POLYNOMIAL SURFACE MODELLING OF FLOW FRONT DATA FOR IN-PLANE PERMEABILITY CHARACTERIZATION OF TEXTILE FABRICS BY RADIAL FLOW EXPERIMENTS

E. Fauster[1*], D. C. Berg[2], D. May[3], Y. Blößl[1], R. Schledjewski[1]

[1] *Montanuniversität Leoben, Processing of Composites Group, Leoben, Austria.*
[2] *Clausthal University of Technology, Department of Polymer Materials and Plastics Engineering, Clausthal-Zellerfeld, Germany.*
[3] *Institut für Verbundwerkstoffe GmbH, Kaiserslautern, Germany*
*Corresponding author (ewald.fauster@unileoben.ac.at)

Keywords: *liquid composite moulding, in-plane permeability characterization, radial flow experiments, polynomial surface model fitting*

In-plane permeability of textile preforms is one of the most important input parameters for flow simulation in liquid composite moulding processes [1]. Characterization of in-plane permeability by radial flow experiments involves three major steps [2]: (1) tracking of the fluid flow front during the experiment by acquisition of specific sensor data, (2) geometric modelling of the flow front by processing the acquired sensor data and (3) calculation of the in-plane permeability tensor entries. The work at hand addresses the modelling of flow front data acquired during the radial flow experiments.

In a paper recently published by the authors [3] the fundamental geometric nature of the temporal flow front advancement in radial flow experiments was studied. It was shown that the well-known solution for flow in isotropic porous media [4–6]:

$$r_f^2\left(2\left(\ln r_f - \ln r_0\right) - 1\right) + r_0^2 = \frac{4k\Delta p}{\eta\epsilon} t, \quad (1)$$

which involves the radius of the injection gate r_0, the radial flow front extent r_f, fluid viscosity η, preform porosity ε and permeability k, pressure difference Δp as well as experimental time t, can be well approximated by means of a simple parabola equation. A similar finding was derived empirically for the flow in anisotropic porous media. In addition, the authors proposed to collect the entirety of flow front data points acquired during the experiment and to approximate a specific type of elliptic paraboloid model. This in turn allows for the analytic computation of the in-plane degree of anisotropy, i.e. the ratio of minor and major principal in-plane permeability values, from the ratio of two paraboloid model coefficients: $\alpha_{Par} = \frac{q_1}{q_3}$. This 'paraboloid method' significantly reduces the computational costs of the permeability calculation algorithm, as – following the original work of Adams et al. [7] – it otherwise requires a nonlinear iterative solution. Moreover, the paraboloid method adds robustness to the overall data evaluation strategy compared to the conventional 'ellipse method' [3].

In a continuation of the work described above, fitting of an even-order term fourth order polynomial surface model was studied. Compared to the elliptic paraboloid, this model allows for a higher level of fitting accuracy, particularly with respect to the flow front data acquired in the early stage of the radial flow experiment. Similar to the 'paraboloid method', the degree of in-plane anisotropy can be found analytically from a number of polynomial surface model coefficients a_k:

$$\alpha_{Poly4} = \frac{a_{1,1}}{a_{1,2}}\left(\frac{a_{2,2} + \sqrt{a_{2,2}^2 - 4a_{1,2}\left(a_{3,2}t + a_{4,2}\right)}}{a_{2,1} + \sqrt{a_{2,1}^2 - 4a_{1,1}\left(a_{3,1}t + a_{4,1}\right)}}\right). \quad (2)$$

Evaluating an sample data set from characterizing the in-plane permeability of a natural fiber woven fabric, Figure 1 shows a comparison of the degree of in-plane anisotropy calculated according to three different methods: (a) the conventional 'ellipse method', (b) the 'paraboloid method' and (c) based on the even-order term fourth order polynomial surface model. The plots reveal a high level of conformity among the results, particularly during the last stage of the experiments, which validates the applicability of the approach. The high level of variation in the data found with the 'ellipse method' in the first stage of experiment shows the sensitivity of this method to the transition of the initially circular flow front to the elliptic shape characteristic for the material under test.

