NEW CHALLENGES IN STRUCTURAL DESIGN AND ANALYSIS OF COMPOSITE STRUCTURES

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OVERVIEW

With a 9% of growth every year for the aerospace sector since 2003 (source "JEC"), composite materials are progressively integrated in all the primary structures of aeronautical sector:

- 100% of NH9O and TIGRE Helicopters fuselage are today 100% in composite,
- 26% of the A380 aircraft is also made mainly of carbon fibre composite with Major primary structures as aircraft rear fuselage, central wing box, horizontal and vertical tail plane,..etc
- At least 50% of the next aircraft generation,

The main driver to explain the continuous CFRP introduction being the direct weight saving with direct opportunity for additional pay loads or additional systems integration for passenger comfort, aircraft operability or passenger safety.

Compared to the metallurgical sector considered as a pillar for many of our industries in the last century, composite technologies are much younger sciences with great innovation perspectives. Their tailored, neat to shape abilities and/or cost reduction perspectives by function integration explain their attractiveness for the aeronautical sector.

In order to strengthen the aeronautic sector competitiveness, or passenger survivability, researches in the field have been very active for the latest years and supported by many researches only possible at European level.

Starting from research in materials or processes highly product oriented, researches for new sizing criteria and methodologies have been carried out.

The present paper illustrates the results of prospective and intensive researches on preforms and injection technologies for structures with the way forward for robust design methods:

- LRI and LRI VAP know how for large scale panel manufacturing,
- dry preforms made by tow fibre placement,
- dry weave and braid textiles from design to production cycle by highlights on the product lifecycle behaviour prediction,
- dry preform assembly Z-pinning process for function integration and evaluation of structural behaviour.
- highlights for future research on topics like impact of defects,

1. MEANS FOR PREFORMS AND INJECTION TECHNOLOGIES AND ASSOCIATED MODELLING TECHNIQUES

For approximately two decades, EADS Innovation works has been carrying out intensive research on Resin Transfer Moulding Technology and its derivate technology types: (LRI, RFI, LRI VAP,…) in order to be able to manufacture complex geometries with a maximum of function integration. Such a route allows to go beyond the classical prepregs edification route where each individual part often has to be finally assembled mechanically (bolts, rivets,…) or by bonding technologies. With infusion and textile preforms technologies, final part geometries of complex shapes are targeted with very limited final operation compared to other manufacturing routes.

Technologies to manufacture fibrous preforms are of different types varying from level of automation and geometries complexity from 2D to 3D. Fibrous preforms can be built up by process such as manual laying up of different fabric layers, weaving, in plane or 3D stitching, Z-pinning, braiding technologies,…etc.

Automation level offers potential for cost reduction whereas 3D reinforcements offer high potential for improve damage tolerance, structural integrity and energy absorption.

Due to the complexity of this tailored material to structural route approach, understanding of process principles, behaviour laws, and mechanical failure prediction are much more complex to assess and need to be developed in parallel to the technologies. In several cases, continuous models as industrially used up to day, need to be replaced by discrete models and modelling approaches need to integrate multi scales from at least meso to macro. Factors to be taken into account are such as friction (eg. like encountered in forming), fibre waviness, drapability, infiltration, tooling…… Most of know how and tools in this field remains at a research level and industrialisation deployment remains very low with a case by case demonstration.

2. DRY FIBRE PLACEMENT

2.1. Means for dry fibre placement technology

Dry fibre placement is an automated tow deposition laying up process.

Dry Fibre placement technology is developed in order to propose an industrial and liable preforming solution fully automated for the manufacturing of dry preforms of complex geometry parts. It is a solution that spreads out the scope of application of LCM technologies and that should limit preforming costs.

2.2. Dry fibre placement principle

EADS Innovation works is actually developing the Dry Fibre Placement [1] jointly with Dassault Aviation on the basis of a 7 Cartesian axes shared machine able to lay-up bands of 8 tows of 3.2mm each. A dedicated tow placement head has been adapted on a pre-existing Thermo set fibre placement machine from ADC.

Figure 2.2.a shows a picture of PIRUS machine used for dry fibre placement development with the help of some well adapted modifications made by EADS Innovation Works and Dassault Aviation.

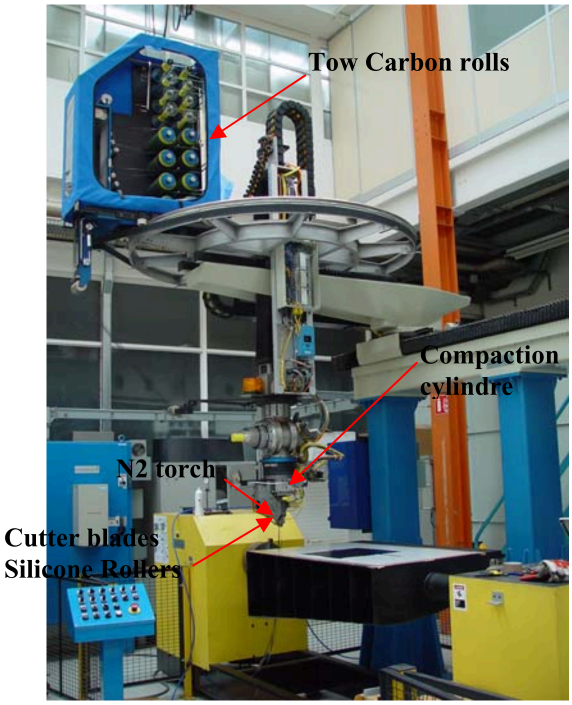

FIG. 2.2.a: Fibre Placement PIRUS machine shared with Dassault Aviation, Eurocopter France and AIRCELLE

2.3 Dry Fibre Placement feasibility trials

Within ALCAS FP6 Business Jet Fuselage platform, EADS Innovation Works in cooperation with Dassault Aviation has run the first feasibility trials with this new technology. The targeted application was carbon inserts aiming to reinforce the sandwich skin fuselage in the areas of the rear engine beam junction, rear engine frame junction and front fin spar junction.

