6. ANKARA INTERNATIONAL AEROSPACE CONFERENCE AIAC-2011-082

14-16 September 2011 - METU, Ankara TURKEY

ANALYSIS, DESIGN AND MANUFACTURING A WINDOW FRAME WITH RTM METHOD AND ASSEMBLING CURED WINDOW FRAME TO UNCURED PANEL WITH CO-BONDING METHOD

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ABSTRACT

This paper outlines the analysis, design and manufacturing processes of a window frame (WF) produced with RTM (resin transfer molding) method and then co-bonded to a fuselage skin. The dimensions of window frame have assumed to be similar to the ones of A320. The main reasons to choose RTM method are to obtain tight dimensional tolerances, good surface quality on all sides, repeatable process standards in complex shapes and fewer trimming and finishing operations.

Regarding analysis activities; pre and post processing work was performed with MSC.Patran 2008r2. MSC.Nastran 2005r3b was used as solver. Ply number and lay-up sequence were determined per the applicable loads and methodologies. Analysis results were verified via coupon tests. Catia V5R18 was used for modeling studies. Design of window frame and skin panel was completed per analysis results and manufacturing capabilities. In the meantime studies are carried out to improve manufacturing capabilities.

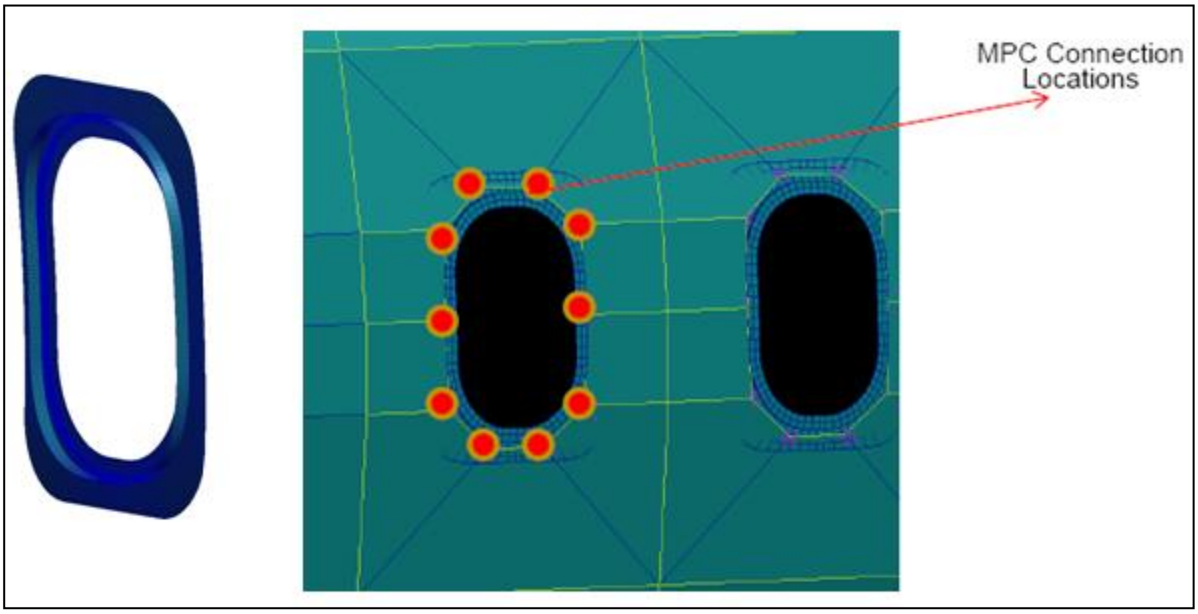

Fig. 1: Connection between barrel and Window Frame FE Model

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ANALYSIS and DESIGN OF WINDOW FRAME

The following analyses have been carried out for window frame;

- Damage Tolerance Analysis
- Buckling analysis
- Unfolding analysis
- Plane strength analysis
- Bonded joint analysis
- Filled hole analysis (Repair solution)
- Delamination Analysis for Delta zone

Typical barrel geometry of a single aisle airplane and typical loads on forward fuselage have been generated to be the inputs of analysis. A typical single aisle aircraft barrel was created by Catia. Typical loads were defined according to that geometry. Also, a GFEM was built per that 3D model (Figure 2). 24 ea window frames were utilized within that barrel. G0926 D1304 INJ E01 2F 5HS fabric and_RTM6 resin is the material chosen for WF. Five different types stacking sequence have been considered. Analyses have been carried out for all window frames.

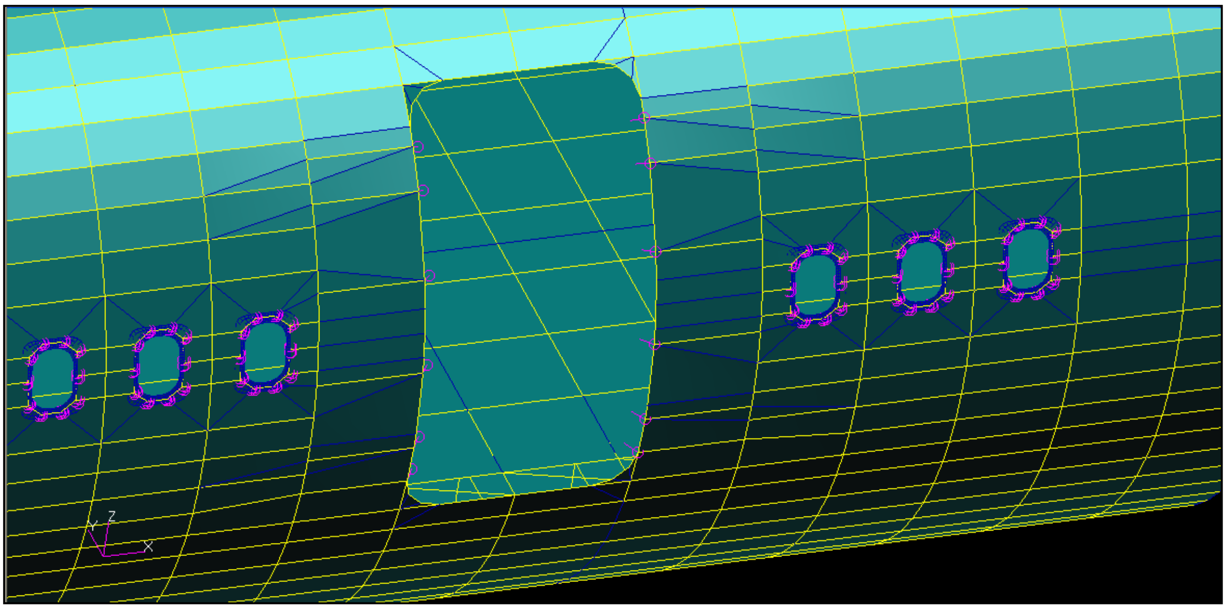


Fig. 2: Barrel Global FE model including Window Frames

There are 53 load cases applicable to window frames. The loads on window frame were extracted from GFEM. Bonding between WF and panel is simulated by MPC elements (RBE2 element). Between each window frame and panel approximately 10 connection elements were created.

