LIQUID COMPOSITE MOLDING FOR AERONAUTICAL STRUCTURES*

[a]S. Laurenzi, [a]M. Marchetti, [b]E. Anamateros

[a]School of Aerospace Engineering, University of Rome “La Sapienza”, Rome, Italy.
[b]Agusta-Westland S.p.A, Aerospace Composites Center, Anagni, Italy

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Abstract

Liquid Composite Molding (LCM) has gained popularity recently due to environmental concerns associated with open tool manufacturing. One subclass of LCM processes, that is gaining current research interest in aerospace field, is Resin Transfer Molding (RTM).The increasing number of papers and conferences about RTM shows that it is a very interesting technique in the aerospace, automotive and military industry. The reason why RTM is attracting a lot of attention is its potential of reducing manufacturing cost and creating an integrated part with complex geometry and high fiber volume fraction. Nevertheless, industry hesitancy to adopt this class of manufacturing process is due to unfamiliarity with the process, especially from a qualification point of view.

This paper describes an application of procedure to improve reliability and predictability of RTM technology in order to decrease development cost and make the risk of quality defects during production as small as possible. Numerical and experimental results are reported. The helicopter transmission gearbox has been identified as a candidate for being redesigned using RTM technology. It gives details of the preferred style and offers templates to ease paper preparation.

1. General Introduction

Composite structures are often not selected because they are not cost-competitive. Most of the time, manufactured a composite part requires a long production cycle due to the labor intensive traditional methods as hand lay up. Moreover, new techniques must compete with well-known metal technologies. It is obvious that composites share increases only developing cost-effective manufacturing techniques. The aerospace field demands low production series but with elevated mechanical characteristic of parts: reducing manufacturing cost is the priority of industry, but the product must maintain the quality. The principal criterion for selecting fabrication technology is the cost of investment in relation to the producing series. Graphic (Fig.1) reports the order of magnitude of investment per part produced and parts manufactured per year for the principal composite manufacturing processes.

Hand lay up requires low initial investment but recurring costs associated with direct labor and material waste made it more expensive per product then the other techniques Compared with Compression Molding (CM), RTM requests lower tooling cost due to the absence of press system to compact the preform. RTM seems to meet both low cost/high volume of automotive industry (500 to 50000 parts per year) and low number/high performances (50 to 500 part per year) of the aerospace industry requirements [1-3]. In fact, RTM can guarantee the demanded performances for the aeronautical production: reduction of the mass, increase of the operating life, aimed design, reduction of the production times. In this period a boom of parts realized in RTM is observed due to the

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development of new resins and the technology of the performing. In addition, such technique is suitable, with only small adjustments, for the realization of large, complex and thick-walled structures for the use in infrastructures and military applications. Once the technology is chosen, an expensive series of tests and analysis have to be done in order to set significant variables for qualification requirement, often interconnected.

This paper gives a generic procedure to produce a prototype given the bases for following qualification. An example of procedure applied a primary structure is reported. The selected component is a helicopter gearbox transmission of class A.

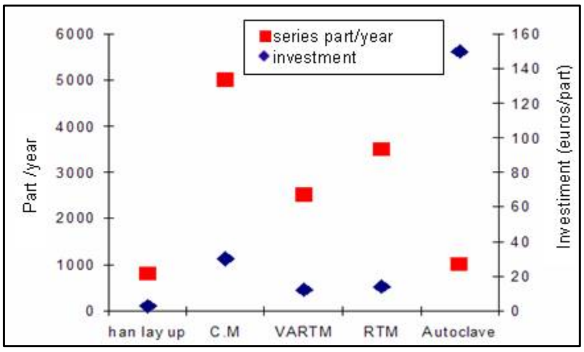


Fig. 1: graphic highlights the difference for initial investment respect to part produced and parts manufactured per year for the principal thermoset composite manufacturing processes.

