MANUFACTURING OF HIGH COMPLEXITY AIRCRAFT STRUCTURE IN PREIMPREGNATED CARBON FIBER BY MEANS OF DOUBLE VACUUM DEBULKING PROCESS

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ABSTRACT

Double Vacuum Debulking (DVD) is an innovative process which can be the alternative to cure thermoset preimpregnated carbon fiber materials, which have been specially created for autoclave curing, in a process using out of autoclave equipment [5]. Traditionally, there exist methods using a double vacuum bag system, getting advantageous conditions on the prepreg laminate during the out of autoclave curing process. [3-5].

Works were focused in the manufacturing of carbon fiber prepreg elements, with a defined location for vacuum bag and a parallelepiped bulkhead covered by the external vacuum foil. [1]. Curing cycle consists of two phases, allowing the movement of volatiles and air trapped between layers out of the system but exerting pressure enough for compaction and very low porosity levels. Panels and trials for manufacturability assessment were produced using the DVD technique. Curing equipment was composed of a heating compartment with independently controlled areas and a control system including software. Flat panels with 2 different thicknesses were produced, for laboratory test screening. A final demonstrator of a real aircraft front spar (aprox.1900mm length and four T-shaped stiffeners) was produced as well. This element entails high complexity, due to the integration of stiffeners onto a skin, difficulties related to the web radios, roving filling and location or the correct configuration of stiffeners.

Positive results were obtained regarding porosity and mechanical behaviour, extent of cure and Tg for all the panel thicknesses. Dimensional tolerances were respected as well, with no more scattering of results than in autoclave curing process for the same specimen.
DVD process is able to produce correct and acceptable elements with the same properties and materials than autoclave cured specimens. The removal of autoclaves can lead to great savings of power consumption and time in the composites industry, having as a direct consequence the decreasing of costs associated to the process.

Figure. 1 Front Spar cured using DVD technique

1. GENERAL INTRODUCTION

The aerospace industry has employed and certified preimpregnated materials for decades, which is directly translated into important investments in complementary equipment. The works described in this document show a manufacturing process useful to avoid autoclaves and effective to obtain complex structures that respect the aerospace threshold values for porosity, attenuation and laboratory testing and guarantee process repeatability and robustness.

Autoclaves originally have been designed to cure carbon fiber preimpregnated materials, regarding strict curing cycle control for temperature, vacuum applied to the specimen and external pressure. The costs of the process must add other aspects, especially for large scale and more complex structures which can require even more time for load and unload operations in the autoclave, special surveillance for bag leakage and a higher initial investment for a bigger autoclave.

First, flat thick panels of 13mm (aprox.70 layers) and 24mm (aprox. 130 layers) have been produced to check specimens could be obtained using DVD technique with the same quality characteristics than the references. Finally, a front spar was produced as example of complex structure produced with DVD technique.

1.1. PREVIOUS TESTS

Autoclave and carbon fiber preimpregnated materials traditionally have been a guarantee of security and robustness to produce composite elements. Double Vacuum Debulking (DVD) method employed here omits the autoclave from the equation, therefore process costs are meaningful reduced, and is able to obtain mechanical and physicochemical properties above the acceptance thresholds.

Previous tests have shown DVD is able to get acceptable values of porosity and mechanical properties using autoclave preimpregnated materials with thermoset epoxy matrix and carbon fibres.

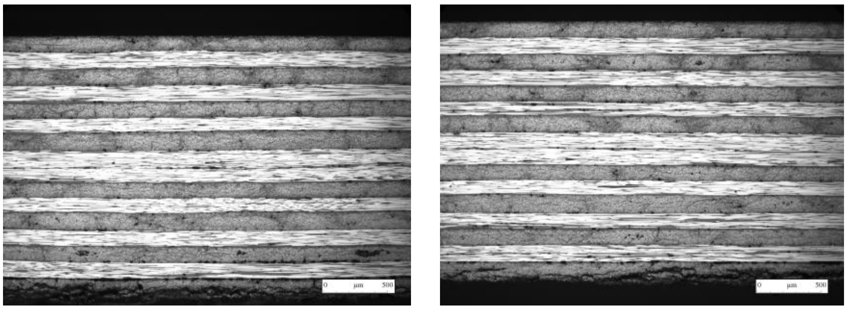

Figure 1. Micro-photos extracted from previous tests in FIDAMC using DVD technique

Flat panels of 13mm (aprox.70 layers) and 24mm (aprox. 130 layers) thicknesses and unfavourable layup distribution were produced, just to ensure the process capability to evacuate volatiles and air trapped between layers. The employed material for the tests was a composite tape of high curing temperature, with thermoset M21 epoxy matrix and T800 carbon fibre, easy to find in common suppliers.

