STRATEGIES FOR IN-PLANE THERMOPLASTIC MELT IMPREGNATION OF GLASS-FABRICS

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Introduction

Thermoplastic composites (TPC) feature a number of desirable properties compared to thermosets, such as recyclability, toughness and weldability. TPCs can be either produced by compression molding of pre-impregnated sheets or by reactive impregnation of the dry reinforcing fabric in a closed rigid mold. Compared to the former, the latter process, known as Resin Transfer Molding (RTM), allows for a higher degree of shape complexity, low equipment cost, no need of intermediate materials (e.g. pre-pregs) and inclusion of functional features. However, the need to precisely control the polymerization reaction and the effects related to the formation of by-products represent major disadvantages. The recent development of TP matrices with intermediate melt-viscosity (in the range 10-100 Pa.s) is paving the way to the development of production routes that involve direct impregnation of the fabric with the matrix in the melt-state[1]. The main deterrent is represented by long impregnation time, which is inversely proportional to the resin viscosity, considerably higher than for reacting resin systems (< 1 Pa.s). In this study, we investigate strategies to reduce the impregnation time for in-plane flow in the melt-RTM process. Impregnation strategies are tested in a custom-made tool, which allows melting of the polymer and injection under constant applied pressure.

Materials and Methods

A polyamide-6 with a melt viscosity of ca. 30 Pa.s at 280°C (*Solvay*) is used as matrix polymer. Two different types of glass fabrics are used as reinforcement, both with sizing compatible to polyamide, a twill 2x2 and a non-crimp fabric (G-Weave® and G-Ply®, *Chomarat*). In G-Ply under compaction meso-channels of varying shape and size are formed, which are responsible for considerably high values of permeability, in the order of 10^{-9} m^2 at 46% fiber volume fraction, as demonstrated in [2]. In G-Ply, bundles in the two directions are bound with glass stiches, thus allowing processing at high temperature. In some cases, rods made of 52%-carbon-fiber-reinforced PEEK and of 1.4 mm diameter are inserted in the middle of a stack of G-Weave, so as to induce the formation of meso-channels. The tool for in-plane impregnation is schematically shown in Figure 1. It embodies a squared cavity (of size 158x98 mm and 5 mm thickness) for the fabric; two pots for melting the polymer pellets; two pistons to inject the melted polymer into the cavity; two gates which can function both as inlet and outlet; three heating cartridges and holes for thermocouples. The tool is conceived to be operated in a hot-press, which provides additional heating from both upper and lower plates, and allows to apply a constant force on the pistons, thus forcing the melted polymer to flow under constant pressure in the underlying fabric cavity. The presence of two gates/pistons allows for injection from either one or two inlet-points. In addition, when single-inlet configuration is chosen, it is possible to connect a vacuum-pump at the outlet, in order to remove air from the cavity and facilitate the impregnation. Finally, the cooling step is also performed in the press, by circulating water in the proximity of the two hot plates, allowing to maintain an applied pressure on the solidifying matrix.

Flat plates of size 11x7.5x0.5 cm and glass fiber volume fraction around 45% are produced following different strategies, which are listed in Table 1. In all cases, injection is performed at around 280-285°C. In tests labeled as "Standard", impregnation proceeds from inlet to outlet with slug-flow morphology. In samples with channels (G-Weave+Spacers and G-Ply) the resin flows preferentially in the channels, which can result in large unsaturated areas [2]. Therefore, a saturation step is sometimes added, consisting in closing the outlet gate once the resin has reached it, and continue the injection in order to saturate the fabric ("Vacuum + Saturation"). Finally, in "Double Inlet" injections, impregnation proceeds from the two opposite points, and the two flow-front meet in the middle of the plate.

Results and Discussion

The produced sample plates are shown in Figure 1b. It can be noticed that G-Weave is not capable to sustain a high fluid pressure, because of its low permeability, resulting in fabric displacement. As a result, a lower pressure has to be applied, which makes it practically impossible to achieve complete impregnation in reasonable time. Conversely, the two preforms with channels can be impregnated at higher pressures. Samples 4, 5 and 6 show the need of a saturation step, without which all the resin flows at the outlet and the fabric remains largely dry. With the addition of this step a better impregnation is achieved, particularly visible in sample 6, for which the pressure was increased from 7.1 to 28.5 bar, although few dry spots are still visible on the sides. Finally, all G-Ply samples appeared well impregnated in fairly short time. For instance, in the double-inlet injection flow distance is halved, thus impregnation time, which is linearly dependent on the square of length, is expected to be reduced of a factor 4.

In conclusion, the fastest impregnation was obtained for tests conditions 8 and 9, although test 6 shows that the use of spacers is promising for flow enhancement. The experimental work will be integrated with qualitative and quantitative analysis of the impregnation at the micro-scale by optical microscopy and burn-off analysis, and mechanical properties will be measured in 3-point-bending in order to compare the different preform architectures. In particular, the presence of spacers is expected to lead to an increase of bending stiffness.

Table 1: *List of prepared samples*

#	*Fabric preform*	*Configuration*	*Pressure* (bar)	*Impregnation time* (min)
1	G-Weave	Standard	3.6	15
2	G-Weave	Standard	1.6	15
3	G-Weave	Standard	1.6	45
4	G-Weave + Spacers	Vacuum (no saturation)	3.6	15
5	G-Weave + Spacers	Vacuum + Saturation	3.6	7
6	G-Weave + Spacers	Vacuum + Saturation	7.1-28.5	7
7	G-Ply	Vacuum + Saturation	3.6	7
8	G-Ply	Double Inlet	3.6	2.5
9	G-Ply	Vacuum + Saturation	7.1	2.5

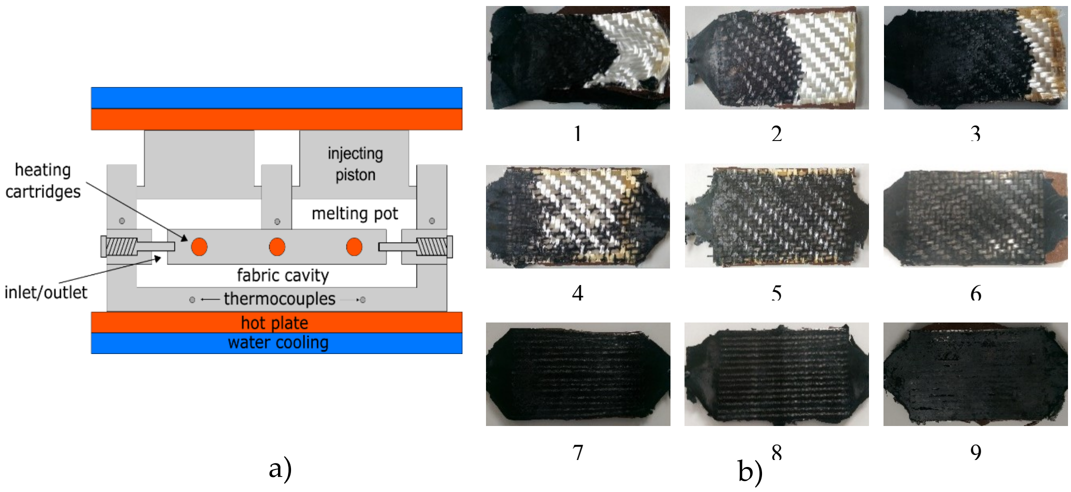

Figure 1: *a) Schema of mold for impregnation. b) Plates produced (see Table 1 for samples' labeling).*

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