COMPARISON OF PERMEABILITY MEASUREMENTS OF SEVERAL FIBRE TEXTILES USING DIFFERENT MEASUREMENT METHODS

H.Grössing[1, 2, *)], M.Wolfahrt[1, 3)], A.Müller[3)], R.Schledjewski[2)]

1) Polymer Competence Center Leoben GmbH, Roseggerstraße 12, 8700 Leoben, Austria
2) Department Polymer Engineering and Science, Chair in Processing of Composites,
Montanuniversitaet Leoben, Otto Gloeckel Str. 2, 8700 Leoben, Austria
3) FACC AG, Fischerstraße 9, 4910 Ried/Innkreis, Austria
**Corresponding author: H.Grössing, harald.groessing@stud.unileoben.ac.at*

Keywords: permeability, textiles, reproducibility

Abstract:

The liquid composite moulding (LCM) process is a well-established process to saturate fibre based preforms. In LCM technologies the preform permeability is a key factor for mould designing and in flow modelling. Due to orientation effects of the textile preforms, a two dimensional permeability characterisation system is required. Two permeameter systems, a dielectric capacity based and an optical system were used to investigate the preform permeability of non-crimp fabric (NCF) and unidirectional (UD) textile preforms. In this study the influence of injection pressure and the influence of number of layers on the permeability were investigated. The number of layers and the injection pressure showed no significant influence on the preform permeability. Due to inhomogeneous areas in the preforms, the NCF resulted in a higher standard deviation. Generally, the reproducibility of the UD preforms, standard deviation less than 6%, is much better than the reproducibility of the NCF preforms.

1. Introduction

Nowadays fibre based polymer composite materials are used in aerospace, automotive, and wind power industry because they are lightweight materials for high performance applications including helicopter rotor blades, wind turbine blades or car crash boxes [1, 2]. Using carbon based reinforcements on large passenger aircrafts or huge wind turbine blades the whole weight can be reduced by approximately 20% [3]. A widely used technology for producing fibre based polymer composites is the liquid composite moulding (LCM) process, such as resin transfer moulding (RTM). During RTM process a dry preform gets saturated with resin. The most valuable advantages of this process are low costs, low solvent emission, high and reproducible quality and versatility [4]. To achieve the highest levels of quality and properties, the parameters of the LCM process have to be evaluated.

The RTM process starts with placing a porous medium, the fibre preform, into the cavity and goes on with mould closing. During the closing process the material gets compacted and compressed. The compaction of fibre preforms reduces the pores and gaps between the tows (fibre bundles). A side effect of the compaction process is the elastic deformation of fibre bundles including the shifting of each single layer of the preform, also called nesting [4]. After the closing process the liquid medium (resin), is injected into the mould under pressure. The fibre based reinforcements can be described as a dual- scale porous medium with inter-tow macropores and intra- tow micropores in which the resin can flow through. In the area of the macropores the resin flow is driven by the externally driven applied pressure. In intra- tow micropores the impregnation of fibre tows is also driven by capillary pressure [5, 6]. The infiltrated fluid follows the path of least resistance [7]. The resistance of the porous medium to the liquid flow is called permeability [8]. Local changes and inhomogeneous spots in the preform can have a great influence on the mould filling process and the permeability [7]. Exact permeability data are very useful for numerical flow simulations. An important parameter for the RTM process is the textile impregnation time, which is directly related with the permeability of fibre preforms. The permeability data are used as well for mould designing [5]. The most important equation for permeability calculation is Darcy´s law [9, 10, 11]. It is the generally accepted equation (Eq.1) to describe the one dimensional flow through a porous medium,

$$\mathrm{v}_0 = -\frac{\mathrm{K}}{\eta}\frac{\Delta\mathrm{P}}{\Delta\mathrm{x}} \tag{1}$$

where v_0 is the superficial velocity (m/s), K is the permeability (m^2), η is the fluid viscosity (Pa*s), ΔP is the imposed pressure difference (Pa) and Δx is the flow length. A mathematic formulation for the two dimensional flow is described in literature [12]. The most significant influence on the permeability takes the fibre volume fraction and the porosity [13, 14]. Viscosity [5, 15, 16] and injection pressure [17] have no significant influence on the permeability. To describe the fluid´s flow and to measure the permeability of a variety of fibre orientations like unidirectional layers or woven fabrics, two primarily methods can be used. The unidirectional flow method is used to characterize the permeability in one flow direction. Generally the permeability of fibrous structures is anisotropic. Especially due to this fact, it is necessary to measure the in- plane permeability with a radial flow in two directions. Using the unidirectional flow method the unsaturated and the saturated permeability can be obtained. To get knowledge about the two dimensional in-plane permeability only unsaturated preforms can be measured. The information of the unsaturated permeability is more important than the saturated permeability, because it is more relevant to real processing [5, 6].

