# INVESTIGATING FLOW MECHANICS WITHIN A NOVEL NON-DESTRUCTIVE INJECTABILITY MEASUREMENT FOR FIBRE PREFORMS

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## Introduction

Non-destructive quality assessment of semi-finished textiles is a key objective for effective and reliable production of CFRPs. In particular, permeability and compaction response have been shown to be influential on the subsequent resin injection process [1]. In addition, permeability and compaction response are important material properties for process simulation and design [2].

The previously introduced Non-Destructive Preform Tester (NDPT) [3] detects different material features by interpreting injectability (an approximate measure of permeability) and compressibility of the tested preforms and stacks. The prototype was developed in cooperation with the BMW AG to monitor the quality of semi-finished products, and utilises radial or through-thickness air flow to detect material variation from part to part. In contrast to the commercial goal, the failure detection of stacks and preforms, this research is focused on the flow mechanics imposed by the non-destructive injectability measurement. In the initial proposed method, the textile product is compressed to a certain target thickness between two flat plates, while monitoring the required force of compaction. A transient air pressure pulse, supplied from a pressure reservoir, is then applied to determine injectability.

## Non-destructive Quality Assessment of Semi-finished Textiles

The preforming step of the RTM process is the most critical step affecting the part's quality, inducing unwanted material features due to the draping process while forming a 3D shaped preform. All process variation and material uncertainties affect the textiles stack's draping behaviour and a variety of features therefore appear during the preforming step. Most common features will influence the local areal weight leading to densifications and/or thinning. These features can interfere with the RTM filling and can result in dry spots, wash outs of single plies and fibre rearrangement. Optical detection methods cannot be applied or implemented to detect these defects.

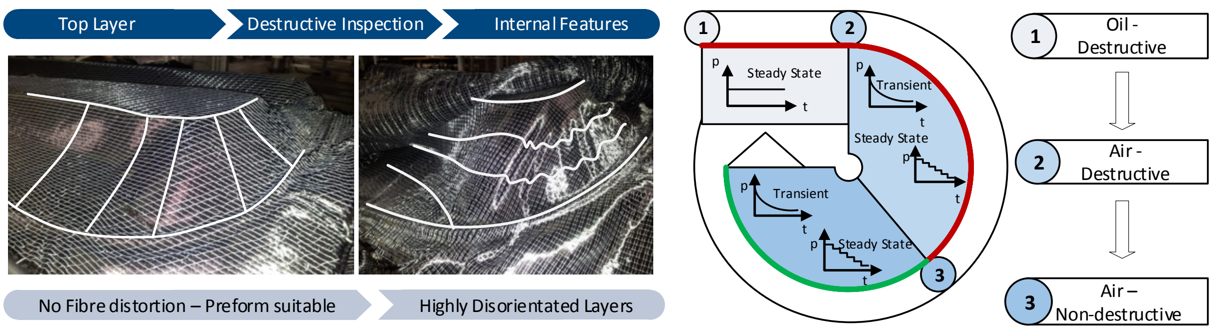


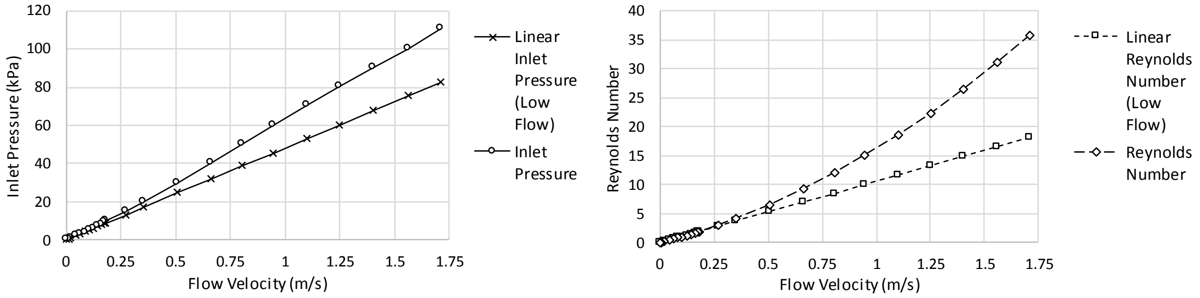

**Figure 1:** *Industrial problem and research approach*

## Methodology

This study is focussed on understanding the flow mechanics during the non-destructive quality assessment of semi-finish textiles. A comparison between analytical data and experimental results requires a classical permeability measurement with clearly defined sample borders (see Figure 1). Moreover, this assessment provides information about different flow effects appearing at certain flow regimes. Five different flow scenarios for fluid flow through porous media were compared (Darcian flow, Compressible flow, Klinkenberg flow and incompressible and compressible Forchheimer flow). Nine-layer carbon fibre non-crimp textile preforms were used as a fluid flow domain.

## Results and Conclusions

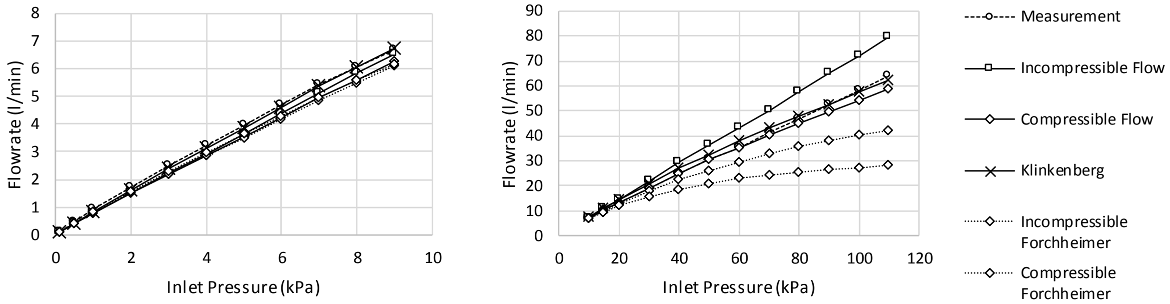
The Reynolds number and the flow velocity are useful parameters for evaluating the flow. The flow regime evolves with increasing Reynold numbers. Figure 2 illustrates the development of Reynold numbers and inlet pressures for low flow velocities for a simple 1D-flow scenario. A linear function was fitted to the experimental data, confirming expected linear behaviour between flow velocity and Reynold numbers/inlet pressures. A good correlation is obtained for Reynold numbers below 1.0, respectively flow velocities below 0.1 m/s.




(A) (B)

**Figure 2:** *Evolution of inlet pressure (A) and Reynolds number (B) with increasing velocity.*

The deviation between the linear model and the experimental data becomes significant for higher flow rates, whereas increasing inlet pressure leads to nonlinearly increasing Reynolds numbers. Darcy's law is no longer applicable, and an appropriate flow model must be assumed. In the same context it must be highlighted that a flow model should be applied within its flow regime.




(A) (B)

**Figure 3:** *Evolution of flow rates depending on various analytical models; (A) low flow, (B) high flow.*

Figure 3 presents the flow rate vs. inlet pressure evolution for the different analytical flow models. It was not possible to determine a realistic Forchheimer quadratic coefficient β for the Forchheimer flow case shown in Figure 2. The Forchheimer coefficient, which is used to describe inertia flow effects, leads to unrealistic flow rate values when calculating air permeability values. The experimental data exhibits a compressible flow. Inertia effects can be neglected within the observed flowrate. Compressible Klinkenberg flow shows the best fit compared to experimental data.

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