COMPOSITE BEHAVIOR OF ASSEMBLIES WITH AEROTISS® O3S TECHNOLOGY

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Abstract

AEROTISS® O3S technology is based on a stitching process where two fabric preforms are linked together with yarns which are implemented by a needle in one side. This paper outlines tests performed on T-joints with different stitching patterns and combined tensile-shear loading conditions. The main part of the paper concentrates on the analysis of the experimental results with finite elements modelling. Therefore the role of the resin and the stitching yarns has been analyzed. The study has revealed that pure shear stresses were not achieved with the ARCAN test device. A non linear mesoscopic model has been proposed to describe behaviours of the samples and has clearly demonstrated the yarns are not equally loaded. The instrumentation of the samples with strain gages and displacement sensors has permitted to corroborate the computed results.

The combination of two directions of stitching yarns offers the advantage to have a better distribution of the load giving a quasi constant ultimate tensile strength even when out of-axis loaded.

1 Introduction

Design of structures out of composite materials poses the problem of the assemblies of different components made of composite or metal. The methods most often used are based on rivets or bolts assemblies mainly used in aerospace sector. Adhesive joining is as much as need used in the space field to optimise mass savings but structural adhesive joining is more complex to master as well in its realisation as in its justification when complex mechanical loading conditions are encountered.

With RTM process (Resin Transfer Moulding) or its derivatives, stitching technology offers new ways of composite parts assemblies by combining the integration of functions as soon as possible in the process and by obtaining higher mechanical resistance than adhesive bonding.

In addition to master this process in terms of stitching conditions (e.g. type of thread, stitch pattern, stitch density, stitch length, thread diameter,..) arises the problem of the understanding and modelling of the behaviour of such advanced joining under combined mechanical loads.

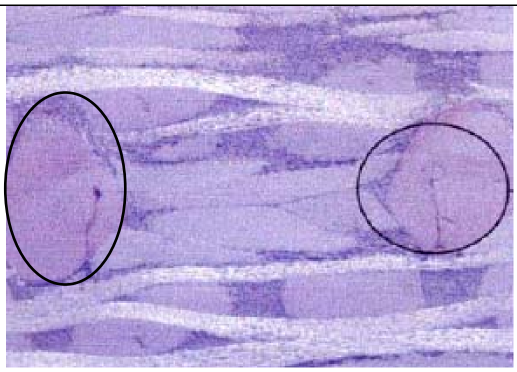
This paper is dealing with the AEROTISS® O3S technology developed by ASTRIUM and issuing experimental data obtained on samples loaded with an ARCAN test device in order to reveal the performances of such joint in a given loading domain. A detailed analysis of the behaviour of these samples is presented.

2 AEROTISS® 03S technology

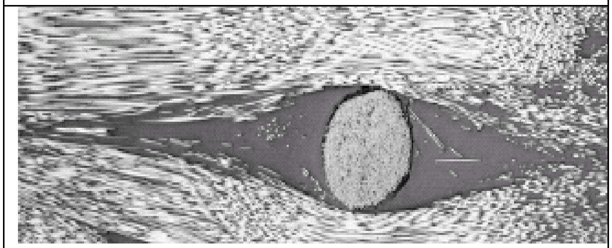
AEROTISS® O3S technology is based on a stitching process where two fabric preforms are linked together with yarns which are implemented by a needle in one side [1], [2]. This process can lead by using robotized tooling coupled with CAD tools to assemble complex parts. The limitation is generally governed by the RTM mould used also for the stitching operation, yarn size, yarn density and yarn pattern are chosen with respect to loading conditions. Stitched wrap-knit textile composite materials are currently being considered for use in primary aerospace structures. Recent work on stitched lap joints has shown a twofold increase in static strength due to stitching and similar increase could be found in fatigue strength [3]. It has been observed the stitches were quite effective in arresting further damage growth. Similar conclusion has been drawn with Z-pinning technique [4].

Compared to Z-pinning technique, the stitches don't introduce resin cavity as depicted in Fig.1. Because of the effecient embedment of the stitching yarns inside the fiber preforms, load transmission is more efficient.

