

TECHNICAL NOTE

Influence of carbon fiber non-crimp fabrics stitching parameters on the out-of-plane permeability in liquid composite molding process

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Abstract

The widespread use of carbon-fiber-reinforced plastics (CFRP) has attracted many industries such as defense, and aerospace as well as in sailboats, automotive, and rotor-blades, where high strength-to-weight ratios are required. For the aerospace and defense customer today, the importance is no longer just on minimum weight and therefore performance, but primarily on cost of ownership. Textile-manufactured composites, particularly of non-crimp fabric (NCF) type offer significant cost savings in terms of reduced labor time and higher deposition rates over the unidirectional prepreg tape which is the most traditional method. Vacuum vacuum-assisted infusion method is the most used production technic in CFRP parts which also offers high fiber ratios. The most important goal is the impregnation of carbon fiber package in a through-the-thickness direction to get good quality parts in infusion. The behavior of the impregnability depends mainly on the out-of-plane permeability of the fabric. The fiber type, orientation of the fibers, and the stitching parameters, mainly influence the permeability of the fabric. In this study, the influence of textile parameters on the out-of-plane permeability of UD (unidirectional) carbon fiber NCF was investigated. The stitching yarn parameters (stitch pattern, stitch tension, and stitch length) were varied to see the influence on the out-of-plane permeability. The out-of-plane permeability was measured using a tailored visual flow front monitoring method by measuring resin flow distance on the X and Y axes of the fabric during infusion. The results show that the out-of-plane permeability of the UD (0°) carbon fiber NCF is significantly affected by the stitch pattern, stitch tension, and stitch length.

1. Introduction

Due to exceptional properties such as its high-temperature resistance, mechanical characteristics, and relatively lower price, the demand for carbon fiber has been increasing over the past years. Carbon fiber is the most used fiber in the defense & aeronautical fields due to its stiffness and resistance combined with a low specific weight. The most traditional method for the production of complex parts is to use unidirectional fiber prepreg tapes arranged in a suitable lay-up in a mold and cured in an autoclave. This process has been successful and widespread until now in these industries. However, this manufacturing system represents one of the most important cost items in the production of components in composite materials. In addition, the

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prepreg materials are expensive and require storage in freezers and accurate control of exposure times at room temperature [1]. As the defense & aerospace industries, move to consider larger structural parts, alternative and cheaper, manufacturing approaches are increasingly sought for commercial applications. Therefore, interest has increased in the use of dry fabrics that allow the construction of preforms of varying complexity coupled with manufacturing based on liquid composite molding (LCM) methods. Liquid composite molding consists of a variety of composite manufacturing processes where the liquid state matrix material (e.g., epoxy resin) is forced into the dry reinforced reinforcing material (e.g., carbon fiber fabric). LCM methods comprise resin transfer molding (RTM), vacuum-assisted infusion, and injection compression molding (ICM). The main goal is to achieve complete impregnation as the resin flows between the bundles of fibers [2].

Non-crimp fabrics (NCF), whose structure leads to a synergetic effect of high material properties and excellent drape performance, have received much attention over recent years (Fig. 1). The NCFs show some reduction in performance as compared to those derived from pre-pregs mainly because of the lower fiber volume fractions and the use of lower-performance resins suitable for infusion. The fiber over resin percentage may be enhanced by reducing the tow spacing and by improving the stitching architecture as well as the overall manufacturing process, leading to a product of comparable performance but cheaper than those from pre-pregs [3, 4]. Non-crimp fabric (NCF) composites are built from multiaxial textile preforms with fiber tows stitched or warp-knitted together into a directionally oriented structure (Fig. 2).

The goal of the study is the selection of an optimized stitching architecture in carbon fiber UD NCF, regarding impregnation behavior during permeability test [5–8]. Therefore, the cycle time for impregnation of the textile can be shortened.

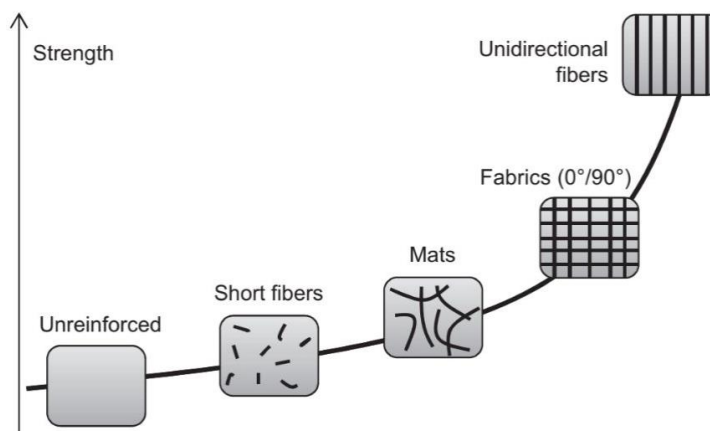


Fig. 1. Strength comparison of reinforcements.