1.1 What is Liquid Composite Moulding (LCM)

Liquid Composite Molding is a class of composite manufacturing processes in which the dry preform laying in a mold cavity is impregnated injecting thermoset resin. After cure, composite is de-molded. Mold can be completely rigid or have one only rigid part and the others flexible. The typology of the mold depends on the way to give compaction to the preform and this characterized the process [4]. Moreover, the typical impregnation phase of the manufacturing process LCM throws the bases for the realization of multifunctional panels, with integrations inside the structure.

RTM is a closed mould process. For a simple case, the lamination sequences is lying in a cavity, determining the thickness of the piece between two closed half-mold and resin is injected by pressure. When the resin reaches the vent, the gate is clamped and the preform is impregnated. After cure, the closed mould is opened and the part removed. The steps are schematized in Fig.2.

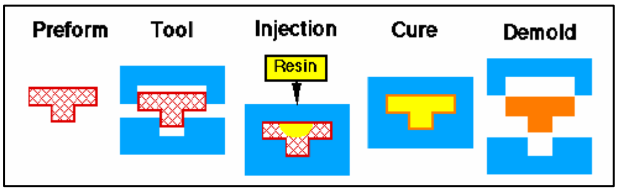


Figure 2: principal steps of RTM process.

RTM has many advantages as producing complex shape with inserts, good surface finish and close dimensional tolerances. It seems to reduce void age compared to hand lay-up so increasing component mechanical properties In addition, RTM design can compete with metal one when prepreg design are not considered to manufacture a product. For all these reason, this technique is suitable alternative to the prepreg technique, which is currently in use for the aeronautical-aerospace industries.

2. Procedure

The purpose of procedure is to set a qualification plan for materials and process parameters to meet the civil aviation regulations and recommendations. The plan should give specific information about the qualification programs regarding all the entities involved in the RTM process: materials, process, tooling, checks. It is important not only to minimize the weight of a component by high mechanical performances but also to limit the variability part-to-part.

The variability can be limited studying the effects of process parameters on selected materials: fiber wash, fiber distortion, etc.

The flowchart in Fig.3 schematizes the procedure.

