In-situ consolidation of integrated thermoplastic fuselage panels: the future in structural comercial aerocomposites

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Abstract

FIDAMC (Foundation for the Research, Development and Application of Composite Materials) has been investigating different technologies, under the frame of several research projects funded by Clean Sky initiatives and Spanish governmental entities, to demonstrate that thermoplastic composites can be directly manufactured via automation without autoclave consolidation and the full integration of the structure by co-consolidation method fusing together the skin and stringers in only one melting step.

Fuselage shells have been developed by Fokker using ultrasonic automated fiber placement for fast lamination of the skin and full integration of stringers and frames by autoclave [03]. FIDAMC has selected the previously described technology for Automation and Out of Autoclave (OoA) processing on account of the cost reduction and the possibility in penetrating primary structures, as fuselage is, on the next generation aircraft.

This presentation provides an overview of these research projects and includes a review of automated methods to lay PEEK, PEKK and PAEK prepreg from the first Automated Fiber Placement (AFP) head with a diode laser as heating source working with one single tow, up to the new multitow head to produce feasibility panels for a research project to develop a full-scale thermoplastic fuselage demonstrator.

1. Introduction

The use of thermoplastic matrix in carbon fiber reinforced components has been growing continuously in automotive and aerospace applications for their significant weight reductions and cost savings compared with conventional aluminium alloys. The future market of thermoplastic components will increase in the next years and recent advances in composite production and processing are making thermoplastic a viable option in a wider array of aerospace application.

In addition, thermoplastics have recognized aspects such as excellent FST (Fire, Smoke, and Toxicity) properties, higher mechanical properties, damage tolerance and inherently superior fatigue performance, chemical resistance, infinite shop life, weldability, reuse of material and shorter manufacturing cycles compared to their competitor thermosets. Thermoplastic resins offer a high potential not only regarding to material properties, but also to process time reduction, operation and life cycle costs [01].

Considerable research efforts have been developed by Airbus and Boeing to adopt these class of materials in flight-critical structures, starting with small parts such as clips /cleats and interior structures, and evolving to new applications for primary structures such as wing boxes and fuselage, now under consideration. Manufacturing processes such as stamping and thermoforming, autoclave molding, diaphragm forming, filament winding, pultrusion and electrical resistance, ultrasonic and induction welding have been used.

The main barrier to reach cost-effective manufacturing of large thermoplastic aerostructures with acceptable level of porosity is the automatization by using out-of-autoclave methods. In-situ consolidation process is currently the main goal of most research and technological endeavours on thermoplastic materials. The aim of this process is to avoid the use of autoclave by reducing the number of processing steps, with a considerable cost reduction, while maintaining competitive properties [01,02].

2. Approach for achieving consolidation for aerostructures.

The In-situ consolidation (ISC) via automated fiber placement is a promising process where laminates are formed by heating unidirectional tapes (UD slit tapes) in a laser assisted tape placement head to their melting or higher temperature and consolidated by applying pressure. The challenge for the in-situ consolidation is balancing the lamination speed and the quality of the part.

FIDAMC aims to demonstrate the feasibility of full integrated structures with thermoplastics in sizes to full scale fuselage demonstrators with two keys: cost and weight, and co-consolidated thermoplastic components skin-stringers structures is one of the industrial solutions fusing together skin and stringers in only one step. FIDAMC relies on the One-step process as the preferred alternative unlike the Two-step approach, with an autoclave or oven post-consolidation step, which is the solution adopted by France (Aerolia) and Netherlands (Fokker).

Figure .1 Evolution of automated lamination technologies: from the partial consolidation followed by autoclave or oven postconsolidation to the complete in-situ consolidation in one step.

FIDAMC has investigated its out-of-autoclave (OoA) thermoplastic composite technology over years under the scope of several research projects funded by Clean Sky initiatives and Spanish governmental entities, aiming that thermoplastic can be directly manufactured via automation without autoclave consolidation [3].

2.1. Thermoplastic Automated Fiber Placement machine description.

Necessarily for those projects, a specific Thermoplastic Automated Fiber Placement machine was developed together with the Spanish supplier MTORRES and installed at FIDAMC facilities eight years ago.