A prototype material was used with High Strength HTS-12K fibres from TENAX, with a E01 binder developed and performed by HEXCEL Les Avenières. The binder E01 is fully compatible with RTM6 resin. Tows are of 3.2mm width.

The process window was studied. Parameters such as torch temperature, compaction pressure, speed of deposition, tension within tows,… were optimised.

Feasibility trials on complex shapes with radius of 50mm were carried out with success as illustrated on figure 2.3.a.

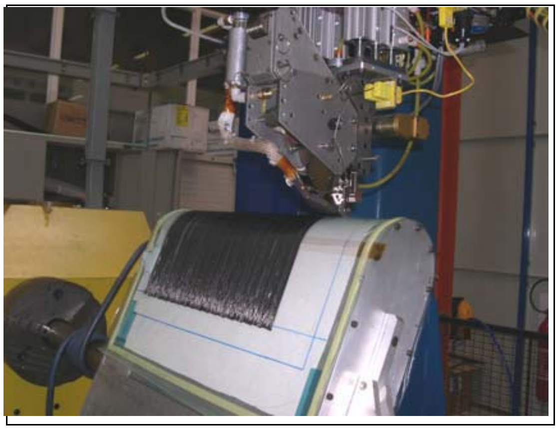

FIG. 2.3.a: Feasibility trials on complex geometries with radius of 50mm (cooperation with Dassault Aviation within the frame of FP6 ALCAS Business Jet Fuselage platform)

2.4 Allowables values

An allowable value program has been carried out. Investigations have been performed on several lay-ups such as:

- Quasi Isotropic 8 plies to verify that the binder rate has no effect on wet ageing mechanical properties compared to dry specimens. Properties such as compression after impact, tensile and compressive modulus, filled hole tensile and filled hole compressive were studied,
- 24 plies Quasi-Isotropic Lay-up for determination of tensile and compressive properties,
- 48 plies, Filled hole tension and filled hole compression properties.

Fibre volume ratio was varying respectively, from 52% on the 8 plies laminate and 57 % on the thicker laminates. Injection was performed by Dassault Aviation.

Results were not showing any effect of wet ageing after 70°C-85%HR up to equilibrium on Tensile, filled hole tensile and filled hole compression loadings. Compression after impact tests were showing a knock down factor of -17.5% due to ageing and tests at 70°C. Similar energy, was giving higher damage compared to thermo set resin system with same fibre, but same residual strength.

Filled Hole Tensile and Filled Hole Compressive results on 48 plies (10mm hole diameter) laminate were close to nominal values obtained with thermo set prepreg.

Figure 2.4.a is showing the lay up of the quasi isotropic 24 plies laminate.

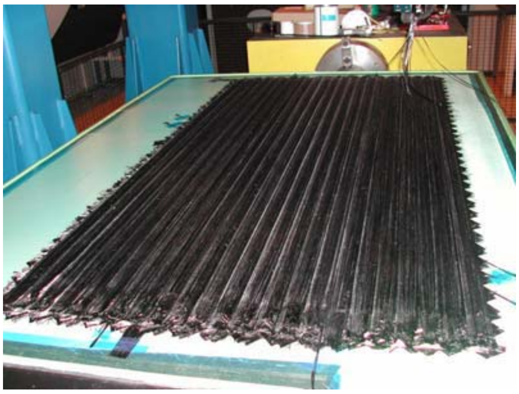

FIG. 2.4.a: View of Quasi Isotropic 24 plies lay up made with HTS-12K/E01 / RTM6 (cooperation with Dassault Aviation within FP6 ALCAS Business Jet Fuselage platform).

2.5 Ply waviness

Figure 2.5.a shows a through thickness micrograph cut of the 2 mm thick laminate with local ply waviness. This behaviour is also encountered in other textile/injection technologies.

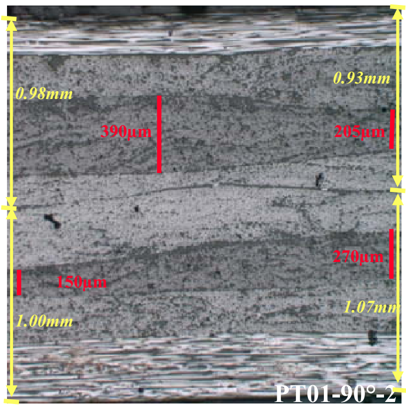

FIG. 2.5.a: through thickness micrograph cut of a HTS-12k/E01 / RTM6 2 mm thick laminate (ALCAS FP6 program – Business Jet Fuselage platform)

2.6 Way forward

Following this encouraging first technology trials phase, technology optimisation will continue. EADS Innovation Works will carry out research on new material solution with innovative binders, in the frame of the FP6 AUTOW (AUtomated preform fabrication by dry TOW placement) research program, started in January 2007. Within the partnership of this STREP, an integrated design engineering approach for dry tow placement will also be developed.

3. LRI AND DERIVATIVE LARGE SCALE DEMONSTRATION USING MOLD VIRTUAL PROTOTYPING

3.1. Liquid Composite Molding

The term of Liquid Composite Moulding encompasses a growing list of processes among which Resin Transfer Moulding, Liquid Resin Infusion, and LRI Vacuum Assisted Process. All LCM techniques involve compressive deformation of the fibre reinforcement prior to, and in many cases during process filling. The Liquid Injection process principle is sensibly the same than RTM process. A highly permeable dispersion medium (like wire netting) is incorporated into the laminated preform to accelerate the surface fibre impregnation and allow infusing through thickness the porous media. The advantages of this process are such that:

- The rigid tooling is replaced by a membrane on the top side which offer significant process tooling cost reductions,
- Larger surfaces can be injected with the same range of injection pressure as for RTM process.