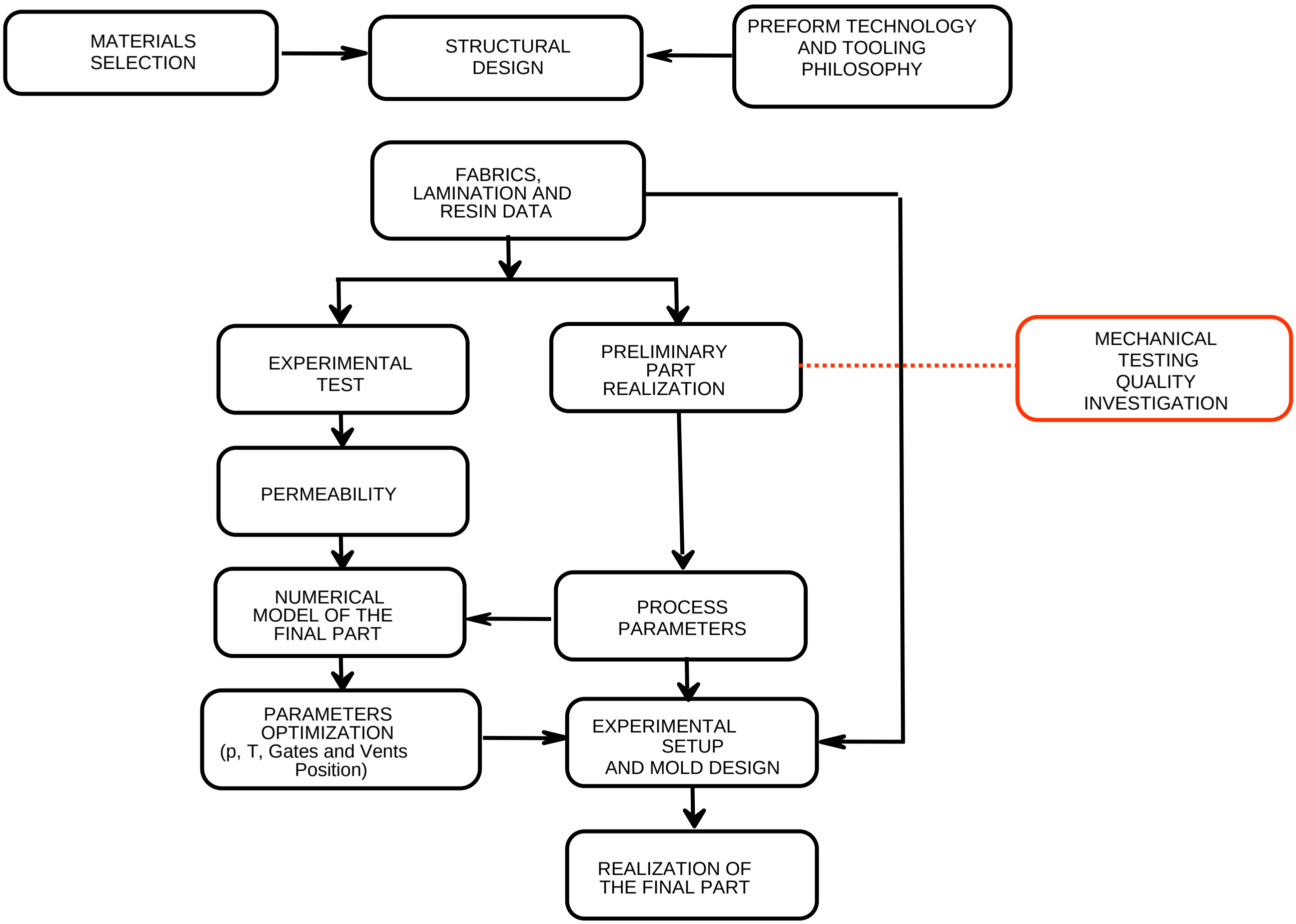


Fig. 3: flowchart of activity.

3. Technical Approach

3.1 Part description

The helicopter transmission gearbox was identified as a candidate for being redesigned using RTM technology. It is a primary structure with complex shape, impossible to re-produce with traditional manufacturing processes. The use of composite implies weight reduction because the higher strength density ratio of composite materials compared to the traditional metals. Moreover, composite parts show better corrosion resistance and damage tolerance than their metallic counterparts. The existing component is made by metal alloy (Fig. 4).

3.2 Preform technology

The gearbox is supposed to be integrated as much as possible to take all advantages from the RTM process. A dedicated study was performed in order to individuate the parts to realize in one shot injection. The principal preform was sectioned in three structural bodies: conical body, base and struts attachment areas. The other non-structural elements as oil filler, oil connector and oil tank, oil ducts, oil jets, oil cap and servo-actuators pads will be consider in a secondary bonding. The braiding technology was selected because of the braiding high torsion stability and conformability to conical shape. Furthermore, braiding allows components integration reducing manufacturing cost. In fact, the base can be realized at the same time with the conical profile and the inserts can be fit on the conical preform during the braiding process after an opportune number of layers.

3.3 Part Design

The component is primary part with high structural geometrical and operative complexity. The external form must be reproduced to guarantee original interface with other components.

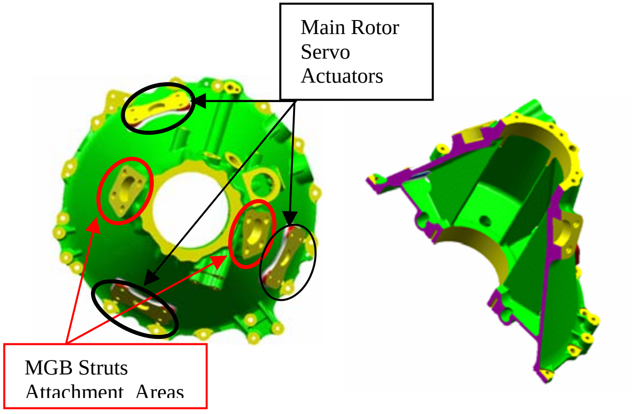


Fig. 4: views of original helicopter gearbox transmission.

