Measuring the Permeability of Preform Packages

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SUMMARY: To obtain useful flow simulations to support mold design, it is necessary to use accurate permeability values. In the work described here, the permeability of carbon fiber preforms with and without stitches was measured. A perform is a multilayer package of material ready to be impregnated using liquid transfer molding technology. The main parameters which vary in the preforms are the stitching pattern, meaning the distance between the stitch rows through the preform, the stitching thread tension and the stacking sequence of the layers. The permeability measurements were carried out using a continuous, two-dimensional radial-flow measurement technique. The measuring device consists of an aluminium mold with integrated dielectric sensors (surface treated to prevent short circuit). The sensor system relies on the change in the dielectric properties of the material as saturation takes place. The results showed that stitching has a positive influence on the permeability. The stacking sequence was found to be the most effective way to influence permeability.

KEYWORDS: preform, resin transfer molding, stitching pattern, thread tension level, stacking sequence.

INTRODUCTION

Resin transfer molding (RTM) is having increasing success in the composite manufacturing industry. In the RTM process, the reinforcement is placed into a mold, resin is injected to impregnate the fibers and the finished part can be demolded after the resin has cured and cooled down. Since resin transfer molding is often used to produce large, structural parts [1], the resin must flow long distances in the fiber reinforcement. This creates a demanding task for the tool makers, who must decide on the number and placement of the injection ports and vents. To be able to predict the flow of the resin through the fiber reinforcement, it is necessary to use accurate permeability values in the computer simulations. The resistance of the reinforcing material to the liquid flow is called permeability. The basic equation [1] generally accepted to describe flow in a porous medium is known as Darcy's law (Eqn.1).

$$Q = \frac{K}{\mu}\frac{\Delta P}{L} \qquad (1)$$

where Q = flow rate (m/s), K = permeability (m^2), μ = viscosity of the fluid (Pa s), ΔP = pressure difference (Pa) and L = flow length (m).
Preforms made from woven fabric show an interlaminar pore structure between the layers [2].

Preforms with stitches exhibit this phenomenon even more distinctly due to the distortion of the fibers caused by the needle and the stitching thread. A fiber-free zone is created which provides an easy pathway for the distribution of liquid.

EXPERIMENTAL

The device used to measure permeability with electrical sensors was developed by the Institute for Composite Materials GmbH (IVW), Germany. The permeameter consists of an upper mold in which the sensors are embedded, the electrical circuit, a pressure vessel and software for the permeability calculation written at the institute.

Materials and Sample Preparation

A 5-harness satin weave, manufactured by Hexcel Fabrics, France, was used in this study. This carbon fabric has a surface density of 370 g/m². Fig. 1 shows the stitch types created at the two thread-tension levels selected for this work. At 480 cN (Newton), the upper thread and the bobbin thread interlock beneath the specimen. At the thread tension level >500 cN the knot is placed between the upper and lower layers of the preform. The exact location of the knot is not known. As can be seen in Fig. 1, when the knot is somewhere between the layers, double the number of resin-rich areas are created. A polyester thread No. 220 – dtex 150(2) from Gütermann, Germany, was used as the stitching thread. The specimens were sewn and cut using an automated sewing machine. All of the permeability measurements were performed on preforms with six layers. At a cavity height of 2 mm, the nominal fiber volume fraction was 62%. Two different stacking sequences were generated in the following way (Fig. 1). For the 2x3 lay up, two layers of fabric were sewn together and three of these two-layer packages were laid in the mold. For the 1x6 preform, six layers of fabric were sewn together forming one package. For comparison purposes, permeability of an unstitched preform was also measured.

The preforms were stitched using two different stitching patterns. Stitch rows cross the whole length and width of the preform with a row spacing of 10 mm or 20 mm. The stitching was at an angle of ±45° to both warp and weft. After sewing, the machine automatically cut the performs out. A circular hole with a diameter of 8 mm, was punched in the middle of the preform specimen to avoid transverse flow through the sample during injection.

Permeability Measurements

Preforms were manually laid inside the mold cavity and the hole in the middle was aligned with the pressure sensor. The upper mold, embedded with 6 sensors, was then clamped on to the lower mold. To obtain the necessary equation for the permeability calculation, the flow front position was needed from 3 sensors. The flow front positions were determined by the relationship between the voltage and the wetted length of the sensors [3]. The values of K1 and K2, the main axis of the flow, and the angle of the maximum flow front (K1) with respect to the mold coordinate system, were given by the software. Since the K2 values were relatively precisely 2/3 of the K1 values, and K1 is considered more important for this study, only the K1 values are presented here. In this study the average angle of the maximum flow front was 58° for the unstitched preform and 62° for the stitched preforms.

