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Transverse impregnation of dry fabrics with thermoplastic melts

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Introduction

Lightweight design in transportation, especially in automotive industry is getting more important with the stricter regulations on CO_2 emissions of the European Union. One way for implementing this is the use of thermoset or thermoplastic composite materials. Compared to thermosets, thermoplastic matrix materials have advantages of recyclability, high fracture toughness, and offer alternative joining processes like welding. On the other hand the thermoplastic matrix materials have a higher viscosity than thermoset resins, which makes the impregnation of fabrics more difficult, especially if a high fibre volume fraction is needed.
The time t of a polymer melt to impregnate a fabric can be described by Darcy's law:

$$t = \frac{\eta L^2}{2KP}$$

where ϕ is the porosity, η is the viscosity, L is the impregnation length, K is the permeability and P is the applied pressure. Whereas the porosity is given by the fibre volume fraction and the impregnation length by the mould geometry, the impregnation time can be either reduced by reducing the viscosity, which is dependent on temperature and shear rate or by increasing the pressure. However, increasing the pressure may also lead to additional compaction of the fabric and hence to a reduced permeability.

Polymer viscosity

The matrix material used in this study was the low viscosity polypropylene (PP) copolymer BJ100HP (Borealis). The viscosity data for a low viscosity PP depending on the shear rate for 200 and 260 °C was measured.
The typical shear rate for impregnation processes is around 1/s , so that that the viscosity is 193 Pas (200 °C) and 84 Pas (280 °C).

Fabric compaction

Two carbon fibre fabrics were used: 200 g/m² (3K tows) and 400 g/m² (12K tows). The fabric compaction was measured on an mechanical testing machine and the compaction curves are described with a hyperbolic tangent fit showed in Fig. 1 and 2.

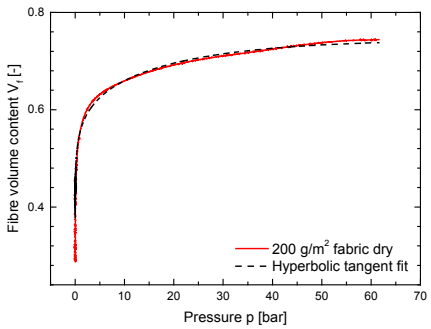

Fig. 1: Compaction curve of the 200 g/m² fabric

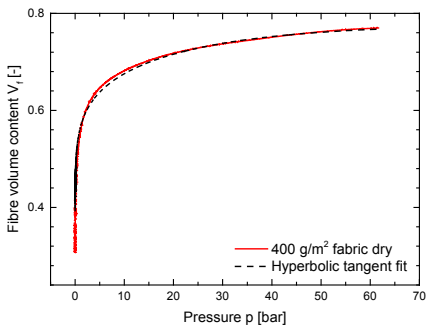

Fig. 2: Compaction curve of the 400 g/m² fabric

Fabric permeability

The transverse permeability was measured with silicon oil (η: 0.1 Pas) as reference fluid by recording the pressure difference and the volumetric flow across a fabric stack with defined fibre volume content. The data was fit with the Kozeny-Carman model, shown in Fig. 3 and 4.

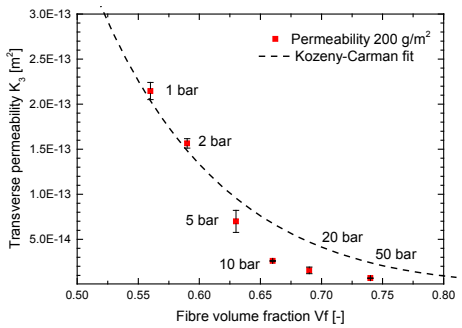

Fig. 3: Permeability curve of the 200 g/m² fabric

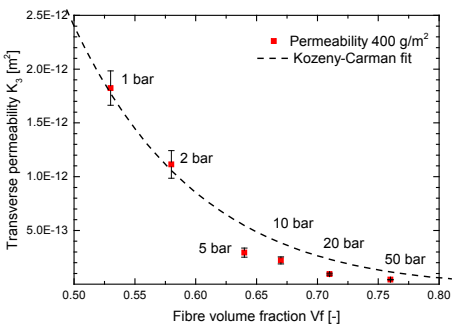

Fig. 2: Permeability curve of the 400 g/m² fabric

CRTM Simulation for thermoplastic impregnation: 400 g/m2 fabric

With the determined input parameters of the matrix viscosity, the fabric compaction behavior and the fabric permeability, a transverse impregnation was simulated to determine the influence of the process parameters viscosity and pressure. Fig. 5 shows the evaluation of the flow front, the top mould and the preform top over time, and in Fig. 6 different viscosities and pressures are compared, showing that an impregnation within a few seconds should be possible.

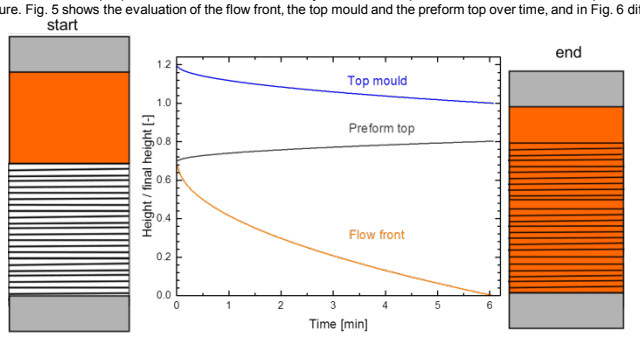

Fig. 5: Evolution of impregnation with 400 g/m² fabric , *Fibre*

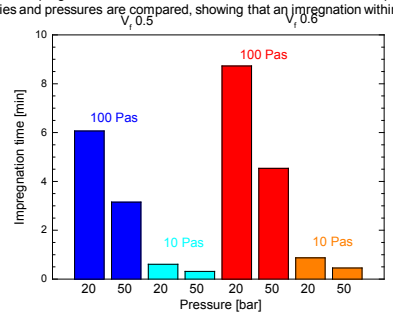

Fig. 6: Influence of pressure and viscosity on impregnation time of a 400 g/m² fabric

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