# AN EXPERIMENTAL INVESTIGATION FOR THE IMPREGNATION OF PARTICLE FILLED FIBROUS PREFORM IN RESIN TRANSFER MOLDING (RTM)

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## Introduction

Particle filled resins are widely used in Resin Transfer Molding (RTM) applications. However, introduction of particles leads to increased viscosity and decreased permeability. The current study compares polymeric compressible hollow microspheres to rigid PVC particles when pre-deposited in the preform, and quantify their respective effect on the saturated/unsaturated permeability. An analytical model is proposed as an attempt to predict the equivalent permeability of the system, as an arithmetic average of the permeabilities of the particle and fabric layers (parallel flow). Particles distribution, flow front evolution and injection times were also investigated.

## Materials

The particles used in this study (Expancel microspheres- AkzoNobel) consisted of polymeric shells containing a gas that expands with increased temperature inducing a large increase in the particle size and a marked decrease in density. Gas remains inside the particles making them compressible under applied pressure; when the pressure is released the particles regain their original shape. Expancel particles have a low density (<0.1 g/cm$^3$) which makes them ideal for lightening the composite parts. Two different sizes of the hollow microspheres were used (Expancel 920 DU 40 with d = 39.4±14.4 µm and Expancel 920 DU 120 with d = 129.6± 32.1 µm). Only one size of rigid fully dense PVC (d ≈ 120 µm, ρ = 1.38 g/cm$^3$) was used. A quasi UD E-glass fabric (Chomarat) with an areal weight of 646 g/m$^2$ and a density of 2.56 g/cm$^3$, Silicon oil (Rhodorsil 47 V 100) with a viscosity µ= 0.1155 Pa.s at 20°C were used in this study.

## Permeability Measurement Experiments

Particles were sieved manually on the top surface of six plies of the fabric, the plies were then heated to enable particles expansion and attachment to the reinforcement surface. The plies were stacked parallelly in a steel bottom and glass top set-up for in-plane permeability measurement. The mold cavity dimensions are: 296 mm length, 100 mm width and 2.85 mm thickness. Silicon oil was injected to the mold cavity at a constant pressure (~1.2bars), to measure the unsaturated permeability along the fiber direction for different particle volume fractions (Table 1). The unsaturated permeability value was deduced following the Concurrent Permeability Measurement Procedure (CPMP) [1]. The saturated permeability was then obtained by weighing the outlet fluid for several pressure difference values with Darcy’s law [2].

## Results and discussion

A more homogeneous particle distribution was observed with Expancel 120 particles, while Expancel 40 particles showed a tendency to agglomerate. On the other hand, PVC particles exhibited a markdly uniform flow front. The experiments showed that addition of particles leads to both unsaturated and saturated permeability decreases (denoted as $K_{unsat}$ and $K_{sat}$ respectively as shown by Fig.1-b). Never the less, $K_{unsat}$ was slightly more affected compared to $K_{sat}$. As for PVC particles, $K_{sat}$ curve has shown a similar trend to previously published study [3], moreover, $K_{sat}$ values for PVC were higher in comparison to plain fabric ones having the same porosity, that’s due to the fact that PVC particles increase macropores volume. $K_{sat}$ for the hollow microspheres increased monotonously with the porosity, and contrary to PVC, they were below plain fabric ones for the same porosity. Despite their identical average diameter, the hollow microspheres and the rigid ones have significantly different curves (Fig.1-a).

The ratio between the unsaturated and saturated permeability ($R_s = K_{unsat}/K_{sat}$) was lower than those for plain fabric (of 6 plies), and $K_{unsat}$ remains lower than $K_{sat}$ even after deposition of 120 diameter hollow or rigid particles for the range of volume fractions studied. However, $K_{unsat}$ was higher than $K_{sat}$ only for small hollow microspheres and for the plain fabric with an increased volume fraction (7 plies). Particle attachment technique was validated by observing discharged silicon oil samples under the optical microscope; it was found that no particles were washed out.

The permeability decrease induced a monotonous increase of injection times as a function of particle volume fractions. Interestingly, it was found that for the same particles diameter and the same volume fraction, the filling time could reach up to 2.5 times higher for hollow compressible particles compared to PVC ones. Generally speaking, arithmetic average model is able to predict to some extent the behaviour of the system, however, fitting the experimental data is a function of variables adjustement.