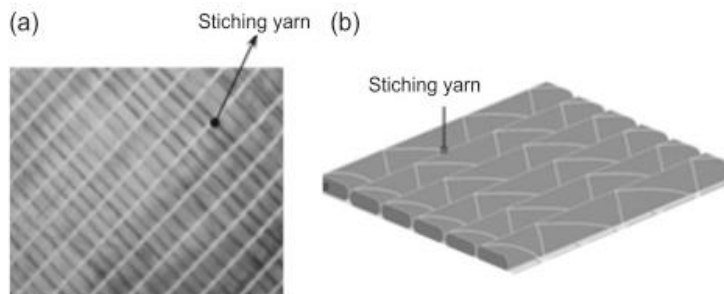


Fig. 2. Presentation of NCFs' types of stitch architecture

2. Experimental study

2.1. Materials

In this study, the out-of-plane permeability of carbon fiber UD NCF is presented. The stitching parameters to investigate the influence on permeability were chosen as stitch pattern, stitch length, and stitch tension. Stitch parameter details are presented in Table 1 and some examples are shown in Fig. 3. All NCFs have a 620 g/m² total areal weight consisting of 3750 tex (50K tow) carbon fiber in 0° direction, 68 tex E-Glass fiber in 90° direction, and 7.5 tex polyester stitching yarn. As the matrix material epoxy resin is used.

2.2. Test system set-up

The permeability was measured via the vacuum infusion method with central resin feeding, surrounded by vacuum channel placement (Fig. 4). 10 layers of fabric were placed in the center of the prepared area and then covered with transparent vacuum film. After the vacuum was applied, a visual track of the flow front was performed while the resin moved from the center to the edges through the fiber stack. The infusion parameters such as mold temperature, vacuum pressure, and resin feeding positions are constant for all measurements.

2.3. Calculation

The resin track distance was measured periodically on the X, X', Y, and Y' axes by getting the origin as the starting point. Flow front charts were created with distance-time curves for the X and Y axes for comparison. The thickness and fiber percentages were also measured and included in comparison tables.

Table 1. Investigated stitching parameters

Stitch Pattern	Stitch Length	Stitch Tension
Pillar	3.1 mm	LOW
Tricot	3.3 mm	MEDIUM
Pillar-Tricot	3.6 mm	HIGH

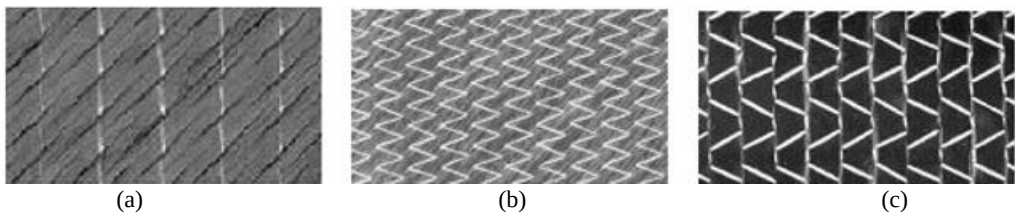


Fig. 3. Examples of stitching patterns for non-crimp fabrics: chain stitched (a), tricot stitched (b), and tricot-chain stitched (c). (Copyright Katleen Vallons [9])



Fig. 4. Representation of permeability test system set-up

3. Results

Permeability test shows that the tricot stitch pattern has a higher resin flow speed than those of pillar tricot and pillar (see Fig.5). In the comparison of stitch tension tests tricot stitched UD NCFs were used. While low stitch tension gives the lowest resin flow speed, Medium and High tensions show higher flow speed and close flow front properties each other (see Fig. 6). To see the stitch tension influence on fiber content, fiber weight ratios were measured and compared. Although it was observed that stitch tension differences did not have the most significant effect on the fiber ratio, it was observed that high stitch tension decreased the fiber ratio, while low tension had an effect in the direction of increasing the fiber ratio (see Fig. 7). Both results can be associated with the fact that the gaps between the fiber bundles that might be created by stitch tension can create paths through which the resin can pass and accelerate the flow. Fig. 8 shows the schematic presentation of how the gaps between fiber bundles might be formed due to stitch tension [5].