The performance of such joint is strongly linked to compromise of the required quantity of stitching yarns and the volume fraction of fiber in the joint area.



Aerotiss® O3S – detail of the stitches



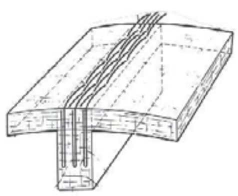
typical resin pocket around a Z-pin

Fig. 1. Photomicrographs of stitched yarn compared to Z-pin

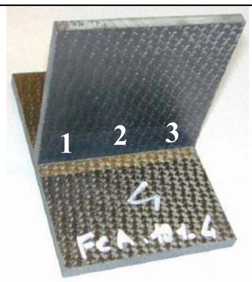
3 Test sample definition

The mechanical performance of the assembling has been studied with T-joint samples which have been loaded in different directions in the plane of web. With an ARCAN type tooling we could combine tension and shear stresses in the joint area.

T-joint samples manufactured with G1151 carbon fabric preforms were stitched with T800H carbon fiber and densified with RTM6 resin as shown in Fig. 2.



AEROTISS® O3S concept



test sample

Fig. 2. T-joint sample

The volume fraction of fibers is about 50% and porosity about 1%. The stitching volume fraction is in range of 4,5% to 5,5%. Several stitching patterns have been studied. This study concerns three simple patterns with one direction of stitching for understanding purpose and a bi-directional stitching.

Table 1. Pattern definition

Pattern	Number of rows	Stitching angle
D1	7	90°
D2	7	45°
D3	9	90°
D4	9	45° (4), 90° (5)

With D4, five rows with 90° orientation were in the middle of the joint and two rows 45° were placed on each side.

These patterns are defined with the same stitching step and the angle is calculated from the flange surface taken as the reference. Therefore a 90° angle means that the yarns are perpendicular to the flange.

4 Test description

T-joints were clamped in a special fixture which was designed to transmit load to the joint in tension or in shear and to avoid undesired out of plane stresses. The flange wasn't glued to the fixture.

The sample was then mounted in an ARCAN test device which allows to change the direction of loading on the sample by a simple rotation (here each 15°) as shown in Fig. 3.

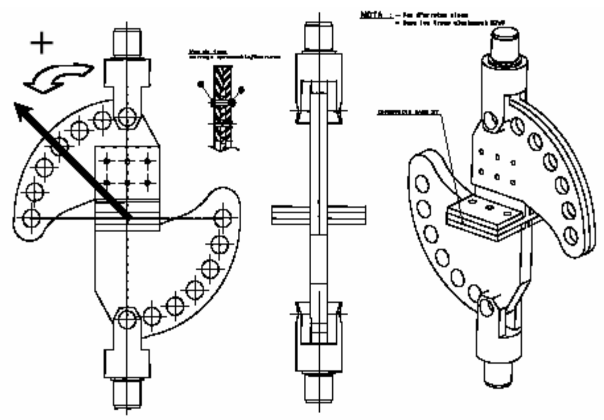


Fig. 3. ARCAN tensile test device

Samples have been instrumented with unidirectional strain gages on both sides of the web in the vicinity of the joint and displacement sensors to measure the vertical displacement of the web and the flange. Samples were loaded at a constant cross head displacement speed.

5 Test results

Strain gages didn't reveal low bending moment of the web. The failure mode was always the same and located at the interface between web and flange. Visual observation of the fracture surface has clearly shown yarns rupture with pull-out which length is concerned with stress distribution. Generally the pull-out length is shorter in configuration of pure tensile stress of the yarn. The photomicrographs presented in Fig. 4 illustrate two fracture surfaces one with pull-out yarns and the second with holes which can be observed equally on the two pieces. In any case pull-out length is less than the flange thickness (here 10 mm).


pull-out yarns


extracted yarns

Fig. 4. Typical fracture surfaces

No visual delamination and fiber rupture in the vicinity of the fracture area has been reported for both pieces.

Test results are given as load fluxes at failure for different angles of loading (table 2).

For some cases we were surprised to have rupture in the web in net tension mode at the first line of bolts. This is noted in table 2 with ">" symbol.

