TOOLING OPTIMIZATION FOR COMPOSITE MATERIALS PARTS

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Keywords: tooling, simulation, autoclave

Abstract

This Project studies manufacturing process optimization for complex composite materials parts trying to reduce costs.

First of all "springback" effect produced in curing cycles has been tried to be simulated in order to anticipate possible solutions and reduce reworks in the final and assemblie parts.

On the other hand, tooling-part thermal behavior has been tested to be simulated during autoclave cycle in order to optimize thermal distribution and save in energy and ecological costs.

All processes have been developed together with design and manufacturing of a representative part (curved skin with stiffeners) and a tooling, with innovative system, that allows light geometry/curvature changes in order to correct expected defects beforehand.

Obtained conclusions deal with manufacturing, correction, assembly, autoclave cycles times reduction with subsequent energy and CO2 emission savings.

1. Introduction

Starting from actual working processes study for aeronautic parts manufacturing, tooling and carbon fiber materials curing processes aspects are tried to be improved.

Stiffened and curved parts in composite materials are actually cured on tooling under curing autoclave cycles. Tooling plays an important role because of its influence in factors as vacuum, tightness, contact ply behavior, thermal expansion coefficient differences that have to be taken into account during the whole process and during tooling design and manufacturing.

Lack of consideration of these parameters drives to parts deformation, precharged zones, breaks and final assembly costs increments.

1.1. State of the Art

Not taking into account complexity of the manufacturing part, these are the usual composite materials tooling types:

- Female tooling: good for open sections, gives good surface finish and has low tensions during curing.

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– Male tooling: worst surface finish (may need caul plates). It needs a carefully design taking into account unmoulding of the part.

Regarding to the materials used in tooling construction, it is very important to consider their thermal expansion coefficients (should be close to those of the carbon fiber composites) and ease use. According to Re-Steel [1], Invar, despite its high cost, meets these requirements.

Sometimes tooling part in contact with final carbon fiber part is manufactured with Invar and the rest of the tooling structure is constructed with a cheaper material. When this occurs, because of different dilatations, supporting structure should allow some slippage of the other part, and this brings a significant increase in design complexity.

2. Tooling Design and Manufacturing

Requirements to fulfill with the tooling in this project are:

– It should allow to manufacture a fuselage type stiffened panel 2x1m in dimensions
– It should be rigid and accurate enough
– It should resists typical autoclave cycle conditions (180ºC and 7 bars)
– TEC should be close to that in composite materials
– Durability should be guaranteed for a great number of cycles
– Should be light in order to be quickly heated
– Should be easy to transport and manipulate
– Should be easy to modify and repair

All these aspects drive to a tooling option in which both main plate and supporting structure are Invar made. Also, in order to allow certain degree of freedom between both parts and also some variations in geometry, interface between them was think as tensor bars. This system also minimizes possible influences from one part to the other in dilatations and heat transmission.

For a perfect control in main plate geometry, a system with removable templates was designed. These can also help in case more rigidity is needed in the whole structure (i.e. for automatic tape laying on the same tooling). Main function of these templates is to fit as guides and stoppers as the main plate is deformed to the final geometry with the tensor bars. They can be easily changed or reworked if some small changes in geometry are needed.

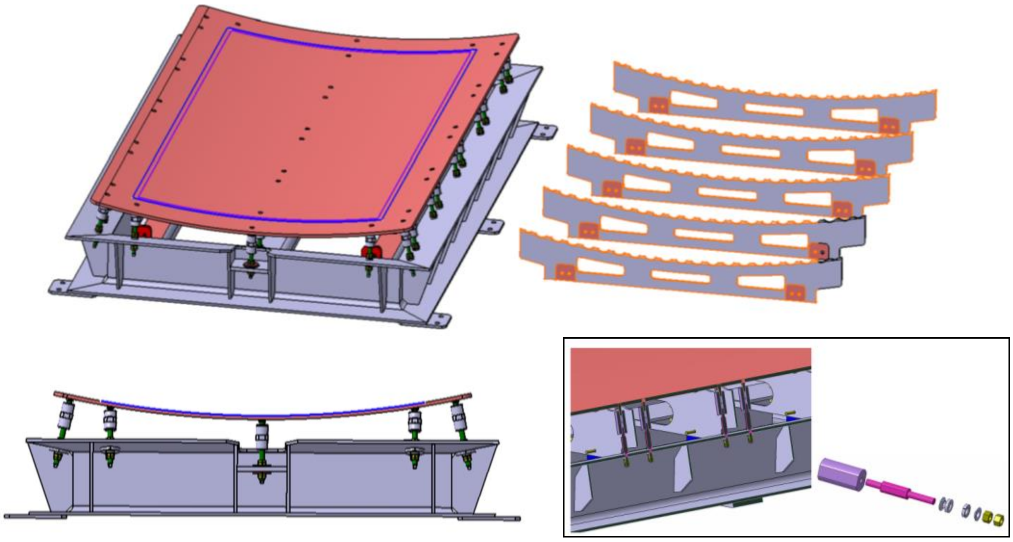

Figure 1. Conceptual Design.