A big panel was layed up by the Automatic Tape Layup machine and cut into pieces that were piled and compacted by the operator to get configurations in table 1. Curing assembly for each of the panels was prepared using two different vacuum circuits, a first one for the inner vacuum bag and a second one for the outer vacuum bag.

Nominal Thickness	Lay up	Surface	Panel ID
13mm	Combination 0,+/-45, 90º	300x300mm	Panel 1
24mm	Combination 0,+/-45, 90º	300x300mm	Panel 2

The first or degasification step of the curing cycle tries to maintain pressure lower in the inner vacuum bag than in the outer one. All the gases appearing in the CFRP element due to the temperature increasing, possible chemical reactions in the resin and air trapped between layers can find a path to move out of the system fast and easily with no external pressure to avoid their or produce load losses in their movement. During the second step, temperature must raise again to achieve the curing values given by the manufacturer, 180ºC in this case, and stay at that temperature for a determined period, known as stabilization.

All the panels were inspected by ultrasonic techniques using automatic equipment TRITON 8000 TT and Probe Technisonic 5MHz. Measurements were made in areas bigger than 36mm^2, with volume porosity dimensioned with a back-wall echo drop of 12dB considered as acceptance threshold.

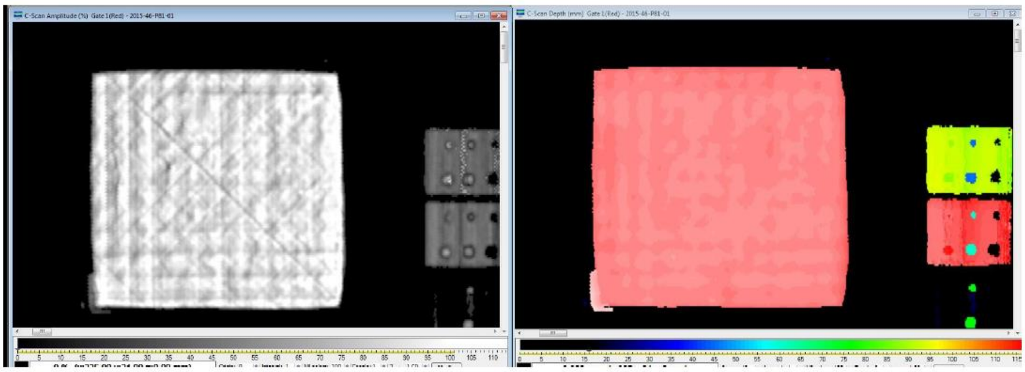

Figure 2. Specimen 13mm thick.
Amplitude C-Scan reveals high signal level, which means no attenuation; thus, porosity level is low enough compared to the reference.
Thickness C-Scan reveals a very low thickness variation (0,12mm).

