# Improving the Vacuum-Infusion Process to Manufacture High Quality Structural Composite for the Aeronautic Market

L. Oliveira[1*], J.P. Nunes[2], F. Ferreira[1]
[1] *PIEP - Pole for Innovation in Polymer Engineering, 4800-058 Guimarães, Portugal*
[2] *Inst. Polymers & Composites/I3N, Minho University, Azurém, 4800-058 Guimarães, Portugal*
* *luis.oliveira@piep.pt*

## ABSTRACT:

In last year's, the vacuum-infusion processing method is being replacing successfully autoclave technologies to manufacture advanced composite structures, namely, the carbon-fibre reinforced plastic (CFRP) ones applied in aeronautical and aerospace applications [1]. The high investment associated with autoclave "prepreg" manufacturing has prompted interest in the use of alternative vacuum-infusion technologies that proven to be much more cost-effective processing methods [2]. The present work presents, describes and discusses improvements and developments made on an existing vacuum-infusion process to obtained high quality and reliable CRFP structural components to the aircraft industry. The first aim is to use the developed technology to produce elevator control surface of a medium military transport aircraft. An additional heating stage was added to the initial standard vacuum process to enhance the quality and reliability of the final manufactured composite parts, namely in terms of void reduction and control of fibre content and orientation. A prototype part was manufactured by using this improved vacuum-infusion process to be tested in order to validate the developed technology. This paper will present and discuss the results obtained in the manufacturing and characterization tests made on the produced prototypes.

## 1 INTRODUCTION

### 1.1 *Infusion process*

Fabrics are laid up as a dry stack of materials in the mould (see Figure 1). Then the fibre stack is covered with peel ply and with a flow media fabric. The upper part of the mould is sealed with a vacuum bag and vacuum is applied. Once bag leaks have been eliminated, maximum vacuum is applied and temperature is raised up to 90°C. After some hours, moisture has been removed and resin can be allowed to flow into the laminate. Due to high temperature, there is the possibility of leakage originated by seal tape softening. In order to avoid any problem during the infusion, a vacuum channel is applied in mould contour, reducing leakage probability.

### 1.1 *Materials*

In this study, two different types of high tenacity carbon fibre fabrics were used: a 195 g/m$^2$ (TR30S) plain fabric and a 200 g/m$^2$ (TR50S) unidirectional fabric. The chosen thermosetting resin was a Ten-Cate RS50 epoxy one, due to its high performance properties, low viscosity and high glass-transition temperature. Since the cure of the part will be done at 177°C during 2h, all infusion consumables were selected for a working temperature higher than 180°C.

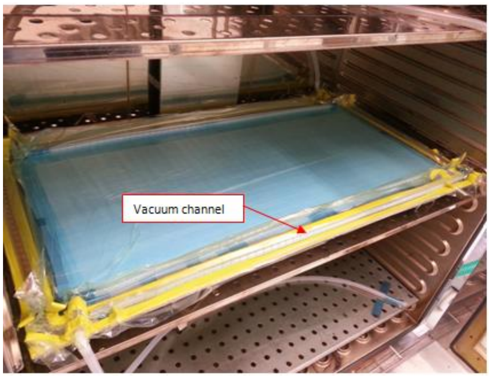

Figure 1. Resin infusion

### 1.2 *Laminates production*

Various infusion parameters were varied and studied in order to optimize the final laminate quality. Such operating conditions include infusion curing temperatures, infusion vacuum intensity and verification of the pressure differential between inlet and outlet of the resin. Visual inspection (dry fibers and pin-holes are some examples of rejection) and weight measurement of samples were used to choose the following best operating parameters: vacuum intensity between 40 and 100 mbar; infusion temperature of 90°C; using a post-curing cycle after part is cured.

One flat plate using each type of fabric under study was also manufactured by high temperature infusion and submitted to tests to evaluate the mechanical proprieties and quality of processed composite parts, . While a laminate $[0^\circ]_9$ was used in the plain fabric plate, the unidirectional fabric one was manufactured by using a $[0^\circ]_{11}$ stacking sequence. These stacking sequences were chosen in order to achieve the thickness required by the mechanical tests.

### 1.3 *Mechanical and laminate quality results*

The fibre volume and void contents were determined according to ASTM D3171-99. Three specimens of each type of fabric were tested. The obtained results are shown in table 1.