Damage Tolerance Analysis

The damage tolerance analysis was considered to cover the impact of potential damages which might occur at any time on window frame, such as tool drop on part (Figure 3). Damage tolerance analyses were performed with the following assumptions:

- Impact Energy = 35 Joule
- Impactor Diameter = 16 mm
- Impactor Young modulus = 210000 Mpa
- Impactor Poission = 0.3
- Cut off Denth Depth =1.3 mm
- Operating Temperature = 70 ° (Celsius)

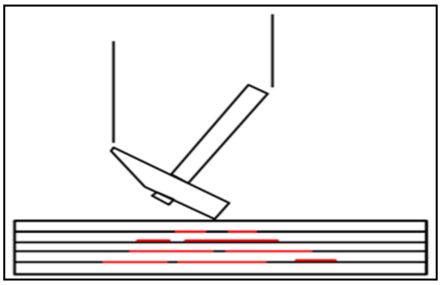


Fig. 3: Damage occurred by tool drop

A window frame having damage as described above can accomplish its mission without any insufficiency.

WF was split into three different zones as per the potential damage occurring scenario (Figure 4). These zones are;

A) Aerodynamic Flange
B) Bonding Flange
C) Inner Flange

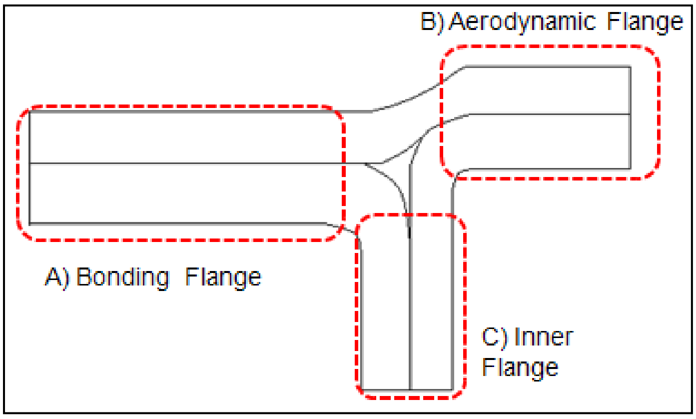


Fig. 4: Potential Damage Occurring Zones

Stress concentration effect on damage tolerance analysis has been considered. The damage of 35J impact is expected to occur at any location between the free edge and cutout edge which was formulated as r = (A+L/2) (Figure 5). Damage Tolerance RFs have been reduced by taking into account stress concentration factor. Only hot/wet condition was taken into account. Cold condition will be analyzed in next loop.

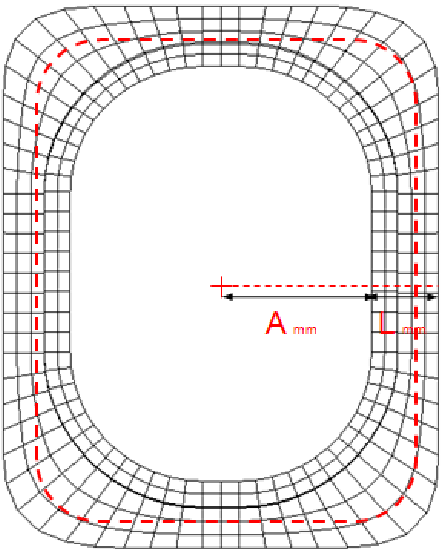


Fig. 5: Stress concentration factor application zone.

Buckling Analysis

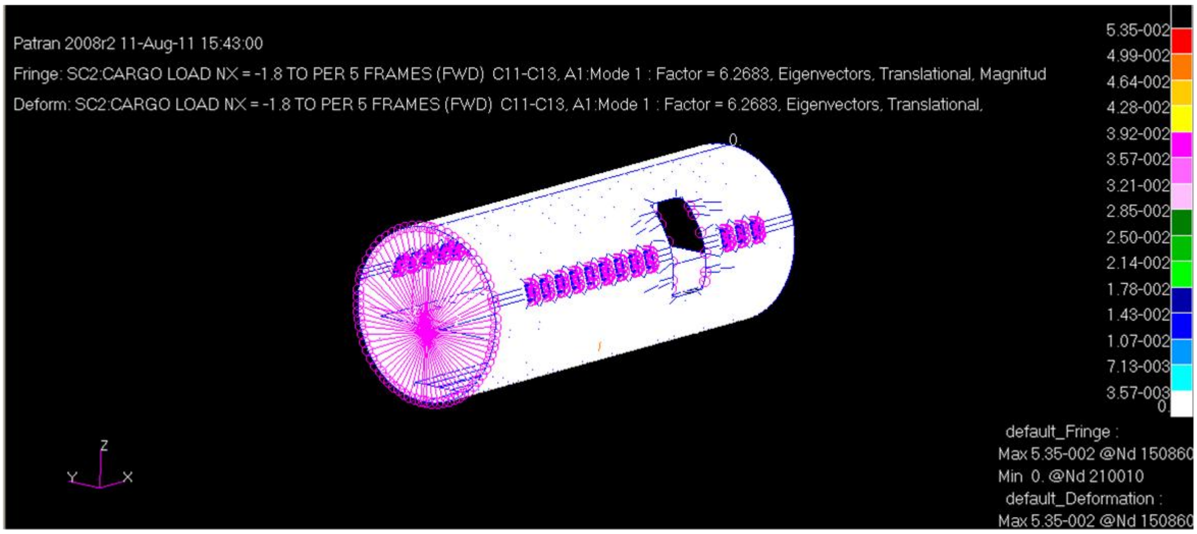


Fig. 6: Global buckling result at load case "-1.8 TO PER 5 FRAMES (FWD) C11-C13"

The FE model which was used for static analysis was also used for buckling analysis because its element size was considered to be sufficient. No FE model refining study was done. All of 53 load cases were run in Nastran 2008 r1 a. Minimum 0.1 and maximum 9.00 Eigens are analyzed in FEM.

No critical buckling mode has been observed in window frames.

Unfolding Analysis

The object of the unfolding analysis is to analyze the through the thickness stresses in composite structures. A bi-dimensional analysis of a WF typical cross section is performed. It is assumed that window frame has two T sections and one L section (see Figure 7). Failure of L profile was occurred at radius zone but failure of T profile is more complex where different failure mechanism can occur.

