Standardizeable Permeability Work Cell for Fibrous Reinforcements

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SUMMARY: A permeability measurement work cell was developed at the Institut fuer Verbundwerkstoffe GmbH. It consists of an aluminum mold with integrated dielectric sensors and a LabVIEW-based control software. These sensors allow to monitor the progression of the flow front at any point in time. Consequently, the 2D permeability of any given fabric can be determined within minutes. This paper introduces the set-up, the software, and the capabilities of a standardized approach to measuring the 2D permeability of fibrous reinforcements in an easy and efficient manner.

KEYWORDS: permeability, 2D measurement, dielectric sensors, automated set-up, RTM.

INTRODUCTION

Liquid composite molding technologies such as RTM have established themselves in the industry. In the case of RTM the potential of this process encompasses short cycle times, high fiber volume fractions, high surface quality, and the possibility of implementing complex geometries. With growing popularity of this manufacturing technique, process simulations like LIMS [1] have become important since they enable engineers to predetermine the precise location of injection gates and vents in RTM molds according to the properties of the fibrous reinforcement to be used. To use these process simulation tools, engineers are required to know the components of the permeability tensor of the reinforcing material as a function of the degree of compaction, i.e. fiber volume fraction. There are two ways of determining the required permeability values, i.e. either to measure it experimentally or to rely on the use of software that will provide the permeability based on the assumption of representing a reinforcement structure by means of idealized unit cells.

Permeability measurement

The first approach, i.e. experimental determination, provides well-established and verified methods of obtaining the in-plane permeability values and is the subject of this paper.

Experimental methods of measuring the in-plane permeability of a porous media can be differentiated by the characteristics of the injection gate. Hence, one can differentiate between 1D injection methods (line gates) and 2D injection methods (point gates).
While the mathematical evaluation of the permeability within the 1D method is very straight forward, the experimental set-up itself provides challenges. The race-tracking phenomenon [2], preform slippage inside the mold, and the requirement to know the major flow directions of the material under investigation prior to the experimental investigation are just a few of the problems to be mentioned. The result of a successful 1D measurement is *one* permeability value for *one* of the main axes of flow at a specific fiber volume fraction.
Performing a 2D measurement is rather simple but the mathematical procedure to calculate the permeability is more demanding. With the 2D method neither edges need to be sealed off, nor does the preform tend to slip inside the mold. With one experiment one generates a complete set of permeability values for a given fiber volume fraction.
The usage of metal molds generates the need to use sensor systems to determine the flow front position inside the closed mold. Researchers [3], [4] found different approaches to meet these challenges. A more recent approach [5] suggests to use an array of mold-embedded, resistance-based point sensors to obtain the time the flow front reaches each of the positions of the sensors inside the array. Ideally, an analogue lineal sensor system should be introduced into the mold since this allows to obtain the desired flow front position at any instant of time.

Permeability measurement work cell

Such a lineal sensor system has been developed, and patented [6], [7] by the Institut fuer Verbundwerkstoffe GmbH. The permeability measurement work cell is formed by a permeability measurement tool, mounted on a RTM-Press, a computer which runs the measurement and data acquisition software LabVIEW®, and an injection unit.
The permeability tool shown in Figure 1a) has a mold cavity area of 640 mm by 420 mm and consists of two 80 mm thick aluminum plates. By means of spacer plates virtually any fiber volume fraction can be achieved. Temperature control of the tool up to a maximum temperature of 160 °C allows using reactive resin systems.
The upper mold provides three possible injection locations (1 gate, 2 vents) and contains six dielectric lineal sensors, as it can be seen in Figure 1a). The sensor system implemented in the permeability measurement work cell depends on the change of the dielectrical properties of the materials inside the cavity due to a fluid which gradually saturates the porous media. In general, dielectrical sensors can not be used with conductive reinforcing materials such as carbon fibers. The system developed at IVW prevents the sensors from generating short circuits through a surface treatment, thus eliminating this limitation.
During an experiment, the test fluid enters the mold cavity through the center gate and starts to saturate the preform inside the mold. As the flow front reaches the first horizontal sensors, the previously constant sensor outputs continuously start to rise over time (ellipse 1 in Figure 1a). As the experiment progresses, the next ellipsoidal flow fronts are obtained (2, 3 in Figure 1a). These ellipsoidal flow fronts generate the respective sensor output levels documented in Figure 1b). Whenever a sensor is completely wetted, the output voltage remains constant over time and forms a plateau. With the knowledge of the actual sensor length and the plateau voltage, a relation between voltage and length scale can be determined for each lineal sensor, which allows to transform the sensor signal into the desired flow front position.

