

BRIDGING THE PERFORMANCE GAP BETWEEN PRE-PREGS AND CONVENTIONAL FABRICS

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SUMMARY: We will explore the performance envelope offered by symmetrical 3D woven fabrics called NCS (Non Crimp Structure). This class of reinforcement addresses issues with stitched NCF (Non Crimp Fabrics) materials. Used with infusion techniques they provide an alternative to preimpregnated fabric (prepreg) performance. Very large composite structures are economically feasible. The geometry of the symmetrical 3D woven provides mechanical and processing advantages. Properly designed NCS fabrics of no less than three layers (90°/0°/90°) allow for even interlaminar resin flow regardless of the number of plies, stacking sequence or orientation. Optimum interlaminar shear strength is obtained when mirror image orientation allows nesting of one fabric into the next. Examples of successful applications from the industry are presented with their main features. Single layer permeability is such that the NCS fabric can be used as a flow medium and structural layer between two adjacent cores. Used for manufacturing infused composite tools, either glass or carbon, the NCS fabrics allow exceptional dimensional stability matching established prepreg technology at both lower cost and labor. While this paper is more art than science, the empirical evidence shows interesting avenues to explore more rigorously as suggested in future works.

KEYWORDS: stitching, symmetrical 3D weaving, nesting, non crimp structure, delamination

INTRODUCTION

Stitched fabrics or Non Crimp Fabrics (NCF) have offered the advantages of reduced crimp, improved delamination resistance and cost effective stacking of fibers at any angle and in any combination [2]. In the past 15 years closed mold technologies have been accepted by the general composite industry. It has been particularly true for boat building. Truly massive composite parts are infused today. The stitched fabrics are the standard. In order to improve both the process and the properties one can look at the next step up in reinforcements: NCS, Non-Crimp Structures that are woven. This family of reinforcement can be described as orthogonal 3D woven. Of particular interest is the symmetrical 3D woven geometry.

SYMMETRICAL 3D WOVEN DESCRIPTION

3D woven fabrics are constructed using weaving technology inspired by velvet manufacturing. 2, 3, 5 and 7 layers are possible with various inputs for example. The same techniques can be applied to increase the layers even further [3].

A particular case is the $90^{\circ}/0^{\circ}/90^{\circ}$ geometry where smaller 90° inputs sandwich a heavier 0° input for a nearly balanced fabric. The degree of 90° or 0° bias is a choice of the fabric designer and a reflection of the end use. For relatively light fabrics (1125 g/m^2 and less) a polyester yarn is the preferred choice as it imparts impact resistance. On heavier fabrics (1830 g/m^2 and more) a small glass roving takes that role. The added benefit is that it acts as a resin carrier or path through the thickness of the material.

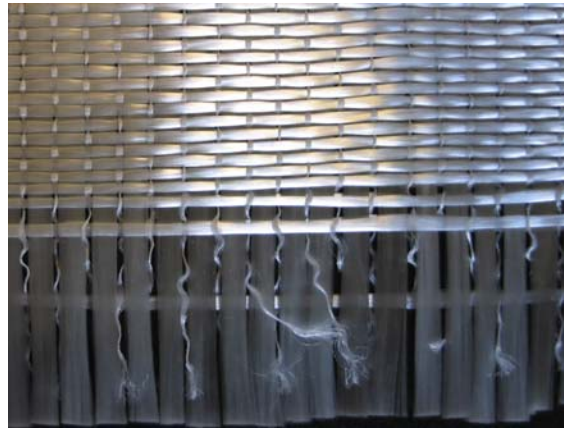


Fig. 1 JB Martin TG-22-N Non Crimp Structure 3D symmetrical woven is shown (744 g/m^2). Two 90° layers of 275 tex glass roving sandwich a 0° layer of 1100 tex layer. The overall effect is high drapeability, high in-plane permeability while maintaining constant channel width and orientation.

A 1125 g/m^2 $90^{\circ}/0^{\circ}/90^{\circ}$ glass construction (similar to Fig 1, only heavier) is very conformable and will follow mold shape closely. This reduces the risk of voids. Voids in the mold create resin race tracking while infusing.

Because the binder is well aligned in the 0° direction it doesn't tighten itself on the glass roving, like a stitching or a knit, creating stitch yard distortions (SYD). Hence the resin flow in the XY plane is more predictable [4]. Since there is no stitching process there are no needles to go through the fibers, reducing fiber breakage significantly. This helps mechanical properties and is believed to increase fatigue life. Finally, as the relative spacing between the tows is constant in both directions and relative to one another, the crimp along the 0° or 90° is non-existent compared to a stitched material (Fig. 2), again enhancing the flow predictability [1].

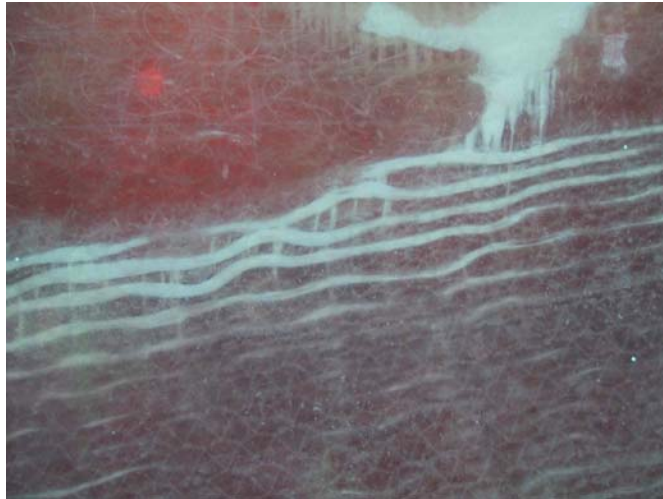


Fig. 2 Failed infusion highlighting how a stitch NCF can show poor fiber alignment (in the 0° direction in this case).