In order to establish the new thickness profile satisfying the structural requirements, a structural optimization design for braided preform was performed implementing an iterative procedure in the code MSC NASTRAN based on static analysis. The numerical design was a constrained minimization problem. The procedure minimized the weight of the structure (objective function) through reduction of the total thickness with preservation-improvement of the mechanical performances (project variables). The objective function satisfied failure index criteria: the Tsai-Wu criterion was used in plane and the maximum shear stress criterion out-plane. Sequences of lamination at ± 30°, ± 45°, and ± 60° were investigated [5].

Structural optimization design has been carried out using braided composites qualified design allowable. The material was a braided AS4 6K GP / 3M PR 520 for the conical shape. The mechanical characteristics were from “Material Qualification Methodology for 2X2 Biaxial Braided RTM Comp. Material Systems” AGATE (NASA-INDUSTRY-FAA) report and from Agusta S.p.a. databases. Because of the possibility to use different materials for struts attachment area, a dedicated design has been performed in order to select the right material conducting a saving weigh. Table1 reports the structural optimization procedure results considering titanium for the struts attachment area: the best results were obtained using a lamination with braided angle at ± 30°. The optimised configuration of the composite transmission case weighs 23.5% less than the original cast metallic. Moreover, using composite materials permits to simplify the structures eliminating the internal stiffeners. Modal analysis has been performed to confirm the validity of the static design.

Table 1: Results obtained by structural optimization procedure.

aided angle	V_f range cone shape and base	Weight optimized (Kg)	Max failure index	ILSS (braided)	Saving weight(%)
± 30°	0.58÷0.61	8.29	0.901	67.64 MPa	22.5 %
± 45°	0.64÷0.65	8.87	0.9001	44 MPa	17.1 %
± 60°	0.69÷0.71	9.34	0.9	24 MPa	12.7 %

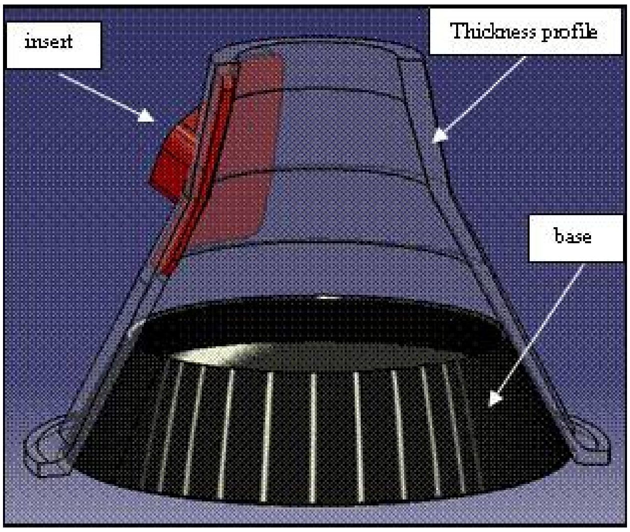


Fig. 5: section of composite component.

3.4 Process investigation

The quality of composites is governed by the process parameters and materials used. One of the most important quality aspects is the void content in the finished part. These defects are often caused by unbalanced resin flows, which are directly related to the fiber preform permeability variation [3,6-7]. Knowledge of the permeability is also important because it determines the flow patterns inside the preform and the filling time of the mould. For these reasons, an important step is the determination of permeability and the investigation of the effects of process parameter on the final piece. In order to evaluate the braided behaviour and parameters necessary for flow simulation, several experiments have been conducted: permeability tests and simple part realization in order to highlight eventual problem as fiber wash and take confidence with materials.