Finally, after all sensors have been wetted completely, the injection is stopped and the experimental part is concluded.

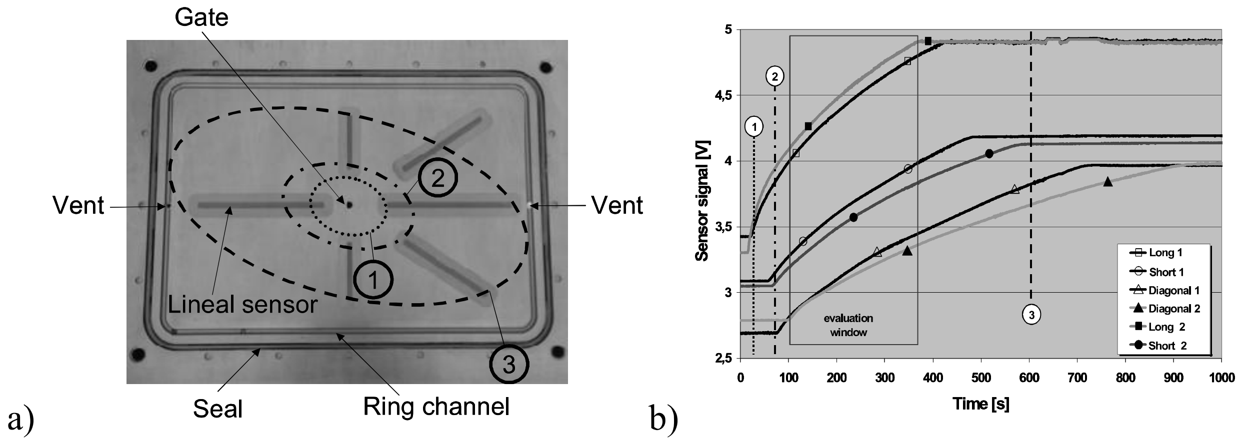

Figure 1a) IVW-permeameter with integrated dielectrical lineal sensors. Schematics of typical flow front ellipses during a permeability experiment are provided in 1a) with their corresponding sensor output voltages displayed in 1b)

Now the permeability can be calculated from pressure, fiber volume fraction and flow front position over time. Figure 2 shows the interface created to provide injection control and to perform a variety of permeability evaluations.

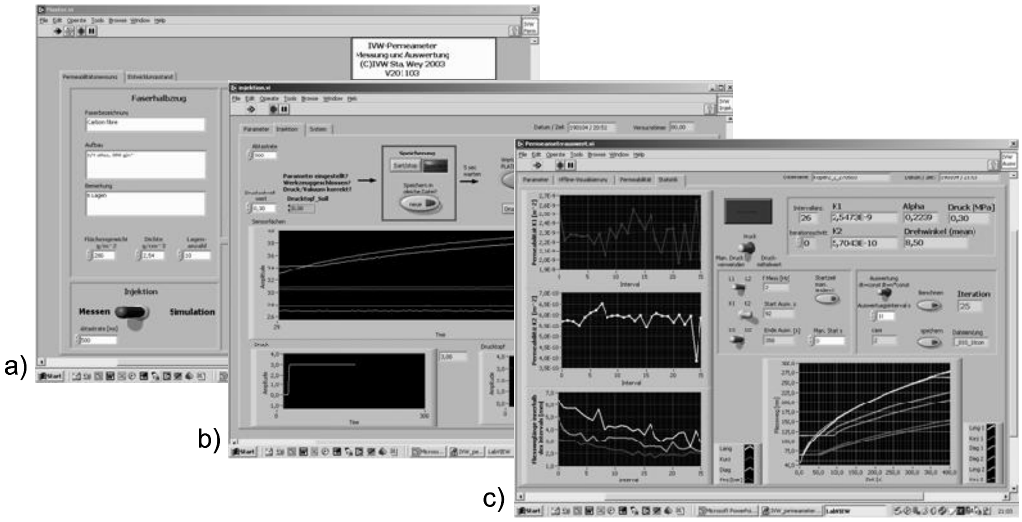

Figure 2: Front panels of permeability measurement and injection control software programmed with National Instruments LabVIEW®. a) Input of experimental parameters b) Injection control with on-line sensor output and c) Permeability evaluation front end