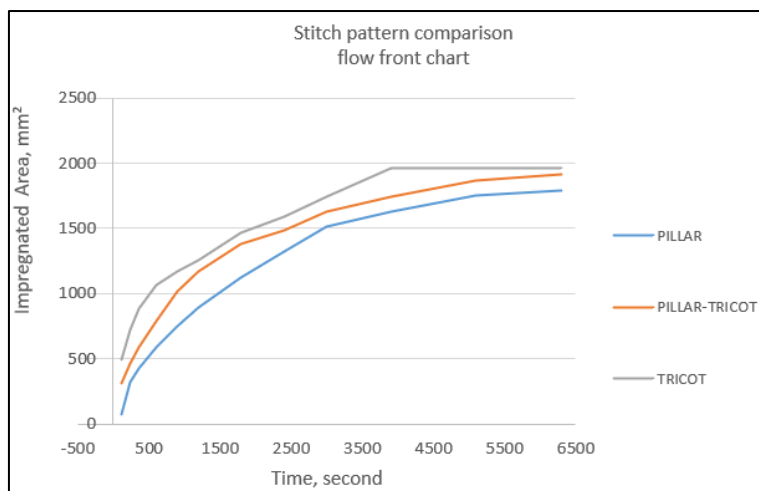


Fig. 5. Stitch pattern flow front chart

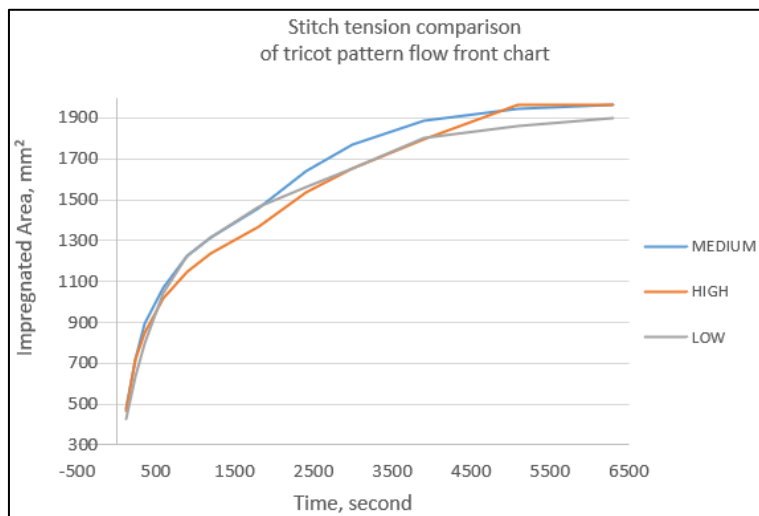


Fig. 6. Stitch tension flow front chart

There is no dramatic effect observed In the stitch length trials, on X-axis direction larger stitch length (3.6 mm) showed the highest speed, while there is not much significant difference between other lengths respectively 3.1 mm and 3.3 mm (see Fig. 9). In Y-axis trial, larger stitch length (3.6 mm) shown the highest speed and the 3.1 mm stitch length shown very low flow speed with 3000 seconds to impregnate all fiber stack area (see Fig. 10).

