INCREASING PERMEABILITY OF DRY-FIBER-PLACED PREFORMS

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Introduction

Dry-fiber placement (DFP) combines very high lay-up rates with little scrap and high mechanical performance. However, the highly aligned, unidirectional fibers and the presence of binder lead to a low permeability of such preforms. In order to fully exploit the potential of DFP, permeability must be increased to enable rapid resin injection and curing. In this study three different concepts to increase permeability were tested and compared. The strategies tested were intentionally placing gaps between the tracks, tailoring the binder material to act as flow promoter and the integration of special flow promoters such as polymer filaments and nonwovens.

Methods

Six configurations with intentionally placed gaps were produced. Three different patterns of distributing the gaps were used. Gaps where 2mm respectively 4mm wide. The nominal areal weight was kept constant.

Binder influence was studied with 16 configurations, altering spray pattern (omega / random), activation temperature (110°C / 145°C), activation time (60s / 120s) and binder areal weight (5g/m² / 15g/m²).

12 unique configurations with added flow promoters where tested. One consisted of an 8g/m² polyester nonwoven from TFP Ltd., UK. The others employed different polymer filaments (PET monofilament: 0,1mm, 0,15mm, 2x0,1mm twisted; PET multifilament: Taslan & Serafil; multifilament bonding yarn C-140 from EMS Griltech) placed between layers in varying stacking/spacing sequences and angles between 0° and 90° relative to the fiber direction.

All specimen, including the reference samples, where cut from unidirectional material manufactured on Compositence GmbH dry fiber placement systems directly from Toray T620SC 24k carbon fiber roving. On top of each layer, binder (Epikote Resin 05390 from Hexion Inc.) was applied with an ITW Dynamelt SR05 system (with exemption of the specimen with EMS bonding yarn). Additional flow promoting materials were added manually between the layers. Stacks were consolidated in a hot press with displacement control.

Permeability was measured using the 1d in-plane as well as the 1d out-of-plane facilities described in [1]. A Newtonian fluid, sunflower oil possessing a viscosity of ~ 70 mPas @ 20°C was used as measuring fluid. Rectilinear flow experiments were employed. In-plane permeability was measured in unsaturated state using automated optical flow front detection as well as in saturated state. Through-thickness experiments were conducted in saturated state only.

Results

Specimen of all three studies showed large variance of permeability. Specimen with intentionally placed gaps showed no significant increase over the reference specimen. Average unsaturated K_x of the reference was 5,92E-12 m². Average K_x for the tested configurations of gaps was between 4,87E-12 and 9,23E-12 m².

Average K_x of specimen with different binder configurations was between 2,61E-12 and 6,88E-12 m² for the different configurations. Although none of the variables showed a significant effect it seems that random binder spray pattern is advantageous for in-plane permeability.

Specimen with different interlaminar flow promoters exhibited average K_x between 1,04E-11 and 5,20E-11 m². The reference average was 7,21E-12 m². No definite effect of the variables was observable but +/- bias filaments in one layer and larger filaments may increase K_x.

K_y could only be measured for the specimen with interlaminar flow promoter. For the reference and other flow promoters the experiments were hampered by race-tracking and fiber washing.

However the K_y of the reference is certainly lower that 5E-13 m². For interlaminar flow promoters the average K_y was between 2,28E-12 and 1,06E-10 m² depending on configuration. The filaments open a fish eye shaped flow channel between the plies while the veil forms planar flow areas (see Figure 1, left). Large diameter fish eyes and flow channels close to the 90° direction increase K_y. Filament flow promoters in 0° direction show a different characteristic as they nest with the tows and have no effect on K_y (see Figure 1, right).

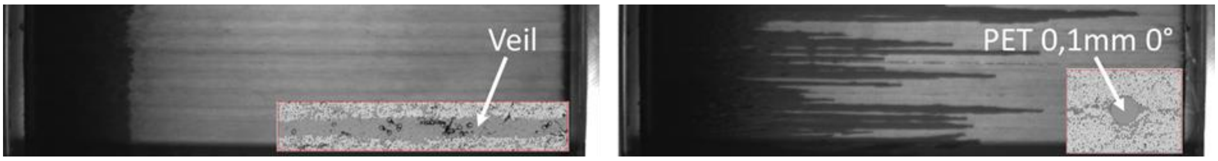

Figure 1: *0° permeability experiments 60 sec. after start with micrograph of configuration. On the left a veil is used as an interlaminar flow promoter, leading to a smooth flow front. The 0° oriented filaments used on the right nest with the laminate. They act similar to gaps and the frayed character of the flow front is indistinguishable from the reference.*

A further effect observed during K_x experiments was the smoothing of the flow front by the interlaminar flow promoters other than 0° oriented filaments (see Figure 1). To quantify the “fraying” of the flow front, the total length of the flow front was divided by the width of the specimen. For K_y experiments the average of this value was generally close to 1, for K_x it varied between 4,7 and 12,6 for the specimen with optimized binder and 1,2 and 3,7 for the interlaminar flow promoters with orientation other than 0°. For 0° oriented filaments the average value was 9,3.

K_z was measured for the interlaminar flow promoters only. No positive effect was observed.

Discussion

The large variance in the tested preforms combined with the small amount of repeats made the interpretation of results challenging. The DFP machines used to produce the preforms were prototypes. The specimen showed a large variability in fiber distribution, especially concerning gaps between the tows. This is due to the process placing tows that have not been stabilized in any way, and are only fixated on the substrate at beginning and end of the tracks. This led to the observed high variance in permeability both between specimens as well as locally within individual specimen. It must also be noted that all specimen were unidirectional. It is unknown how the results translate to multidirectional laminates. While placing gaps or tailoring binder might have a positive influence on DFP preform permeability [2] [3], no effect of these methods could be proven during this study. The placement of flow promoting materials between plies was shown to be effective mainly in K_y as well as in attenuating the effect of unintentional gaps on K_x thus decreasing race-tracking within the preform (observed as fraying of the flow front). No positive effect of the interlaminar flow promoters on K_z could be observed. Other studies have shown that tufting [4] (which forms fish eyes in the off-plane direction similar in shape to those formed in-plane by the filaments in this study) as well as gaps in a multiaxial layup [2] are effective in increasing K_z.

Conclusion

Variance in the results made definite findings difficult. The most promising approach to increase permeability was found to be tightly spaced flow channels generated by placing polymer yarns as linear flow promoters between plies. This significantly increases in-plane permeability while maintaining a relatively uniform flow front in a preform afflicted with gaps.

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