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INFLUENCE OF STITCHING SEAMS ON TWO-DIMENSIONAL PERMEABILITY

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ABSTRACT: Textile preforming is the stitching, cutting, and assembling of reinforcement textiles to enhance mechanical properties or optimize the RTM-tool loading. The stitching of the reinforcing textile has direct influence on the permeability of the preform. In this paper the influence on permeability of two different stitching patterns with 5 different seam distances is described. The two-dimensional permeability has been determined continuously in a matched metal tool incorporating capacitive sensors. Beforehand the glass twill weave textile has been thoroughly evaluated to determine the permeability behavior of the textile without stitching in dependence on the fiber volume fraction and the cavity height. The paper will reveal the significant influence of the stitching seam distance and the stitching pattern on the permeability values K1 and K2, the orientation angle of the flow front ellipse, and the anisotropy of the preform for two different fiber volume contents.

KEYWORDS: permeability, Resin Transfer Molding (RTM), preforming, stitching

INTRODUCTION

Stitching has been used to enhance the mechanical through-the-thickness properties of a laminate (e.g., the impact or delaminating behavior). Nowadays stitching is also used to improve the process ability, handling, and the tool loading by building up more complex net shape textile geometries. It reduces manual work and therefore cuts liquid composite molding (LCM)-cycle times and costs [1, 2]. The influence of the stitching process [1-4] and the thread behavior on the mechanical characteristics [5, 6] of laminates are widely examined. Only relatively few research works were published concerning the processability of stitched preforms [7-9]. This investigation revealed significant influences of the stitching seam on the permeability. Not described is the relevance of the seam distances and the stitching pattern. To be able to judge the influence of the stitching on the flow behavior of the injection fluid, the glass fiber twill weave textile is thoroughly evaluated beforehand. The material has been measured at 4 cavity heights at three V_f each to determine the exact dependence of the permeability on the cavity height and the V_f. The stitching thread selection and the selection of the stitching parameters have been carried out in accordance with [1] and [3]. This study examines the effects of different seam distances of a diagonal stitching pattern (+45°) and a stitching grid (+/-45°) on the permeability values K_1, K_2, the anisotropy α, and the ellipse orientation angle β at a V_f of 51.5 % and 55 %.

METHODS

The permeability measurement cell consists of 8 capacitive lineal sensors integrated in stellar arrangement around a central injection port into a matched metal tool [10]. The thickness of the aluminum tool is 160 mm on each side to guarantee a deflection-free measurement. Direct conclusions can be drawn from the output signal of the sensors to the position of the flow front as there is a linear relation between the (by injection-fluid) covered sensor area and the measured capacity values [11, 10]. The flow front values are averaged and an ellipse is calculated on top of these data. The permeability algorithm is based on the one developed by Adams and Rebenfeld [12, 13]. The operation and data acquisition is executed with LabView.

MATERIAL

The measurements have been conducted with seven and ten layers of a glass fiber twill weave textile (390 g/m²) from Schlösser & Cramer (art. no. 3106) equipped with a finish for epoxy resin (K 506). The textile is built up quite balanced: the linear density in weft direction is 272 tex and there are 6.7 yarns (picks) per cm, the linear density in warp direction is 68 tex x 5 t0 (multiple wound yarn) with 6.0 yarns (picks) per cm. A thoroughly evaluation of the twill weave textile (no stitching) showed the expected dependency of the V_f on the permeability (Fig. 1). The measurements have been conducted with ten layers at a cavity height of 3 mm to achieve a V_f of 51.5 %, and with seven textile layers at a cavity height of 2 mm to achieve V_f of 54.9 %.

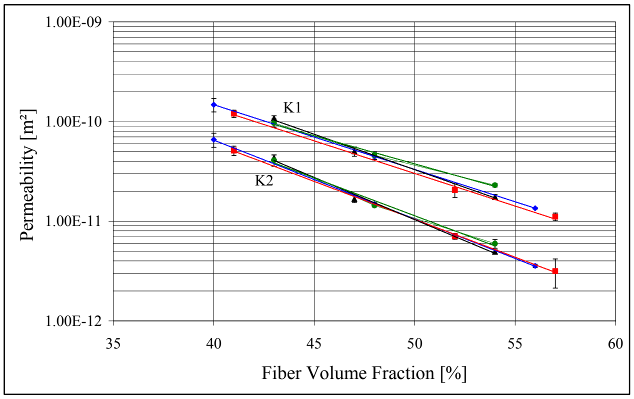

Fig. 1 Permeability data K1 (upper lines) and K2 (lower lines) plotted against the V_f. Four cavity heights (1.95 mm, 2.97 mm, 3.95 mm, 6.00 mm) are displayed.