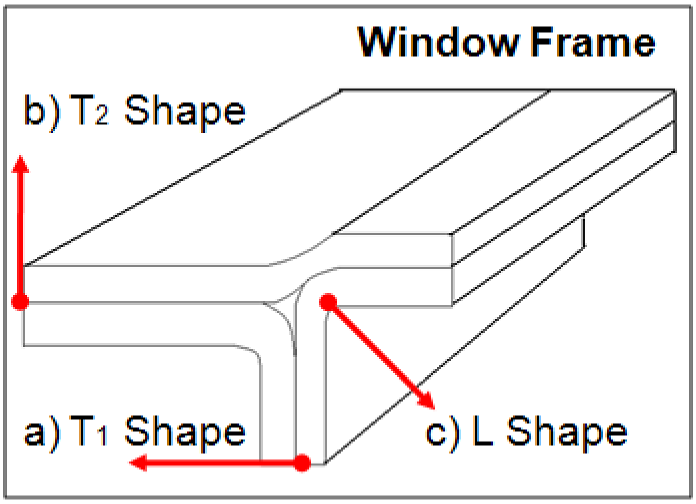


Fig. 7: Unfolding Critical Sections

T Profile Possible Failure mechanisms

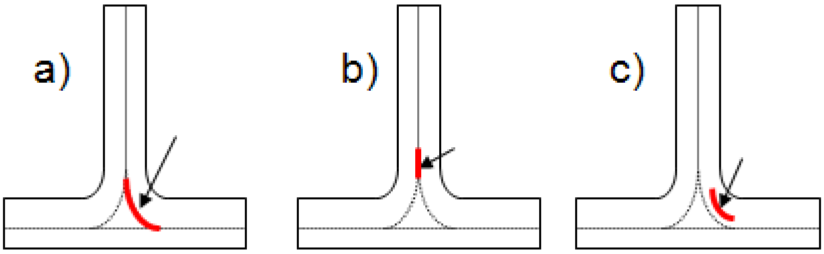


Fig. 8: Failure locations

a) Failure of the interface between the outer surface of radius and delta zone.
b) Failure in the web adjacent to the radius
c) Failure thru the radius.

For both L shape and T shape shell forces and shell moments are extracted from all flanges (see figure 9).

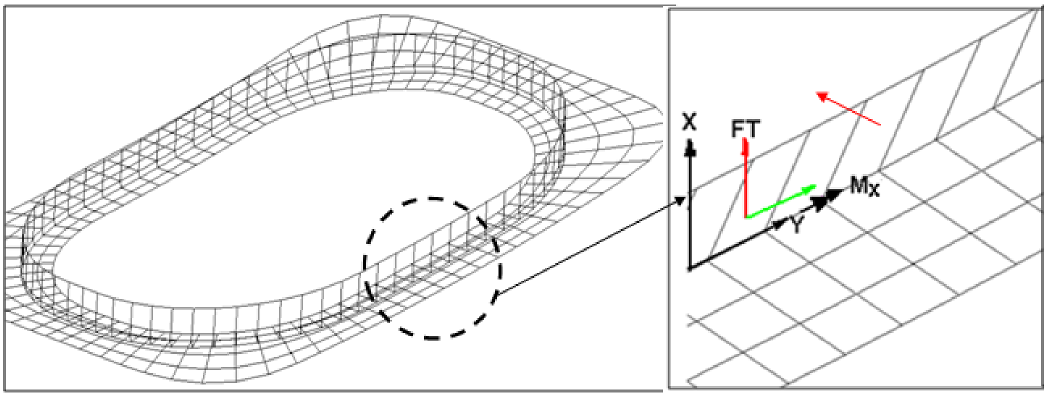


Fig. 9: Load Extraction Method for Unfolding Analysis

During the calculation process for L profile, two failure criteria are considered:

a) Yamada-Sun: harmonized in-plane failure criterion
b) Kim & Soni: harmonized criterion for delamination failure

During the calculation process for T profile, one failure criteria is considered:

a) Delamination failure
b) Bonded analysis of delta zone is not taken into account. This analysis will be performed at section “Delamination Analysis for Delta zone”

Plain Strength Analysis

The plain strength calculation method is used to predict the failure strength of plain composite laminates of window frame. Fibre failure is calculated using Yamada-Sun criterion and matrix failure is calculated using Puck criterion. Plain strength analyses were verified by test results (Fig 10 and Fig 11).

Fig. 10: Compression test specimens

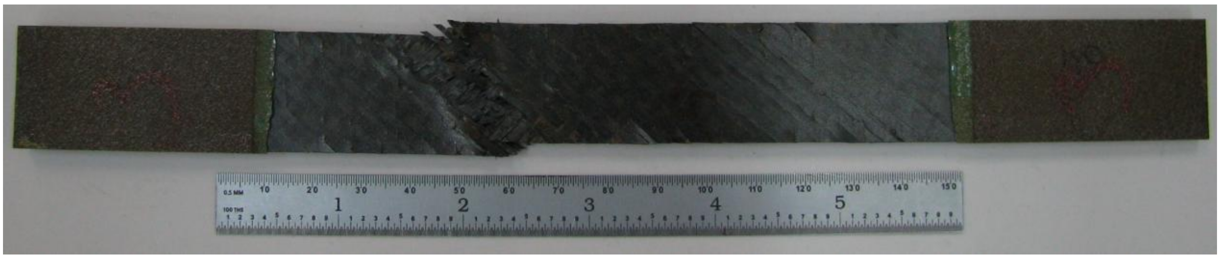


Fig. 11: Tension test specimen

Bonded Joint Analysis

The leading goal of Maaximus project is to assemble WF to barrel without using any mechanical fastener. This goal is trying to be achieved by co-bonding precured WF to skin by the help of adhesive film. Figure 12 shows bonded RTM WF on skin panel. In Figure 13, red surface is highlighted to show the bonding surface on WF. The blue surface shown in Fig 13 is the aerodynamic surface.

Mechanical tests are being conducted to determine the mechanical strength of the bonding material which will be used for bonding of precured RTM window frame to skin panel via cobonding process.

