EFFECTS OF STITCH PATTERN ON THE MECHANICAL PROPERTIES OF NON-CRIMP FABRIC COMPOSITES

Leif E. Asp, Fredrik Edgren and Anders Sjögren

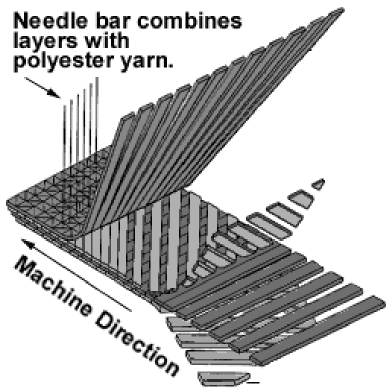
SICOMP AB, P O Box 104, SE-431 22 Mölndal, Sweden

ABSTRACT

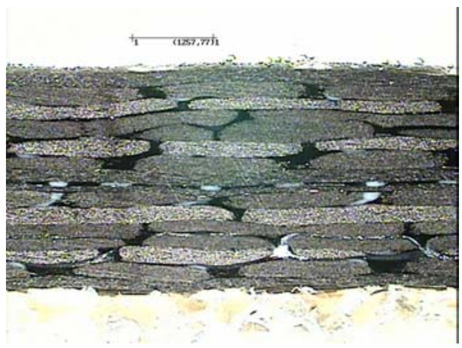
Mechanical test data for NCF composites presented in the open literature are ambiguous; both indicating improved as well as impaired performance in tension and compression. These data are generated for a wide range of GFRP and CFRP NCF composites. This paper presents a study isolating the effects of stitch pattern on the mechanical properties and behaviour of an aircraft grade CFRP non-crimp fabric composite. The experimental data presented in the current paper imply little or no effect of the stitching parameters on the tensile and compressive strength and stiffness. The tension-tension fatigue life performance, however, seems to be improved by the NCF fabric when compared to that of a competing prepreg composite.

1. INTRODUCTION

Non-crimp fabric (NCF) composites are built from multiaxial textile preforms with fibre tows stitched or warp-knitted together into a directionally oriented structure (DOS), see Fig. 1a. The NCF composite is built from a number of preforms stacked on top of each other and infiltrated by a thermoset resin.



a)



b)

Fig. 1. a) Schematic of a NCF preform manufacturing (from Vectorply); and b) a cross section of quasi-isotropic NCF composite

The use of non-crimp fabric composites has substantially increased during the recent years. The reason for this is that high quality composites can be manufactured both easier and cheaper with NCFs than with prepregs, and that mechanical properties (stiffness and strength) usually are better with NCFs than with woven fabrics. However, NCFs are generally less geometrically stable in the manufacturing process than woven fabrics, which can lead to internal defects and thereby deteriorated mechanical properties. Parameters such as stitch pattern and stitch-thread tension are therefore of great importance for NCF composites. Although the name non-crimp fabrics indicate differently, the NCF composite laminae are indeed wavy. Both stitch pattern and tension affect the waviness of the fibre tows in the individual layers in the preform.

A reasonable amount of mechanical property data for NCF composites has been generated during the last decade. An important drawback when analysing the NCF performance is the baseline material used to compare them with. In fact, some authors either do not use any reference material at all or they use unsuitable baseline material with very different fibre volume fractions or fibre proportion in the load direction [1,2]. In addition, there are considerable discrepancies found in the literature regarding the relative reduction/improvement of NCF composites' basic mechanical properties when compared to prepreg laminates:

Tension: It is generally recognised that the tensile strength of NCF composites is lower than that of equivalent prepreg ones. The degree of the strength reduction, however, ranges from a slight decrease around 1% [3] to as much as 30-35% [4]. The stiffness reductions were reported by Godbehere et al. [3] to be between 3% and 10% when compared to prepreg composites.

Compression: The compressive strength for NCF composites seems to be in general agreement on the reduction of compressive strength of prepreg composites. However, the drop in strength is, once again, found to vary significantly (6-38%) [5,6]. The more severe strength reduction is found for glass fibre reinforced NCF composites and is usually attributed to poor adhesion between fibres and matrix. The average degradation for CFRP NCF composites has been reported to be in the range 15-18%. Godbehere et al. [3] report a contradictory result with 2-10% increase in NCF compressive strength. In addition, Godbehere et al. [3] reports a surprising increase in the compressive stiffness when compared with with UD prepreg composites. Results from Dexter and Hasko [5] imply a 15% reduction in the compressive modulus for NCF composites.

On the basis of this ambiguity in the results presented in the literature an investigation of the influence of stitch pattern on the in-plane mechanical properties of CFRP/epoxy NCF composites is pursued in the current paper.

2. EXPERIMENTAL

Materials

An experimental survey on the effect from stitch pattern on in-plane strength, stiffness and fatigue life is performed on CFRP/epoxy NCF composites. The composites were manufactured from stacked T700 50C 12K fibre tow (from Toray) unidirectional fabrics infiltrated by RTM6 epoxy resin from Hexcel. In total, ten fabric types, each with a unique stitch pattern, were studied (see Fig. 2). The NCF fabrics were manufactured by Devold AMT, Norway, and shipped to SICOMP for composite manufacture. The composites were manufactured from six stacked fabric layers by resin transfer moulding (RTM). During this process the resin was heated to 80ºC to decrease its viscosity. The composite plates were cured at 160ºC for two hours and post-cured at 180ºC for three hours. The manufactured plates had a thickness of approximately 2 mm and a nominal fibre volume fraction of 55%.

