Characterization of Out-of-Plane Capillary Pressure of Textiles

Björn Willenbacher, David May, Peter Mitschang
Institut für Verbundwerkstoffe GmbH
Erwin-Schrödinger-Str., Geb. 58
67663 Kaiserslautern

Textile permeability characterization often follows an unsaturated approach, i.e. a dry textile is impregnated by a fluid and flow front movement is monitored. For permeability calculation based on Darcy`s law, a pressure-driven injection is commonly applied. Depending on flow velocity, capillary pressure can also contribute to flow movement, which would lead to a calculation error if not considered. This again requires capillary pressure determination. Capillary pressure determination in in-plane direction has been extensively investigated and various measurement methods are known[123]. However, these measurement systems are not suitable for measuring capillary pressure in out-of-plane direction, which is highly complicated due to difficult flow direction monitoring, unknown surface tension and contact angle etc..

In the present work, a novel measurement system for out-of-plane capillary pressure based on weight increase was developed. The measurement system is shown in Figure 1. Two plates with a defined gap allow the adjustment of a defined fiber volume content. Distribution media, with a much higher capillary pressure compared to the sample, under and on top of the samples, ensures constant liquid flow and ventilation of the sample. The samples are sealed with silicone to avoid any flow in in-plane direction and boundary effects in the edge areas. For determination of the capillary pressure the weight increase of the distribution medias and the sample resulting from progressing fluid flow, are tracked. With the mass difference between saturated and unsaturated distribution media and sample the flow front progress over the time can be determined. This again allows calculation of the capillary pressure with equation 1:

$$P_c(z_c;t) = z_c * \left(\frac{\mu * e * z_c}{2 * K * t} + \rho * g\right) \tag{1}$$

where μ is the viscosity, K the permeability, e the porosity and z_c is the climbing height of the flow front (t, ρ und g are time, density and gravity constant)[4].

During the measurement, the fluid level in the oil container will decrease, which leads to a reduction of the buoyancy force. The hereby caused error over the complete measurement is calculated to be 4 % of the capillary pressure value and is therefore assumed to be negligible.

With this system, the out-of-plane capillary pressure of a random mat glass fiber (*PD FiberGlass Groupe,* 300 g/m²), a twill 2/2 woven glass fabric (*Hexcel 1202*, 290 g/m²), and a non-crimp biaxial glass fiber (*Saertex X-E-444,* 444 g/m², ±45°) was measured. Exemplarily measurements with a glass fiber twill 2/2 woven fabric with an area weight of 290 g/m² and a FVC of 50 % are shown in Figure 1. It is remarkable that the same textile with the same FVC shows a quite large variation in absolute saturation time. It is assumed that this is due to the variations resulting from the permeability of the textile, which is included in the calculation.

The permeability of the textile has been determined in separate experiments and ranged from 1E-12 to 5E-13b at a fiber volume content of 50 % it. Table 1 shows the capillary pressure for the three tests depending on the permeability value used for the calculation. One can see that the variations in permeability have a huge influence that can explain the capillary pressure variations. However, a further investigation is necessary.

Table 1: Results of the capillary pressure measurement of *Hexcel 1202* depending on the permeability.

	Permeability		
	1E-12 m²	7E-13 m²	5E-13 m²
Measurement 1	0.0068 bar	0.0096 bar	0.0132 bar
Measurement 2	0.0038 bar	0.0052 bar	0.0071 bar
Measurement 3	0.0045 bar	0.0062 bar	0.0084 bar

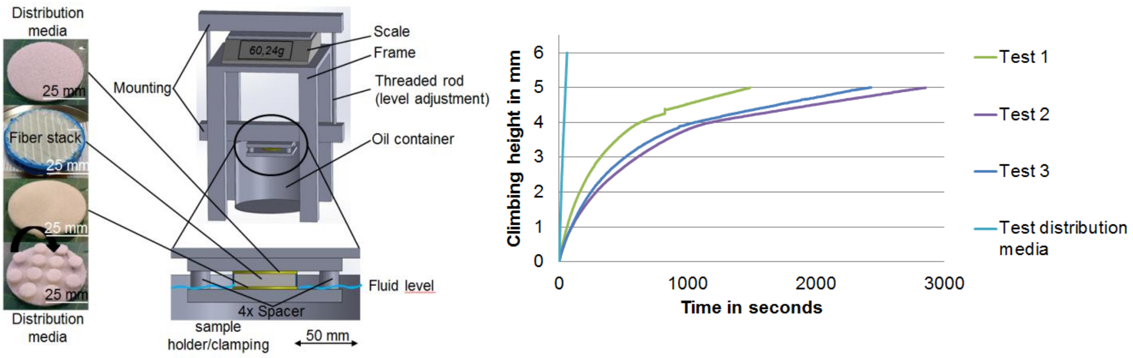

Figure 1: Progress of the capillary pressure measurement in out-of-plane direction of *Hexcel 1202 with* an area weight of 295 g/m² and a Fiber Volume Content of 50 %. The very left curve is the comparison measurement with the distribution media.

If a detailed process understanding is the target, the out-of-plane capillary pressure must be taken into account. For macro level K3 permeability measurements, the capillary pressure is not relevant. These results will be exploited in a joint research project of IVW and ETH Zürich with the aim of modeling effects during unsaturated out-of-plane measurement (including hydrodynamic compaction) and the development of a combined simulative-experimental approach.

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