MANUFACTURING PROCESS FOR Ω STRINGERS WITH HIGH CURVATURE IN PREIMPREGNATED CARBON FIBER

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Keywords: CFRP, preimpregnated, hot-forming, industrialization

ABSTRACT

The evolution of aviation market is leading an exponential growth of annual aircraft deliveries, what forces to increase the production rates and demands significant cost savings. For these reasons, it is required to study low cost technologies and high rate production methods in composites components for aircrafts to be competitive [1].

Taking into account these requirements, a development plan to improve the manufacturing process of aircrafts components and industrialization solutions has been accomplished. Particularly, we have focused on the manufacturing of Ω stringer with high curvature where the main goal is to reach the automatic hot-forming process for large and complex stringers with high curvature, for example Ω stringer in fan cowls, because the actual process is completely manual (hand lay-up of fabric patterns on a male tool)

During the last years the hot forming process of complex prepreg parts has been improved in terms of industrialization [2]. Firstly, hot-forming technique with membrane has been used to fold laminates to its final shape before curing. This technique is restricted to simple parts with smooth surface and low thicknesses and low production rates. The next step was the press forming technique which allows folding more complex laminates with more aggressive shapes, higher thicknesses and at higher rates. However, these methods cannot be used with large complex parts because the machines would be outsized and challenging.

For these reason, a new hot forming process is developed to manufacture these complex parts. The manufacturing process follows an automatic continuous process to reduce lead time and recurrent costs. First, the laminate is lying up with an automatic tape lay-up machine (ATL), and then the hot forming process is divided in two steps to achieve the final complex geometry. Several trials are carried out with this developed process and the results are satisfactory obtaining a good quality part of 2.5m long with high curvature [figure 1].

FIGURES

Figure 1: Ω stringer manufactured by the developed hot-forming process.

1 GENERAL INTRODUCTION

The aviation market is increasing their production rates because of an exponential growth of deliveries. For these reasons, it is required to reduce the recurrent costs introducing low cost technologies and high rate production methods in composites components.

For these reasons, new manufacturing processes have been developed to achieve this automatization of aircrafts components. Mainly, we have focused on the manufacturing of Ω stringer with high curvature where the main goal is to reach the automatic hot-forming process for large and complex stringers with high curvature, for example Ω stringer in fan cowls.

The main objectives of this development are:

- High quality and repetitive process to be implemented in serial production.
- High level of automatization (high rate)
- Reduce recurrent costs (RC) and lead time (LT)

Considering these objectives, the actual manufacturing process for fan cowl stringers is studied to find the key steps to industrialize the process. In figure 2, the flowchart of the current process is shown:

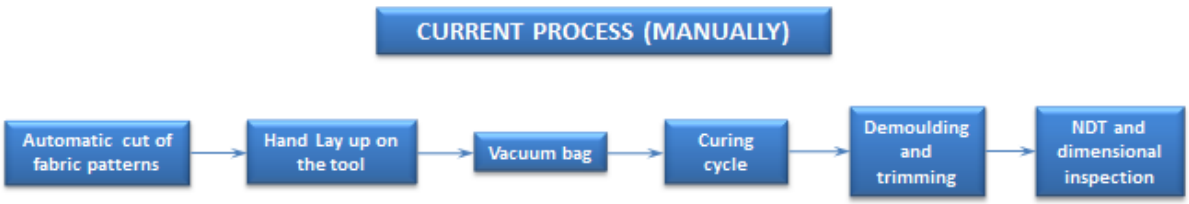

Figure 2: Current manufacturing process for fan cowl stringers.

In this manufacturing process, the part is made manually by hand lay-up of fabric patterns on a male tool. Then, the part is cured in autoclave. After the trimming process, the NDT and dimensional inspection is done to validate the quality of the part. The hand lay-up step has to be automatized to increase the rate of production and reduce recurrent cost. This step could be done with an automatic laying up and then, a hot-forming process to get the final shape.

There are different techniques for hot forming process; most of them have been improved in terms of industrialization. Firstly, hot-forming technique with membrane has been used to fold laminates to its final shape before curing. This technique is restricted to simple parts with smooth surface and low thicknesses and low production rates. The next step was the press forming technique which allows folding more complex laminates with more aggressive shapes, higher thicknesses and at higher rates. However, these methods cannot be used with large complex parts because the machines would be outsized and challenging. For this reason, a new concept is settled taking into account the machines and devices available in Fidamc facilities to validate the new development.