A simple analysis of the results shows the ultimate fluxes decreases when the load is not in the stitching direction. The increase of number of stitching rows doesn't increase proportionally the ultimate fluxes. With D2, one can notice that the loading at 0° which corresponds to -45° with the stitching yarn direction gives a lower performance compared to D1 tested at 45°. This is due to the fact the resin at the interface is in this case loaded in tension and not in compression as D1. With the condition of -90° loading, D2 type sample behaves in the same manner. Another point concerns tests at 90° which have shown a good performance even better than at 60° for D1 and D3.

Table 2. Load fluxes at failure

	Ultimate tensile flux in KN/mm				
angle	**D1**	**D2**	**D3**	**D4**	D4*
-90°		0,34			
0°	0,94	0,33	1,47	0,86	0,86
15°	0,9				0,9
30°	0,75	0,7	1,1	1,1	0,94
45°	0,58	1,03	0,92	>1	1
60°	0,54		0,71		0,89
90°	0,69	>0,96	0,79	>0,94	1,03

With D4, results are more interesting in terms of the lower variation of the ultimate flux with the direction of loading in the range of 0° and 90°. The potential in tension of this joint is 0,8KN/mm for 9 rows of stitches.

A preliminary theoretical estimation of the ultimate flux of D4 samples has been established based on experimental results obtained with the basic patterns represented by D1 and D2. A linear calculation has given a quite good prediction if we compare results from D4* with D4 in table 2.

6 Analysis of the test samples behaviors

In order to better understand the behavior of the samples, a 3D finite elements model has been developed with SAMCEF software. The main difficulty is to well compute the interface composed by yarns and resin along the test sample. The first step was to consider the rows are homogenous along the sample. In the case of D1 (7 rows) tested in tension 0°, the flange bends and the load distribution over the joint width is no longer homogeneous as illustrated in Fig 5. Therefore with this condition of sample fixture, the majority of the load is supported by the two external rows and the calculated stress at the joint interface is then twofold the average stress of the joint (ultimate load divided by joint surface) Fig. 6.

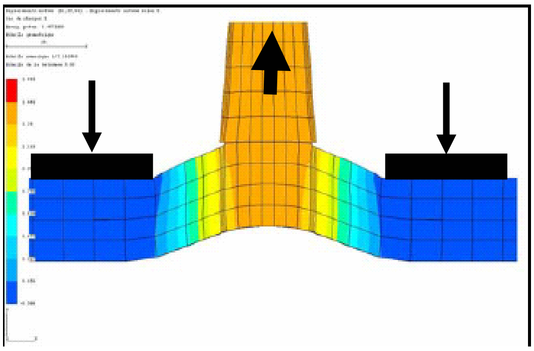


Fig 5. Deflection of the flange (x 3)

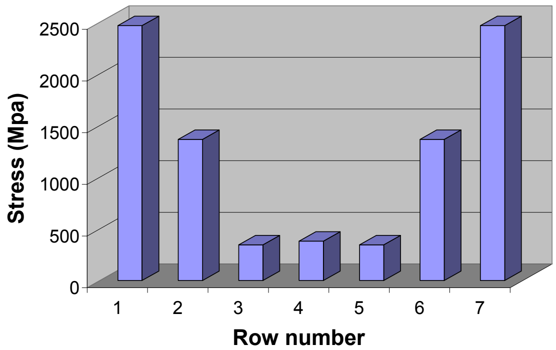


Fig. 6. Stress evolution of the yarns along the joint (tension 0°, D1, 0,94KN/mm)

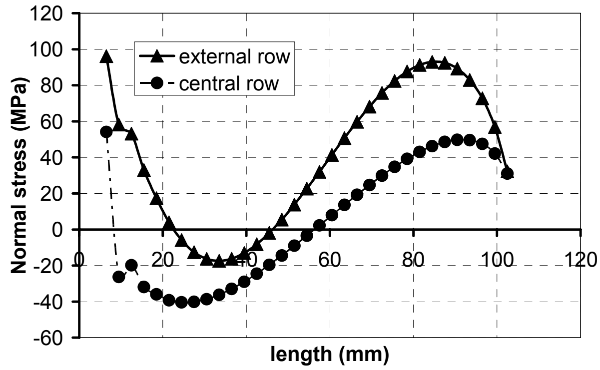


Fig. 7. Normal stress distribution of the yarns in the bond (tensile 90°, D1, 0,69KN/mm)