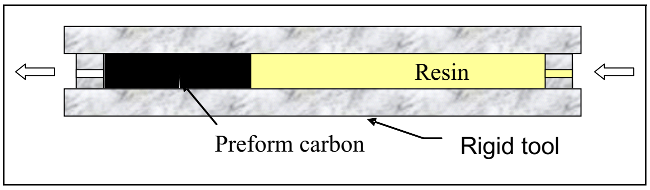

FIG. 3.1.a: Resin Transfer Moulding (RTM) principle

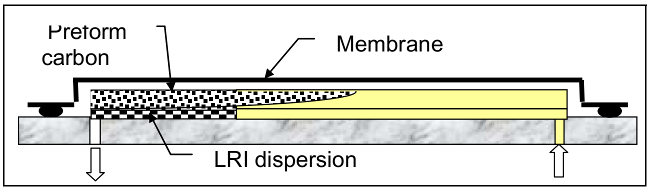

FIG. 3.1.b: Liquid Resin Infusion (LRI) Process

Focussing on the filling and curing stages during LCM process, successful 2D models with finite element control volume approach have been developed for more than 15 years in collaboration with Ecole Polytechnique of Montréal to optimize mould virtual prototyping, especially efficient for low thickness and large parts (thin shells). Unfortunately, these models give poor predictions of total filling time in the case of flexible injection processes like LRI or LRI VAP. The existing flow simulation software (as PAM-RTM from ESI) has been validated for RTM simulation but has shown limitations for LRI processes. This limitation is due to an important ratio between carbon permeability and dispersion media permeability combined to a high differential of fibre content.

With its background experience on LRI technology, gained for example with LRI TANGO fuselage panel (figure 3.1.c) where injection process was simulated by EADS innovation works, previous to panel manufacturing, EADS innovation works has developed with Ecole Polytechnique de Montréal [2], a methodology (numerical and associated characterisation) to compute three-dimensional flows of the LRI process, based on a composite shells with multi-layer reinforcements. This specific module has been validated from numerical method, specific material characterisation, numerical and experimental validation within the frame of ALCAS Business Jet Wing FP6 program in cooperation with Dassault Aviation.

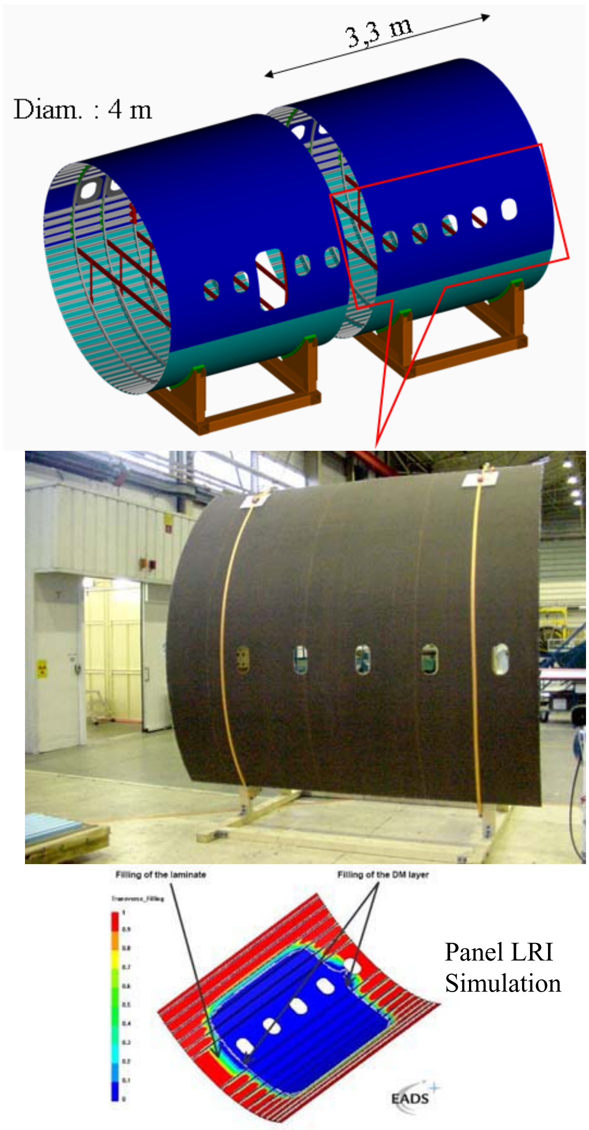

FIG. 3.1.c: EADS Innovation Works (ex EADS CCR) RTM LRI panel in RTM6-multi axis NC2 for BARREL TEST of TANGO composite fuselage program

3.2. 3D flow simulation of LRI process

The simulation module validated is based on a Darcy's law evolution. For example, the flow in the fibrous preform is expressed by equation (1).

in-plane flow through-thickness flow

$$\vec{v}_{fib} = \frac{K_X^{fib} \cdot \Delta P_X^{fib}}{\Delta x \cdot \mu}\hat{x} + \frac{\tilde{K}_Z \left(\Delta P_Z^+ + \Delta P_Z^-\right)}{2 \cdot \Delta z \cdot \mu}\hat{z} \quad (1)$$

Where:

$\mathbf{v}$ is the average superficial fluid velocity,

∇P is the pressure gradient between two adjacent cells, named + and – in the equation.

$[\mathbf{K}]$ is the permeability tensor of the porous medium,

μ the resin viscosity and,

ϕ denotes the porosity of the porous medium.

In the case of the LRI process, a highly permeable dispersion medium is added above the fibrous preform to facilitate resin impregnation of the laminate (see FIG. 3.2.a).

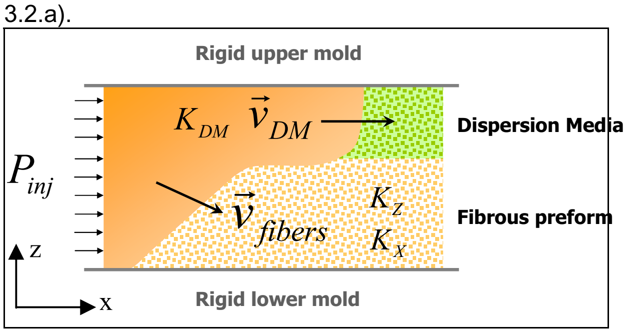

FIG. 3.2.a: LRI flow principle

In order to identify LRI on UD Priform material (FAW 226 g/m2) (material selected for ALCAS Business Jet Wing Sub Scale Wing Box) and to validate the model, EADS Innovation Works has used its fully instrumented permeability bench (figure 3.2.b&c).