Existing machine, shown in Figure 2, consists in a laying up head that executes the process to melt, deposit and cool the thermoplastic unidirectional tapes, ply by ply on a tool. The machine includes guidance systems for feeding unidirectional tapes of 1/4” or 1/2” widthness and the next mechanisms: cutting unit, compaction unit by means of an elastomeric roller and the heating source . a diode laser. The laser heats the substrate and the incoming material above the melting temperature of the thermoplastic polymer and by the action of the compaction roller both are pressed and welded. An infrared camera is attached to the head with the goal of measuring the temperature in the heated area (including NIP point), its lectures are taken by a close loop system which continously updates and adjusts the laser power.

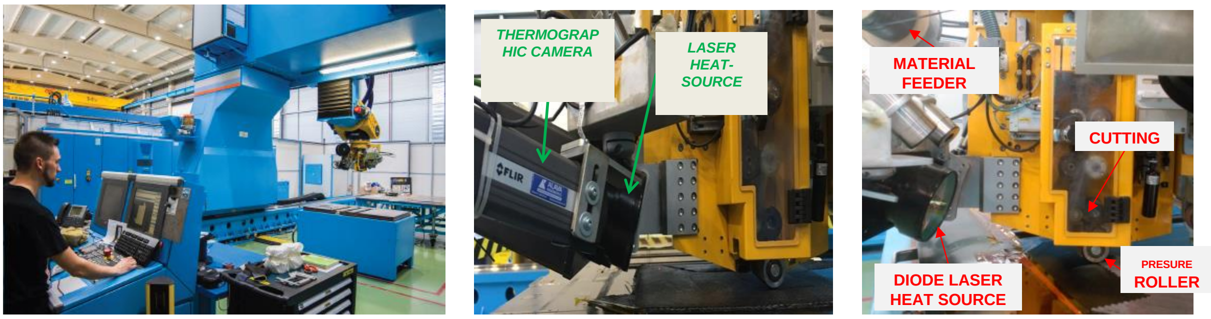

Figure 2 Automated equipment (MTorres AFP head) used for Fidamc.

The parameters to be controlled during the process to achieve enough consolidation are the lamination speed, the temperature by means of laser power, and the pressure. The diode laser is equipped with a scanner which permits the selection of diferent laser profiles for each material and lamination speed. The speed is directly related to the exposure time of the material to temperature, and to the heat transfer through the whole laminate. Different laser profiles heat greater or lower lengths of the tape during lamination that results in longer heating time to improve consolidation [03]. Just now, a new eight–tows head has been incorporated into the gantry of the existing machine in order to improve the productivity and with a new 6kW optic laser to create a wider profile which heats 50 mm width instead of the 6 mm of unitow equipment. It is shown in Figure 3.

Standard In-Plane Shear Strength (IPSS) tests are performed to establish the degree of consolidation (DOC) in comparison to autoclave or oven samples as shear is the dominating factor in the ply interface.

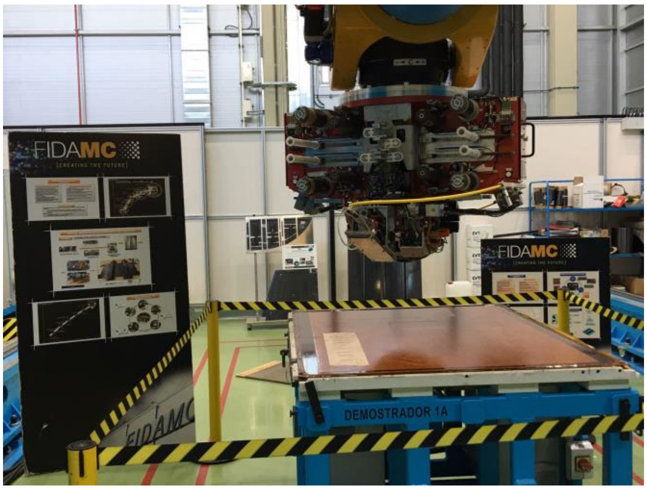

Figure 3 Industrializing the process with a 8-tows equipment (MTorres head)

2.2. Thermoplastic Development Roadmap in FIDAMC.

Thermoplastic development in Fidamc has been based on the support and fundings of Clean Sky and Clean Sky2 and with the target of reaching a technology readiness level (TRL) 6. FIDAMC has produced multiple demonstrators, all in only One Step In-situ Conslidation (ISC) and Out of Autoclave (OoA).