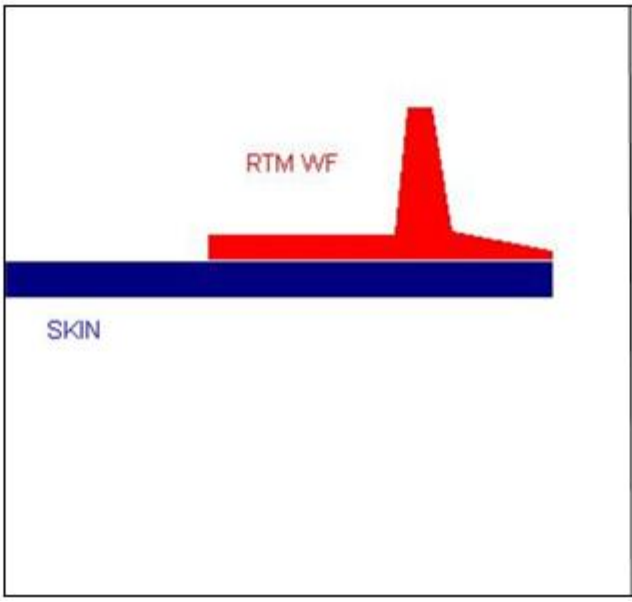


Fig. 12: Cobonding RTM WF and skin panel

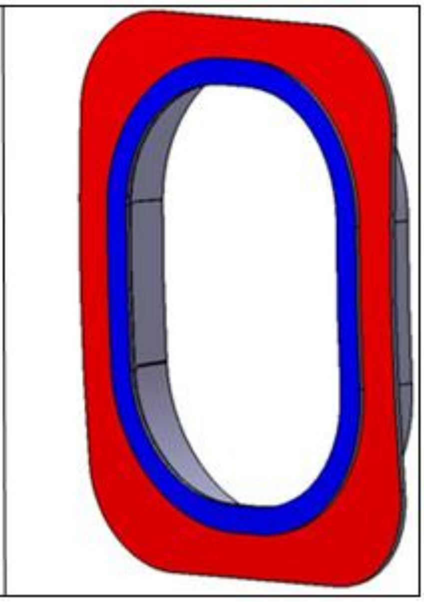


Fig. 13: Bonding surface on WF

The following failure modes will be analyzed for bonded joint;

1) Adherend Failure

a) Interlaminar Tension/Shear of adherend

Adherend failure occurs in composite laminates where, under peeling stresses, the interlaminar strength of the composite adherend is exceeded and fracture occurs (Figure 14).

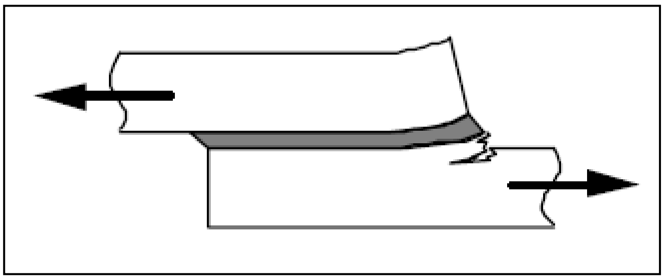


Fig. 14: Interlaminar Tension/Shear of Adherend

2) Cohesive Failure

A cohesive failure occurs when the fracture is through the adhesive and not the bondline interface.

a) Shear Failure (Fig 15)
b) Peeling Failure (Fig 16)

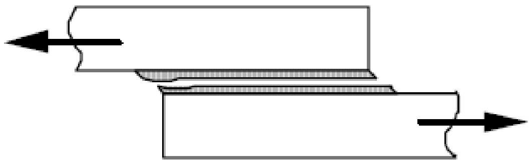


Fig. 15: Shear failure

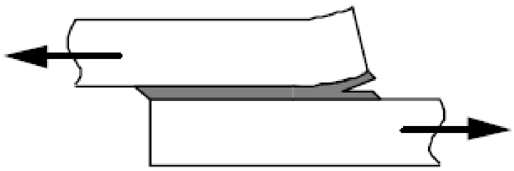


Fig. 16: Peeling failure

3) Adhesive Failure

Failure at the adhesive interface is the least preferred failure mode as it is typically a result of poor adherend surface preparation. This is the most common reason failure occurs at a load below the design strength.

a) Shear Failure (Fig 17)
b) Peeling Failure (Fig 18)

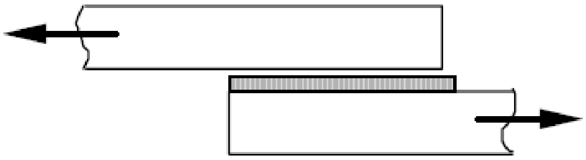


Fig. 17: Shear failure

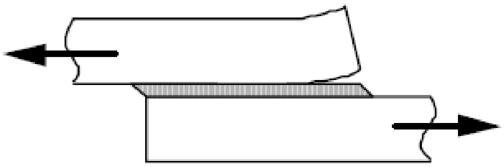


Fig. 18: Peeling failure

Single lap joint analysis will be performed upon adhesive test results will be available.

Filled hole analysis (Repair solution)

This analysis will be performed at next phase of project.

Delamination Analysis for Delta zone

A delta zone is formed due to the cross section geometry of WF. Within that delta zone it is suspected to occur delamination failure at points A, B and C (Fig 19). This analysis will be studied at next phase of project.

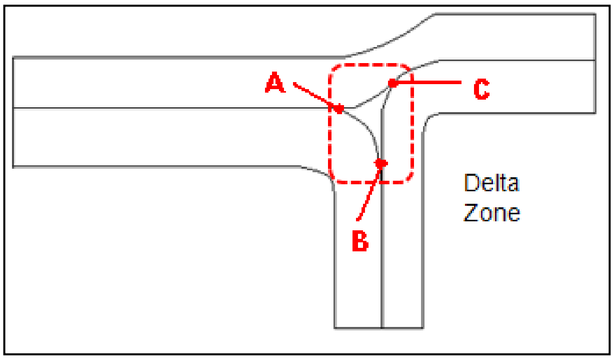


Fig. 19: Delamination Analysis for delta zone

COUPON TESTS

Some coupon tests have been conducted to verify some analysis results (figure 20 and figure 21). Test results proved that the analysis program is more conservative.