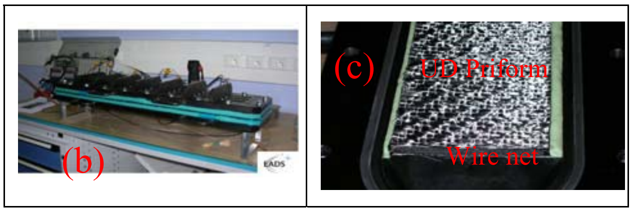

FIG. 3.2.b & c: (b) Instrumented Permeability bench for in plane flow (pressure, flow front in time, vacuum,… (c) Permeability measurements on UD Priform material on a wire net

The use of the validated module to perform LRI flow simulation was applied with success by Dassault Aviation for the optimisation of the infusion strategy and tooling design of the sub-scale wing box article (figure 3.2.d simulation performed by Dassault Aviation).

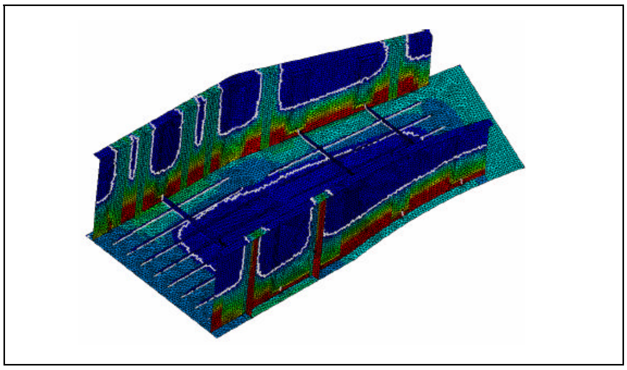

FIG. 3.2.d: reduced scale Business Jet Wing Box of 2.5m*1m PAM-RTM Infusion simulation (Courtesy of Dassault Aviation)

3.3. Further industrial large scale feasibility with LRI VAP process

Within ALCAS FP6 program Central Wing Box, EADS Innovation Works in partnership with Airbus France had the responsibility to manufacture the full scale upper panel with LRI VAP technology.

After a set of feasibility trials with medium scale panels, the full panel was manufactured successfully and is shown on picture figure 3.3.a.

Due to the non availability of infusion process model involving a constant volume of resin, no previous simulation to infusion could be performed.

The panel is a 4m*2.8m, made of HS fibre Saertex multi axis with fibre orientation 0° span wise. 109Kg of RTM6 resin were injected in 120 minutes. The panel integrates 18 stiffeners and has a maximum thickness of 19mm.

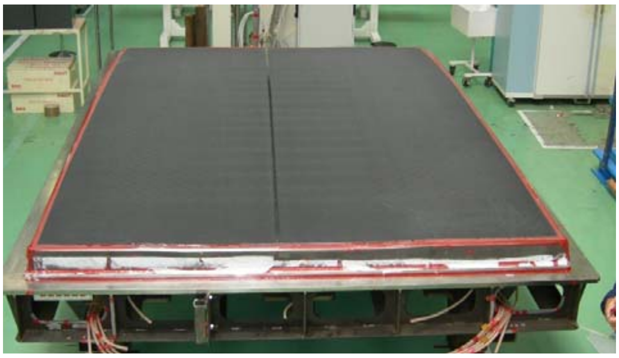

FIG. 3.3.a: FP6 ALCAS program Central Wing Box extrados panel made of LRI VAP technology (AIRBUS France in cooperation with EADS Innovation Works)

4. LIFECYCLE PREDICTION OF DRY PREFORMS

4.1. Behaviour of dry preforms

Because of the interlacing of warp and weft yarns, woven textile reinforcements are especially efficient in the case of double curve geometries. The textile provides large in-plane shear strain abilities. Nevertheless, one of the main difficulties is the prediction of the directions of the reinforcements after shaping and prediction of any defect occurrence. Moreover, variation of permeability can appear from the variation of local reinforcement density after forming. Such an effect can influence the injection/infusion process. Strength prediction which relies up to day on FE implementation of simple unidirectional homogenisation methods of fibre and matrix properties is limited to ply wise behaviour. For 3D fibre architectures homogenisation, voxel-type representative volume elements have recently been developed but failure prediction remains far beyond due to non linearity like cross-over points friction, 3D fibre/matrix interaction.

In order to close the gap between missing knowledge and proved advantages of dry fibre textiles, the FP6 Integrated TOOL for simulation of textile composites ITOOL project is actually on going. It should provide an integrated simulation tool for textile preforming technologies.

4.2. Highlights on some FP6 ITOOL project results

The mechanical behaviour of fabrics is complex and its prediction relies on a multi-scale approach. Within ITOOL, a semi-discrete approach between continuous and discrete is developed for textile forming [3], [4], [5], [6]. A finite element method is associated to a mesoscopic analysis of the woven unit cells. The mechanical behaviour of the woven cells can be obtained experimentally or by 3D FE simulation as shown in figures 4.2.a & 4.2.b [6]. The yarns are modelled as continuous material with a hypo elastic law to strictly follow the direction of the fibres. Lateral contact between yarns is also handled during the simulation through the boundary conditions to avoid shear locking effect.