It's visible that for all materials in exam, the permeability value, parallel to the mandrel axis decreases with braided angle increasing. This appears to be due to the change in tow spacing with braid angle. The tows became not in line with the flow direction, producing an addition of resistance to flow of resin [6]. Same result was found from other authors [7]. The structural optimization analysis established that the best configuration is obtained with braid angle at 30°. From the graphic in Fig. 6, which reports the in plane permeability values for the three different materials investigated at 30° braided angle, it is possible to evince two consideration. The first one is that the permeability value relative to the normal direction is too low respect to the value in flow direction and this result shows difficulty to impregnate a shape with abrupt geometric changing due to the inserts. So a similar value in both directions should be better to control the flow pattern. The other one is the tows dimension seems to influence the permeability: there is no a big difference between 6k and 12k, but the permeability decreases a lot for 24k. This is an important result because the mechanical performances are optimum for 6k, but the braiding process, in this application, imposes to use a bigger tow. So, adopting a 12k carbon braided with configuration at 45° braided angle is a good compromise between manufacturing and mechanical performances.

The parallel activity performed to study the parameters process relative to carbon braided/resin selected highlighted the existing of a restrict range of injection pressure and fiber volume fraction that does not conduct to fiber washing for 12K. Fiber volume fraction equal to 50% has been positive processed using just vacuum. A maximum of 1 atm could be reached with fiber volume fraction equal to 67%.

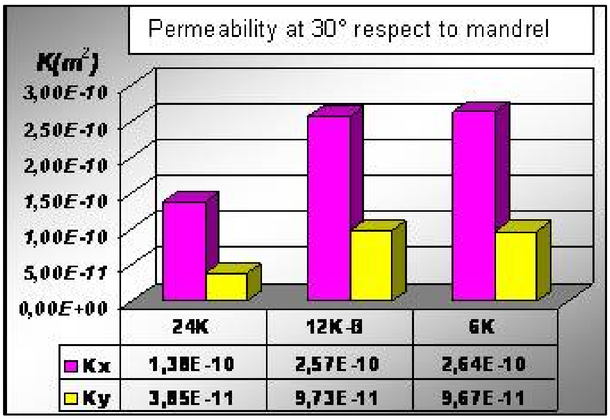


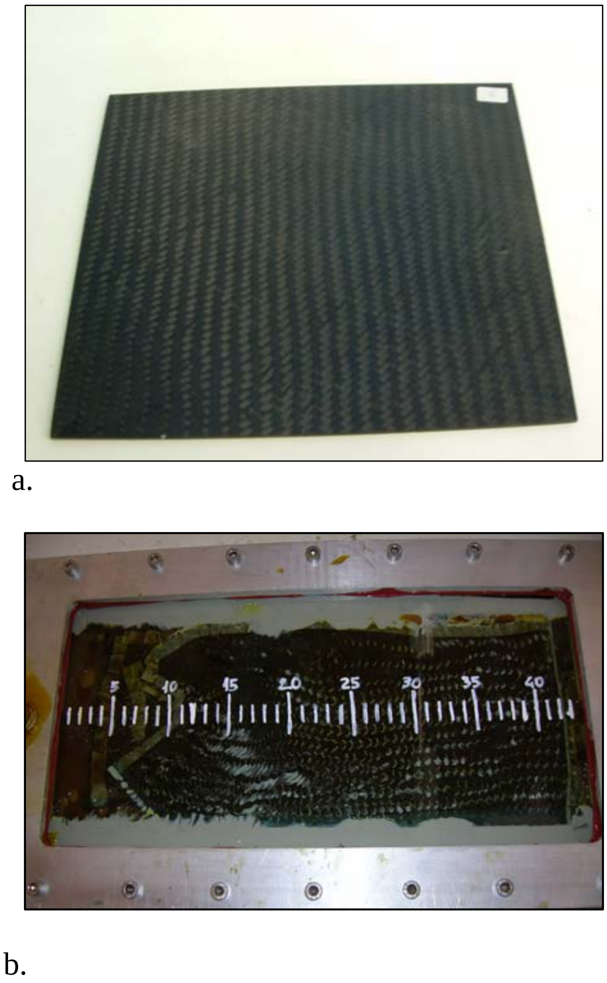
Fig. 6: permeability value parallel (Kx) and normal (Ky) to the mandrel axis for three different carbon braided 6k, 12k, 24k at 30° braided angle.