Table 1. Fibre volume fraction and voids contents.

| Fabric | Sample | FVF [%] | Voids [%] |
|---|---|---|---|
| Unidirectional | 1 | 51.40 | 1.46 |
| | 2 | 50.65 | 2.17 |
| | 3 | 50.97 | 2.34 |
| Plain | 4 | 53.80 | 1.48 |
| | 5 | 53.36 | 1.51 |
| | 6 | 54.57 | 1.63 |

As values presented in Table 1 show a good consistency of results were found in both laminates.

To determine the ply thickness measurements were made in 50 different points of the produced test plates. Table 2 shows the results determined.

Table 2. Ply thickness of the different fabrics.

| Fabric | Mean thickness per ply [mm] |
|---|---|
| Unidirectional | 0.2027 ± 0.0031 |
| Plain | 0.2077 ± 0.0045 |

Once again obtained results have shown that accurate that the manufactured plates presented small dispersion of thickness.

Mechanical tests were performed to determine the tensile (ASTM D3039/D3039M-08), compressive (SACMA 1R-94) and shear (ASTM D5379) mechanical properties at different temperature and moisture conditions. Eight test specimens were used at each condition. Table 3 summarises the results obtained at 24°C and 50% RH.

Table 3. Laminates mechanical proprieties.

| | | Plain 0° | UN 0° |
|---|---|---|---|
| Tensile | Strength [MPa] | 781 | 1598 |
| | Modulus [GPa] | 60.7 | 99.7 |
| | Strain [%] | 1.23 | 1.36 |
| | Poisson | 0.05 | 0.34 |
| Compression | Strength [MPa] | 591.02 | 844.17 |
| | Modulus [GPa] | 34.00 | 48.67 |
| | Strain [%] | 1.36 | 1.44 |
| Shear | Strength [MPa] | 78.8 | 81.7 |
| | Modulus [GPa] | 3.93 | 3.69 |
| | Strain [%] | 5.0 | 5.0 |

Tests made allowed to conclude that the produced plates presented mechanical properties compatible with those required by advanced markets, such as military, aeronautical and aircraft industries.

## 2 PRODUCTION OF AN AERONAUTICAL PROTOTYPE PART

### 2.1 *Aeronautical prototype part in study*

A reinforcing rib (Figure 2) from an aeronautical primary structure was produced using the new developed vacuum-infusion process. This composite part was selected due to the relevancy of its role in aeronautical structures and reduced dimensions when compared with other components. As primary structure it will be subject to a long sequence of restrictive rules and quality inspections, which imposes a very severe control of the manufacturing process in order to get the final component approval.

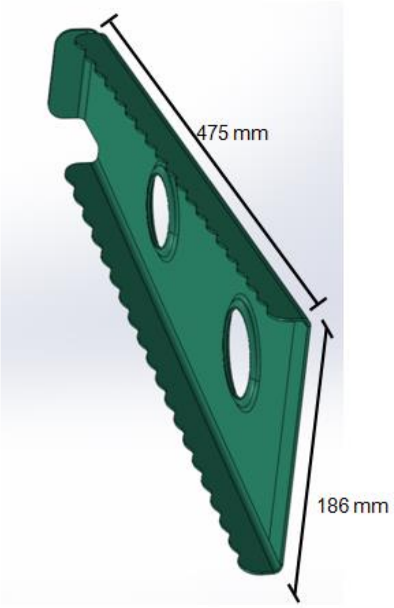

Figure 2. Rib

## 2.2 *Preform*

Manufacturing a rib with such geometry (small radius fillet) may origin undesirable compression of fibres against the mould surface, which usually results in resin excess or even entrapped air along the component edge. To avoid the problem a pre-form (Figure 3), having the rib shape was produced to improve the desired fibre fitting to the mould.

Figure 3. Rib preform

The carbon fibre fabric plies were placed in an aluminium mould and, then, the selected vacuum and temperature was applied. While vacuum press fibres tightly to mould surface, temperature promote the adhesion between plies due to the presence of a thermoplastic yarn in the fabric has. This pre-form is constituted by a plain fabric laminate $[(45^\circ/0^\circ)_3]_S$.

## 2.3 *Rib manufacturing*

The rib shown in Figure 4 was produced using an aluminium mould.