2. Experimental

2.1. Materials

Two types of carbon fibre reinforcements, a biaxial non crimp fabric (NCF) with a 0°/90° fibre orientation and a unidirectional (UD) fabric, were investigated

The NCF had an area weight of 541 g/m². The UD material had an area weight of 292 g/m². Corn oil was used as test fluid for both measurement systems. To measure carbon fibre preforms with an optical permeameter, it is needed to dye the corn oil with a non polar colour. The used colour was SUDANRED IV (Sigma Aldrich). The viscosity of the coloured plant oil was measured with a couett rheometer and the determined viscosity was 64.8 mPa*s at room temperature.

2.2. In-plane permeability measurement

For permeability characterization, two different permeameter systems were used. The dielectric capacity permeameter consists of a lower mould (tool) in which eight dielectric capacity line sensors are embedded, an upper mould (tool) in which the injection hole is located, a cavity frame, a pressure pot, and a computer. The mould cavity dimensions of the dielectric capacity permeameter are 465 by 465 mm. To measure the preform permeability with a different number of layers but with the same fibre volume fraction, cavities with several heights are available. The plant oil is collected in the pressure pot. If the saturating process starts, the plant oil is driven by the pressure in the pressure pot. The plant oil flows through the oil gate line and passes the cavity through the injection hole in the upper mould. During the saturating process of the preform with the plant oil the dielectric capacity of the preform and the air inside the mould are changed. To obtain the necessary equation for the permeability evaluation, the flow front positions of three dielectric capacity sensors are needed. The flow front positions are determined by the wetted length of the eight dielectric capacity sensors. After the mould filling process, a Labview calculation tool was used to calculate the permeability with the dielectric capacity sensor data. The values for the permeability in the major- (K1) and minor axis (K2) are given by the software. Figure 1 shows the used dielectric capacity permeameter at the IVW GmbH in Kaiserslautern, Germany.

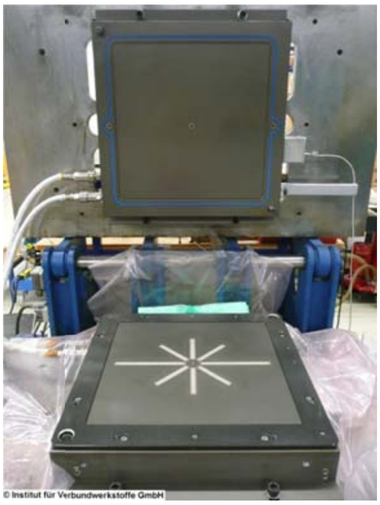
© Institut für Verbundwerkstoffe GmbH

Figure 1: Dielectric capacity permeameter at the IVW GmbH, Kaiserslautern, Germany