Nesting of same orientation layer-to-layer enhances the bond by providing a greater surface area. This nesting effect explains the superior delamination resistance of a $90^\circ/0^\circ/90^\circ$ laminate over an 8HS laminate. The architecture leads to very high fiber content in the range of 68-70% by weight for glass for infused laminates. The nesting effect accounts for a thickness reduction that is a function of the number of plies. For a 6 layer 1125 g/m^2 laminate, the effect of the nesting is 2-3% thickness reduction versus alternating the orientation of each ply.



Fig. 3 Nesting of two adjacent layers of 3250 g/m^2 (7 layer $90^\circ/0^\circ/90^\circ/0^\circ/90^\circ/0^\circ/90^\circ$) 3D woven reinforcement.

Limitations

Contrary to stitched fabrics, with the 3D weaving process only 0° and 90° are possible. 30° , 45° or 60° degrees are not possible. The cost per kg can be higher due to slower machine speed and typically smaller input roving and yarns compared to similar aerial weight stitched. Combining felt or mat materials requires a separate operation. NCS Fabrics are prone to fraying if cut compared to stitched. When fabric stability is critical, some form of thermoplastic locking is required.

CASE STUDIES

Process

It has been found that the resin flow in a symmetrical 3D woven laminate is the same for 1 or 3 or 6 layers showing constant in-plane permeability. A variant of the experiment with the same number of plies of the same fabric (3 layers) oriented in the 0°, the 90° and at alternating 45° showed a similar result.

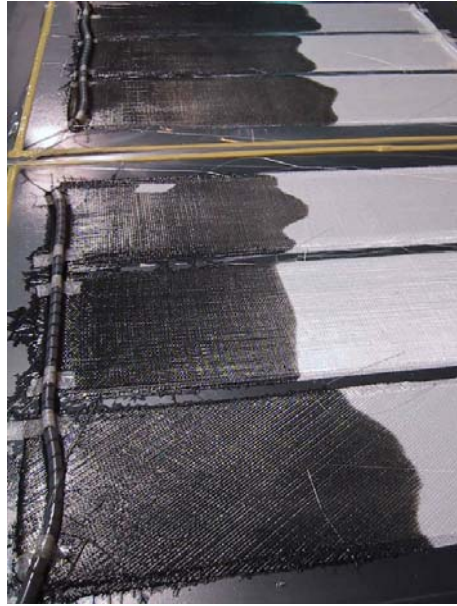


Fig. 4 Six ply sequence experiment (1 ply, 3 plies, 6 plies, 3 plies at 0°, 3 plies at 90° and 3 plies alternating at 45°) show similar in-plane permeability with 518 g/m² symmetrical 3D woven NCS.

Applications

Large parts that cannot be economically produced with prepregs can be infused. Hulls measuring over 70 meters (151 ft) in length are infused in a single step using combinations of symmetric 3D woven and stitched +/-45°.

Because structural cores are limited in the maximum thickness available, it is sometimes necessary to combine two core layers. In such a case, under infusion, it is critical to provide an interface between the two layers that will flow the resin and have cohesion to the core that exceeds its strength. A symmetrical 3D woven with preferential in-plane permeability has been used successfully. The adhesion to the core is superior to the core integrity, thanks in part to the non-crimp structure providing maximum contact area. Double sandwich panels tested to failure showed better performance with the symmetrical 3D woven layer when compared to mat, continuous strand mat, stitched or other.

Tooling for industrial parts (glass) and aerospace (carbon) have been fabricated using symmetrical 3D woven and infusion. VE infused glass tools can be made very stable because of the high volume fraction of 70% or more. Mold shrinkage for the NCS/VE resin has been

measured at 1×10^{-6} m/m (0,0004 inch/inch). These production tools have seen constant heat cycling and have shown better longevity than conventional tools. Epoxy carbon tools have also been made with success. An added benefit of the symmetry of the fabric is that the operators cannot make a stacking sequence mistake compared to a $0^\circ/90^\circ$ NCF.

CONCLUSIONS AND FUTURE WORK

Symmetrical 3D weaving provides robust building block reinforcement for closed mold processes and particularly infusion. Proper design of the NCS fabric creates a balanced permeability (channel flow speed versus bundle wet out) in all directions, perfect alignment and a high resulting fiber ratio. The geometry leads to higher mechanical strength compared to conventional fabrics using smaller inputs or compared to stitched fabrics using heavier inputs. Delamination resistance is high due to layer-to-layer nesting (unique to this architecture), low void content, reduced number and size of resin pockets (reduction of stitch yarn distortion (SYD)). In-plane flow is predictable because of constant channel size and smaller fiber input bundle. Processes involving in-plane flow give better results than those favoring through plane flow. The performance of symmetrical 3D woven is close to preimpregnated laminates nearly matching the volume fraction and void content while reducing the cost and labor. The delamination resistance in the field needs to be studied and quantified. FE modeling of the $90^\circ/0^\circ/90^\circ$ stacking would provide an interesting tool where stitch yarn induced distortion (SYD) is minimized by the construction. Impact and fatigue properties will be investigated in summer 2008.

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