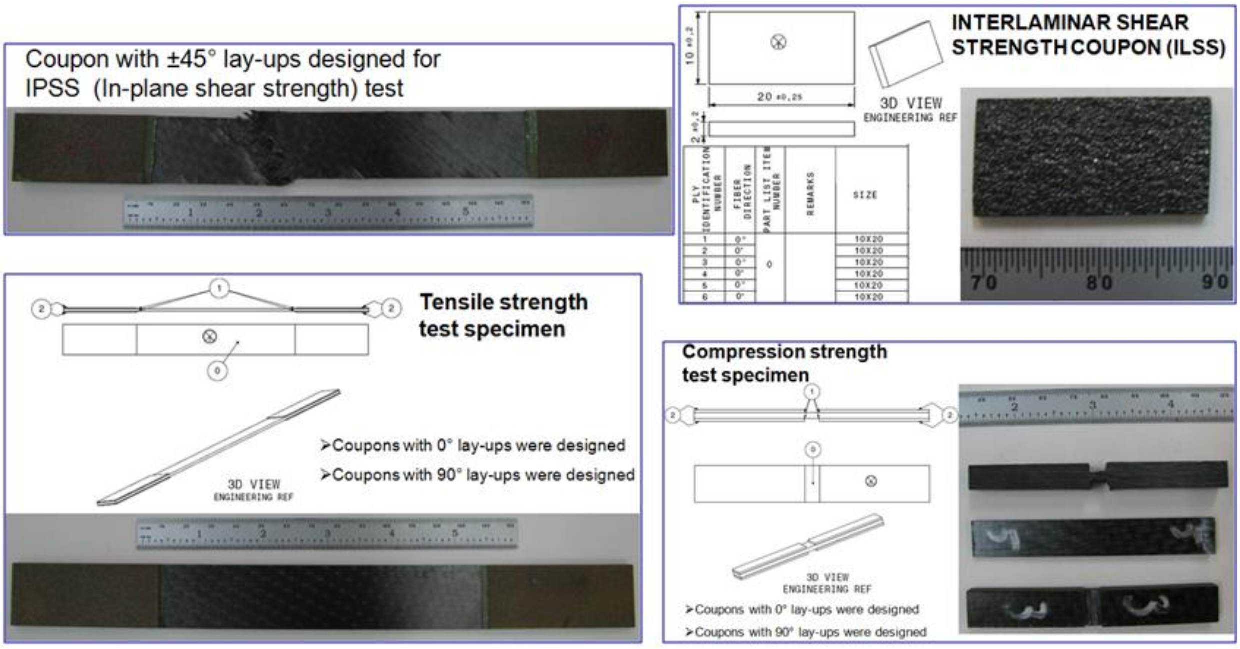


Fig. 20: Manufactured coupons

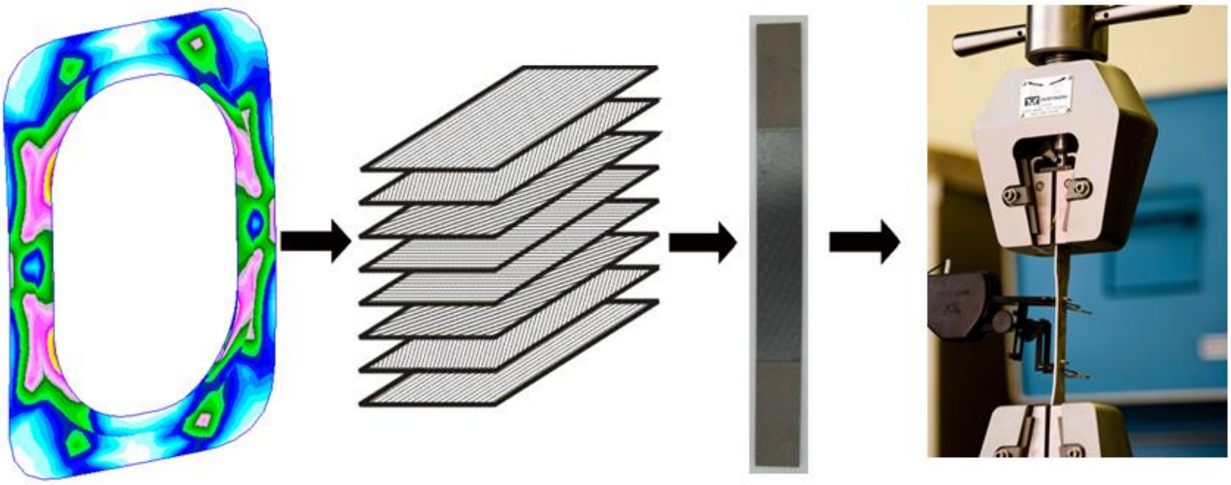
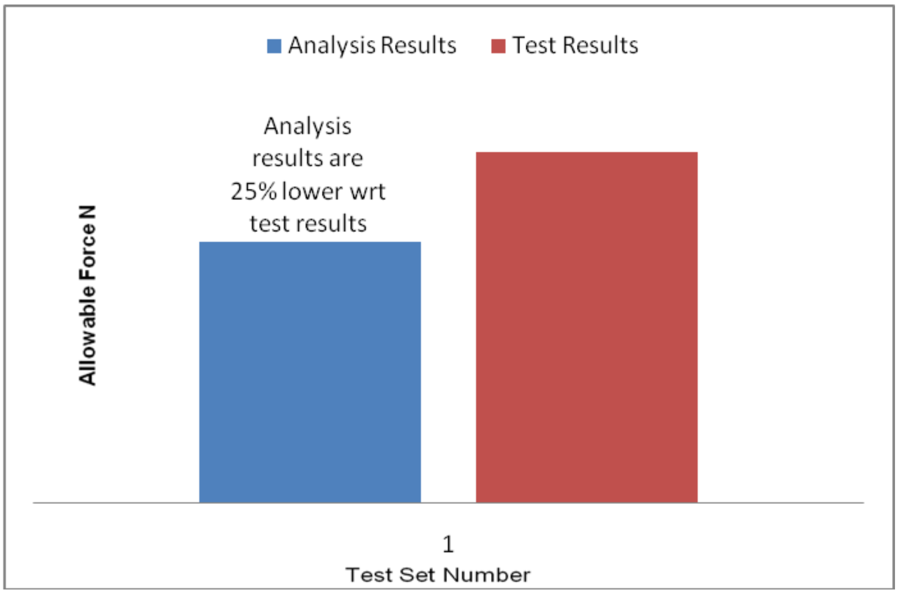
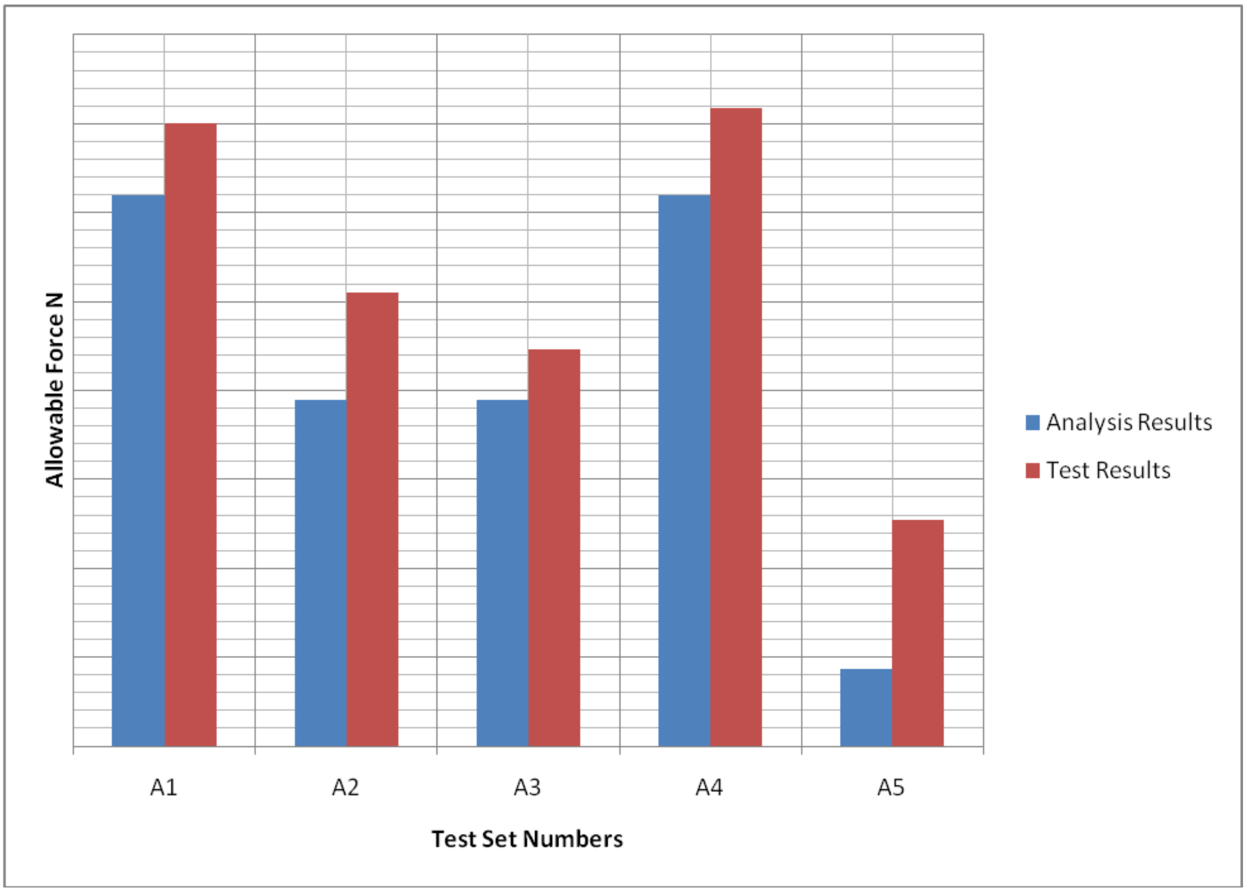