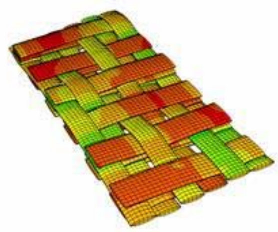	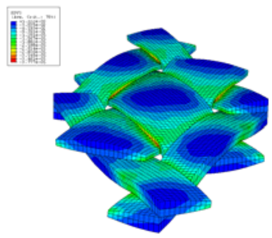
FIG. 4.2.a: Interlock G1151® in biaxial tension ($\varepsilon_{11}/\varepsilon_{22}$=1). Transverse strain (from INSA de Lyon)	FIG. 4.2.b: Plain weave in pure shear. Transverse strain (from INSA de Lyon)

The approach associates a finite element method based on specific element of a discrete number of woven unit cells and a mesoscopic analysis of the woven unit cell. The approach considers that there is no translation sliding between the yarns. This approach is developed for classical fabric reinforcements. The hypothesis are such that the tension do not depend on the shear angle and that the shear couple do not depend on the axial strain (for this last assumption, experiments have shown that this angle can be neglected). In the element made of woven cells, the nodal interior load components can be calculated from the strain interpolation of the element and from the tensions and shear couple. Figures 4.2.c (tension based approach without wrinkles) and 4.2.d (with added shear show wrinkles) show example of the computed deformed shape after forming on a double curved geometry. The wrinkles present in figure 4.2.d from INSA de Lyon are explained by the effect of shear locking that leads to out of plane solution to reduce this shear.

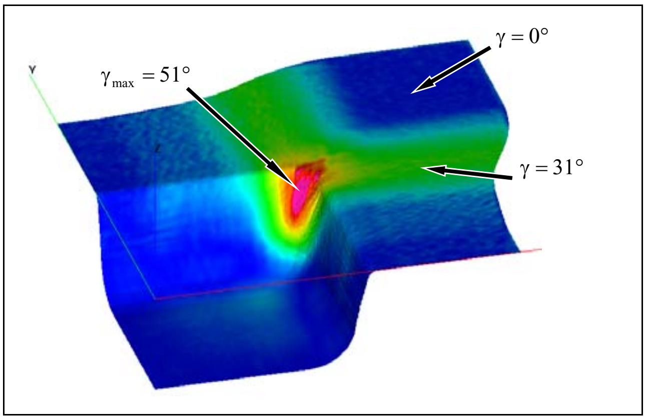

FIG. 4.2.c: Deformed shape and shear angle (Tensile energy only)- (Picture from INSA de Lyon)

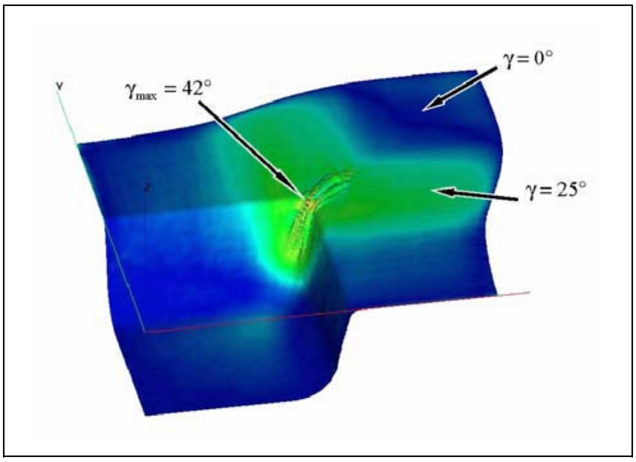

FIG. 4.2.d: Deformed shape and shear angle (Tensile + in plane shear energy). (Picture from INSA de Lyon)

Within ITOOL, simultaneous forming of several plies is studied with some promising results.

An other development performed within the ITOOL project by EADS Innovation Works is an homogenisation technique to predict elastic meso-mechanical stiffness and strength properties of a Representative Volume Element [7]. The values can be used as entry points for macro-mechanical simulations of parts build with textile. Comparisons with experimental tests from K.U Leuven were achieved. Figure 4.2.e show an example of the simulation performed with MSC Marc of the stress σ_{11} inside the yarn for a tri-axial braid for a strain $\varepsilon_{11} = 1\%$.

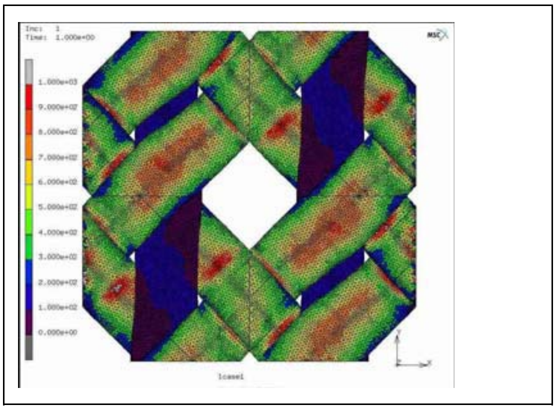

FIG. 4.2.e: MSC Marc simulation RVE of tri-axial braid σ_{11} properties for a strain $\varepsilon_{11} = 1\%$ (EADS Innovation Works).

5. Z-PINNING ASSEMBLY OF DRY PREFORMS

5.1. EADS Innovation works Z-pinning technology

Z pinning technologies have been developed for some years:

- AZTEX developed a process, which is based on the use of an ultrasonic hammer to pin rods into the preform through a foam, but it is limited to very small pins, and the main application remains 3D reinforcement of 2D preforms.
- HEXCEL Composites developed also a specific process based on the use of a vibrating needle to drill the preform, and to install in a second step the pins into the hole. This technology permitted, such as the ASTRIUM process O3S stitching, to assemble 3 D textiles preforms, according to different angles and lengths of implantation.

The main advantages of a pinning technology can be thus summarised by:

- Capability of assembly with metallic pins, if required by the application.
- Reliability and Simplicity (easy automation).
- Reinforced quality control with capability of a numeration of the implanted pins.

According to the results of different studies, which were led on 3D preform assembly processes, EADS Innovation Works has decided to invest in the development of a specific Z pinning technique [8]&[9], as an alternative to the stitching O3S process used by AIRBUS and ASTRIUM. The objective was also to work on the optimisation of this process.

The originality of the EADS Innovation Works process results in the combination of the two steps of the process in only one , i.e. preforms drilling and pins installation and also in the complete automation of the process.