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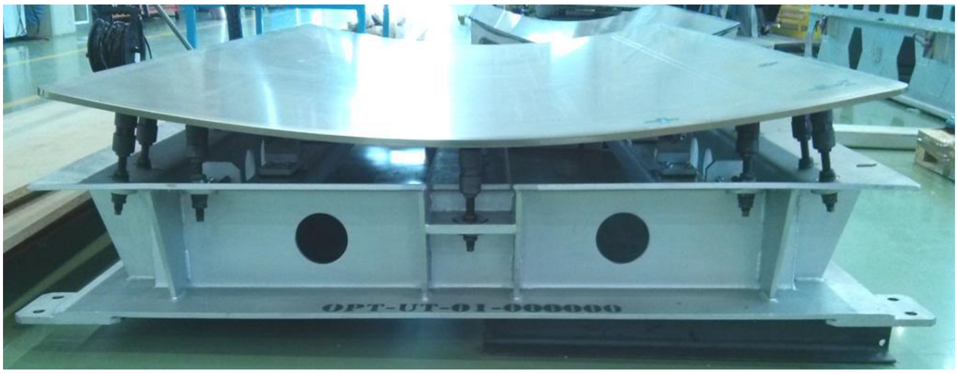

Figure 2. Manufactured Tooling.

3. Simulations

Simulations in this Project have been performed with PAN-Distortion 2013 and SYSPLY software. In the first one, only the tool was submitted to a typical autoclave cycle (180ªC, 600 mm Hg vacuum and 90 psig pressure). This showed a maximum absolute displacement of 0,35mm in tooling surface (0,3mm in longitudinal, 0,2mm in transversal and 0,1mm in vertical directions). Because composite material cures at certain temperature, it was important to show a very uniform distribution during the cycle; simulation showed that maximum differences were around 0,5ºC. An empirical demonstration was performed with the manufactured tool in a real autoclave cycle with 14 thermocouples distributed in its surface.

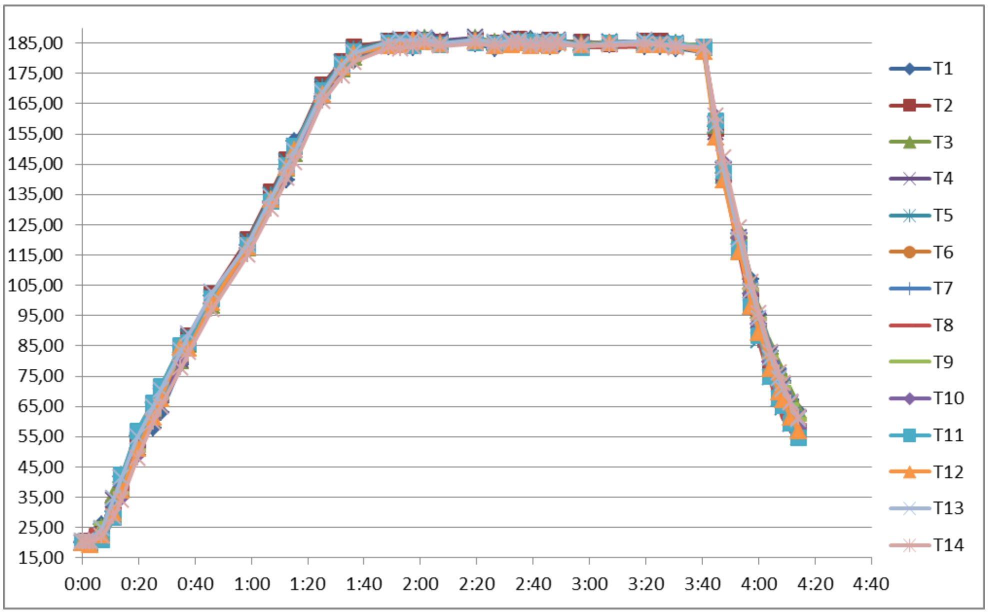

Figure 3. Temperature (ºC) vs Time (h:mm) – Tool in Autoclave.

For the "springback" simulation of the part (carbon part deformation) first steps were to select and characterize working material: HEXPLY M21/34%/194/T800S-24K according to Hexcel [2]. Smaller (but similar to final) parts were designed and manufactured in order to make adjustments and compare results with real specimens. 500x500mm coupons were tried, some of them with non-symmetrical lay-up distribution in order to force deformation in the part.