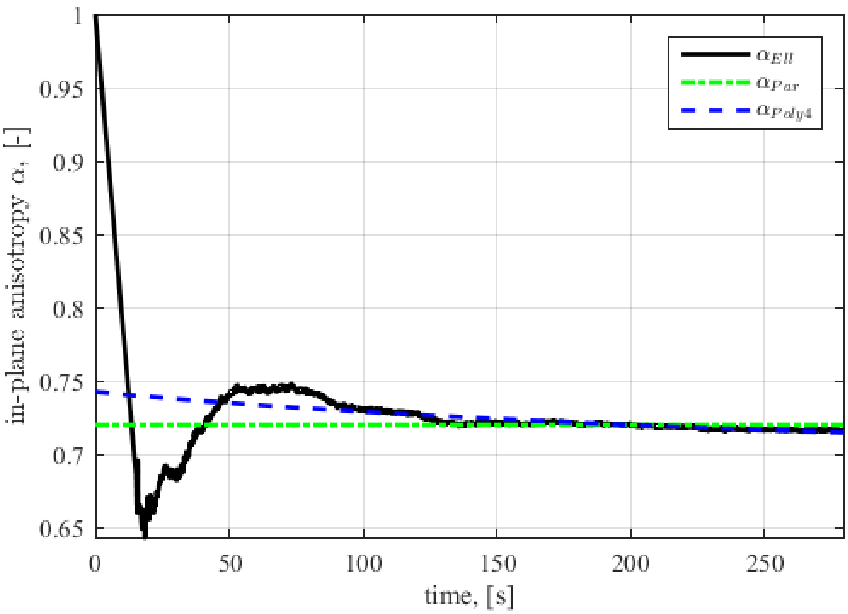

Figure 1: *Characteristics of the degree of in-plane anisotropy based on fitting elliptic geometry models (solid), an elliptic paraboloid (dash-dotted) and an even-order term fourth order polynomial surface (dashed).*

The method is universally applicable to evaluate various types of sensor data: flow arrival time data determined by means of point sensors, saturation length data from linear capacitive sensors or flow front data from optically tracked radial flow experiments.

Acknowledgements

The authors kindly acknowledge the financial support through project MoVeTech (project no. 850466) provided by the Austrian Ministry for Transport, Innovation and Technology within the frame of the FTI initiative "TakeOff", which is administered by the Austria Research Promotion Agency (FFG).

References

[1] Advani SG, Sozer EM. Process modeling in composites manufacturing. 2nd edn. Boca Raton, FL: CRC Press; 2011.

[2] Neitzel M, Mitschang P, editors. Neitzel M, Mitschang P. Handbuch Verbundwerkstoffe: Werkstoffe, Verarbeitung, Anwendung. München: Hanser; 2004.

[3] Fauster E, Berg DC, May D, et al. Robust Evaluation of Flow Front Data for In-Plane Permeability Characterization by Radial Flow Experiments. Advanced Manufacturing: Polymer & Composites Science. 2018.

[4] Carter EJ, Fell AW, Summerscales J. A simplified model to calculate the permeability tensor of an anisotropic fibre bed. Composites Manufacturing. 1995;6:228–235.

[5] Chan AW, Hwang S-T. Anisotropic in-plane permeability of fabric media. Polymer Engineering and Science. 1991;31:1233–1239.

[6] Adams KL, Miller B, Rebenfeld L. Forced in-plane flow of an epoxy resin in fibrous networks. Polymer Engineering and Science. 1986;26:1434–1441.

[7] Adams KL, Rebenfeld L. Permeability characteristics of multilayer fiber reinforcements. Part I: Experimental observations. Polymer Composites. 1991;12:179–185.