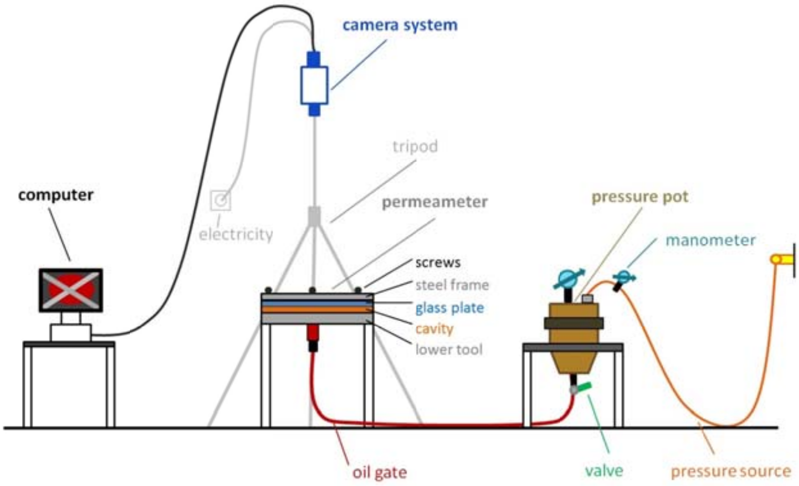

Figure 2: Schematic of the permeability measurement setup

The second system used, shown in Figure 2, was an optical permeameter manufactured by the FACC AG. It consists of a lower mould with the dimensions of 400 by 300 mm, a 20 mm thick composite glass plate, a 20 mm thick steel frame, a lower plate with an injection hole in the middle, a pressure pot with the plant oil in it and a camera system with a monochromatic camera. The camera is assembled on a tripod and takes continuously pictures of the spreading flow front. The tripod is needed to have a fixed and constant distance between the camera lens and the glass plate. The pressure source ensures a constant injection pressure in the pressure pot. During the infiltration all captured images are saved on the computer for the following ellipse evaluations. After the infiltration a Matlab program determines the major and minor radius of the elliptic flow front. A second Matlab program is responsible for the permeability calculation of the major and minor axis.

2.3. Testing plan

Dielectric capacity measurements:

For the dielectric capacity permeability characterization the NCF preforms were cut by an automatic textile cutter with a blade. After that, a hole with a diameter of 12 mm was punched right into the middle of the preform and then it was laid inside the square mould cavity. All the permeability measurements were carried out at room temperature. The actual room temperature was noticed for the permeability evaluation. To determine the influence of the injection pressure on the permeability a constant cavity height of 1.95mm was used. The fibre volume fraction was determined by following well known equation [11] (Eq. 2),

$$V_f = \frac{n * \xi}{1000 * d * \rho_f} \tag{2}$$

where V_f is the fibre volume fraction (%), n is the number of layers (1), ξ is the fabric area weight (g/m²), ρ_f fibre density (g/cm³) and d is cavity height (mm). The dielectric capacity permeameter was used to measure NCF preforms with a fibre volume fraction of 62.5 % and an injection pressures of 2 bar, 4 bar, six bar and 8 bar respectively. UD preforms with a fibre volume fraction of 60% and injection pressures of 2 bar, 4 bar, and 6 bar were investigated. The thickness of the cavity could be adjusted by using different spacers. To get knowledge about the influence of the number of layers on the permeability the cavity heights of 1.95 mm, 2.43 mm, and 7.00 mm respectively were used. Because of the different cavity heights and the different numbers of layers it was not possible to use exactly the same fibre volume fraction for all measurements. A fibre volume fraction of approximately 62% was aimed. All tests to determine the influence of number of layers on the permeability were measured with an injection pressure of 6 bar. Another aim of this study was to show the influence of material handling on the permeability. At first the injection holes of each layer were cut with a scissor. The second handling should show what happens with the permeability properties, if the orientation of the preform will be disordered. Also the influence of packaging and transportation of the preform was determined. All the NCF preforms investigated here had a fibre volume fraction of 62.5 % and were tested with an injection pressure of 6 bar.

Optical measurement:

All the optical permeability measurements of the NCF textile preforms were performed in the rectangular mould cavity with a cavity height of 1.95 mm and a fibre volume fraction of 62.5%. To investigate the influence of the injection pressure on the permeability the injection pressure was varied from 0.5 bar to 3 bar.

3. Results and discussion

3.1. Influence of injection pressure on permeability

Dielectric capacity measurement:

Figure 3 shows the influence of the injection pressure on the permeability of NCF preforms with a fibre volume fraction of 62.5%. K1 represent the permeability of the major axis and K2 is the permeability of the minor axis.

Figure 4 shows the influence of the injection pressure on the permeability of UD preforms with a fibre volume fraction of 60%.