The new manufacturing process follows an automatic continuous process to reduce lead time and recurrent costs. Firstly, the laminate is laying up with an automatic tape lay-up machine (ATL), and then the hot forming process is divided in two steps to achieve the final complex geometry. Then, the curing cycle and inspection is the same process as the actual one. The new concept is shown in figure 3.

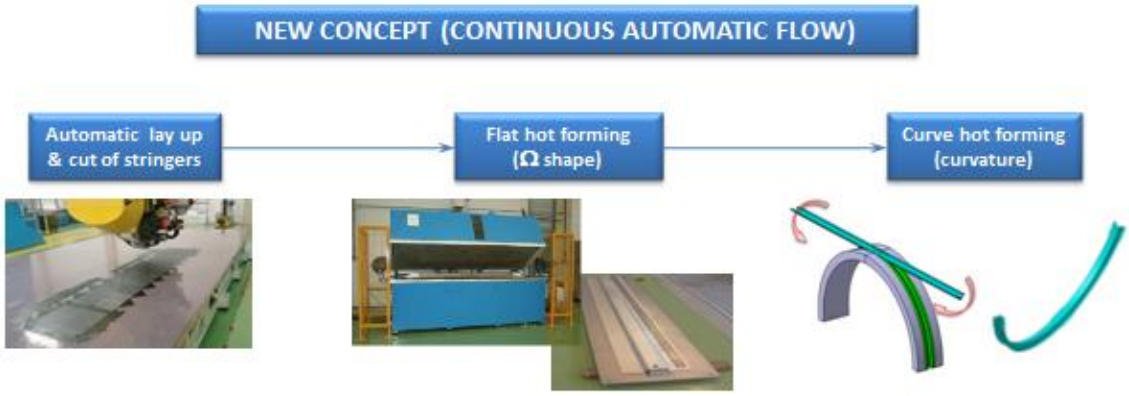

Figure 3: New conceptual manufacturing process for fan cowl stringers.

Finally, several trials are carried out with this developed process to validate the technology for serial production.

2 DEVELOPMENT

The first study, carried out before the trials, is defined the material, stacking sequence and laying strategy. As it was explained before, the actual process uses fabric patterns (carbon fibre fabric with resin 8552), so the material will be changed to UD prepreg tape (UD carbon fiber with resin 8552) for automatic laying up in ATL machine.

Secondly, the stacking sequence is modified since UD tape material is going to be used instead of fabric because they have different thicknesses. According to stress studies, keeping the same thickness in the laminate using UD tape, the stiffness will be higher since there will be more plies. For this reason, the new sequence is defined maintaining the thickness of the actual stringer and the percentage of plies in each direction.

Notice that the actual part has continuous plies in these directions +/-45º and 90º, only has 0º direction in the head of Ω stringer. In addition to this, there are several small reinforcements in the four directions (0, +/-45º, 90º)

The new sequence in UD tape is going to preserve this distribution of plies; complete plies in +/-45º and 90º directions and only plies of 0º direction in the head of Ω stringer. In the trials; only the baseline sequence will be considered at first and then, reinforcements in the extremes will be included to validate the technology.

Finally, some geometrical inputs of the real stringers are considered for the trials as:

- Length: ~3.5m
- Radius: ~1m
- Ω Height: ~48mm
- Ω Constant section.

The height of the Ω stringer and the radius are going to be critical in the forming process to get the part with good quality and without wrinkles.

The following point is to define the tooling required in the trials and test plan. The main tooling in the hot-forming considers the machines and devices available to reduce the cost of the project. Of course, for serial production, a complete working line will be design to optimize the process. However,

using these machines, devices and tooling, the development can be validated.

For **flat hot forming (Ω shape)** is required a membrane system and a forming tool with Ω shape [figure 4].