**Table 2: Experimental results for unsaturated and saturated permeability values**

| *Particles type* | *Particles volume fraction ($v_p$) [%]* | *Porosity ($\Phi_p$) [%]* | *Particles weight ($W_p$) [g]* | *Experimental Filling time ($t_s$) [s]* | *Experimental Permeability [$10^{-11}$ $m^2$]* | | *Experimental $R_s$ [$K_{unsat}/K_{sat}$]* |
|---|---|---|---|---|---|---|---|
| | | | | | $K_{sat}$ | $K_{unsat}$ | |
| Expancel (120) | 3.75 | 43.1 | 0.289 | 983 | 3.14 | 2.28 | 0.73 |
| | 1.63 | 45.3 | 0.147 | 582 | 4.86 | 4.59 | 0.94 |
| | 0.93 | 45.9 | 0.072 | 472 | 6.32 | 5.44 | 0.86 |
| | 0.47 | 46.4 | 0.036 | 406 | 7.75 | 6.68 | 0.86 |
| Expancel (40) | 1.63 | 45.3 | 0.120 | 376 | 5.85 | 5.96 | 1.02 |
| | 0.93 | 45.9 | 0.061 | 360 | 6.19 | 6.49 | 1.05 |
| PVC (120) | 3.75 | 43.1 | 4.466 | 382 | 7.14 | 5.94 | 0.83 |
| | 1.63 | 45.3 | 2.233 | 339 | 8.06 | 7.18 | 0.89 |
| | 0.93 | 45.9 | 1.117 | 328 | 7.53 | 7.31 | 0.97 |
| | 0.47 | 46.4 | 0.540 | 358 | 8.03 | 6.79 | 0.85 |
| Plain Fabric 6 plies | 0 | 46.9 | 0 | 314 | 8.79 | 8.52 | 0.97 |
| Plain Fabric 7 plies | 0 | 38.0 | 0 | 1176 | 1.71 | 1.96 | 1.15 |

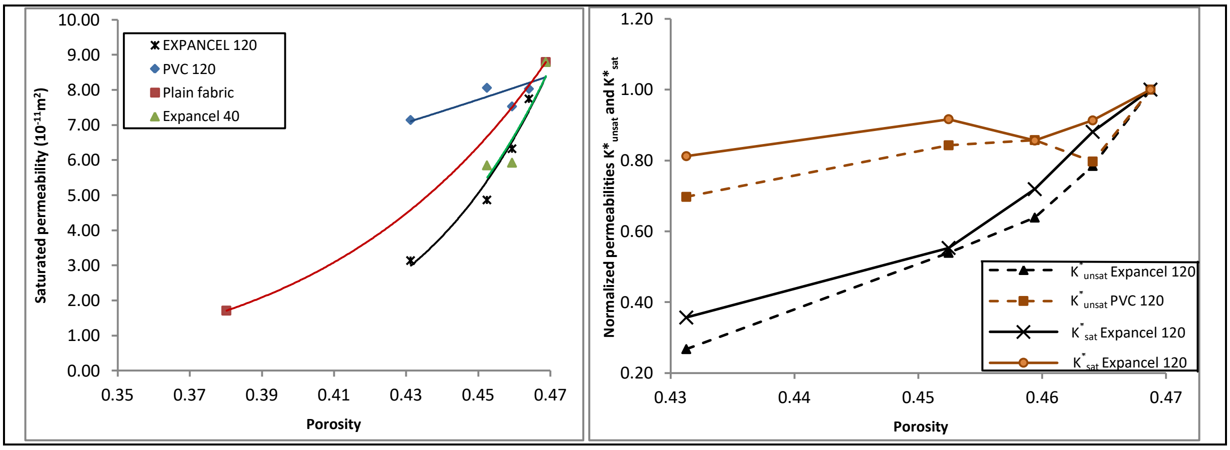


**Figure 1:** *(a) Saturated permeability values* *(b) A comparison between the permeability values for the rigid and hollow microsphere, normalized to the plain fabric ones ($k^*_{unsat}$ and $K^*_{sat}$)*


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## References


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