The angle is measured moving away from the positive x-axis towards the positive y-axis. The results given here are the average of 3 measurements.

A vegetable oil with a viscosity of 0.006 Pa s (Pascal seconds) was used as the test fluid.

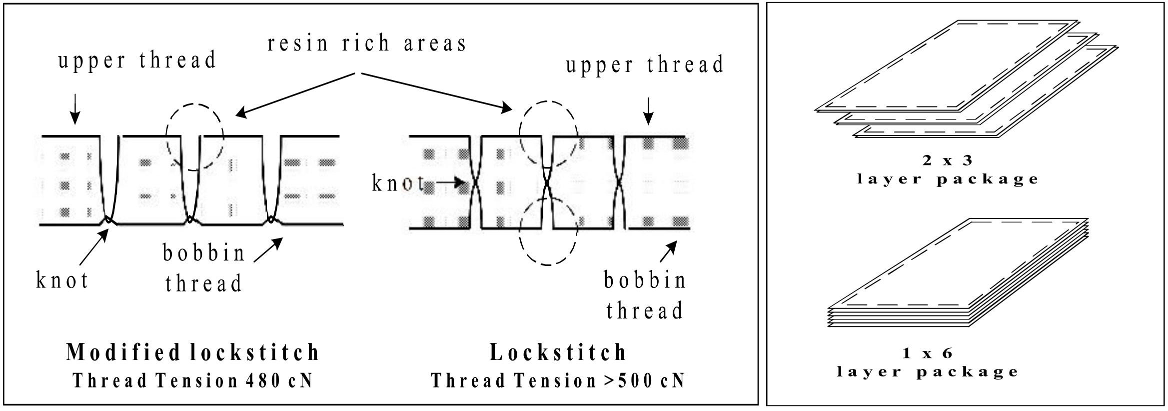


Fig. 1 Modified lockstitch, lockstitch and resin rich areas presented on the left side. Stacking sequences of the preforms presented on a right side

