# THERMOPLASTIC MELT IMPREGNATION OF COMPOSITE LAMINATES BY INJECTION-COMPRESSION PROCESS

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## Introduction

The inability to produce parts of complex geometry with short cycle time and controlled cost prevents the use of thermoplastic composite materials for applications in medium to large series, despite the major advantages of these materials as their low environmental impact and their good mechanical behaviour (damage resistance). Among the different manufacturing processes of composite structures, the low pressure impregnation of a dry preform in a mould (Liquid Composite Molding) presents a major interest in the production of parts with complex geometry (non-developable surfaces) with the possibility of integrated functions. First tests on RTM TP process (Tapas-LCM project) with polymer injection in a closed high temperature mold showed low viscosity melt ($\eta < 25$ Pa.s) and high permeability preform ($K > 0.5\ 10^{-10}$ m$^2$) are mandatory.

To address the high rate production requirement, a new injection-compression process has been developed: injection of low viscosity melt TP polymer, and fast impregnation of the preform by closure of the mold (C-RTM TP).

## Injection-Compression process (C-RTM TP)

The C-RTM process has been developed with thermoset resin precursors [1, 2]. In our case, with TP melt polymers, it involves the placement of a textile reinforcement (net shaped preform) in a two-sided solid mold, partially closure of the heated mold before melt injection, the mold is then further closed driving the melt through the preform with compression-driven flow. The closure of the mold to the final thickness can be velocity controlled or force controlled. Finally, the part consolidation is obtained by cooling down, and released from the mold after crystallization.

The simultaneous injection-compression can reduce either the mold filling time or injection pressure significantly compared to resin transfer molding (RTM). This establishes a compression-driven flow, which completes wet-out of the fibre preform, and provides the potential for significantly faster cycle times. A specific lab tool has been built around an injection press (Billion, F) and a high temperature mold (Pernoud, F). Main characteristics of low viscosity PA used (PA6, PA66) are listed in Table 1.

**Table 1:** *Main characteristics of high fluidity Polyamide (PA66 & PA6) at RH0.*

| | Viscosity η at 285°C (Pa.s) | Tm (°C) | Tc (°C) | Xc (%) | E (GPa) |
|---|---|---|---|---|---|
| Standard PA66 | 225 | 264 | 216 | 40 | 3.1 |
| PA66 Evolite® | 50 | 262 | 220 | 40 | 3.0 |
| PA6 Evolite® | 30 | 220 | 184 | 35 | 2.8 |

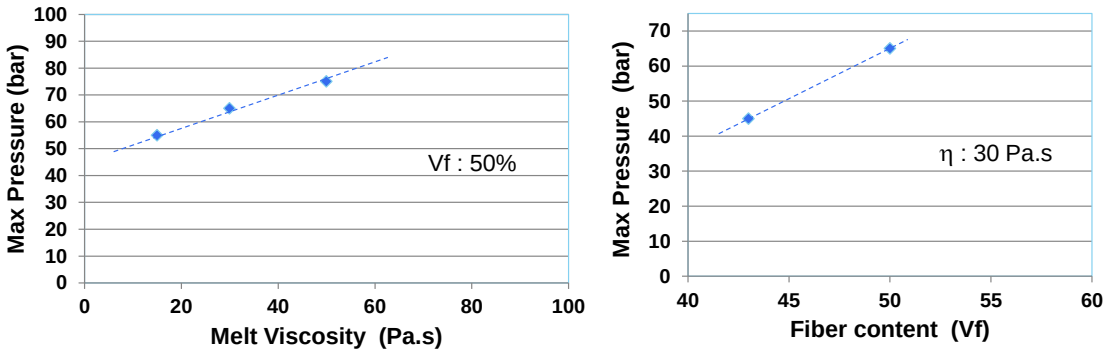
Permeability has been measured by compression of saturated preforms [3]: Table 2.

First results based on PA6 and glass fabrics show the technical feasability of injection-compression process (C-RTM TP) with complete impregnation (void < 0.5%) at low injection pressure (P < 2.5 bar).

**Table 2:** *Main characteristics of glass fibrous preform (Vf = 50%).*

| | *Surface weight* (g/m$^2$) | *K in-plane* (m$^2$) | *K transverse* (m$^2$) |
|---|---|---|---|
| G-WEAVE™ 600T/PA | 600 | $1.3\ 10^{-10}$ | $1.5\ 10^{-12}$ |

Injection-compression cycle takes about 200 to 230 sec., with a maximum pressure measured inside the mold of about 40 to 65 bar according to the fiber content and melt viscosity ; the pressure applied by mold closing depends on the fiber content, up to 45 bar at 43% Vf, and 65 bar at 50% Vf (Fig. 1). Small gap size, injection flow rate and compression rate can be used to achieve the minimum mold filling time with complete filling. One of the problem is to avoid any deformation of the fibrous preform during injection and compression steps. Fiber contents between 50% and 60% vol. leads to high performances composites.



a) Melt viscosity effect on mold pressure

b) Fiber content effect on mold pressure

**Figure 1:** *Evolution of max pressure P (compression) with melt viscosity η a) and fiber content Vf b) PA6 and plain glass preform system*

Optimization has to be done on preform permeability and polymer characteristics (rheology, and physico-chemistry) to improve the process cycle time. Several difficulties have to be overcome to develop such new process: thermal cycle (fast heating/cooling), wettability and high rate impregnation of a given fibrous structure (deformable perform, with variable permeability), and in-situ polymer crystallization during consolidation (cooling).

## Laminate TP composite consolidation

Results have been obtained with different polyamides (PA6, PA66) and glass fabrics (Plain, Twill 2x2): production of 200x300x2.75 mm composite laminates plates with 50% vol. fibers. The consolidation is complete, with no inter and intra-mesh porosity (Fig. 2).

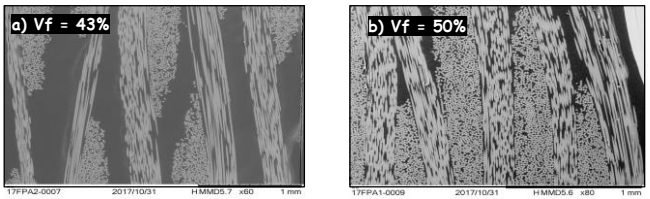



**Figure 2:** *Microstructure of C-RTM TP plates obtained from low viscosity PA6 and plain glass preform (low viscosity PA6 ; 15 < η <50 Pa.s) : a) 43% vol. fibers ; b) 50% vol. fibers).*

Mechanical properties are similar to that obtained on a hydraulic press with hot plates : with PA6/Twill 2x2 glass, tensile strength σt at 0° = 510 MPa with modulus E = 27 GPa, at 50% vol. fibers.

## Conclusion

It has been demonstrated that the compression-RTM TP process can be used to manufacture components with a high fiber volume content at short process cycle (t ~5 min). However, there are technical challenges that must be overcome, as well as analysis to identify and understand the influence of various materials and process parameters, before becoming attractive for wide-spread use.

## References

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