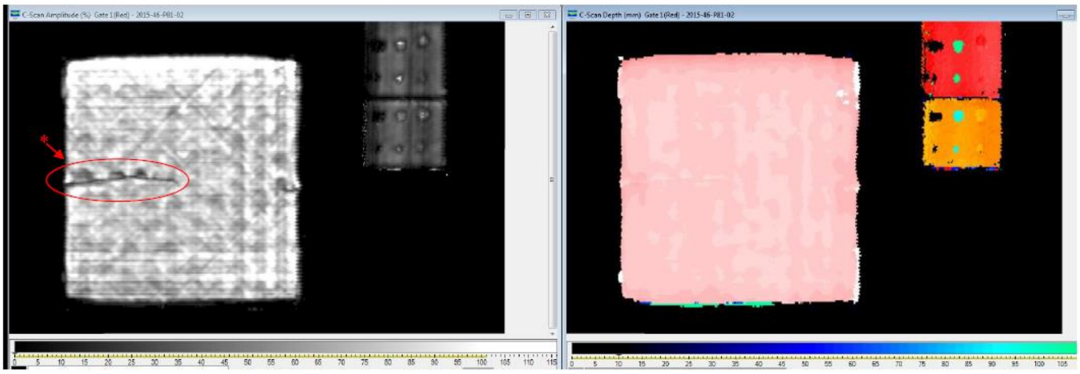

Figure 3. Specimen 24mm thick.
Amplitude C-Scan reveals high signal level, which means no attenuation; thus porosity level is low enough compared to the reference.
Thickness C-Scan reveals a very low thickness variation (0,2mm).
*) Thermocouple location for monitoring during curing cycle.

2. MANUFACTURING ASSESSMENT

Complex aerospace structures usually combine basic elements to get a system for high performance applications. The structure in this study is a front spar, which integrates a skin reinforced by a perimeter frame and four T shaped stiffeners. The chosen material has been preimpregnated carbon tape, with M21 epoxy resin and T800 fiber, commercially available.

The skin is 1886mm long and its width slightly varies between 320mm and 275mm on each of the ends. The skin and stiffeners present slope changes on their central areas, which complicates the oneshot integration of all the structure. Stiffener webs are about 50mm high, which gives the element a total height of 80mm. Skins and frame have been layed up and cut to the correct dimensions by automatic means using an MTorres Automatic Tape Layup machine. Skin and frames configurations combine 0, +/-45º and 90º layer orientations, with thicknesses of less than 4mm each.

Stiffeners were layed up by automatic means and their shapes modified using hot forming process by means of silicone membrane, temperature increase and vacuum. Elements copied the tooling surface shape in a 90º angle that allows forming T shaped stiffeners. Roving fillers were placed to preserve continuity in the material, taking into account parameters such as the radii formed by the stringer feet and web or the skin thickness.

After assembly of all the parts, the carbon fiber structure was covered with the first or inner bag and vacuum was applied. The second vacuum bag was made, covering a cap placed over the specimen to avoid contact of both bag films. Vacuum bags were prepared in a way that volatiles and air could be removed easily, using air weavers and mechanical balance between films was suitable to avoid holes and leakage. Thermocouples and vacuum register were placed for monitoring purposes.

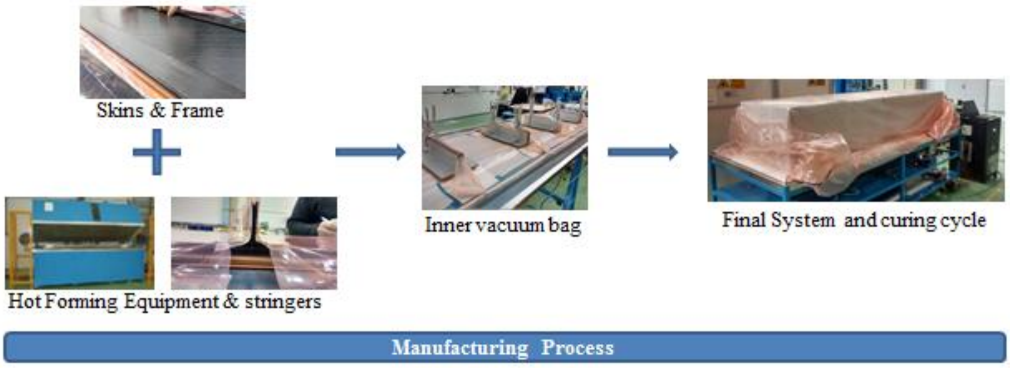

Figure 4. General Scheme of front spar manufacturing

Curing cycle uses the directions given by the material supplier and implies a two steps curing.

	1 step	2 step
Heating rate (ºC/min)	5	5
Stabilization (ºC)	<150	180
Time (min)	15	120
Demoulding temperature (ºC)	---	60ºC

Successful trials have been made until the moment. Specimens have been tested using the same ultrasonic technique and equipment than for flat panels and the results show that no meaningful attenuation takes place.