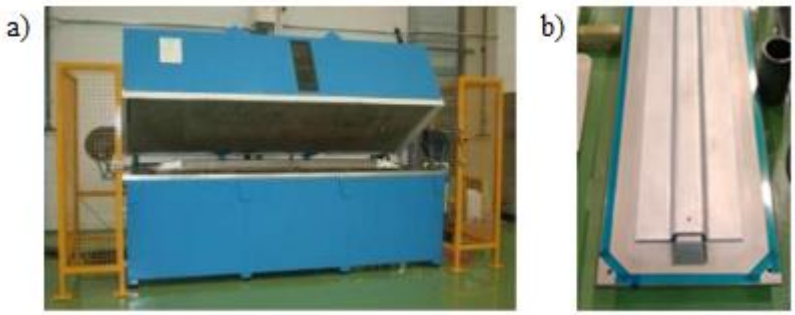

Figure 4: Required tooling for flat hot forming; a) membrane system, b) forming tool.

For **curve forming (curvature)** is needed a flexible tool (rubber), an oven and a male tool for curve forming [figure 5].

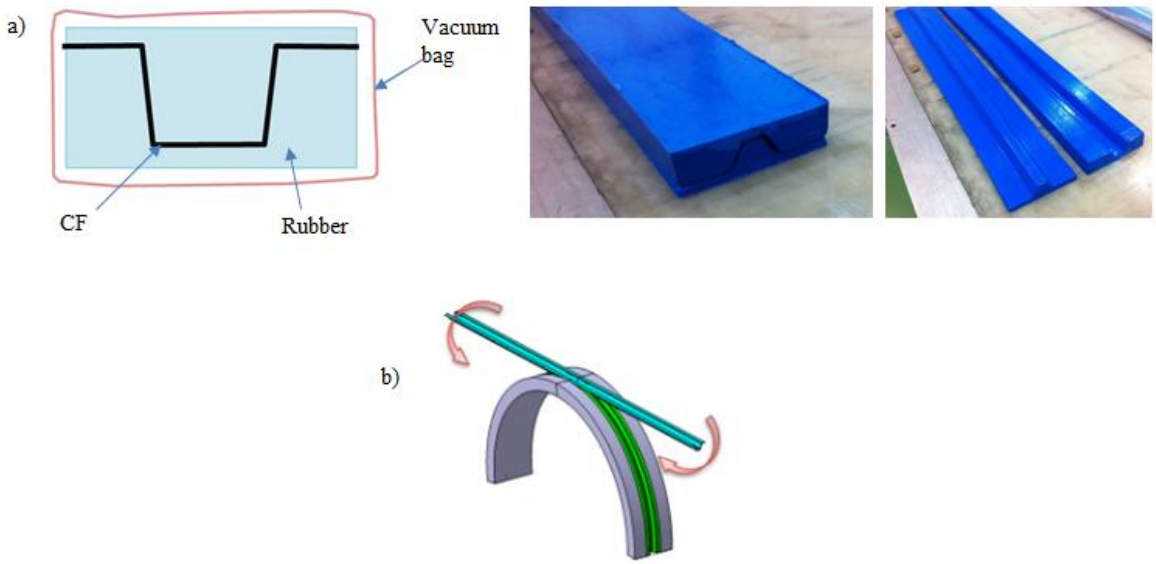

Figure 5: Required tooling for curve forming; a) flexible tool (rubber), b) male tool for curve forming.

The test plan takes into account the quantity of tools that are needed to manufacture the trials. To save budget, it is decided to use an existing tool for the first manufacturing trials to confirm and validate the technology. If the results of these trials are satisfactory, a new tooling with the real dimensions of the demonstrator will be designed. The test plan is divided in two parts; first manufacturing trials and secondly, final demonstrators with the real geometry.

In the **first manufacturing trials**, a small geometry in relation to the real one is considered to make use of an existing tool. As the geometry is different from the real one; the stacking sequence has a higher number of plies and it is necessary to extrapolate the dimensions to be conservative in the results. For this reason, in these trials the following dimensions and sequence are going to be used:

- Height of Ω stringer will be 30mm instead of 48mm
- Radius will be 730mm instead of 1m
- Length will be 1m instead of 3m
- Basic sequence 11 plies
- Basic sequence + reinforcements in the extremes of stringer, simulating the demonstrator geometry

In the **demonstrator trials**, the real geometry of fan cowl stringers is used; for this reason, a specific tool for flat hot forming process is required. Finally, the dimensions and stacking sequence considered in these trials are shown:

- Height ~48mm
- Radius ~ 1m
- Length ~2.5m
- Basic sequence 9 plies + reinforcements in the extremes of stringer, simulating the real geometry of the stringer.

