziskonis, G., "Edge Delamination in Laminated Composites", Composite Structures, 1992.

5. Wu, K.W., Lee, C.-L., Chang, Y. C. and Ong, C. L., "Compressive Strength of Delaminated and Repaired Composite Plates", Mater Chem Phys, 43, 1996, pp.173-177.

6. Li Henry, C.H., Chou Heng Yi and Herzberg., "Israel Modelling and Validation of Pinning Repair for Delaminated CFRP Laminates", Proceedings of the 12th Australian Aeronautical Conference, 2007.