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# INFLUENCE OF THE COMPACTION SPEED ON THE TRANSVERSE CONTINUOUS PERMEABILITY

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**ABSTRACT:** The compaction of composite preforms and the flow of resin through the fibrous network take place simultaneously during the Resin Film Infusion process. An experimental device, set up to impose combinations of hydraulic and mechanical loadings (Hydro-Mechanical loadings) to fibrous preforms is used to evaluate the transverse permeability in a continuous manner using different compression speeds for a glass satin weave and a carbon non crimped fabric. The transverse continuous permeability curves of the two fibrous reinforcements evaluated using fast compression speeds are not similar to the ones evaluated using low velocity. The fast compression speed permeability curve is the result of transient phenomena acting on the measured pressure. It therefore reflects the instantaneous permeability behaviour of the reinforcements. This may improve the accuracy of the permeability used to model processes such as RFI where the compression speed is not constant.

**KEYWORDS:** Resin film infiltration; Fabrics/textile; Resin flow; Continuous transverse permeability.

## INTRODUCTION

The permeability behaviour of fibrous reinforcements and especially the transverse permeability evaluated in the z direction is a key entry parameter for the modelling of processes such as Resin Film Infusion (Resin Film Infusion) or VAP (Vacuum...).

The saturated transverse permeability of fibrous composite reinforcements has been evaluated and discussed by Drapier *et al.* [1]. This “classical” method consists of evaluating pressure/flow rate couples after injecting a test fluid through the fibrous preforms. This technique consumes a large amount of time as a set of pressure/flow rate couples has to be determined for every fibre volume fraction of interest. Scholz *et al.* [2] developed a continuous technique to measure the transverse permeability during

compaction therefore reducing the experimental time. It consists in injecting a Newtonian liquid or a gas through the preform that is compacted continuously.

During the RFI process, a strong coupling takes place between the compaction of the preform and the flow of resin. During the process, the permeability of the fibrous medium varies simultaneously according to the evolution of the compaction of the preform. As a consequence, the values of the transverse permeability measured using a continuous technique that better reflects the coupling phenomenon between the flow of test fluid and the compaction of the preform may not be similar to the values determined using the “classical” method.

In a previous study, Ouagne and Bréard [3] showed that for low compression speed (0.5 mm/min) the continuous technique gives similar values to the “classical” technique for four composite reinforcements of very different nature. This is the case if fibre and bundle rearrangement has the time to occur within the reinforcements during the compression of the reinforcements. A rearrangement of the fibres and bundles in a more “stable” positions favours pressure relaxation, a reduction of the measured pressure and prevent a drop in permeability.

For higher compression speeds, fibre and bundle rearrangement may not have the time to happen and it is expected that the transverse permeability value is affected. This work suggests investigating the effect of the continuous compaction speed upon the transverse permeability values. Particularly, a comparison between continuous transverse permeability curves evaluated using different compaction speeds is carried out for two different fibrous reinforcements.

## **EXPERIMENTAL PROCEDURE**

### **Experimental device**

A device to establish simultaneous hydraulic and mechanical loads (hydro-mechanical coupling loads) to the fibrous preforms was set up in Le Havre. This apparatus as well as its setting up has been described into details in a previous study [3]. A constant flow rate of a newtonian fluid (silicon oil) is applied in a transverse manner to two different fibrous reinforcements and the induced pressure rise is measured with a pressure sensor. The transverse permeability  $K_z$  is calculated using Darcy's law [4]. Since the piston compresses the fibrous medium at a constant speed,  $K_z$  is measured in a continuous manner as a function of the increasing fibre volume fraction.

The tested silicon oil has a viscosity of 0.1 Pa.s. The carbon non crimped fabric and the glass satin weave used in this study have respective areal weights of 1120 g/m<sup>2</sup> and 620 g/m<sup>2</sup>. s are cut into 100 mm diameter discs by a specially made cutter. Stacks of twenty layers of flax or glass mats are compressed at different speeds varying between 0.5 and 10 mm/min and are submitted to a constant flow rate of 0.67 cm<sup>3</sup>/s.