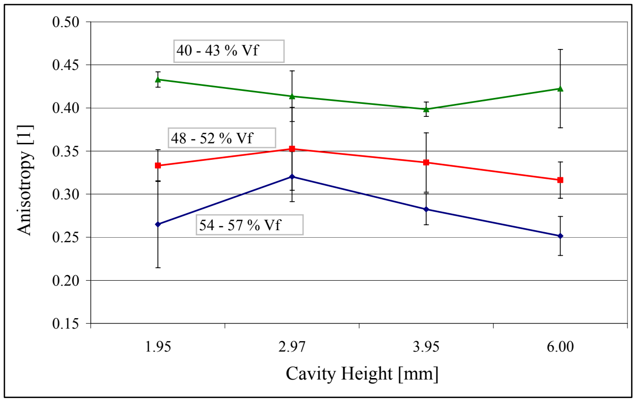

Fig. 2 Anisotropy (K1/K2) of three V_f plotted against four cavity heights.

As the measurements are conducted at two different cavity heights it had to be determined, how the permeability is influenced by the cavity height. The cavity height has no influence on the permeability. Interestingly a dependency of the anisotropy on V_f has been observed (Fig. 2). The stitching yarn is a polyester core spun yarn with a linear density of 225 dtex x 3. (A core spun yarn has a core made of numerous multi-filaments with cut staple spun around.)

STITCHING PROCESS

An overall of eight stitching patterns has been applied on ten and seven twill weave layers with a modified double lock stitch. Ten layers have been measured at a cavity height of 3 mm resulting in a V_f of 51.5 %. Seven layers have been measured at a cavity height of 2 mm resulting in V_f of 54.9 %. The stitching is done in +45° and in +/-45° on a double lock stitching machine (Pfaff Industrie Maschinen AG, Kaiserslautern: class 918). This is a typical assembling seam pattern as warp- and weft-crossing-points are fixed hereby. Three measurements per preform version have been performed. The stitching yarn tension was always 45 cN for the needle thread and 110 cN for the bobbin thread. With these tensions no resin rich areas are created in the area of the stitching hole. This has been revealed by cut polished images. Table 1 shows an overview of the different stitching patterns that have been applied on the ten and seven twill weave layers.

Table 1 Overview of the preforms prepared for permeability measurements: one preform as a reference without stitching, five preforms with a diagonal stitching pattern and three preforms with a stitching grid.

Version no.	1	2	3	4	5	6	7	8	9
Stitching pattern [°]	without stitching	-45°	-45°	-45°	-45°	-45°	+/-45°	+/-45°	+/-45°
Seam distance [mm]		7.5	10	12	15	20	7.5	15	20

The stitching seams take up a volume in the laminate of 0.2 %, for the diagonal stitching pattern with a stitching seam distance of 20 mm and a volume of 1.6 % for the grid pattern with a stitching seam distance of 7.5 mm. Fig. 3 shows the two stitching patterns. The 12 mm diameter die cutted hole in the middle guarantees a pure 2D impregnation.

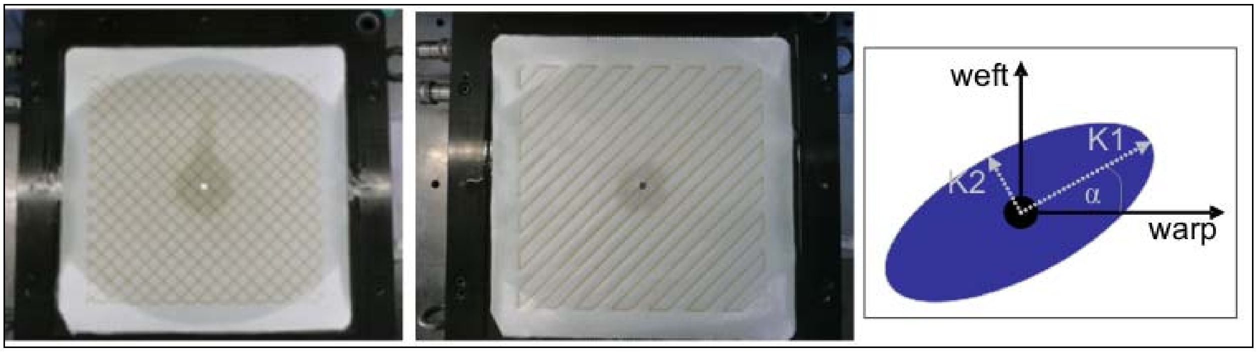

Fig. 3 Preforms, after permeability measurement. Left: stitching grid (+/- 45°); Middle: diagonal stitching pattern (+ 45°); Right: description of K1, K2, and the orientation of the flow front ellipse.