Fig. 21: Coupon tests to verify analysis results

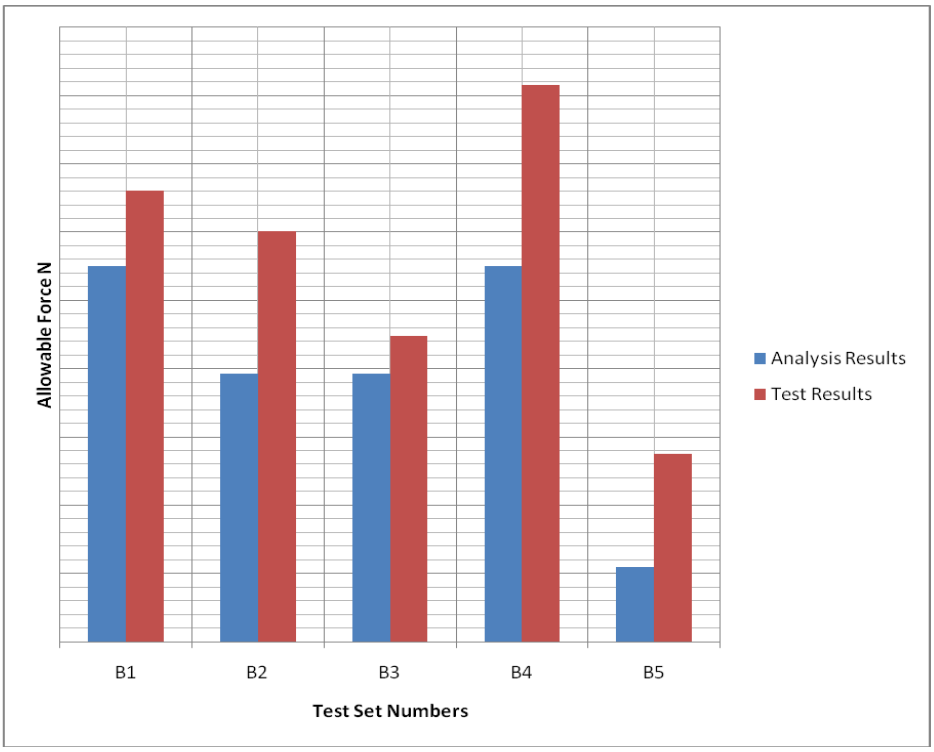
Comparative results of tests and analysis are shown in Graph 1, Graph 2 and Graph 3.



Graph 1: Shear properties comparison, analysis vs. test



Graph 2: Tension properties comparison, analysis vs. test



Graph 3: Compression properties comparison, analysis vs. test

RTM TOOL DESIGN

An RTM tool was designed per the final geometry of WF (Fig 22). Resin flow inside the tool was analyzed and simulated by RTM-Worx v2.8 Beta release program. According to the simulation results internal resin channels have been adapted to the tool design. Tool was manufactured and accomplished the trial WF manufacturing.

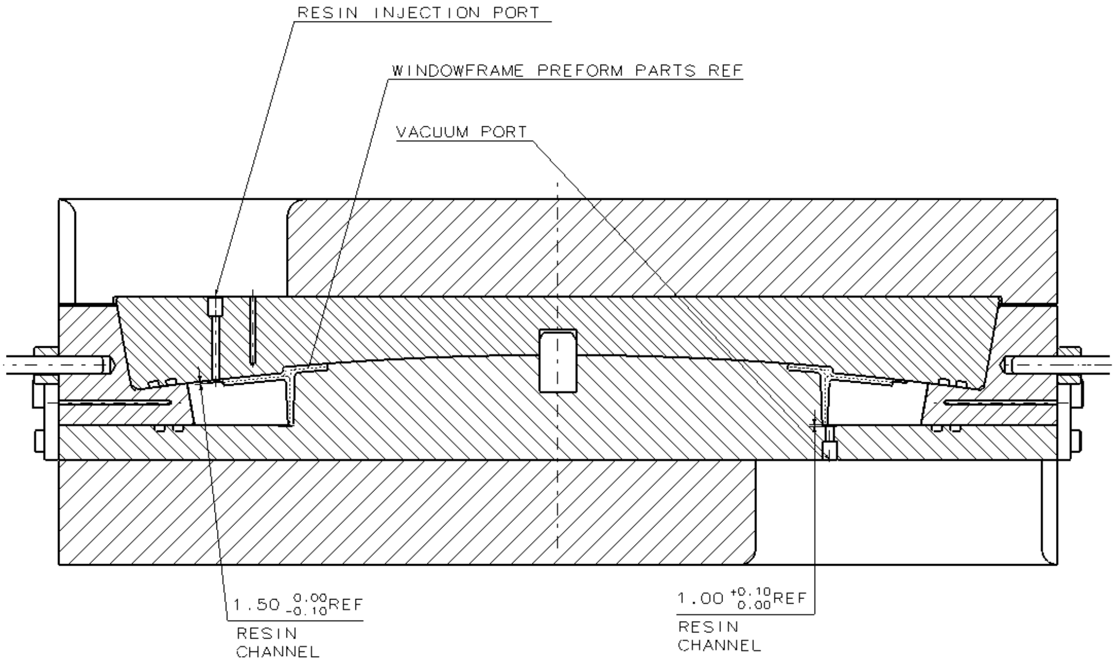


Fig. 22: Designed RTM tool

RTM MANUFACTURING PROCESS

RTM (Resin Tool Molding) is a closed mold process in which matched upper and lower mold parts are used to form the desired composite part volume. Firstly, the volume is filled by dry preformed reinforcing fibers. Then hot resin mix is injected into tool cavity and fibers are impregnated. Once the resin injection is completed composite part is cured according to the component specific cure cycle.