2.1 MANUFACTURING TRIALS AND RESULTS

Several manufacturing trials with a small geometry are carried out to show the viability of the process and check the quality of the part, especially wrinkles or waves. In table 1, all the manufacturing trials are enumerated:

Trial	Description
1	Hot forming trial
2	Curing trial
3	Hot forming trial with release film
4	Hot forming trial with complete plies in 0º direction
5	Hot forming trial with reinforcement in one extreme
6	Hot forming trial with reinforcement in one extreme changing sequence
7	Hot forming trial with reinforcement in both extremes changing sequence
8	Hot forming trial with reinforcement in both extremes
9	Hot forming trial with reinforcement in both extremes

Table 1: List of the first manufacturing trials.

All the trials follow the process described in figure 3. The first ones only include the baseline sequence to assure that the part has good quality after the forming processes obtaining a preform without wrinkles. The results of these kinds of laminates are acceptable; figure 6 is shown as example.

Figure 6: Results of the trial 1with baseline sequence without reinforcements; a) Ω stringer: length 1m, b) detail of quality in extremes without reinforcements.

The next step is to introduce reinforcements as the actual part to validate the technology. The results are satisfactory because the process is repetitive and the quality of the part is suitable, without wrinkles. The results can be seen in figure 7 as example.

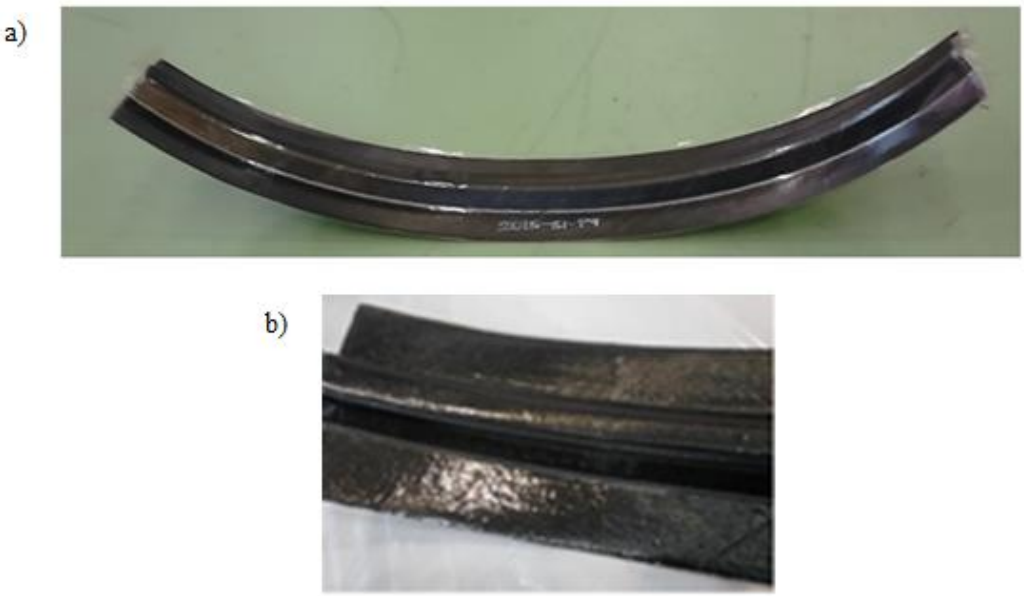

Figure 7: Results of the trial 9 with baseline sequence and reinforcements. a) Ω stringer: length 1m, b) detail of quality in extremes with reinforcements.

Only one trial is cured to carry out the NDT and dimensional inspection, it is acceptable according to standards in manufacturing composites. In addition to this, the quality of the parts is acceptable since there are not wrinkles or waves.

These manufacturing trials show the viability of the process and repetitiveness. During these trials the main lesson learnt to guarantee good quality of the parts are the next ones:

- Release film during the forming
- Good level of vacuum during the forming
- Correct temperature during the forming

Taking into account these results and lesson learnt, the next step is to manufacture a representative demonstrator similar to the real geometry.

Several manufacturing demonstrators are carried out to show the quality of the part and the repetitiveness of the process to validate the serial production. In table 2, all the manufacturing demonstrators are registered:

Trial	Description
10	Hot forming trial real geometry
11	Curing trial omega real geometry
12	Hot forming trial omega real geometry
13	Curing trial omega real geometry
14	Curing trial hybrid fabric-tape real geometry

Table 2: List of manufacturing demonstrators.