RESULTS

Stiching pattern + 45°

In the following K1 is displaying the first main axis (longer axis) of the flow front ellipse and K2 the second main axis of the ellipse. α is displaying the anisotropy, i.e. the relation between K2/K1, β is displaying the angle of orientation of the ellipse against the textile warp direction.In the following diagram the permeability measurement results (K1 and K2) are displayed for each stitching seam distance.

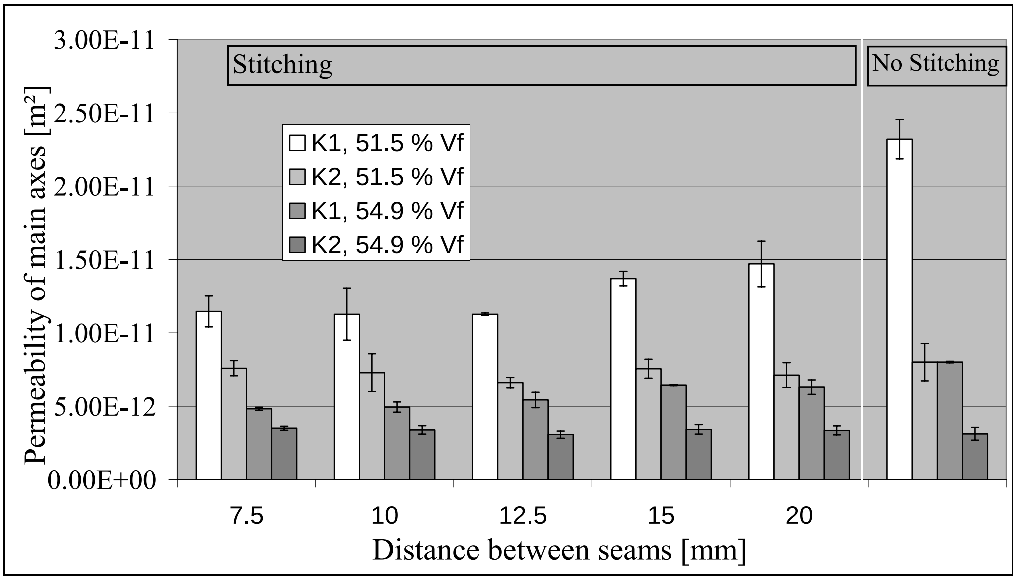

Fig. 4 Permeability data K1 and K2 plotted against the stitching seam distance of the + 45° stitching pattern for both V_f.

At 51.5 % V_f, K1, with a stitching seam distance of 7.5 mm, shows only half the permeability compared to the unstitched textile. No difference has been measured for K1 between a stitching seam distance of 7.5 mm, 10 mm, and 12.5 mm. From 15 mm to 20 mm K1 is increasing. This is the same for the V_f of 54.9 %. No trend can be observed for K2 (at both 51.5 % and 54.9 %). K2 seems to be unaffected by the stitching.

The influence of the stitching seam distance on the orientation angle of the flow front ellipse is pronounced (Fig. 5). The orientation of the flow front ellipse for the textile without stitching is in the direction of the weft yarn, about 0°. With a decreasing stitching seam distance the ellipse is guided more and more in the direction of the stitching seam.

At the higher V_f, differences in the orientation angle are less pronounced compared the orientation at only 51.5 % V_f. Even at a very close stitching seam distance of only 7.5 mm the orientation of the main axis of the ellipse is only 20° (the orientation of the stitching seam has been 45°).