The detailed window frame manufacturing process is described below [1]:

Dry reinforcing fabrics are cut to size according to the required dimensions and orientations given in drawings by an NC machine (Fig 23). Cut plies are identified per the stacking sequence specified in drawing. Plies are protected against dust and moisture within temperature limits.

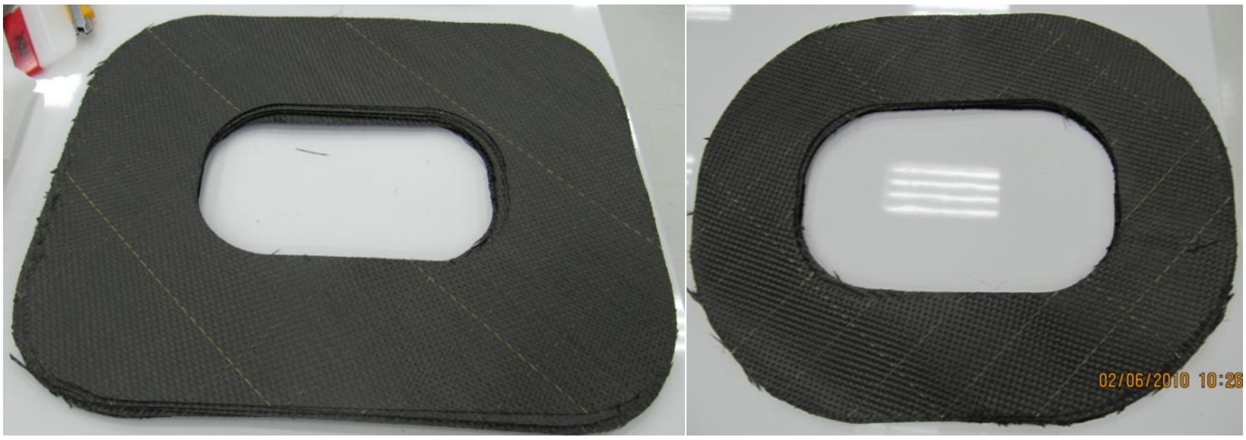


Fig. 23: Cut plies according to required orientation and dimension

All tool surfaces are cleaned out of dust, residual resin and contaminants. Release agent is applied on molding surfaces. Dry fabrics are laid up on mold surface and each and every layer is subjected to compaction (Fig 25). After compaction fabrics are heated up to definite temperature in order to activate binder in fabrics while maintaining vacuum with the help of a vacuum bag. Binder helps to prevent disintegration of the preform by sticking plies to each other (Fig 24).

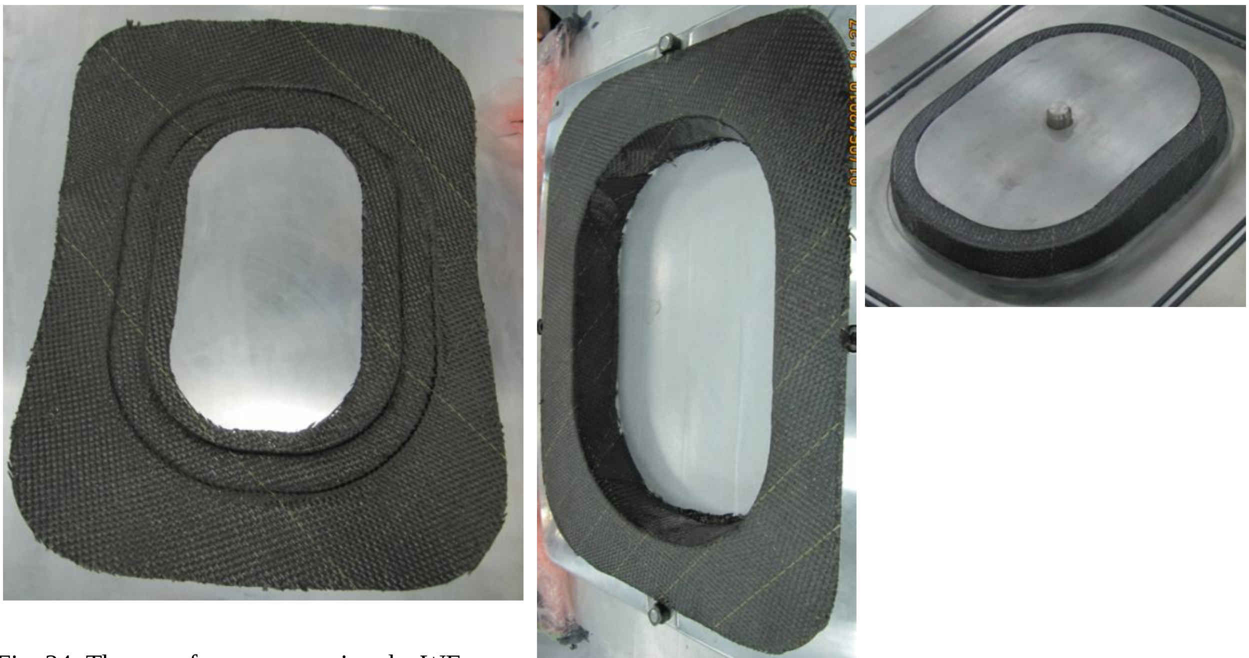


Fig. 24: Three preforms composing the WF

Fig. 25: Compaction and heating process of preform

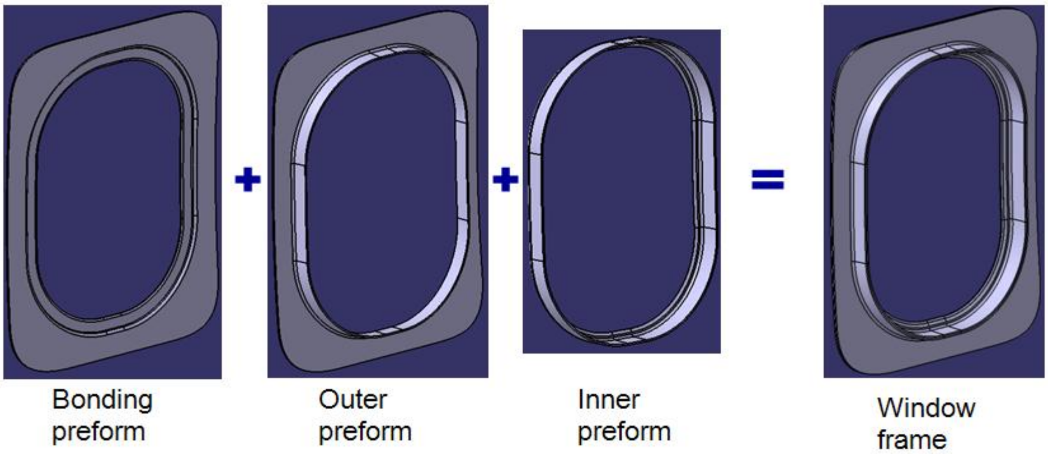


Fig. 26: Integration of preforms

The RTM tool is cleaned and release agent is applied prior to injection. The assembled performs (Fig 26) are placed in injection mold. Thermocouples are located at predetermined positions. Tool is closed and sealed. Then, a definite vacuum pressure is applied within a fixed time interval. A predetermined amount of resin is heated in injection system up to the specified temperature and degassed. At the same time RTM tool was heated up to specified temperature. The resin is injected into tool till a bubble-free flow was observed at tool exit. Upon the completion of injection phase, curing cycle is initiated and performed per applicable special process document [2]. The RTM injection system is shown in Fig 27.

