STITCHING PREFORMS MANUFACTURED BY DRY FIBER PLACEMENT TO OPTIMIZE PERMEABILITY – AN EXPERIMENTAL EVALUATION

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Introduction

Dry Fiber Placement (DFP) enables the manufacturing of preforms with load-related fiber orientation at a minimum of production scrap. Nevertheless, permeability of these preforms is by far smaller than for textile semi-finished products such as fabrics [1, 2]. A previous study conducted by the authors [2, 3] showed that insertion of macro flow channels by stitching of the preform led to an increase of permeability of about two decades.

The present study deals with the influence of a stitching step on out-of-plane permeability (K3) of DFP preforms as well as mechanical properties of the finished laminate depending on a variety of sewing parameters. In total, 6 parameters shown in Table 1 have been examined and out-of-plane permeability has been measured using a saturated principle [4]. A full complete factorial experiment would require $2^6 = 64$ single measurements. This test plan has been reduced to a resolution of VI with $2^{6-1} = 32$ single measurements. Hence, main effects are only confounded with five-factor interactions and two-factor interactions are only confounded with four-factor interactions. Thus, main factors and two-factor interactions can be clearly determined. Following the design of experiments theory [5], the effect of the factors can be calculated by subtracting the mean values of the different steps. The calculated effects are shown in Table 1. When calculating the confidence interval, true and random effects can be distinguished. True effects are provable within the considered parameter range while random effects are unverifiable.

In Figure 1, it can be seen that the most significant effect on K3 was the stitch density (resulting from stitch distance and seam distance). With an increase of the stitch density from 0.22/cm² to 4/cm², permeability increased by about factor 15. While also denier influenced permeability significantly, variation of thread tension and seam displacement had only negligible effects. For the layup, it can be stated, that alternating layers reduced out-of-plane permeability compared to pure UD layup. This can be explained by the resulting stitch channels which have an almond-like shape with the longer axis in direction of the fibers. For alternating layers, only the middle section of these stitch channels overlaps, thus the active area for through-thickness flow of the flow channels is reduced.

For mechanical properties of the laminate, it can be stated that the presence of stitching channels in thickness direction leads to a minor decrease of tensile in-plane properties (Figure 2) while reducing bending properties significantly (up to 30%). It can be assumed that the presence of stitches generally leads to a weak point inside the material. The tested samples show compression failure at the stitching seams which is an indication for this assumption. Due to the presence of the upper thread connecting the single stitches, the fiber bundles are locally pressed down during resin injection leading to waviness in thickness-direction that could lead to a local weak point as well.

All in all, stitching is a promising measure to enhance the permeability and thus impregnability of DFP preforms to a level comparable to conventional textile semi-finished materials. Mechanical properties are decreased up to a certain degree in the present tests, but this might be inevitable to reach a proper impregnability for fast and reliable processes.

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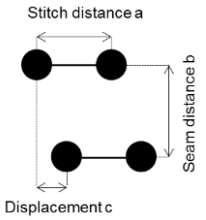
Table 1: *Factors for comparison of sewing parameters*

Factor	Name	Steps	
		-1	1
A	Thread tension	Increased	Normal
B	Denier	80 tex	40 tex
C	Stitch distance a	5 mm	15mm
D	Seam distance b	a	2a
E	Displacement c	0	0.5a
F	Layup	$[0]_8$	$[0/90]_4$



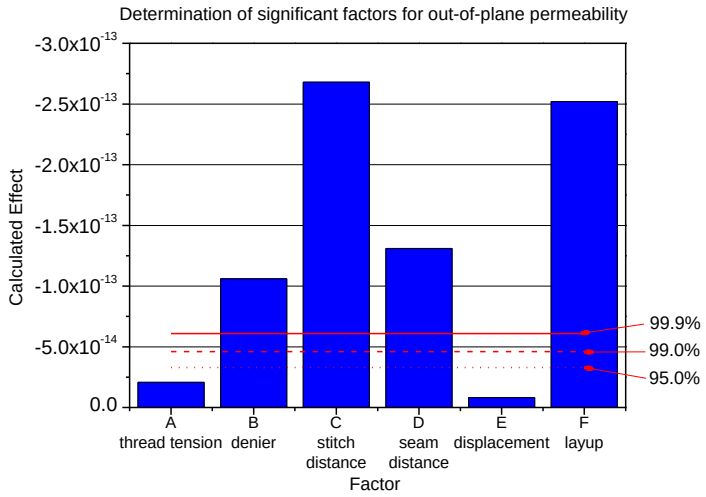


Figure 1: *True effects above confidence interval and random effects below confidence interval for out-of-plane permeability measurement – stitch and seam distance as well as denier and layup are dominant effects, while thread tension and displacement have no clear influence*

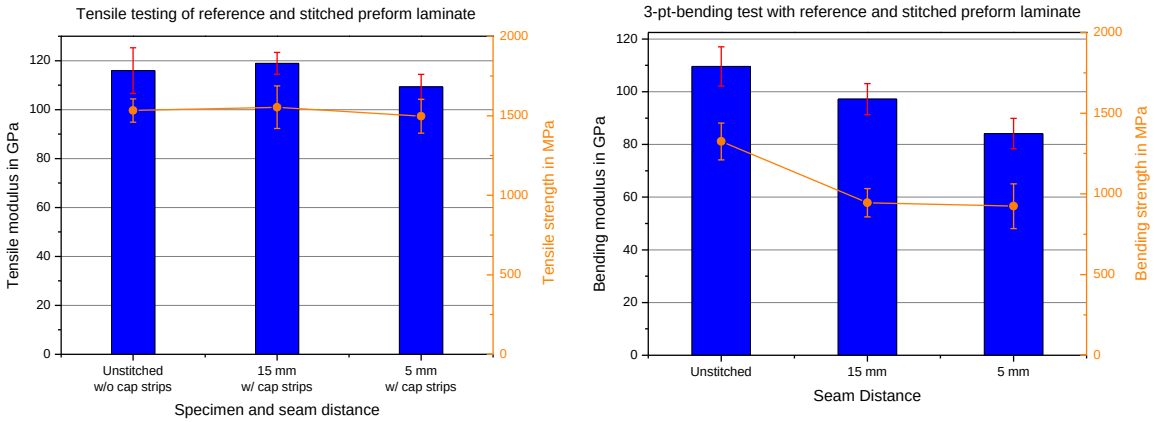


Figure 2: *Results of tensile tests and 3-pt-bending tests for laminate made of unstitched preforms and preforms with 15 mm and 5 mm seam distance*

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