All the trials follow the process described in figure 3. The results are satisfactory because the process is repetitive and the quality of the part is acceptable, without wrinkles or waves. The results can be seen in figure 8.

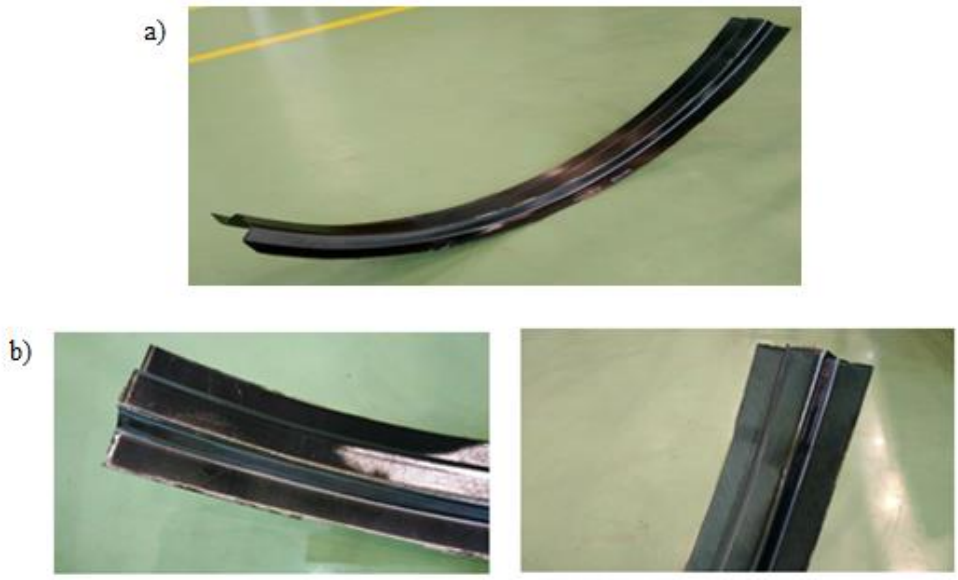

Figure 8: Results of the trial 11 (full scale) with baseline sequence and reinforcements; a) Ω stringer: length 2.5m, b) detail of quality in extremes with reinforcements.

Three components are cured to carry out the NDT and dimensional inspection; they are adequate according to standards in manufacturing composites. In addition to this, the quality of the parts is acceptable since there are not wrinkles or waves in any of the trials.

3 CONCLUSIONS

With this development, the manufacturing capabilities of Ω stringer with high curvature are verified, using UD prepreg carbon fiber for lying up in ATL machine and forming process.

The results are satisfactory and acceptable from standards of inspection. The NDT and dimensional inspections of the cured specimens are acceptable according to standards in manufacturing composites. In addition to this, the quality of the parts is adequate since there are not wrinkles or waves using the improvements and lesson learnt during the manufacturing trials:

- Release film during the forming
- Good level of vacuum during the forming
- Correct temperature during the forming

In addition to this, the process is robust and repetitive for serial production and validates an automatic flow to obtain a high rate production. Finally, this new development reduces recurrent cost and lead time what is really important for serial production.

The way forward will be to study a complete industrlization of the working line to optimize the process to introduce this new concept in serial production.

ACKNOWLEDGEMENTS

Authors would like to acknowledge the financial support of the *Fondo Europeo De Desarrollo Regional-FEDER* (Programa Operativo de Crecimiento Inteligente 2014-2020) and *Ministerio de economía y Competitividad* through *Centro para el Desarrollo Tecnológico Industrial-CDTI* (IDI-20141333) and the leadership of *Airbus Group* as part of the association in this project included in ESTENEA plan (study of low cost technologies and high rate production in composites).

REFERENCES

[1] Huybrechts, S. M., Meink, T. E., Wegner, P. M., & Ganley, J. M. (2002). Manufacturing theory for advanced grid stiffened structures. *Composites Part A: Applied Science and Manufacturing, 33(2), 155-161*R.

[2] Pinillos, A. Martínez-Cerezo, A. Pérez-Pastor. Matcomp 2015. *Evolución de la técnica del conformado en prensa y el impacto presente y futuro en la fabricación de piezas de material compuesto*.