RESULTS AND DISCUSSION

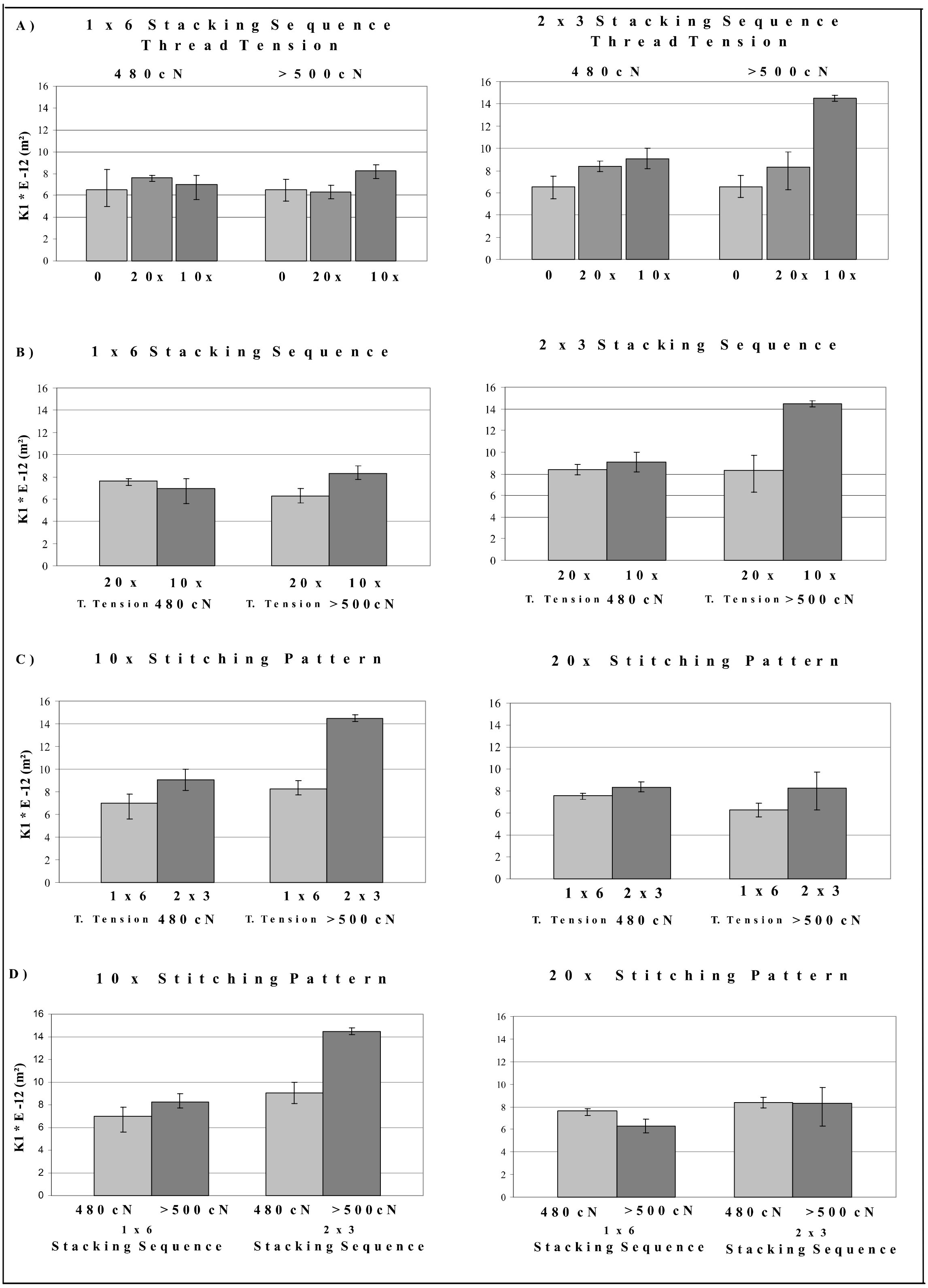
Comparing the results between stitched and unstitched (0) preforms at the first row (A), it can be seen that stitches are influencing the permeability. Values increase as the number of stitches increases. This results from the fact that the stitch holes create high-permeability channels throughout the preform in which the liquid is able propagate easily.

The influence of the stitches is also seen in the tables in the second row (B). The 10x10 stitching pattern exhibits higher permeability than the 20x20 stitching pattern because of the greater number of flow paths for the resin. The first set of columns is an exception to this pattern. It is assumed that the lower thread tension level (Fig. 1) gives enough space for the fiber tows to move and nest in such a way that the fiber-free area created by the stitch decreases and no longer provides an easy pathway for the liquid.

The 2x3 stacking sequence has a higher permeability in all cases (Row C). An easy flow passage between the interfaces is created by laying three packages, each having two layers of fabric stitched together, into the mold. It is assumed that the flow penetrates the packages through the stitch holes and simultaneously increases the flow in the adjacent interface. The 1x6 package is a tight structure of fiber tows and the flow through the whole preform is therefore much more complex than that through the 2x3 stacking sequence preform.

Looking purely at thread tension (Row D), no clear trend can been seen. If however only 10x10 stitching pattern is considered, the higher thread tension level is found to yield higher permeability in both stacking cases. This could be a result of larger stitch holes created by the tauter stitching thread. As explained above, the lower thread tension level allows the fibers to reorganise around the stitching thread and diminish the gap area. It is possible that the number of stitches present in the stitching pèYå monstrate the same behavior.

Table 1 Permeability results



* The error bar shows the minimum and maximum measured values

CONCLUSION

In this work the permeability of preforms made of woven carbon fiber fabric was measured. The preforms had a number of different characteristics whose influence on the permeability have been discussed. The main variables of the preforms were the stitching pattern, stacking sequence and stitching thread tension. The tests have shown that the stitches have a positive influence on the permeability if compared to the perform without stitches. The stitching style, in this case a stitch row distance across the whole preform of 10x10 mm or 20x20 mm, made a difference. The 10x10 mm stitching pattern resulted in a higher permeability due to the larger number of stitches. Thread tension levels (480 cN and >500 cN), did not seem to show any common trend when comparing the results. However, when the 10x10 mm stitching pattern alone was examined, it was found that the higher thread tension level resulted in higher permeability. Stacking sequence was however discovered to be the most effective way to influence permeability. Stacking three preform packages into the mold yields higher permeability results than one preform package, where both constructions have the same total number of layers.

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