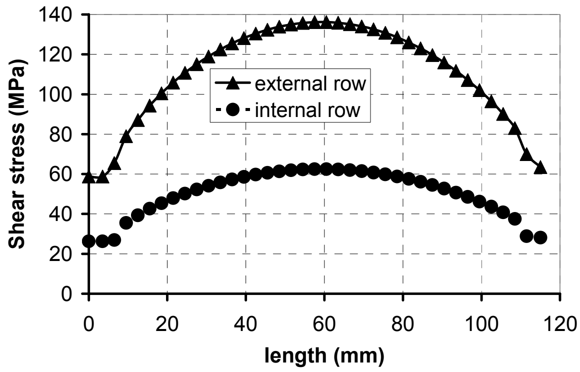


Fig. 8. Resin shear stress distribution in the bond (tensile 90°, D1, 0,69KN/mm)

With 90° loading configuration applied to D1, external stitching yarns were also overloaded. Moreover the stress distribution varies along the test sample. This is explained by the in-plane rotation of the flange that the fixture system cannot avoid. Hence the 90° configuration with the ARCAN device cannot simulate pure shear condition. This is illustrated by the curves in Fig. 7 where the distribution of the normal tensile stress along the row of stitching yarns is plotted and with Fig. 8 with the evolution of the shear stress in the matrix versus the length of the joint. Again the computed shear stresses at the edge of the joint are significantly beyond the ultimate shear strength of the RTM6 resin.

This could simply explain the mechanism of failure is driven by a progressive damage from the edge of the joint with a progressive reloading of stitches until they could not sustain the applied load causing a sudden failure of the sample.

The 3D finite element model has been improved to take into account each yarn individually and resin as well which were modeled by discrete nodal forces placed so to mimic the physical reality.

The behavior law being used in this study is based on assigning stress to zero when the failure criterion for each element is exceeded.

This non linear modeling allowed simulating the evolution of the load with the displacement of the applied force on the web (including the bending deflection of the flange). This advanced model has given a better description of the test sample behavior. Progressive matrix rupture from the edge to the centre of the joint is simulated. For instance the ultimate failure of the D1 loaded at 0° was predicted when debond has reached the third row of stitches which were unable to sustain the load. The flux calculated at failure is less than 3% of the experimental value.

Fig. 9 and Fig. 10 give respectively the simulated tensile curve and the experimental one.

Experimental and theoretical curves are quite similar and the flux drops are pure numerical artifacts. The two displacements sensors show the yarn debonding is significantly observed just before failure.

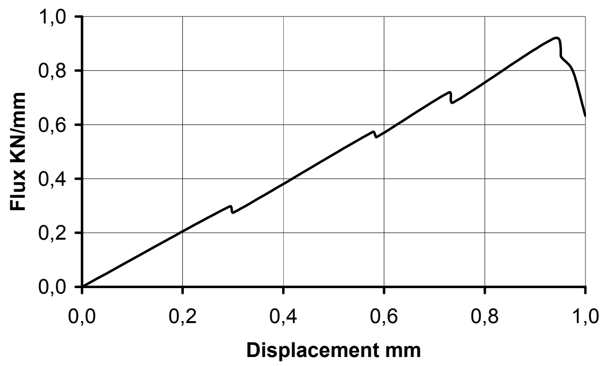


Fig. 9. Simulated tensile curve (D1-0°)

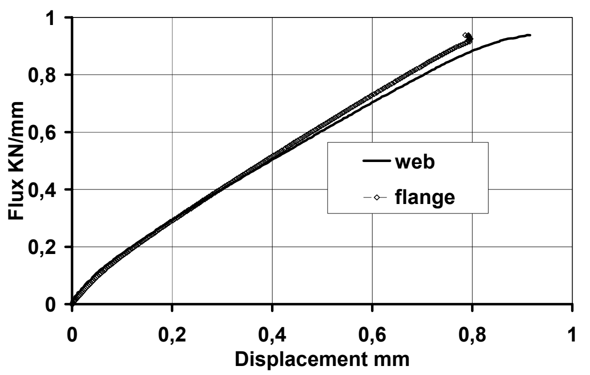


Fig. 10. Experimental tensile curves (D1-0°)

With the unidirectional strain gages, fruitful information has been obtained. Flux/strain curves were obtained by calculating the average strain of the face to face gages. The gages referenced as gage 1-1' and gage 3-3' were located at the ends of the sample and the gage 2-2' in the middle as illustrated in Fig. 2. Strain gages measure the surface strains in the vertical direction of the web.