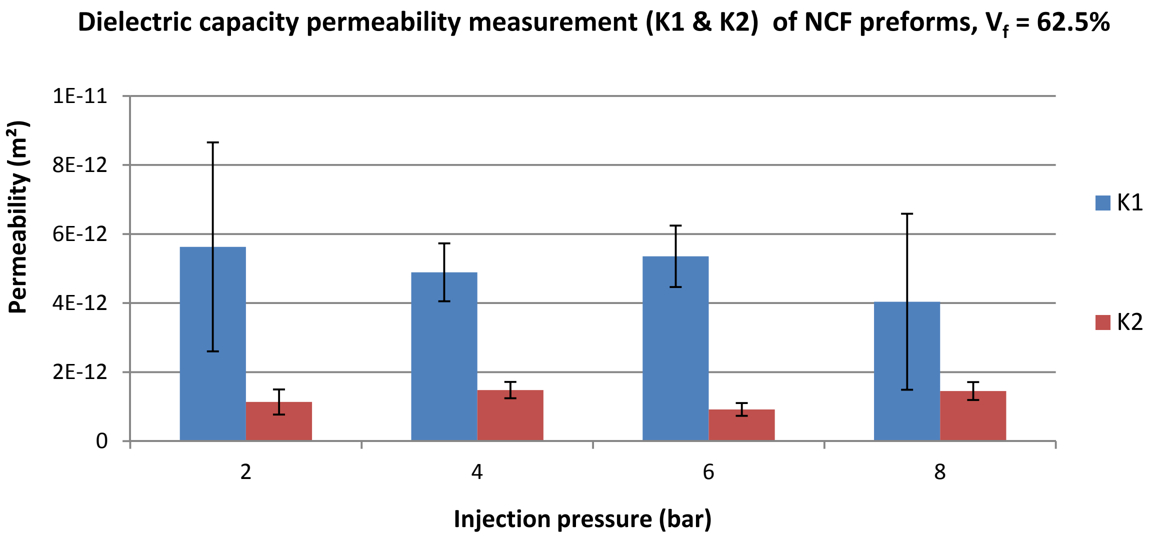

Figure 3: Influence of the injection pressure on the permeability of NCF preforms

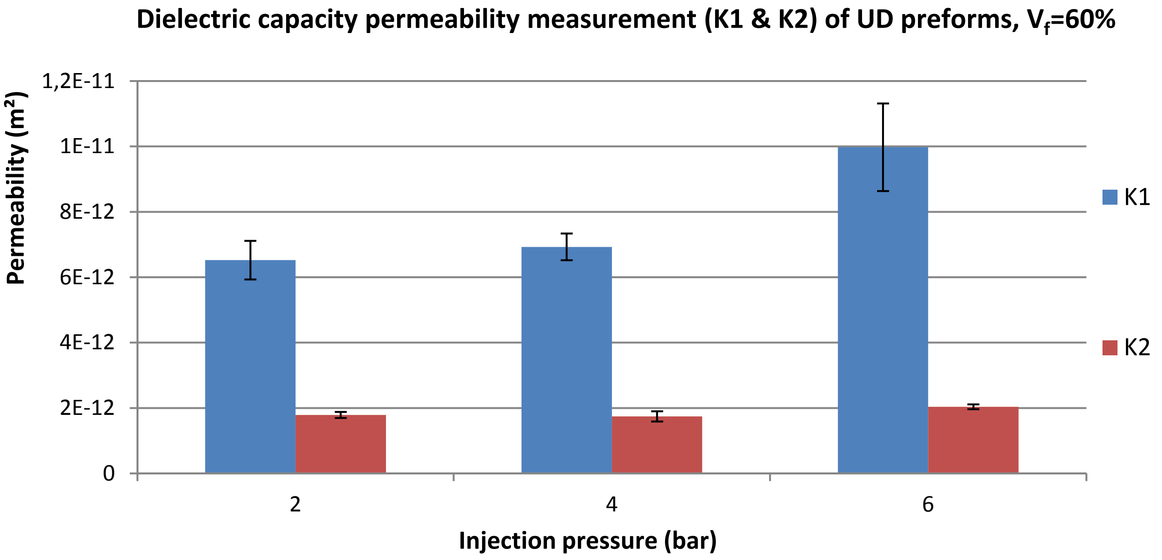

Figure 4: Influence of the injection pressure on the permeability of UD preforms

The permeability characterization measurements of NCF- and UD preforms with the dielectric capacity permeameter showed, that the injection pressure has no significant influence on the permeability. The measurements with the UD material are more reproducible compared to the NCF material. Very high standard deviations of more than 50% for K1 and 30% for K2 were observed for the NCF preforms due to inhomogenities in the material. The highest standard deviation of the measured UD material is nearly 14% for K1 and 9% for K2.

