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Development of a melt Thermoplastic Resin Transfer Molding (mTP-RTM) process

Thermoplastic composites have great potential as lightweight materials to replace steel in automotive components, in order to reduce fuel consumption and CO2 emission. In this project, development of a Resin Transfer Molding (RTM) process, involving direct in-plane impregnation of glass fabrics with melt thermoplastic resin, is investigated. Strong point of this process is the ability of processing complex parts in a single-stage process, thus minimizing the need of joining different parts and reducing post-processing steps and waste. Main issue is cycle time, which directly depends on resin viscosity (η) and inversely on fabric permeability (K). In order to explore the feasibility of the process, selected matrices and fabrics are selected and characterized. Moreover, a lab-scale mold is designed and small plates manufactured.

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Introduction

Thermoplastic composites have a number of advantages over thermosets (recyclability, joinability, ductility, etc.), but they are mainly produced by stamp forming, which requires expensive presses to shape a pre-impregnated sheet of composite, and which limits the part design to quite simple shapes. In RTM, the liquid matrix is forced to impregnate the dry fabric preform, which is placed inside the cavity of a rigid mold. Fairly complex shapes can be produced with this manufacturing concept.

Darcy's law for in-plane unidirectional flow at constant fluid pressure, constant thickness, leads to an impregnation time dependent on resin viscosity (η) and fabric permeability (K) of

$$t \propto \frac{\eta}{K}.$$

Therefore low-viscosity resins and high-permeability fabrics are necessary.

Thermoplastic matrices

Chemically modified polyamides (PA) (*Solvay*) show an interesting combination of low viscosity (between 10 and 100 Pa.s) and high strength, which makes them suitable for transport applications. Viscosity of these PAs and of a high-flow i-polypropylene (iPP) were measured in a plate-plate rheometer

- Viscosity intermediate between typical thermoplastics (> 100 Pa s) and thermoset resins (< 1 Pa s)
- Newtonian behavior in RTM conditions (low pressure)
- PAs have good mechanical properties

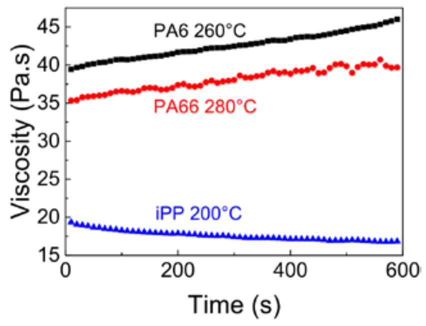

Fig. 1: Flow viscosity at a shear-rate of $1s^{-1}$

Fabrics

G-PLY© non-crimp GF (*Chomarat*). A Normal and an Alternate stacking sequence are investigated (Fig. 2).

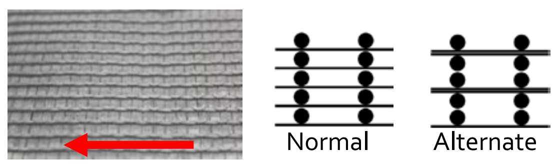

Fig. 2: G-PLY© fabric (left) and cross sectional-view (right)

Saturated and unsaturated permeabilities are measured (Fig. 3) in transparent mold with aqueous solution of PEG 35kDa as test fluid (η~0.1 Pa.s)[1]. Flow is enhanced in Alternate stack thanks to presence of wider channels

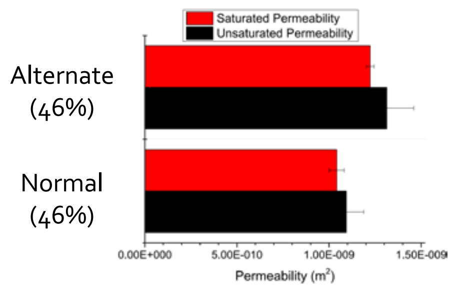

Fig. 3: Permeabilities of the two different stacking architectures

Mold for mTP-RTM

A novel tool (Fig. 4) has been designed to produce thermoplastic composites through in-plane melt impregnation. Polymer pellets are placed in a melting pot. Heating above melting point is performed in oven, then the tool is transferred to a pre-heated press. A constant pressure applied on the piston by the upper plate of the press forces the melt to flow through a hole in the underlying cavity where the fabric preform is placed. Screws allow to open/close inlet and outlet. Impregnation by two sides is also possible, as well as pulling vacuum from the outlet.

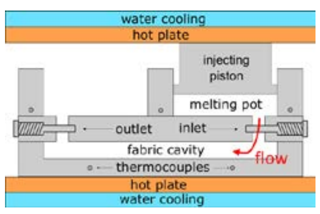

Fig. 4: Concept of compact tool for melt thermoplastic RTM

Plate analysis

As a proof of concept, small plates were successfully produced by impregnating the Normal stack with PA6 at 280°C and with a pressure of 5.6 bar applied to the melt. The matrix is well distrbuted in the inter-tow space, but tows impregnation needs to be improved.

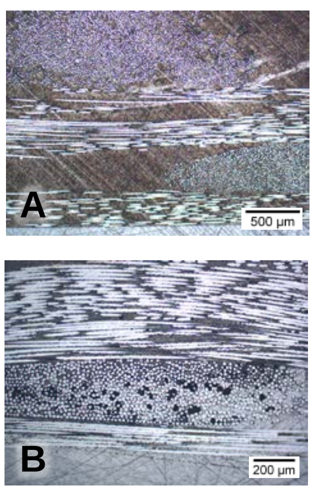

Fig. 5: Cross-section microscopy at 3.5 cm (A) and 7 cm from inlet (B) after 6 min

Expected impact

Lightweighting in the automotive sector needs to implement diversified strategies and solutions, integrating them in an optimized fashion. The process developed in this project will allow the production of small complex thermoplastic composite parts, which would replace parts which are typically made by joining or welding different metal parts, implying less post-processing. In order to quantify the costs and benefits throughout the whole life time of the part, life cycle and cost analysis will be performed.

References

[1] D. Salvatori, V. Michaud. Capillary effects in LCM with high-viscosity matrices and highly anisotropic non-crimp fabrics. *FPCM13 – 13th Internationl Conference on Flow Processing in Composite Materials*. July 2016, Kyoto, Japan.

Partners

Solvay, Centre de Recherche de Lyon, France

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