As expected, D1 and D3 loaded in the direction of the stitches are quasi linear up to failure in homogeneous manner along the sample.

D4 behavior in 0° loading is mainly driven by the 45° external rows which are overloaded. Damage occurs at about 70% of the ultimate flux as recorded by the strain gages along the sample. The load is then redistributed to the inner 90° stitching rows.

Behaviors of samples tested at 90° are more complex to analyze because of the mixed modes of tension, compression and shear. The in-plane rotation of the flange is clearly measured for the three samples as previously predicted by the finite elements model (gages 1-1' in tension and gages 3-3' in compression).

This rotation induces damage again detected by the strain gages.

The lack of 45° yarns for D1 and D3 induce damage via the edges of the joint (resin and probably debond of the first row of stitching yarn). The non linearity occurs at 0,4KN/mm for D1 and 0,6KN/mm for D3. This flux difference is linked tor the number of rows.

With the D4 tested at 90° the behavior is different since the strains increase gradually with the applied flux up to 0,9KN/mm. No significant damage is measured until failure which occurs in the web due to net tension failure of the first bolts line.

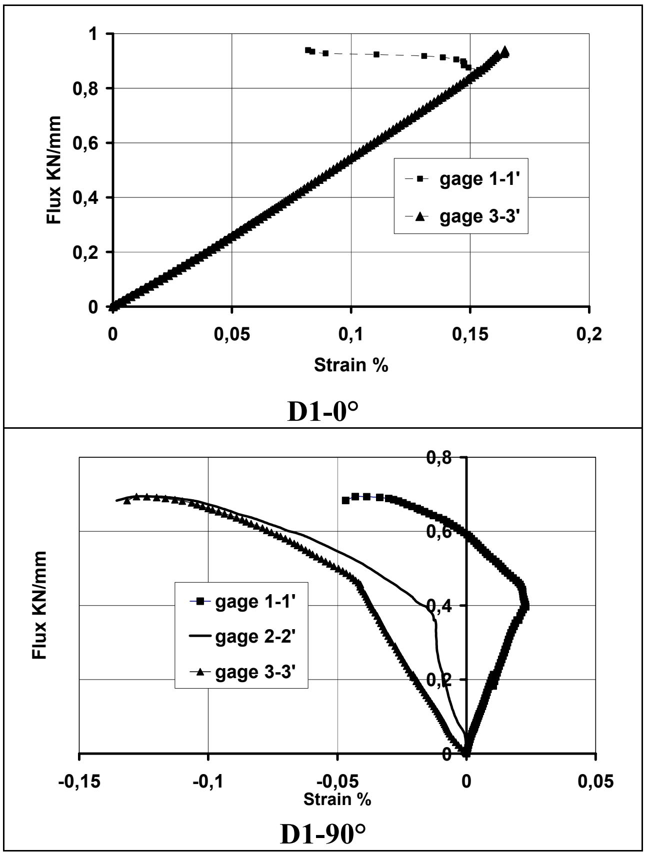


Fig. 11.Flux-strain curves for D1

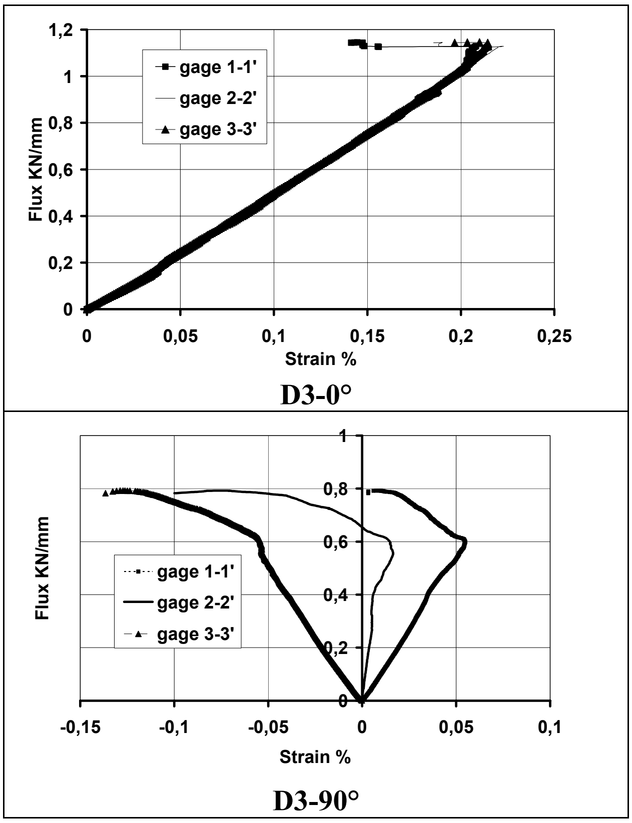


Fig .12. Flux-strain curves for D3

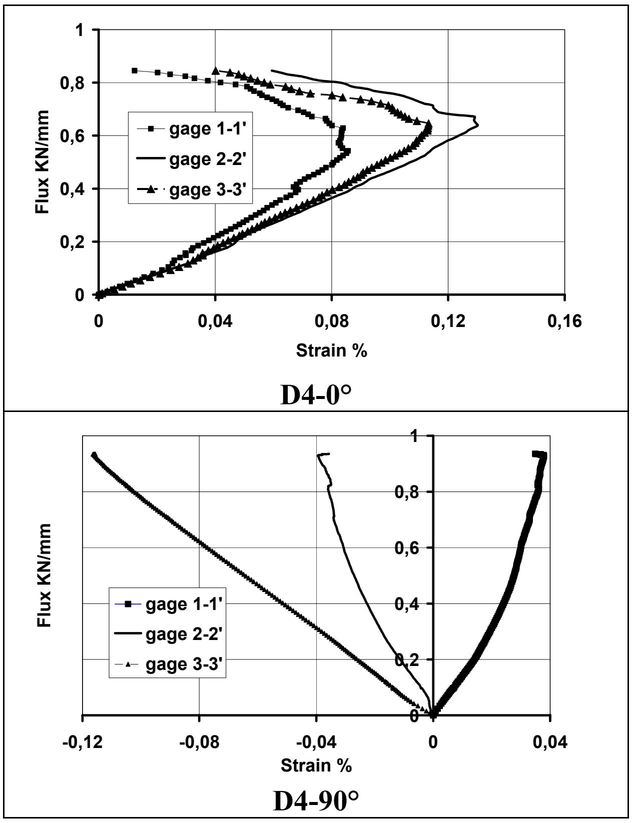


Fig .13. Flux-strain curves for D4

7 Conclusions

These tests performed on simple T-joints samples have contributed to gain a better understanding of the behavior of AEROTISS® O3S stitched joints under static loading with combined stresses. Resin and stitching yarns have different contributions with respect to the combined stresses. The pure shear stress couldn't be achieved with this ARCAN mounting device and the performance of the test samples in such condition couldn't be studied with satisfaction.

The 3D finite element model with a mesoscopic modeling of the joint is essential to understand the test sample behavior and useful in the way to establish failure criteria.

Stitched composite joints with AEROTISS® O3S technology offer an alternative solutions to the classical riveting joints with respect to fatigue or corrosion damages and with cost saving. Better than structural adhesive bond (twofold), this technology has already received a positive interest as secondary composite structures. The feasibility of using such technology has been studied in the frame of a full composite spoiler with high loaded fitting for new load-bearing aircraft structures [5]. This technology can be used to manufacture in one shot complex parts integrating mechanical functions.The limitation in load transfer is governed by the limited quantity of stitches and the potential reduction of performance reduction of the assembled pieces in the joint area.

References

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