Kurzfassung

Das Ziel dieser Arbeit war, den Einfluss der textilen Parameter von Multifilamentgeweben auf die Permeabilität zu bestimmen. Einer sehr umfangreichen Permeabilitätsstudie wurden grundsätzliche Untersuchungen vorangestellt, die beantworten, mit welchen Einschränkungen textile Modelle und Kapillarmodelle zur Berechnung der Permeabilität eingesetzt werden können, worin sich Permeabilitätsmessergebnisse ermittelt über Punkt- und Linienanguss sowie gesättigte und ungesättigte Permeabilitätsmessungen unterscheiden und ob die Lagenanzahl einen Einfluss auf die Permeabilität eines Laminataufbaus hat. In der Hauptstudie wurden die Ebenenpermeabilitäten K1 und K2 von 19 Geweben auf einer Messzelle bestehend aus einem 160 mm dicken Ober- und Unterwerkzeug aus Aluminium mit integrierten Sensoren ermittelt. Festgestellt wurde, dass Leinwandgewebe eine höhere K2-Permeabilität als Köpergewebe und ein isotroperes Fließverhalten haben. Es wurde ermittelt, dass je höher das Produkt aus Fadendichte und Titer, desto größer ist der negative Gradient der Permeabilitäts-Faservolumengehaltskurve. Vier sehr dichte Gewebe dieser Studie zeigen zudem die Besonderheit, dass die Richtung der K1-Permeabilität nicht mit der Kettrichtung des Gewebes übereinstimmt. Der abweichende Orientierungswinkel ist faservolumengehaltsabhängig und nähert sich stets 0° bei Faservolumengehalten von über 55 %. Es wird des Weiteren erklärt, warum Gewebe, die in Kett- und Schussrichtung gleich aufgebaut sind, ein anisotropes Fließverhalten zeigen. Dieser Effekt kann mit der Kettfadenspannung bei der Gewebeherstellung erklärt werden und über die Messung des Crimps ermittelt werden. Wurde eine große Differenz im Crimp zwischen dem Kett- und Schussgarn gemessen, war auch die Anisotropie höher. Neben der Kettfadenspannung bei der Herstellung wurden über ein D-optimal Screening der Titer und die Fadendichte als signifikante Einflussfaktoren auf den Crimp ermittelt.

Die Ergebnisse dieser Studie ermöglichen die Auswahl und das spezifische Design von Verstärkungstextilien mit bestimmten Imprägnier- und Permeabilitätseigenschaften.

Abstract

For the manufacturing of continuous fiber reinforced composites the textiles have to be impregnated with polymer matrix. The resistance of the textiles to the impregnation process is determined by the permeability. Knowledge about the permeability enables the design of a fast and reliable process by allowing the prediction of the flow directions, velocities and pressures.

There is very little stringently certain and generally valid information available about the influence of textile parameters on permeability. Existing capillary and textile models are not yet capable of simulating these effects. By using high resolution µCT pictures of GFRPC laminates with three different fiber volume fractions, a decrease of the yarn cross sectional height with increasing fiber volume fraction was determined. Furthermore, an increase in the undulation angle of the weft and warp yarn with increasing fiber volume fraction due to nesting has been measured. Both effects are not yet taken into account in existing textile models. Capillary models are only capable of describing the fluid flow inside a yarn or in the cross direction of the yarn. For these two cases, the decrease in permeability with increasing fiber volume fraction is the same. The range of the permeability versus fiber volume fraction curves of complex shaped woven textiles or non-crimp fabrics is wide and can therefore not be described by the Kozeny-Carman capillary model.

In the empirical part of this study, 19 woven glass fiber textiles covering a specific variety of weaving type, linear density, yarn density and crimp were selected in order to determine their effects on in-plane permeability. The additional influencing parameters, namely finish and filament diameter have been left constant.

The measurements have been conducted on a stiff two-sided aluminium tool with eight linear capacitive sensors. Using a point injection, the major and minor in-plane permeability values, K1 and K2, were determined. Differences between the unsaturated measurement and the saturated measurement only result due to the capillary effect. The capillary effect only takes place inside the yarn. A formula to calculate the matrix volume inside the yarn by knowing the overall fiber volume fraction and the fiber volume fraction inside the yarn is presented. The matrix volume inside the yarn is only about 20 % - 30 % of the overall matrix volume for conventional textiles. Experimentally measured capillary pressures inside the yarn presented in the literature range from 0,06 bar to 0,6 bar. Therefore, capillary pressures can be neglected in the RTM process and for in-plane permeability measurements if higher injection pressures are chosen.

Before the experimental study with 19 woven textiles was conducted, a study investigating the effect of the number of layers on the permeability was carried out. Tests using between 5 and 21 layers measured at 4 different cavity heights ranging from 1.95 mm to 6 mm showed no significant differences in the determined K1 or K2 permeability values.

It was possible to explain the anisotropic flow behaviour of isotropically built up textiles using the crimp present in the weft and warp yarns. It was observed that a higher difference between the crimp in the weft and warp yarns gave a higher difference between the K1 and K2 permeability values. Different levels of crimp in the weft and warp direction originate from high warp yarn tensions during the production of a woven textile in addition to the weave geometry. A pattern was found to divide textiles into dense and open weave textiles. A generally valid relationship was found between the denseness of a textile and the slope of the permeability-fiber volume fraction line. The higher the product of the linear density of the yarns and the yarn density (picks/cm) of the woven textile, the higher the permeability at lower fiber volume fractions and the lower the permeability at higher fiber volume fractions. Furthermore, it was determined that in very dense woven textiles the direction of the highest permeability is not in line with the warp direction. This was the case for all three 8-harness satin and for one twill weave textile. In a comparison of three identically built up twill and satin weave textiles, it was found that the K2 permeability of twill weave textiles is significantly lower, meaning that twill weave textiles are more anisotropic.

Furthermore, the influence of the injection pressure on the impregnation quality is described. High impregnation pressures lead to a faster flow front advancement between the yarns than inside the yarns. This results in air entrapment. Air entrapment can be addressed by high dwell pressures at the end of the injection.

The results of this study allow the selection and tailoring of woven textiles with specific properties, for example very low or isotropic, permeabilities.