Optical measurement:

Figure 5 shows the influence of the injection pressure on the permeability of NCF preforms with a fibre volume fraction of 62.5%.

The optical permeability characterizations of NCF preforms showed, that the injection pressure has a significant influence on the permeability values. For example the permeability measured with 3 bar is 3 times higher than the permeability carried out with 1 bar.

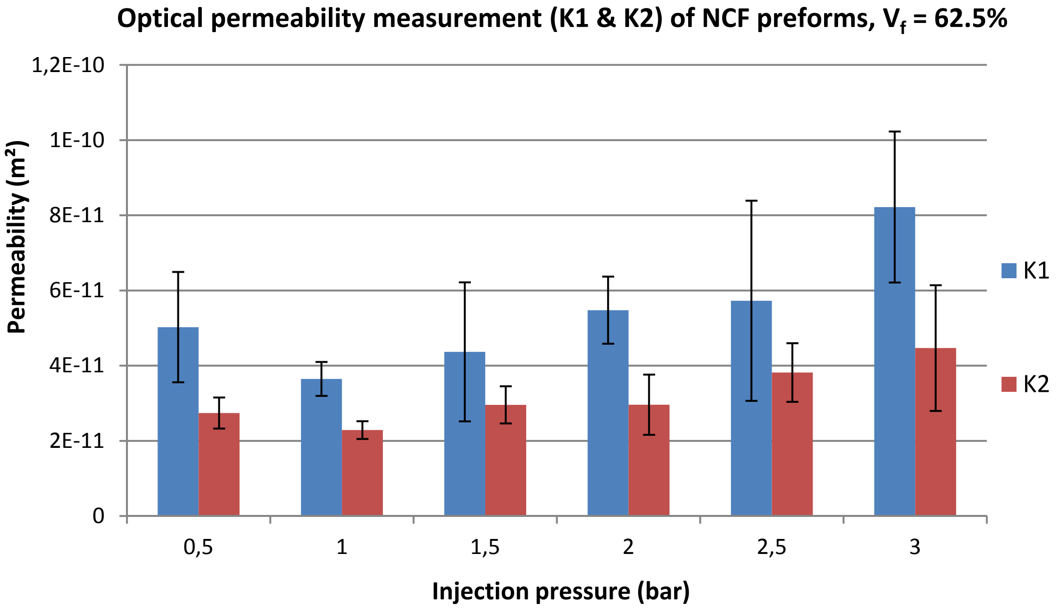

Figure 5: Influence of the injection pressure on the permeability of UD preforms

3.2. *Influence of number of layers on permeability*

Figure 6 shows the influence of the number of layers on the NCF preform permeability measured with an injection pressure of 6 bar. 14 layers in a cavity height of 7.00 mm, 5 layers in cavity height of 2.43 mm and 4 layers in cavity height of 1.95 mm were investigated.

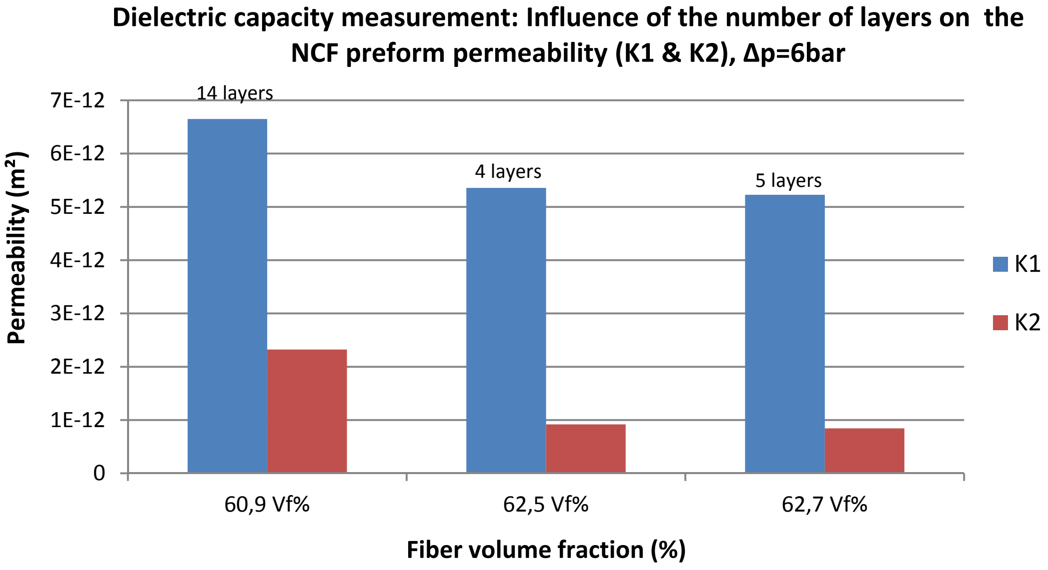

Figure 6: Influence of the injection pressure on the permeability of NCF preforms