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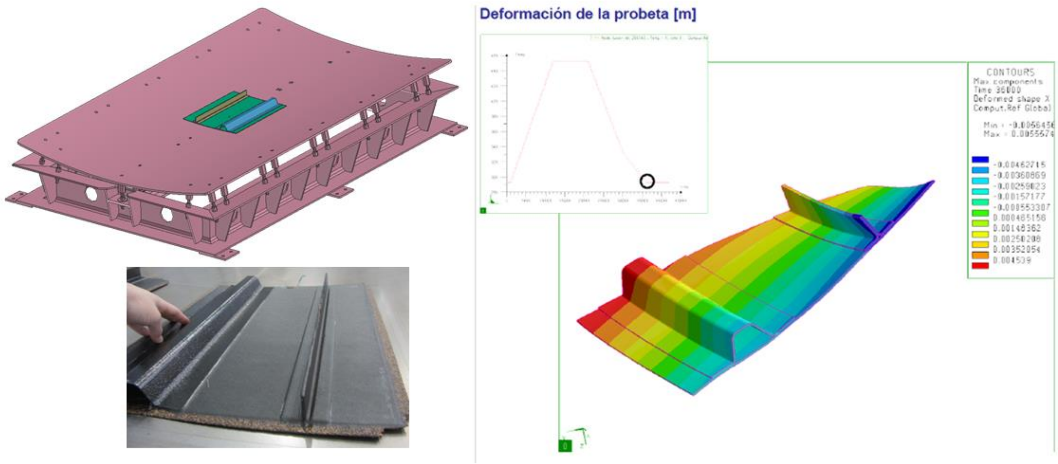
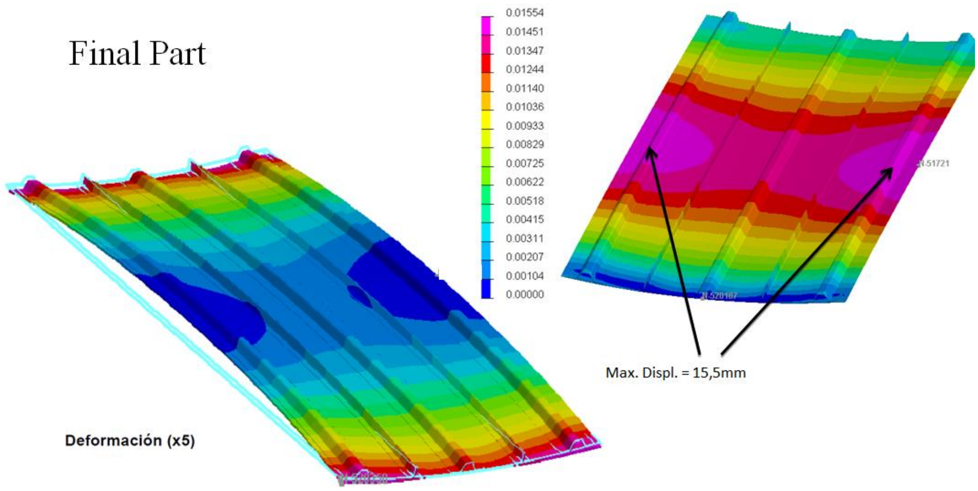


Figure 4. Coupons simulation and Manufacturing.

After finding similar behaviors between simulated and manufactured symmetrical or not coupons, final part was simulated. A 2x1m panel with 14 plies (+/-/0/90/0/90/-/+)S rigidized with a couple of T stiffeners and three with omega section. These are made from 11 plies lay-up (+/-//0/0/90/0/90/0/0/-/+), as the “Ls” from with Ts are constructed.



•Panel : 2x1m, 14 plies (45/-45/90/0/90/-45/45/45/-45/90/0/90/-45/45) + Stiffeners

Figure 5. Final Part Deformation simulation.

Although quantitatively the theoretical results are not very accurate (around double than the real ones), qualitatively they fairly describe the behavior of the part and give us a rough idea of how it will deform.

After manufacturing the part, the observed behavior was found to be as expected, but some adjustments in the simulation are still needed. However, since the characteristics of the tooling allow them, it is possible to play with the settings to get the perfect piece in one or two more executions.

4. Conclusions

Having in mind and look for a low coefficient of thermal expansion of the tool saves problems because it avoids tensions in the layers in contact with him during the curing cycle. Making mold plate somewhat isolated from the rest of the tool also prevents influences of the thermal inertia and allow heating and cooling to be more evenly and quick, reducing stabilization times. Regulated procedures

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generally admit temperature ramps of 0.5 to 3 per minute. Optimizing these ramps to reach 180ºC, time can be reduced about five hours to less than one.

Although this type of tooling may need more time to be developed and manufactured, its mass will usually be 15-30% lower than a more conventional tools, so its price should not differ much.

In addition, this way of working reduces rework time in final assembly of parts and assemblies, as well as shorter cycle autoclave, although the savings will always be dependent on how the series to be produced.

Also, as a result of reducing time in autoclave (high energy costs) and reworking times, significant energy and CO2 emissions savings can be achieved.

Acknowledgments

The project optimization tools for composite parts, also known as OPTOCOM, has been a project developed in the FIDAMC technology center within the 7th Framework Program for a period of 18 months during 2013 and 2014. The authors wish to acknowledge the INMAPA collaboration on design and manufacture of tooling and to CTAG for simulations and characterization of materials.

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