- The first works were focused on the design of a specific holed needle, which is one of the critical elements of the process.
- Secondly, a Z pinning head has been developed. It is installed on a gantry for more precision and

reliability. This head is controlled by a numerical command.

FIG. 5.1.a: EADS Innovation works Z-pinning machine

The main characteristics of the machine (figure 5.1.a) are the following:

- 7 electrical axis machine with a numerical command,
- Automated supply of the pins to the head, with a vibrating pot and a pneumatic system.
- Process programming from CATIA definitions.
- Automated adaptation of the pinning angle to the surface geometry.
    - Pinning angles: from –45° to 45°
- Pinning areas capabilities: 2500mm*250mm.
- Precision: 0.1 mm

The pinning process consists in:

- Installation of preforms into a specific mould,
- Pin supplied into a barrel,
- Transmission of the pin to the needle,
- Pin pushed inside the needle into the preform,
- Needle going up, when pin is maintained into position inside the preform,
- Pushing device coming to its initial position.

5.2. Z-pinning influencing parameters and material behaviour

Optimisation of the mechanical behaviour with Z-pinned pins, relies on the understanding of the influence and the optimisation of the material and processes parameters such as:

- Pins diameter,
- Pins length,
- Number of pins,
- Sequence definition (position of pins).
- Pinning surface density,
- Pinning angles,
- Nature of pins.

Different nature of pins can be used like carbon, titanium …etc. Through several studies, 3 diameters (0.7mm, 1.2mm and 2.3mm) of Hexcel Reinforcement carbon pins have been used by EADS Innovation Works. A typical pultruded carbon pin, of twisted shape, is presented on picture in Figure 5.2.a.

FIG. 5.2.a: View of a twisted carbon pin used in pinning technology.

Depending on the geometry of the parts to be assembled, especially elements thickness, the pinning sequences has to be optimised such as to put the pins in alternate rows as illustrated on picture figure 5.2.b.

Figure 5.2.b shows a micrograph cut of 2 narrow pins pinned in a fabric preform. Both pins show micro-cracks. The surrounding of each pin is an area rich of resin. Pins introduction into the fabric has generated some fibres deviation.

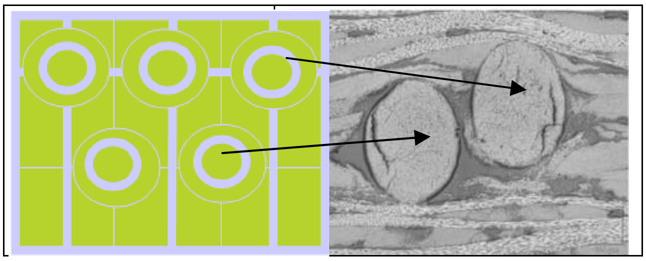

FIG. 5.2.b: Example of a pinning sequence with micrograph cut of a Z-Pinning area.

To be able to determine a failure criteria based on single pin test (figure 5.2.c), a dedicated research program is on-going at LMS ISAE (ENSAE – SUPAERO) (figure 5.2.d).

This research program will allow having a better understanding of the effect of:

- Resin/pin interface,
- Pin implantation (perpendicular or parallel to the fibers),
- Stacking effect.

FIG. 5.2.c: Pull out test pin specimen for a pin of 0.7mm (LMS ISAE). On this picture, the pin is implanted in a resin plate.

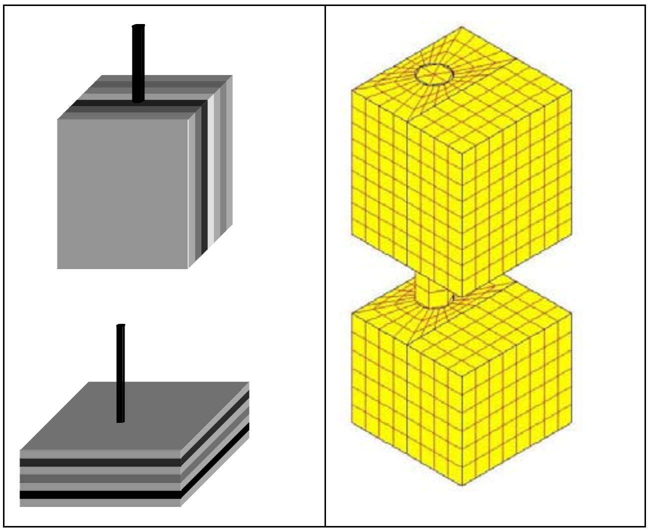

FIG. 5.2.d: Test principle for the understanding of pinned area behaviour (LMS ISAE)

5.3. Manufacturing of ALCAS program Business Jet Sub-scale Wing box representative components

Within the frame of ALCAS Business Jet Wing platform, EADS Innovation works has selected carbon pins of 0.7 and 1.2mm to perform feasibility trials and assembled structural elements, such as T shapes representative of stringer / skin attachment.

Different configurations for junction of composite rib feet to the composite skin and stringers of a Sub-Scale Wing Box were then performed. One configuration of them, is to be able to assembly directly the rib foot preform before RTM injection, to the stiffener veils on one side, and on the panel skin coupled to the stringer foot on the other side. These elements were designed, manufactured and tested to evaluate the Z-pinning technology.

Tooling used for pinning simple T shape specimens is shown on figure 5.3.a. Figure 5.3.b shows feasibility trials regarding pinning sequences, in a UD priform IMS/977-20 (FAW 200g/m2) material. Figure 5.3.c shows the full assembly view. Due to the low thickness of the spar to be assembled, pinning on 3 lines was retained with 0.7 pins (twisted 2*6K) or 1.2mm pins (twisted 2*12K) depending on specimen.