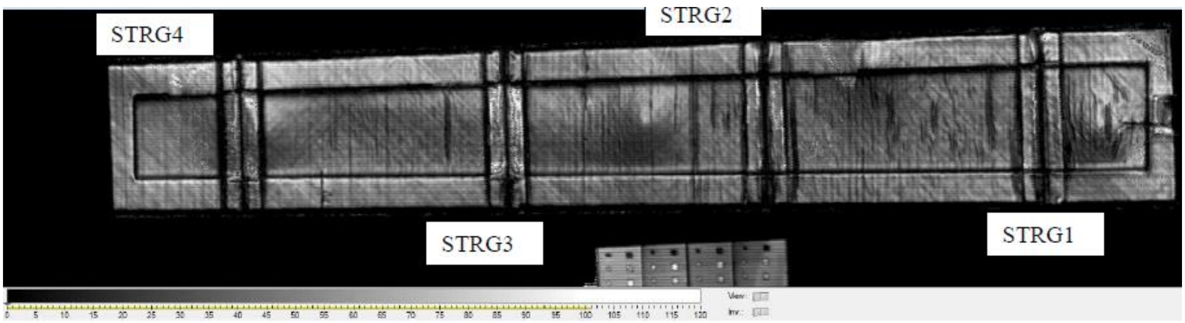

Figure 5. Amplitude C-Scan Front spar inspection

In terms of co-cured integration, it can be observed that stringers have been properly integrated. Some effects can be observed in STRG1, STRG2 and STRG3 in the area close to radii, showing a little attenuation increase, probably due to insufficient volatile extraction and to the simplicity of the employed tooling for stringers to be correctly positioned during curing cycle. Some little effects due to demoulding can be seen near the element edges. Thickness of the specimen (especially in stringer feet) is above 5mm, so the inspection made shows attenuation values fulfil the acceptance requirements. Some surface waviness can be seen as well, due to the simplicity of the employed tooling.

The manufactured specimen is correct and acceptable in terms of integration and curing with a great potential of improvement regarding dimensional tolerances using a more complex tooling in next test campaigns.

Next trials will focus in tooling aspects in order to get even better geometrical tolerances in the element. Current tooling has been thought only to probe the benefits of the DVD technique and to validate its feasibility as a manufacturing process. Further works will control parallelism and perpendicularity of stiffeners, radii and optimization of inner bag and its shape.

3 RESULTS AND CONCLUSSIONS

Double Vacuum Debulking has been proved as a valid curing technique giving as a result specimens in preimpregnated tape of carbon fibre with epoxy resin with the same quality standards than autoclave curing. The possibility of curing “autoclave typical materials” using a simple technique based in heating and inner and external vacuum bag with no additional needs of external pressure or autoclave can be directly important savings. In the future, DVD can mean to industries the reduction of manufacturing costs in equipment, power consumption, process time and other raw materials such as nitrogen in case of inert atmosphere inside autoclaves.

In the first stage of these works, flat thick panels of 13mm (aprox.70 layers) and 24mm (aprox. 130 layers) thicknesses have been produced using DVD technique. The employed material was common preimpregnated tape of T800 carbon fibre and M21 epoxy resin originally created by the supplier for autoclave curing. Results using Double Vacuum Debulking show the specimens cured presented very low attenuation levels in the NDT inspection by ultrasonic means, acceptable and valid if compared with references for autoclave specimens using the same material.

In the second stage of the works, a front spar was produced as example of complex structure with two skins, a reinforcing perimeter frame and for T-shaped stiffeners. The specimen is aprox. 1886mm long, about 80mm high and its width slightly varies between 320mm and 275mm on each of the ends. The employed material was preimpregnated carbon T800 fibre tape and M21 epoxy resin. Double Vacuum Debulking has been employed as curing technique. The obtained front spar is correct in terms of integration of elements (skins, frame, stiffeners) and presents low attenuation levels in the NDT inspection by ultrasonic means. This element is valid as well if compared with references for autoclave specimens using the same material.

Double Vacuum Debulking can achieve thick specimens and integration of complex structures using preimpregnated materials that typically were created for autoclave curing processes. Double Vacuum Debulking produces specimens aligned with the nowadays restrictive quality standards that are applied to the current certified production processes in the aeronautical industry.

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