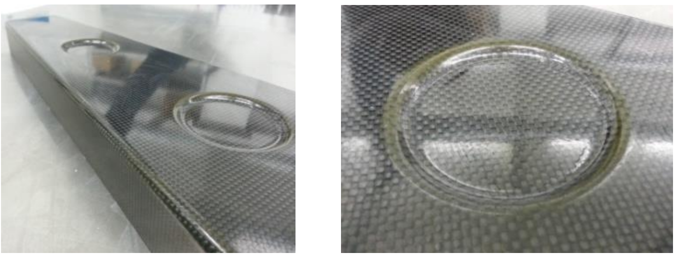

Figure 4. Rib surface

Observing Figure 4 is possible to verify that the rib present a good quality surface without presence of defects, fulfilling the requirements of aeronautical finished parts. However, it was important to quantify the excess of resin on the round edges of the rib. Thus, the produced part was cut and four different points (Figure 5) were analysed in the microscope in order to determine the resin in excess.

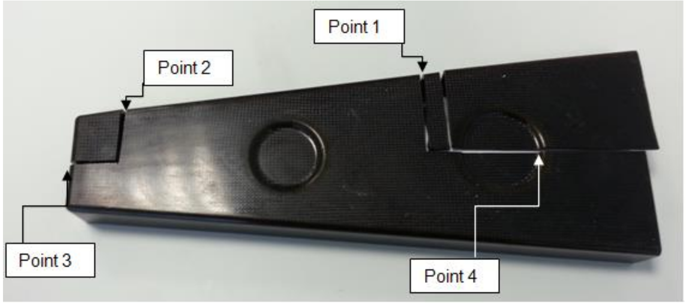

Figure 5. Rib analyzed points

Figure 6 to 9 show microscope measurements done in the points of the component shown in Figure 5.

Figure 6. Resin excess measurements in point 1

Figure 7. Resin excess measurements in point 2

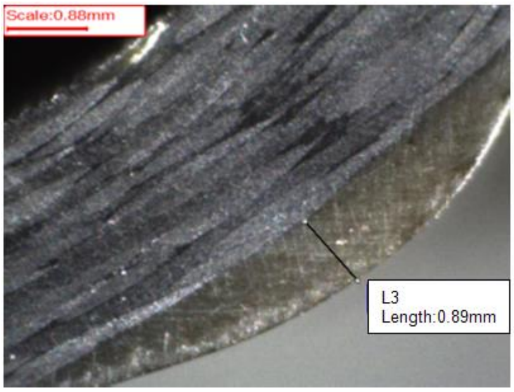

Figure 8. Resin excess measurements in point 3

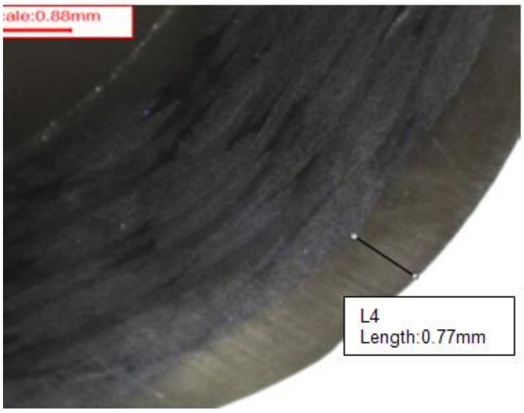

Figure 9. Resin excess measurements in point 4

From measurements made a maximum value of resin in excess of 1.03 mm was obtained. Thus, as aeronautical standards refer a maximum of 2.0 mm for resin in excess for part approval, obtained results indicate that the manufactured rib presented enough good quality to be applied in the aeronautical industry.

## 3 CONCLUSIONS

The laminates manufactured by using the vacuum-infusion process developed in this work have shown to present the mechanical and quality performances required by the aeronautical standards.

This proves that the manufacturing technology studied may replace with advantage, namely, in terms of costs and flexibility, conventional autoclave moulding processes more often applied to produce primary structures for the aeronautic, aircraft and military industries.

## ACKNOWLEDGMENTS

Authors thank the Portuguese Innovation Agency (ADI) for financial support given to the QREN project 24559 – BTTERSKY. Finally, Andreia Vilela, Nuno Gonçalves and Nuno Vieira deserve a special acknowledgement due to all personal support and help given during the tests.

## REFERENCES

[1] Witik, R. A., Gaille, F., Teuscher, R., Ringwald, H., Michaud, V. & Manson, J-A., Economic and environmental assessment of alternative production methods for composite aircraft components, Journal of Cleaner Production, Vol. 29-30, pp. 91-112, 2012.

[2] Gurit, Comparative Cost Study of a 35m Wind Turbine Blade using Infusion and Prepreg Materials Technology, WE Handbook - Blade Cost Analysis: Prepreg vs Infusion Material Technology, Vol. 6.