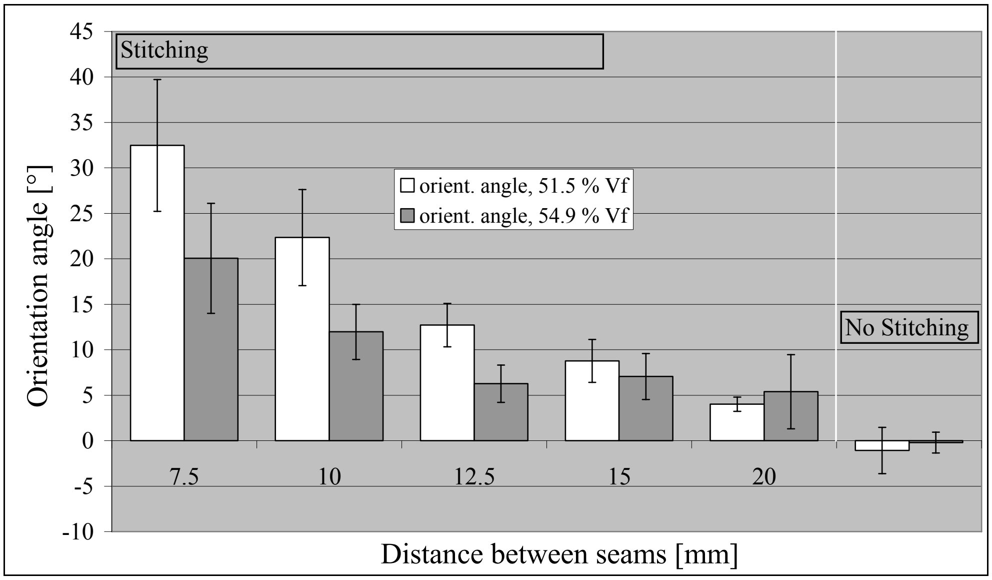

Fig. 5 Orientation angle plotted against the stitching seam distance of the + 45° stitching pattern for 51.5 % V_f and 54.9 %V_f.

Stiching pattern +/- 45° (stitching grid)

K1 is increasing as the stitching distance increases, nevertheless the reference textile has the lowest K2 value. At 51.5 % V_f and 54.9 %, K1 increases with increasing stitching seam distance (Fig. 6). At 51.5 % V_f K2 seems to be unaffected at all three stitching patterns and the reference (without stitching). At 54.9 %, K2 decreases as the stitching seams become wider.

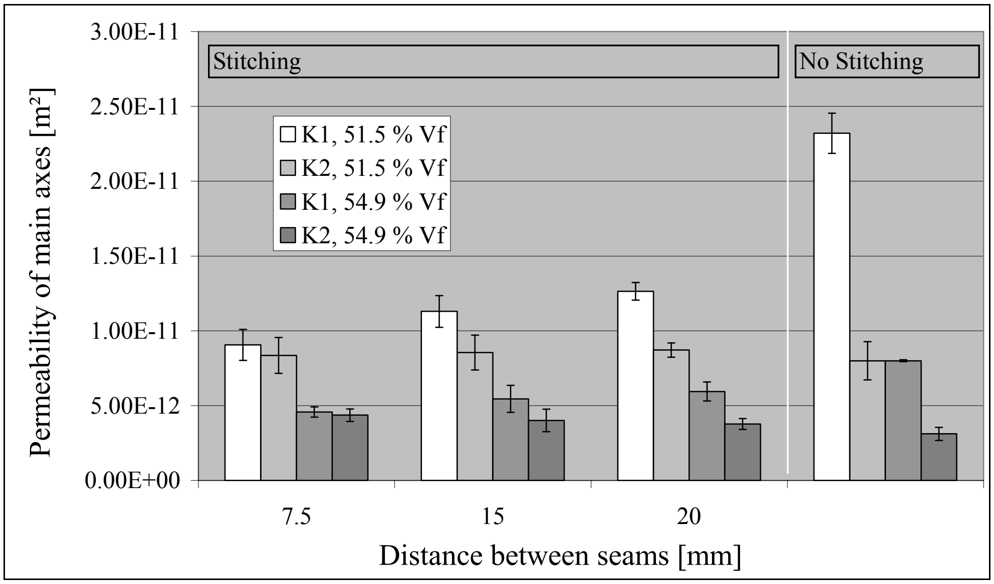

Fig. 6 Permeability of K1 and K2 plotted versus the stitching seam distance of the +/- 45° stitching pattern for a V_f of 51.5 % and 54.9 %.

The +/- 45° stitching pattern leads to an increase of K1 and a decrease of K2. This is highlighted by a plot of anisotropy versus stitching seam distance (Fig. 7). The flow front shape becomes a circle as the seam distances are getting smaller.