The actual computation of the permeability values requires to read the flow front positions of three sensors, to generate a suitable elliptical equation, to determine the respective angle of rotation, to transform the ellipse into the mold coordinate system, and finally to determine the permeability values K1 and K2 according to [8]. Since only three of the six sensors are used for a permeability evaluation, varying the sensor triplets for each calculation allows to cross-check and compare permeability values obtained for the experiment.

This feature can prevent local inconsistencies to affect one sensor, therefore, completely misleading the results of the measurement. It also allows to interpret the homogeneity of the preform under investigation.

Generally, the values determined with different sensor triplets do not differ significantly. Nevertheless, Figure 3 shows that it can be advantageous to obtain a mean value for K1 and K2 by running all possible sensor combinations.

The difference between the respective K1 and K2 values of a single experiment using different sensor triplets in Figure 3 demonstrates one shortcoming of the currently used numerical evaluation procedure. The displayed experimental result shows that generating a flow front ellipse from just three values is not enough. To address this issue, non-linear curve fitting procedures such as the Levenberg-Marquard approach are under current investigation.

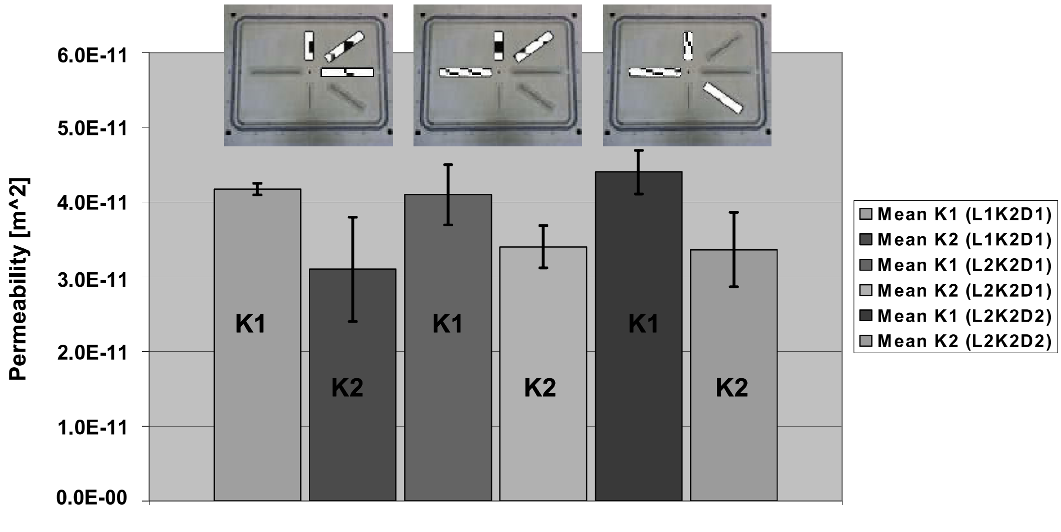

Figure 3: Example of experimentally determined 2D permeabilities using different sensor triplets of the work cell

The data file of each experiment is recorded to the hard disk of the computer, allowing to come back and repeat the permeability calculation or even to replay the actual injection of each experiment performed. Since the set-up and the evaluation of the in-plane permeability values are almost completely automated, a multitude of measurements can be performed within one day. Therefore, this work cell represents a tool to easily obtain the permeability of a preform which is to be used in mold filling simulations.

Conclusion

In this paper a new permeability work cell has been introduced. This work cell enables the determination of the permeability of electrically conductive and non-conductive reinforcing materials due to a dielectric sensor with a special surface treatment. Since the mold as well as the sensors are manufactured from aluminum, the possibility of mold deflections, which are a possible source of error, are minimized. The metal mold allows the use of any kind of curing resin system as test fluid while also providing temperature control up to 160 °C.

This measuring equipment in combination with the software developed for the process control and permeability calculation enables the time-efficient determination of the in-plane permeability values of a fibrous reinforcing structure. Shortcomings in existing evaluation routines have been detected and will be addressed by means of non-linear curve fitting routines.

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