The number of layers has no significant influence on the permeability. (It was not possible to use exactly the same fibre volume fraction, because of the available cavity heights.)

3.3. *Influence of material handling on permeability*

Figure 7 shows different influences of the NCF preform handling (hand cut injection hole, disordered fibre orientation, delivery conditions) on the permeability. A fibre volume fraction of 63% and an injection pressure of 6 bar were used. An untreated NCF preform was used as reference.

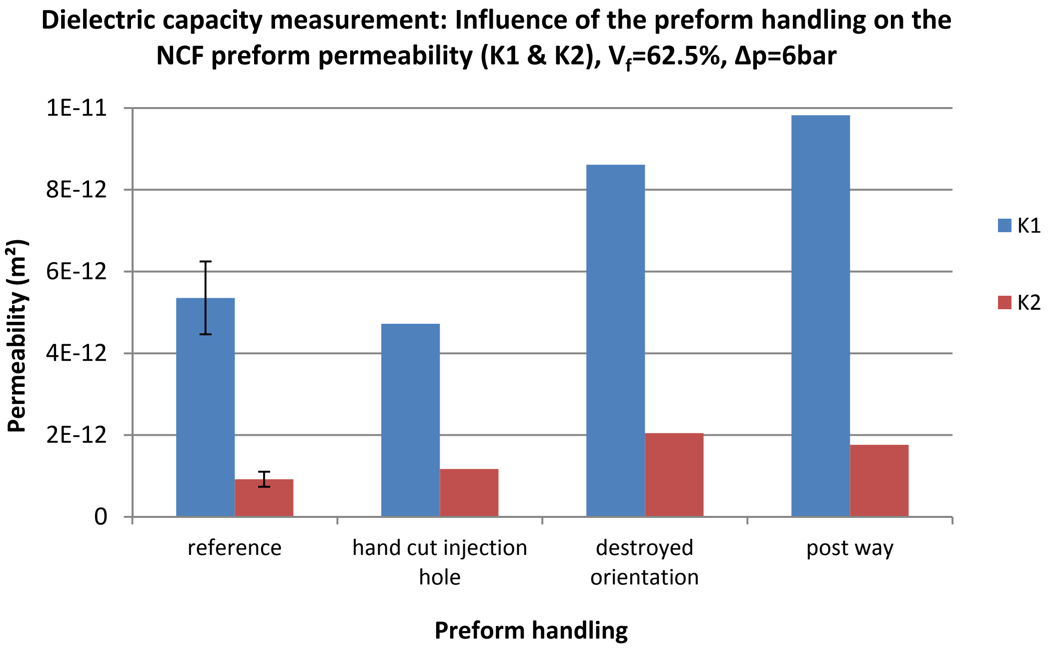

Figure 7: Influence of the NCF preform handling on the permeability

The preform handling tests showed that the handling takes a significant influence on the permeability except the measurement with the hand cut injection holes. To destroy the fibre orientation and bring the orientation back in order, means that the permeability of the major axis will increase by 60% and the permeability of the minor axis will increase by 120%. The main influence on the permeability is by sending the preform per mail. K1 one increases by 83% and K2 increases by 91%.

4. Conclusions

In this study the permeability of carbon NCF- and carbon UD preforms were measured. The tests have shown that the injection pressure has no significant influence on the permeability but only as long as the tool is not bouncing or opened. The reproducibility is dependent on the material quality. Inhomogeneous areas in the fabric are responsible for high standard deviations of permeability characterization measurements. It could also be shown that the number of layers has no significant influence on the permeability, if a constant fibre volume fraction is used. The handling of the preforms is very important. A rough treatment means that the permeability will increase rapidly.