Figure 5.3d and 5.3e show a SEM view and a macro picture of the NCF PRIFORM material. Figure 5.3.e

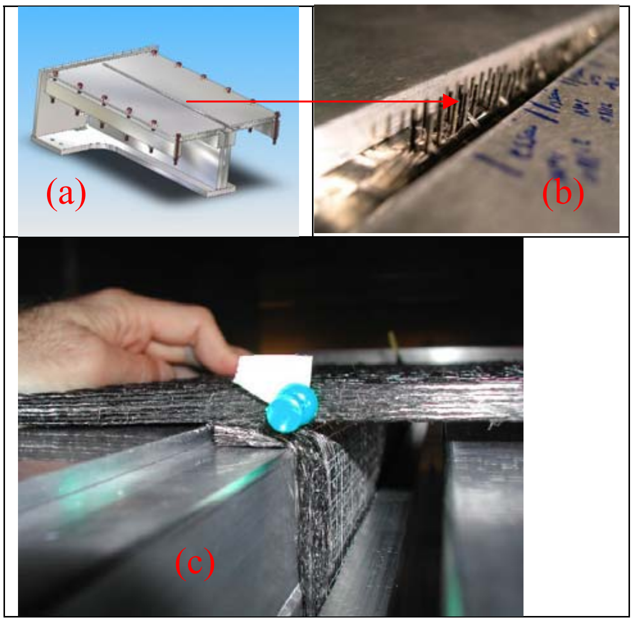

FIG. 5.3.a: T shape specimen pinning tooling device. (b) View of pins positioning during feasibility trials phase. (c) L shape assembly view

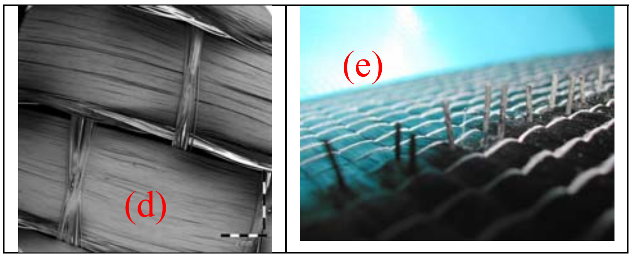

FIG. 5.3.d&e: (d) SEM view of the UD PRIFORM material showing stitching of fibres between tows of 10 to 12 times carbon fibres diameter. (e) Macro view of NCF PRIFORM skin with pins.

The panels representative of ribs feet to skin attachment are 300(0°)*312mm and are made of :

- Non Crimp Fabric type multiaxial PRIFORM from Cytec-Fiberite of [45°, 90° ,-45°] of HTS/977-20 (FAW 450g/m2),
- UD IMS/977-20 (FAW 200g/m2) for the skin.

CATIA design of Z-pinning panels is presented on figure 5.3.f. The pinning definition retained is:

- 1.2 mm diameter pins,
- Length 20mm,
- Pinning angle: alternative +20° & –20°
- 5 lines.

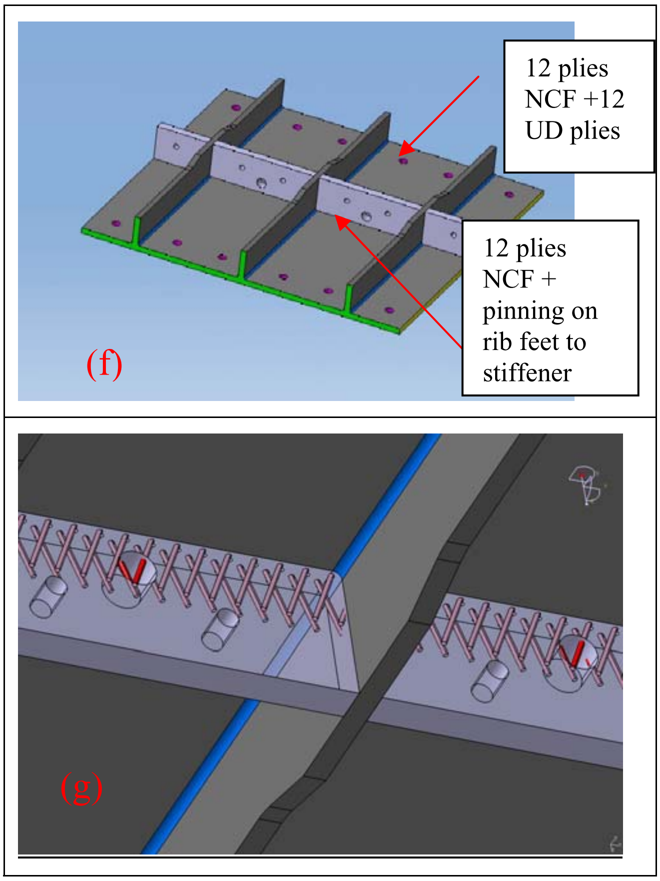

FIG. 5.3.f: Z-pinned rib feet panel CATIA design of EADS Innovation Works panel. (g) CAD view of pins sequences.

On the panel figure 5.3.f and g, pinning is applied on the junction of composite rib feet to the composite skin and stringers.

For the pinning of the central rib, special toolings have been designed in order to maintain the dry preforms in place during the pinning process. Figure 5.3.h shows one panel with the internal structure of the tooling to be prepared for pinning operation.

FIG. 5.3.h: Tooling of Cross ribs feet/skin attachment panel just before pinning operation

Four panels with pins have been manufactured by EADS Innovation Works. In the same time, seven panels with bolted ribs feet have been manufactured by Dassault Aviation. All pinning configurations have then been injected in a close rigid mould and tested by EADS Innovation Works. Six out of seven Dassault Aviation panels of bolted configurations have been tested by EADS Innovation Works.

5.4. Z-pinning structural behaviour and failure analysis

Z-pinning is usually made to better sustain skin/stiffener interface shear as well as skin/stiffener interface pull out.

Previous researches carried out at EADS Innovation Works have allowed performing evaluations of Z-pinned area with carbon pins for both loading cases [9].

Figure 5.4.a and 5.4.b show, respectively, the two kinds of failure types, obtained during a pull out test on T shape specimens assembled with carbon pins. In these cases, both the skin and the stiffener were relatively thick (approximately 8-12mm) made of G1151 fabric and injected with RTM6 resin system.