3.5 Mandrel and Mold

Every composite component requires more tooling design than metallic counterpart, especially in case of complex shape.

Mandrel can be realized in different ways. For example, it built by low melting temperature material or water soluble material permits the part removal. The ceramic soluble has been taken in account. It is easy to use because it's fluid to ambient temperature; it solidifies with thermal cycle, about 120°C and melts by hot water. As shown from several tests have been performed, the disadvantages of a ceramic mandrel are the necessity of a mold, the particular attention for part mixed and environment condition, the brittle behaviour. Moreover, it is necessary predisposing a certain number of hot water connections. For these reasons, the final choice to manufacture a prototype for creating a mandrel is jointing fastened parts as shown in the following Fig. 8.

In this case, the challenge is design an easy-handling mandrel.



a.

b.

Fig. 7: a. carbon braided-BMI RTM 651 panel obtained as preliminary part; b. 12K carbon braided fiber- wash obtained for pressure=1atm and fiber volume fraction=50%.

The external mould should be divided in removable parts recognizing critical areas for tool taking out. Using this mold, surface finishing will be very high, dimensional tolerances very close, component strongly integrated.

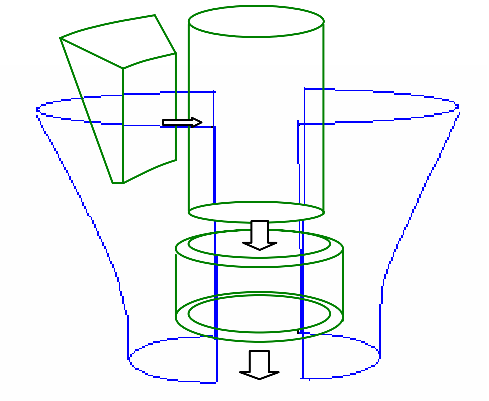


Fig.8: scheme of tool assembly and mandrel.

3.6 Injection Scheme

An important point to investigate was the determination of the optimal position of the injection gates and the vent points for the mould of the prototype. The filling time has to be compatible with the resin pot life to guarantee the homogeneous wetting of the preform. The simulation of the process permits to optimize the injection scheme saving time and waste materials. Starting from the permeability data, a numerical simulation of the injection phase has been used to assess the filling time for the real piece. The simulation process allows reducing the cost-time of design tool and waste material. Different positions affect greatly the filling time and the quality of the finished part. Several different injection schemes have been considered in order to choose the best compromise between requirements of filling time and mould design. Here is reported the injection scheme selected (Fig.9).

In the scheme reported the injection points have been placed on the top border of the conic shape and the venting points on the base. As can be seen in Fig. 10 the total filling time with this configuration is about 40 minutes comparable with the resin pot life limit: the filling time has to be compatible with the resin pot life to guarantee the homogeneous wetting of the preform.

