Identification of the permeability values of fibre reinforcements of composite materials by inverse methods

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English Abstract

Liquid Composite Moulding (LCM), is the state-of-the-art technology for producing textile reinforced composite parts. In LCM, liquid resin is injected into a mould holding the reinforcement material. Once this material is impregnated and the resin is cured, the finished component can be de-moulded. Virtual prototyping software has been developed to assist the engineer in correctly designing the mould. However, for accurate simulations it is absolutely necessary to have reliable input data, of which the key parameter is the permeability of the reinforcement. Measurement of the permeability is not yet standardized, and many different set-ups have been proposed. Moreover, the measurements are very sensitive to various factors and hence prone to error.

The thesis describes an inverse method for permeability identification. The proposed method is a so-called mixed numerical/experimental technique (MNET) for material property identification. The experimental part is represented by the PIERS (Permeability Identification using Electrical Resistance Sensors) 2D central injection rig. The heart of this set-up is a solidly supported steel mould that holds 120 DC-resistance based sensors. The reinforcement is placed inside the mould and is centrally injected with fluid which triggers the sensors on arrival as it propagates through the reinforcement. The numerical component of the technique involves adjusting the permeability parameters in a customized finite element model until it satisfactorily simulates the PIERS experiment.

With a single experiment, this fast and robust MNET allows to determine all components of the in-plane permeability tensor. Furthermore, since the finite element simulation accounts for the entire PIERS experiment, all sensor data can be used in the permeability calculation. In contrast, the typical analytical methods are valid only until the injected fluid reaches an edge of the reinforcement and subsequently reached sensors can not be used in the calculation. It is shown that, for reinforcements that are not approximately isotropic, the finite element simulation significantly improves the precision of the parameter identification compared to the formerly used analytical method.

The thesis also presents a textile-like solid specimen with anisotropic permeability that is produced with a stereolithography technique. It is designed as a reference for calibration and comparison of permeability measurement set-ups and for validation of numerical permeability computation software. Unlike real textiles, the permeability properties of such reference specimens do not vary from test to test. When used for benchmarking, any discrepancy between different measurements on this specimen must be attributed to the set-up and data processing.

In the final section, the reference specimen and the proposed MNET are put to the test. The first experimental measurements of the permeability of the reference specimens are presented and discussed. It is shown that an excellent repeatability of the experiments is obtained. Since the reference specimen allows isolating the variability arising from the measurement technique, a clear assessment of the MNET is obtained. Moreover, statistics from the series of measurements corroborate that the proposed FE-based method, for processing the PIERS measurement data, performs significantly better than the common analytically based method, which was used before. Finally, the experimental results are shown to be in good agreement with the values predicted using numerical permeability computation software.