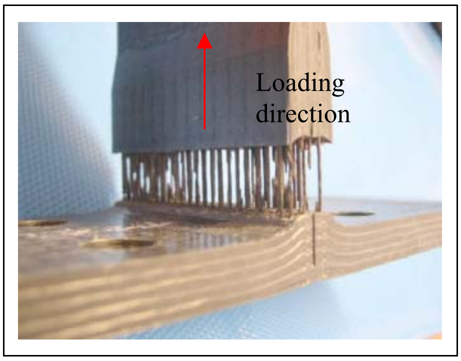

FIG. 5.4.a: Pull out test on a T shape specimen assembled with 1.2 mm diameter carbon pin.

Failure on figure 5.4.a is mostly showing sliding of the pins and shows the weakness of the pin/resin interface.

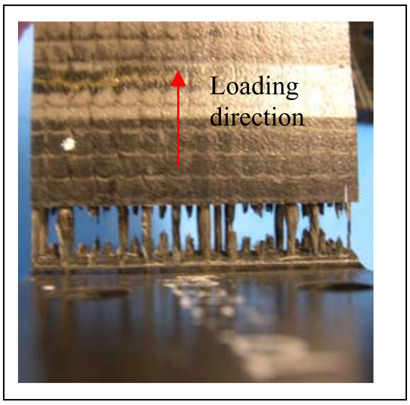

FIG. 5.4.b: Pull out test on a T shape specimen assembled with 1.2mm carbon pin.

Failure on figure 5.4.b is mostly by tensile failure of the pins, which is the optimum expected behaviour.

From previous studies, results were showing that pinning with Carbon pins was at least equivalent to stitching.

Within ALCAS Business Jet Wing program, in cooperation with Dassault Aviation, a specific test has been developed in order to characterize the skin/ rib feet interface assembled with pins (see §5.3).

Figure 5.4.c shows the test set up that has been installed on the panel. The rib is loaded in tension on a 600kN machine through an aluminium plate.

Each panel is equipped with strain gages, and followed up by a video camera focussed on the pinned area. Specimens are painted in white in order to highlight any carbon breakage.

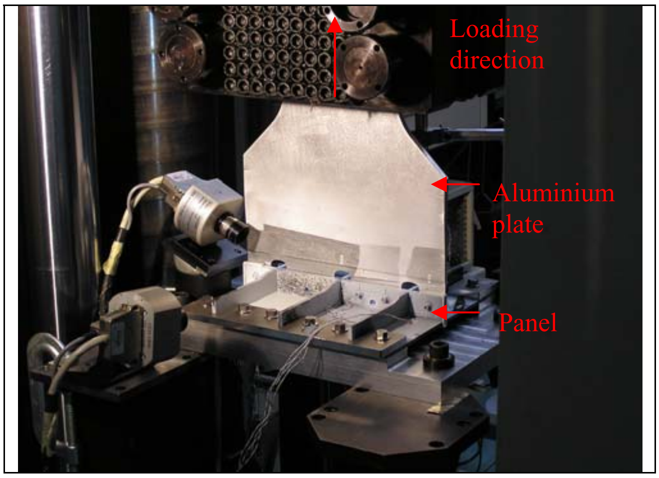

FIG. 5.4.c: ALCAS FP 6 program Business Jet Wing Z-pinned panel test. This study is carried out in close cooperation with Dassault Aviation.

In order to fulfil the test analysis and to correlate the test simulation with the experimental results, a detailed FE model of the test has been prepared (figure 5.4.d). In parallel, pinning failure criteria definitions are carried out at LMS ISAE. Depending on time, discrete modelling of the pinned area with defined failure criteria will be applied for the panels analysis.

Test results on Z-pinning panels are actually under analysis and seem promising for the technology.

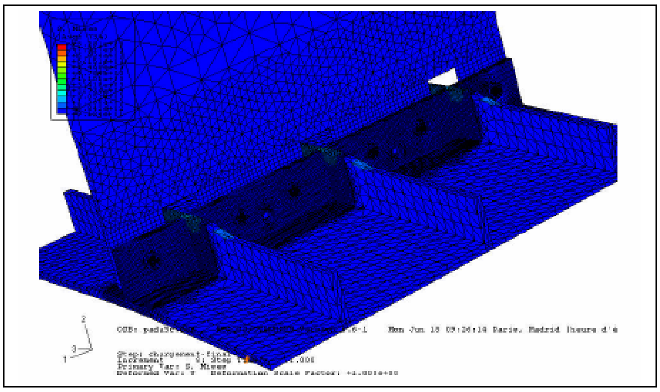

FIG. 5.4.d: ALCAS FP 6 program Business Jet Wing Z-pinned panel test simulation. View of the detailed FE model under ABAQUS (EADS Innovation Works)

6. CONCLUSIONS

This paper presents a selection of the new challenges in structural design and analysis of composite structures regarding textile preforms and injection technologies. A vision of the associated modelling techniques was also given. Means for technology development were explained with the limitations in use. Most of the researches have been performed at European level through several EU projects (TANGO, ALCAS, ITOOL,…). Promising technologies such as: dry fibre placement, Z-pinning assembly, LRI VAP infusion, forming of dry fabric, mechanical behaviour prevision tool for textile technologies were presented. Several experimental techniques have been set up today with success.

Acknowledgements

The authors would like to thanks their colleagues S. Didierjean, R. Esnault, D. Filleul, S. Maison-Le-Poëc, P. Middendorf, N. Swiergiel, for their contributions to the work presented in the present paper.

The work reported in the present paper has been widely supported by the European commission through several EU projects APRICOS, TANGO,...etc with some of them still running: ALCAS, ITOOL, AUTOW, …etc.

Acknowledgements to Airbus France, Dassault Aviation, INSA de Lyon, ISAE, Ecole Polytechnique de Montréal, K.U. Leuven, without whom some parts of the work wouldn't have been possible.

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