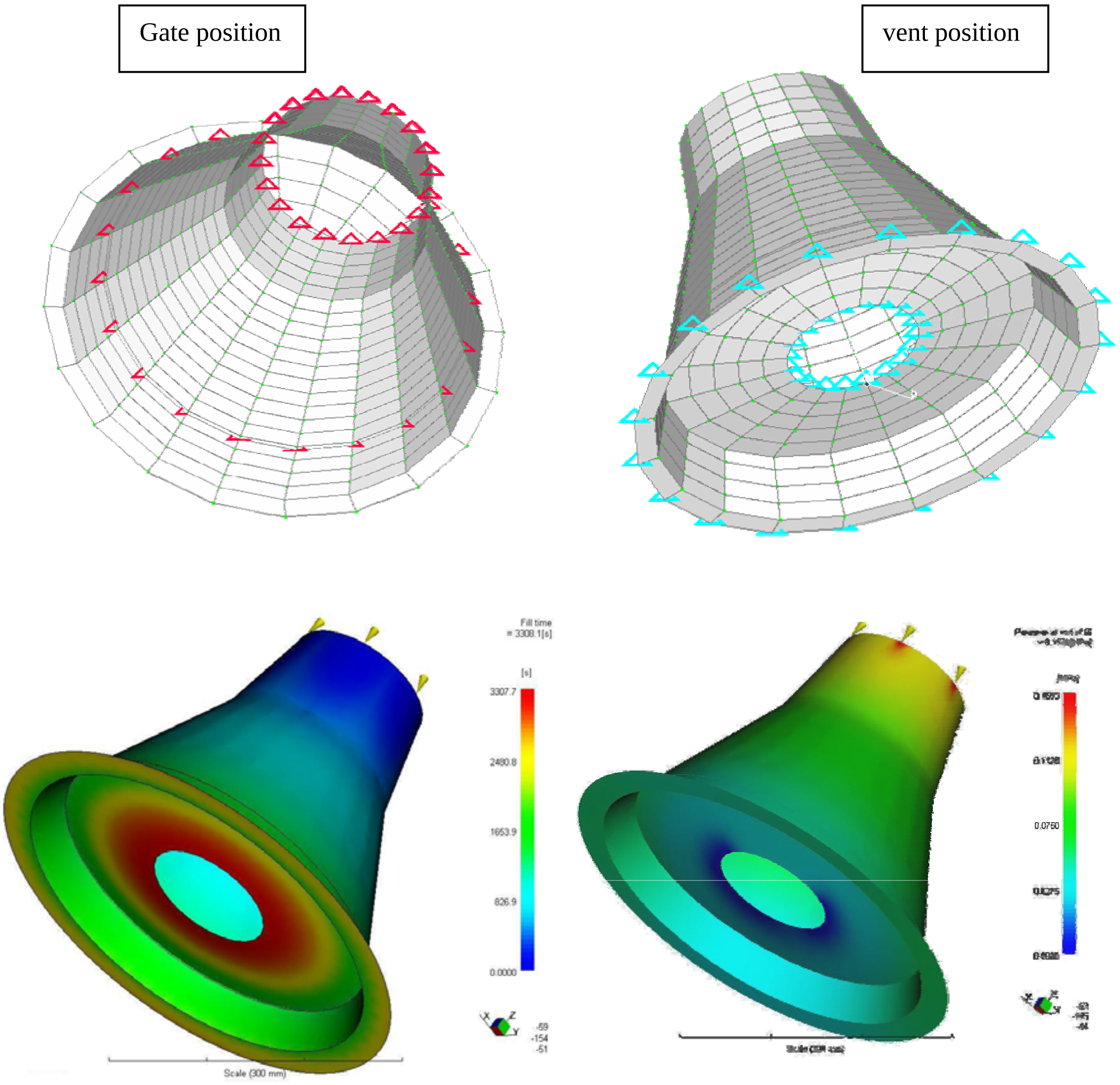


Fig. 10: trend of filling time and pressure gradient inside the preform during impregnation, considering an isothermal injection with resin viscosity of 50cps.

4. Summary

Designing a composite component requires a synergy among structural and manufacturing engineer to satisfy structural requisites with manufacturing aspects. The procedure schematizes this interconnection obtaining and using more information from a single test typology. The aim is obtaining a prototype reducing material and experimental cost as much as possible giving the bases for following qualification. The work performed to obtain a primary complex structure, originally in metal alloy, as gearbox transmission is reported. Composite configuration was reached through out a detailed design study that it led to an optimized composite laminate distribution thickness and fibers angle lay-up. The best results are obtained for sequences of braided laminates with braided angle at 30° respect to axis of mandrel, but the technology requires using a configuration with braided angle at 45° with weight saving of almost 17% respect to metal count part. The study of the resin flows, parallel to structural one was performed for an opportune material choice and tool design. The upper developing activities efforts to guarantee high quality and cost-effective resin transfer molding (RTM) manufacturing within the aerospace standards as requested by the airworthiness regulations. Preform, process operations procedure, tooling configuration, injection and curing parameters definition are determined. Preform and mold are currently in realization. The immediately future work is building a prototype using the injection scheme reported here.

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