## RESULTS AND DISCUSSION

Figure 1 shows a comparison of the transverse permeability values measured by the classical method and the continuous technique for a glass satin weave submitted to three different compression speeds and the same constant imposed flow rate. The continuous transverse permeability seems to decrease when rising compression speeds are used during the test. The relative difference between the classical and the continuous transverse permeability evaluated for higher compression speeds has been evaluated for the glass satin weave. At a fibre volume fraction of 56%, a deviation of about 10% of the relative difference is observed for the 1 mm/min in comparison to the value calculated for the 0.5 mm/min compression speed. A deviation of about 25% is observed for the 5 mm/min compression speed. However, the value of the relative difference between the two techniques remains inferior to 50% for the glass satin weave even for the 5 mm/min compression speed.

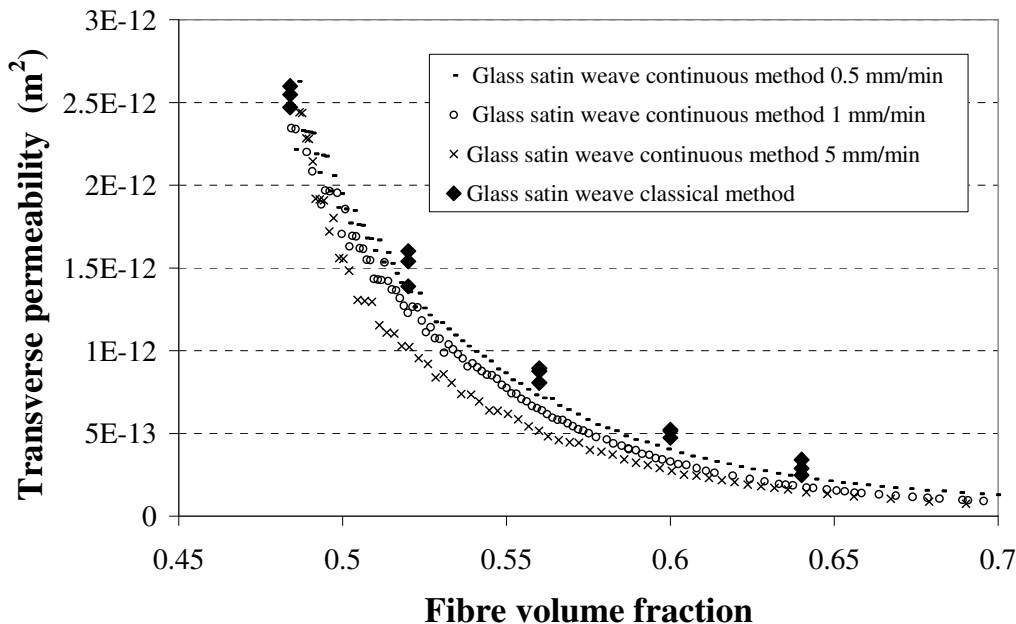


Figure 1: Continuous and “classical” transverse permeability a glass satin weave:  
Influence of the compression speed on the continuous technique results.

Figure 2 shows continuous transverse permeability curves evaluated using different compression speeds for a carbon non-crimped fabric. As described for the glass satin weave, the continuous transverse permeability seems to decrease when rising compression speeds are used during the test. At 56%, the relative difference between the curve evaluated with a compression speed of 1mm/min and the curve evaluated with a 5 mm/min compression speed is of about 6%. A deviation of about 13% is observed for the 10 mm/min curve.

The differences observed between transverse permeability curves evaluated with different compression speeds are probably due to a modification of the pressure field within the reinforcements. In the case of classical transverse permeability measurement, and if one assumes uniform fibre volume fraction, the pressure field is linear as no compression is applied.