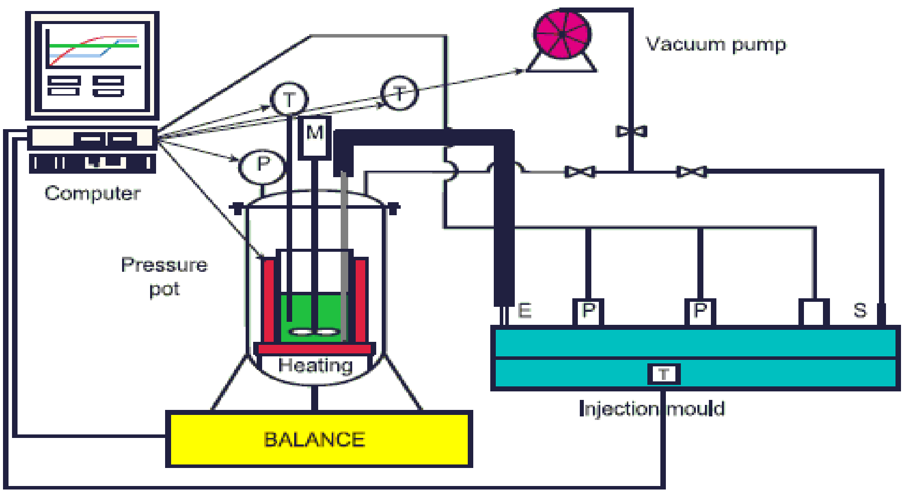


Fig. 27: RTM injection system

Cured part is removed from tool after cure cycle was completed. Cured parts are subjected to non-destructive ultrasonic inspection. An RTM cured window frame is shown in Fig 28.

Fig. 28: RTM window frame

The second phase of the project is to assemble cured window frame on skin panel by co-bonding process (Fig 29). A definite number of carbon prepreg UD tapes will be laid up on a layup tool according to the predetermined stacking sequence. On top of these tapes an adhesive film will be laid up. Then, previously cured WF will be indexed on to film adhesive by the help of a indexing tool. Upon completion of compaction cycle a second cure cycle which is compatible to UD tapes and adhesive film will be carried out [3]. No mechanical fasteners will be used in this component. Cured component will be subjected to non destructive inspection to assure that the component does possess an acceptable quality level. Finally, clamping tabs will be installed on outer edges of component to facilitate the fastening of component to the test jig. The analysis results of this study will be verified thru mechanical tests (Fig 30).

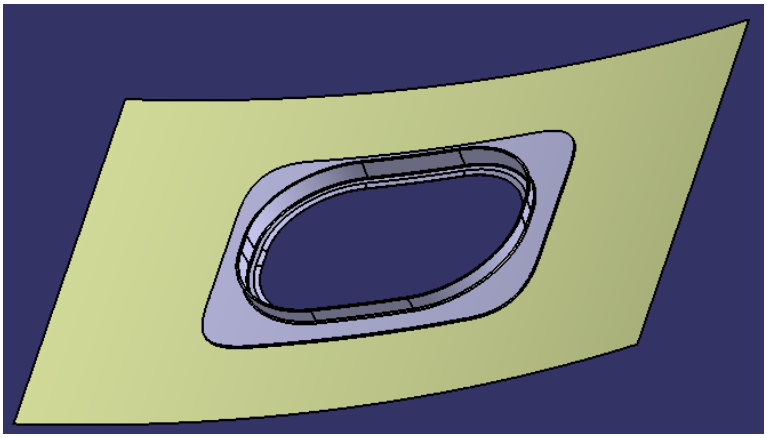


Fig. 29: Co-bonding WF to skin panel

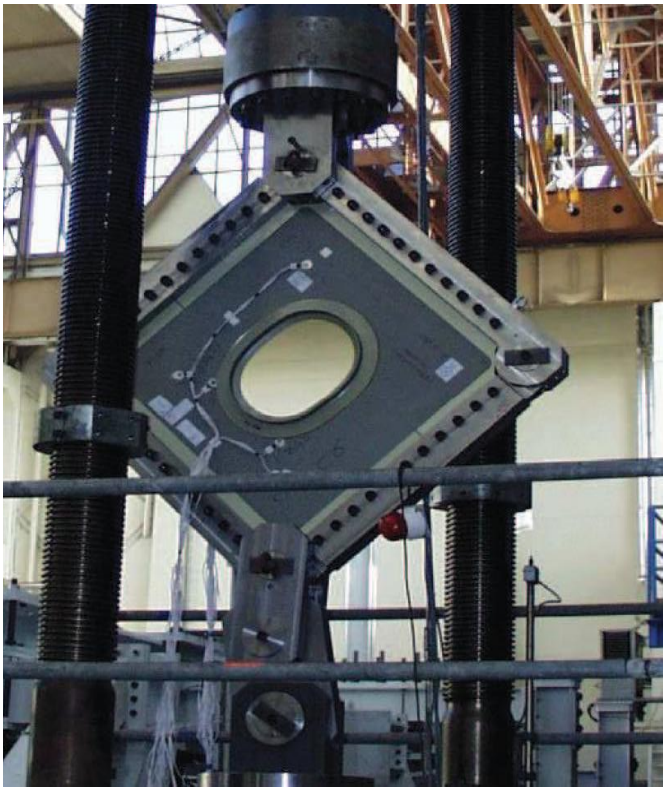


Fig. 30: Testing of component

WAY FORWARD

Repair/reinforcement methods will be studied as a next step in the project. Correlation analysis with respect to test results will be performed upon completion of shear test. Weight optimization study will be redone according to the test results.

References

[1] TAI, TPS-800_RESIN TRANSFER MOULDING, GENERAL, Issue 1, Aug 2011

[2] TAI, SPR_Special Process Requirement Window Frame, Issue 2, Jun 2010

[3] TAI, TPS-740_RESIN IMPREGNATED GLASS AND CARBON FIBER REINFORCED COMPOSITE PARTS (LAMINATE AND SANDWICH) MANUFACTURING, Issue 8, 16.11.2009