The evolution of these works over eight years are shown in Figure 4.. Initial activities were focused on simple flat panels in order to characterize the process parameters and the process window. It has also being produced different full integrally stiffened panels with Carbon Fiber and PEEK and manufacturing trials of window frames structure. Next step has been co-consolidated thermoplastic structures with large sizes and complexities in the stacking, thickness, ply build ups, joggles and drop offs included in both flat and curved structures, culminating with a final demonstrator for wing structures and carbon fiber and PEEK.

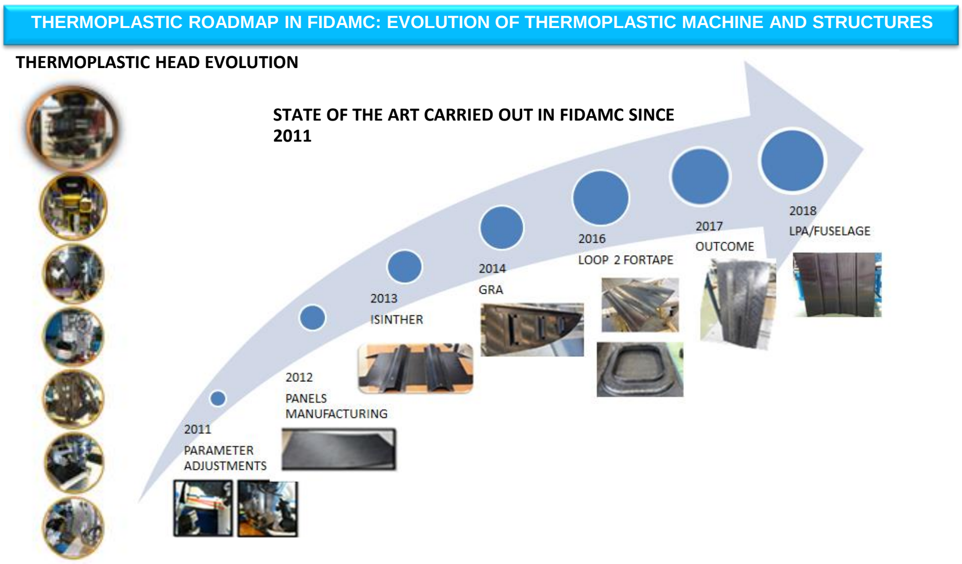

Figure 4 Fidamc evolution of equipment and thermoplastic composite demonstrators.

All the co-consolidated thermoplastic feasibility demonstrators have been built in the same three stages shown in Figure 5 and are:

1. Blanks to produce stringers with plies consolidated by the MTorres laser assisted automated fiber placement (AFP) machine.
2. Thermoforming of the stringers to obtain the “T”or “Ω” shaped stringers by press or oven.
3. Flat and curved skin panel lay-up over the formed stringer flanges. The integration of both parts is obtained in one single step by co-consolidaation method.

The concept of tooling is a self heating mold with vacuum system and cavities where stringers are located with mandrel in their insde to form a flat lamination surface.

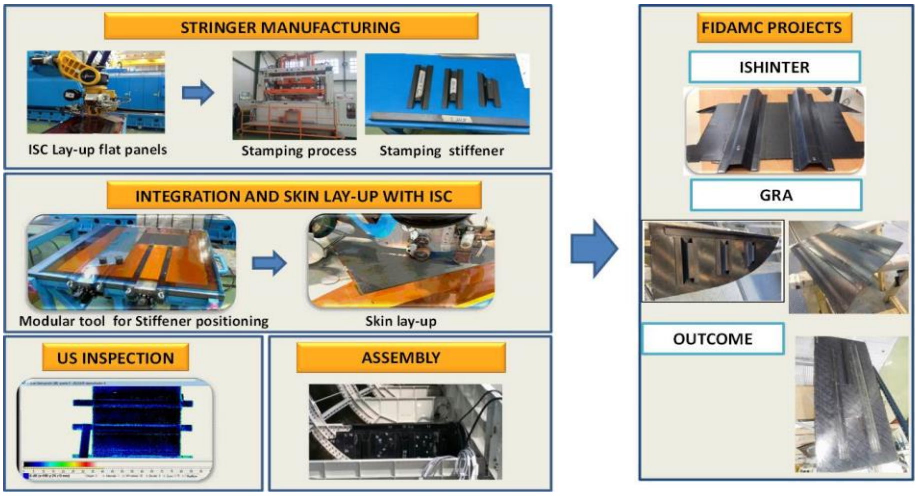

Figure 5 Production of co-consolidated thermoplastic structures

3. Fuselage Shell Demonstrator.

3.1 Objectives.

FIDAMC is currently working in the frame of Clean Sky2 Multifunctional Fuselage Demonstrator, see Figure 6, with the challenge of demonstrating the co-consolidation method as a cost effective alternative to welding for the manufacturing of hollow hat stiffened panels and:

- To implement the technologies on a representative aircraft part (thermoplastic composite airframe panel).
- To validate the feasibility of manufacturing more ecological parts (recyclable, longer life, shorter production time, less scrap material, out of autoclave) at a reasonable cost and excellent mechanical properties.
- Industrializing the process: to improve and scale up with the multi- tow head incorporating in the existing machine.
- To demonstrate that thermoplastics is a faster way of processing.

After developing the co-consolidated skin-stringers structures, FIDAMC is now working in two different fuselage technological demonstrator, one built by ISC in one step and the other by using an oven to join the AFP skin with the thermoformed stringers, each with 1,5 m length and 1 m wide and consisting in a curved panel and three hollow hat stringers. The Figure 6 shows the configuration of the fuselage panel and the window frame.

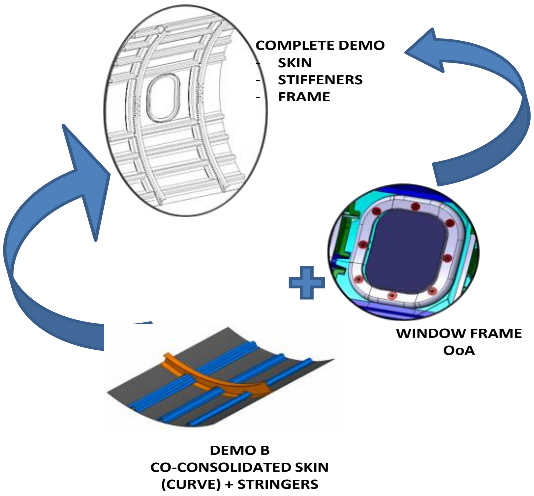

Figure 6 Concept and Configurationf of the thermoplastic fuselage panel and window frame.

3.2 Materials.

FIDAMC has completely characterized the matrix polymer PEEK because it has been the preferred material used in the CleanSky wing panels. Other activities are focused on incorporating alternative matrix polymers such as PEKK and PAEK.

Table 1. Melting and Processing Temperatuers of studied Polymers .

Polymer Type	*Melting Temperature. Tm* (ºC)	*Processing Temperature. Tprocess* (ºC)
PEEK	346	350-420
PEKK	338	320-380
PAEK	310	310-370

Thermal history during lamination, final ultrasonic inspections and comparative results of In plane shear strength of panels built by In Situ consolidation and Oven are shown in Figure 7.

3.3 Fuselage shell demonstrators.

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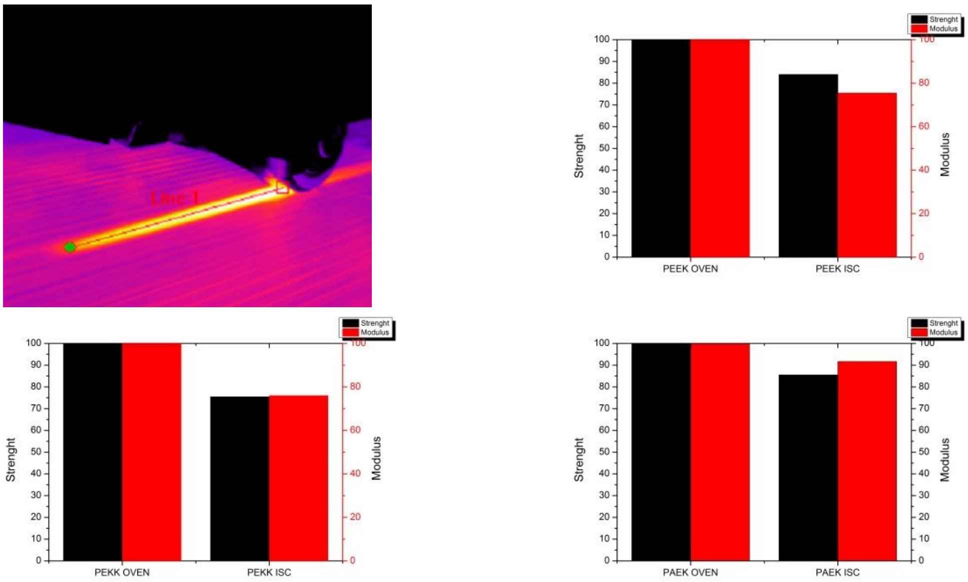