Acknowledgement

The research work was performed at the Polymer Competence Center Leoben GmbH (PCCL, Austria) within the framework of the COMET-program of the Austrian Ministry of Traffic, Innovation and Technology with contributions by the University of Leoben (Chair of Processing of Composite) and FACC AG. The PCCL is funded by the Austrian Government and the State Governments of Styria and Upper Austria.
The authors would also like to thank the Institute for Composite Materials (IVW), Germany for their support.

References

[1] Potluri, P. and Sagar, T. V.: Compaction modelling of textile preforms for composite structures, *Composite Structures*, **Vol. 1-3**, 177-185 (2008).

[2] Kumar, S. B., Sridhar, I. and Sivashanker, S.: Influence of humid environment on the performance of high strength structural carbon fiber composites, *Materials Science and Engineering: A*, **Vol. 1-2**, 174-178 (2008).

[3] Mouritz, A. P.: Fire resistance of aircraft composite laminates, *Journal of Materials Science Letters*, **Vol. 21**, 1507-1509 (2003).

[4] Chen, B. and Chou, T.: Compaction of woven-fabric preforms: nesting and multi-layer deformation, *Composites Science and Technology*, **Vol. 12-13**, 2223-2231, (2000).

[5] Luo, Y. et. al.: Permeability measurement of textile reinforcements with several test fluids, *Composites Part A: Applied Science and Manufacturing*, **Vol. 10**, 1497-1504, (2001).

[6] Arbter, R. et. al.: Experimental determination of the permeability of textiles: A benchmark exercise, *Composites Part A: Applied Science and Manufacturing*, **Vol. 9**, 1157-1168 (2011).

[7] Grujicic, M., Chittajallu, K. M. and Walsh, S.: Effect of shear, compaction and nesting on permeability of the orthogonal plain-weave fabric preforms, *Materials Chemistry and Physics*, **Vol. 2-3**, 358-369 (2004).

[8] Talvensaari, H., Ladstätter, E. and Billinger, W.: Permeability of stitched preform packages, *Composite Structures*, **Vol. 3-4**, 371-377, (2005).

[9] Stöven, T.: *Beiträge zur Ermittlung der Permeabilität von flächigen Faserhalbzeugen*, IVW Schriftenreihe Band 45, IVW GmbH, Hrsg. Schlarb A. K., (2004).

[10] Stadtfeld, H.: *Entwicklung und Einsatz einer optischen Messzelle zur Bestimmung von Kompatkierungs- und Permeabilitätskennwerten flächiger Faserhalbzeuge*, IVW Schriftenreihe Band 67, IVW GmbH, Hersg. Schlarb A. K., (2006).

[11] Kissinger, C.: *Ganzheitliche Betrachtung der Harzinjektionstechnik*, IVW Schriftenreihe Band 28, IVW GmbH, Hrsg. Schlarb A.K., (2001).

[12] Adams, K. L. and Rebenfeld, L.: In- Plane Flow of Fluids in Fabrics: Structure/Flow Characterization, *Textile Research Journal*, **Vol. 11**, 647-654, (1987).

[13] Umer, R., Bickerton, S. and Fernyhough, A.: The effect of yarn length and diameter on permeability and compaction response of flax fibre mats, *Composites Part A: Applied Science and Manufacturing*, **Vol. 7**, 723-732, (2011).

[14] Saunders, R. A., Lekakou, C. and Bader, M. G.: Compression and microstructure of fibre plain woven cloths in the processing of polymer composites, *Composites Part A: Applied Science and Manufacturing*, **Vol. 4**, 443-454 (1998).

[15] Hammond, V. H. and Loos, A. C.: The effects of fluid type and viscosity on the steady-state and advancing front permeability behavior of textile preforms, *Journal of Reinforced Plastics and Composites*, **Vol. 1**, 50-72, (1997).

[16] Lundström, T. S. et. al.: In-plane permeability measurements: a nordic round-robin study, *Composites Part A: Applied Science and Manufacturing*, **Vol. 1**, 29-43, (2000).

[17] Rieber, G. M.: *Einfluß von textilen Parametern auf die Permeabilität von Multifilamentgeweben für Faserverbundkunststoffe*, IVW Schriftenreihe Band 96, IVW GmbH, Hrsg. Breuer U., (2011).