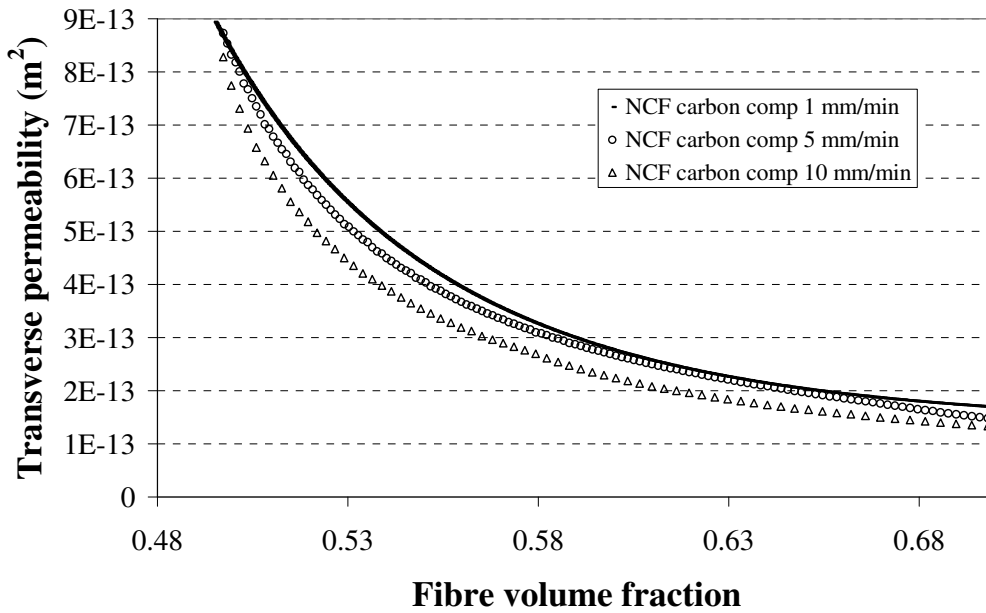


Figure 2: Influence of the compression speed on the continuous technique results for a carbon non crimped fabric

The pressure decreases linearly between the lower grid and the upper grid which is at the atmospheric pressure. If a constant compression displacement is applied on a saturated medium without any imposed flow rate, a squeezing flow occurs and a different pressure field is expected in our device with a maximum value at the bottom of the sample close to the lower grid and the atmospheric pressure at the upper grid as that one is directly connected to the outlet pipe. If an injection flow rate and a mechanical compression are applied, the two previously mentioned pressure field interact. Saouab *et al.* [5] showed that the pressure field takes a parabolic form in the case of CRTM process due to a gradient of fibre volume fraction in the thickness of the sample. In our case of study, a gradient of fibre volume fraction should also occur and a curved pressure field is expected. The curvature of the pressure field depends on the compression speed as the injection flow rate is constant. Under slow compression speed the curvature of the pressure field is low as fast pressure relaxation may take place even during the compression as a result of fibre rearrangement. In those conditions the pressure field should not be very different than the linear pressure field expected in the case of the classical measurement. The pressure recorded should be similar or slightly higher than for the classical case. Under fast compression speed the curvature of the pressure field is higher and the pressure recorded by the sensor higher as pressure relaxation is not expected to take place in this case.

The relative differences observed on the carbon NCF are relatively low in comparison to the glass satin weave even for a compression speed of 10 mm/min. In those conditions, the relaxation phenomenon that is expected to take place for very low compression speed cannot be a correct explanation. One explanation for the low difference between the permeability values curves evaluated with different compression speed may be due to the fact that the flows of fluid do not have the time to be established. In the case of very low compression speed, the pressure has time to build up when the fibre volume fraction increases. For higher compression speeds, the pressure does not have the time

to build up and the flow of fluid remains in a transient regime. In those conditions, the instantaneous pressure is underestimated, and the permeability is overestimated.

The instantaneous permeability evaluated with high compression speeds is expected to be the result of two antagonist phenomena. The curvature of the pressure field has a tendency of increasing the recorded pressure, whereas the transient regime underestimates it.

Ouagne *et al.* [6] showed that the expected compression speed of the glass satin weave fabric submitted to an applied transverse stress ramp is situated in a range 12-0.15 mm/min. In this case, the phenomena described in the previous paragraph also take place and an instantaneous permeability value better reflects what is happening during the process and may improve the quality of the process modelling.

## CONCLUSIONS

The transverse continuous permeability curves of two fibrous reinforcements evaluated using fast compression speeds are not similar to the ones evaluated using low velocity. The fast compression speed permeability curve is the result of transient phenomena acting on the measured pressure. It therefore reflects the instantaneous permeability behaviour of the reinforcements. This may improve the accuracy of the permeability value used to model processes such as RFI where the compression speed is not constant.

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