Figure 7 Thermography and mechanical properties of the characterized materials

It has been used the above explained process for manufacturing blankets to thermoformed them by autoclave or oven, placing them into the mandrel and then the lamination ply by ply over the flanges of hat stiffeners resulting the full integrated structure. The concept tooling is shown in Figure 8.

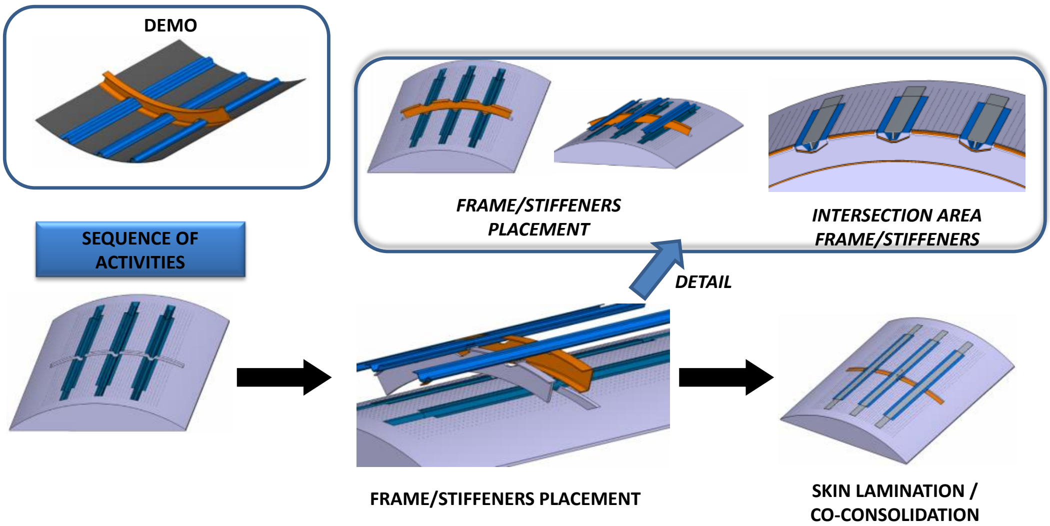

Figure 8. Tooling Concept for co-consolidated full integrated fuselage panel.

The pictures in Figure 9 show the manufacturing steps for the structure simulating a fuselage shell with a curved panel with integrated stringers consolidated by in-situ conslidation in one step.

The alternative of this option consists of thermoformed stringers, loaded into molds, lamination and consolidation of skin by laser assisted AFP equipment and vacuum bagged and final consolidation and integration in oven with only vacuum bag method.

Figure 9. ISC thermoplastic cuved panel in one step.

3. Conclusions

The first manufacturing trials have shown that the full integrated stiffened panels can be manufactured via laser assisted automated fiber placement technology by co-consolidation of stringers with skin and without autoclaving post-consolidation step.

The ISC/AFP process in one step is clearly slower than the two steps option but the number and complexity of tools is much better with one step ISC because the control of geometrical shape of all elements is perfect that the heating only interacts on the last ply of the stringers when lamination is doing.

The target for ISC is to achieve high lay down speeds. Clearly, speed and its influence over voids and crystallinity depends on prepreg quality. Raw materials should be oriented towards improving homogenity of the resin-fiber distribution, rein surface, flat material and accurate tolerances.

The three polymers work perfectly in laser assisted automated fiber placement (AFP) according to demo panels. All of them are potential unidirectional tapes to be used with ISC and with 1 m min^{-1} AFP speed a void content less than 1% and 80% of degree of consolidation (DOC) in comparison to oven samples. With PAEK and PEKK there is much work to do for defining the optimum ISC parameters. PAEK has performed better with low speed AFP ISC machine and without porosity between the plies and acceptable voids level.

In outline, thermoplastic is a real opportunity for a faster processing, lower lifecycle and environmental sustainability.

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