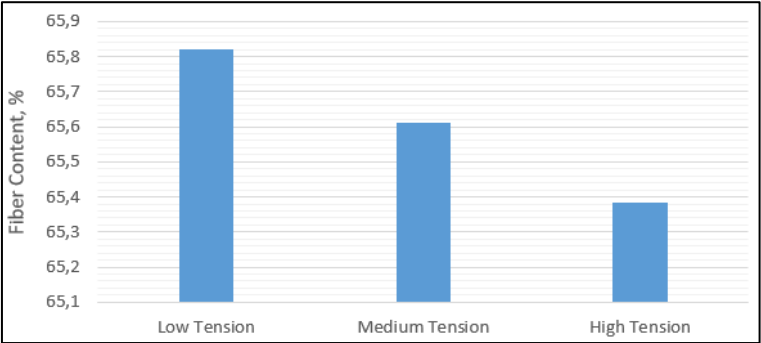


Fig. 7. Stitch tension effect on fiber weight content in composite part

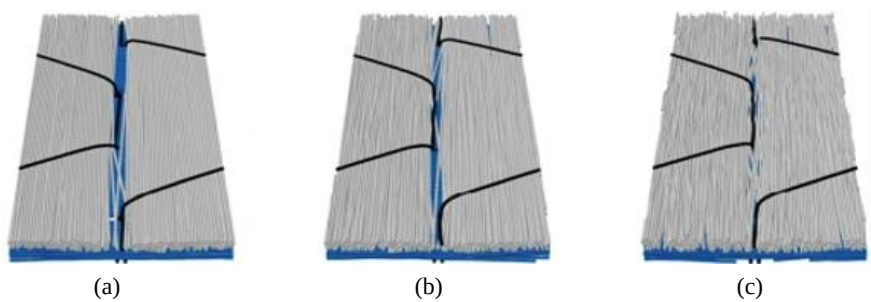


Fig. 8. Presentation of gap formation between bundles due to stitch tension in NCF high tension b) medium tension c) low tension. (Copyright Colin D. [5])

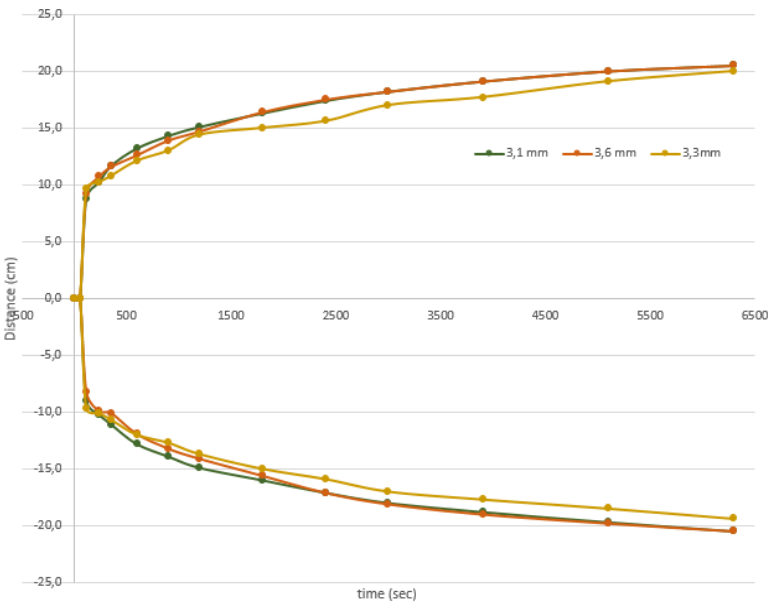


Fig. 9. Stitch length X, X' axis flow front

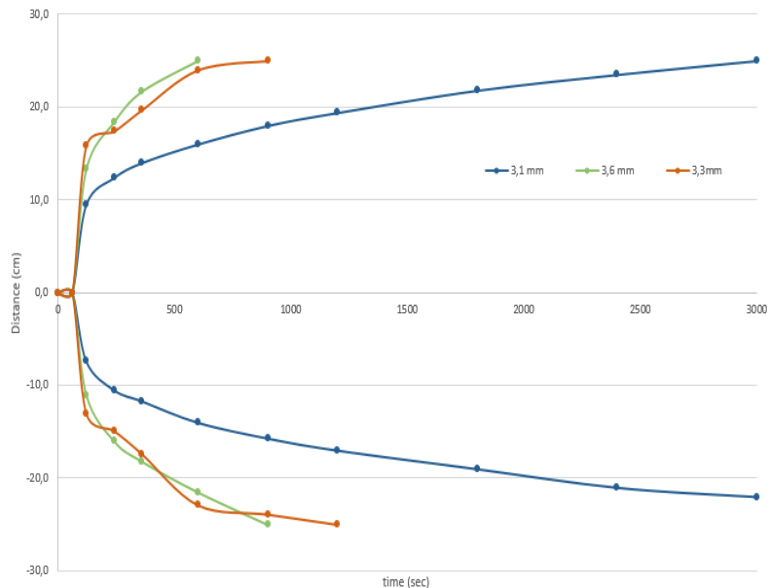


Fig. 10. Stitch length Y, Y' axis flow front

4. Conclusion

This paper presents an experimental investigation of the effects of stitch pattern, stitch length, and tension, on the permeability of unidirectional carbon fiber NCFs during the vacuum infusion process. The results imply that the impregnation quality of NCF is not affected by stitching architecture. In contrast, the permeability speed is sensitive to the stitch pattern, stitch length, and stitch tension, respectively.

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Conflict of interests

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Data availability statement

No new data were created or analyzed in this study.

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