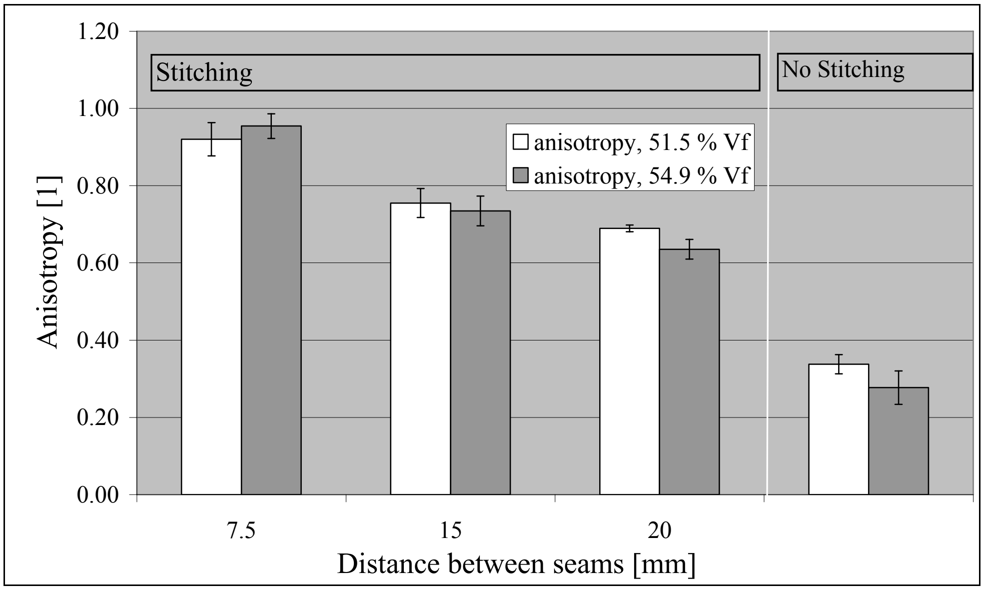

Fig. 7 Anisotropy plotted versus the stitching seam distance of the +/- 45° stitching pattern for a V_f of 51.5 % and 54.9 %.

The permeability in the direction of the first main axis, K1, is slightly lower (10 to 20 %) in the case of a +/- 45° stitching pattern compared to the + 45° versions for both V_f at the accordant seam distance. K2 in turn is slightly bigger (10 to 20 %) when a stitching grid has been applied in comparison to the grid version at 54.9 % V_f (Fig. 6).

DISCUSSION

For a seam distance of 7.5 mm (Fig. 4) the global permeability (sqrt (K1xK2)) is reduced by 24 % by the insertion of the stitching yarn in comparison to the unstitched fabric. This can not be explained with the increasing V_f due to the stitching yarn. The increase in V_f is only 0.8 %, 0.24 % respectively for a stitching seam distance of 20 mm. The stitching seams can be regarded as obstacles that are hard to cross and redirect the injection fluid. When Fig. 4 and Fig. 6 are compared, it can be seen, that for both stitching pattern +45° and +/-45° the preforms show more isotropic behavior with decreasing seam distances. This behavior is more pronounced for the grid pattern than for the diagonal pattern. Even though the direction of K2 is changing up to 32° the permeability value K2 stays constant for the diagonal and grid stitching pattern over all seam distances.

CONCLUSION

The resin flow in LCM processes is highly affected by stitching seams. The ellipse orientation as well as the shape is influenced. Using only one stitching direction (+45°) the ellipse orientation is mainly affected. The closer parallel stitching lines are the stronger the influence on the turning of the ellipse's longer axis towards the stitching direction. By using an orthotropic stitching (+/-45°) a nearly circular flow is achieved at close seam distances.

The ellipse orientation angle changes are more pronounced at the lower V_f (51.5 %). There is a trend that changes of the anisotropy are more pronounced at the higher V_f (54.9 %).The relative influence of the stitching on the overall permeability is about the same for both V_f. The effects of stitching on permeability are summarized in Table 2.

Table 2 Overview on the effects of stitching on permeability

Stitching pattern; V_f	Global permeability (sqrt(K1xK2))	Anisotropy	Orientation angle	K1	K2
+45°; 51.5 % Vf	lower than the unstitched reference textile; no influence of the seam distance observed	increases with decreasing distance between seams	flow front ellipse is redirected from 0° (no stitching) up to 32° at a stitching seam distance of 7.5 mm	increases with increasing distance between seams	no effect or tendency observed
+45°; 55 % Vf	basically lower than the unstitched reference textile; influence of seam distance undetermined	increases with decreasing distance between seams	flow front ellipse is redirected from 0° (no stitching) up to 24° at a stitching seam distance of 7.5 mm	increases with increasing distance between seams	no effect or tendency observed
+/-45°; 51.5 % Vf	tendency to increase with decreasing distance between seams	increases with decreasing distance between seams	no effect observed	increases with increasing distance between seams	no effect or tendency observed
+/-45°; 55 % Vf	tendency to increase with decreasing distance between seams	increases with decreasing distance between seams	no effect observed	increases with increasing distance between seams	decreases with decreasing distance between seams

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