The stitch patterns of the ten unidirectional NCF fabrics are presented in Fig. 2. As shown in the figure, four of the fabrics had a zig-zag stitch pattern (P1, P4, P5 and P8), while four of the fabrics had a mixed zig-zag pattern (P2, P3, P6 and P7) and two had a straight stitch pattern (P9 and P10). The stitch gauge (i.e. the number of stitch points per inch in the weft direction) was 10 for P1-P4 and P10, and 5 for P5-P9. The second stitch pattern parameter that was varied was the stitch length (i.e. the distance between the points in the warp direction). The stitch length was 3.5 mm for P1, P2, P7 and P8, 2.5 mm for P3-P6, and 5.0 mm for P9 and P10. The areal weight of the fabrics was 315 g/m^2.

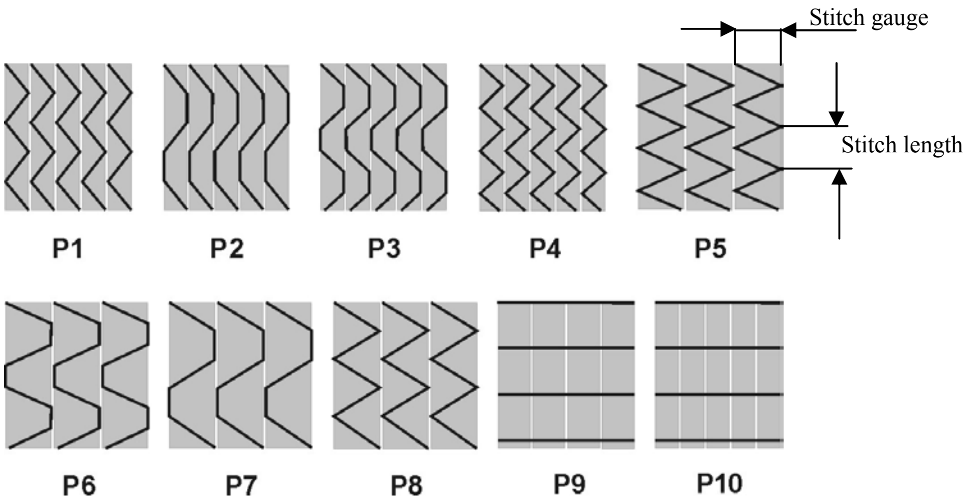


Fig. 2. Stitch patterns studied.

Test procedure

Rectangular shaped test specimens were cut into dimensions (250 mm length and 20 mm width) and end-tabbed on each side using 50 mm long tapered GFRP tabs. Tension and compression as well as fatigue (tension-tension) specimens were cut from the same plate, for each fabric type (P1-P10).

Tensile tests were performed according to the ASTM D3039/D 3039M – 95A standard [7]. From this test the tensile stiffness (Young´s modulus), Poisson´s ratio, strength and strain to failure were measured. Compressive tests were performed in a Mixed Load Transfer (MLT) test fixture designed at the Institute of Polymer Mechanics, Latvia. Details of the MLT test rig are presented in a paper by Joffe [8]. For each fabric type 6 to 8 specimens were tested in tension and compression.

Closed loop, tension-tension, fatigue tests consisting of a sinusoidal load with a frequency of 5 Hz were performed. The stress ratio was continually R=0.1 for various strain levels. By the strain level is here meant the initial (first cycle) peak strain, which was calculated from the applied peak load.

2. RESULTS & DISCUSSION

The results from the static tension and compression tests are presented in Table 1 and Figs. 3 and 4. As shown in the table, very small differences in the strength and stiffness are found for the different fabrics in tension and compression, respectively. However, the performance in compression is dramatically poor when compared to that in tension. The compressive strength is, in general, less than half of that in tension. The average tensile strength was 2020 MPa, while the average compressive strength was only 880 MPa. In addition, the stiffness in compression is approximately ten percent lower than that in tension. The average stiffness in tension was 118 GPa, while the average stiffness in compression was 105 GPa. Scatter bars in the diagrams indicate the scatter in data.

Table 1. Results from static tensile and compressive tests on the NCF composites P1-P10.

Fabric	Stitch style	Stitch gauge (bundles/inch)	Stitch length (mm)	Tensile strength [MPa]	Tensile stiffness [GPa]	Tensile strain to failure (%)	Compr. strength [MPa]	Compr. stiffness [GPa]	Compr. strain to failure (%)
P1	Zig-zag	10	3.5	1884	114.2	1.76	868	104	0.90
P2	Mixed zig-zag	10	3.5	2095	116.4	1.80	861	103	0.92
P3	Mixed zig-zag	10	2.5	2067	117.5	1.76	880	104	0.93
P4	Zig-zag	10	2.5	2015	117.2	1.72	780	101	0.82
P5	Zig-zag	5	2.5	2146	119.7	1.79	894	105	0.89
P6	Mixed zig-zag	5	2.5	1950	118.3	1.65	884	105	0.92
P7	Mixed zig-zag	5	3.5	1950	116.8	1.67	884	106	0.91
P8	Zig-zag	5	3.5	1968	118.7	1.66	885	109	0.88
P9	Straight	5	5.0	2044	125.2	1.64	917	106	0.94
P10	Straight	10	5.0	2086	118.7	1.76	945	107	0.97

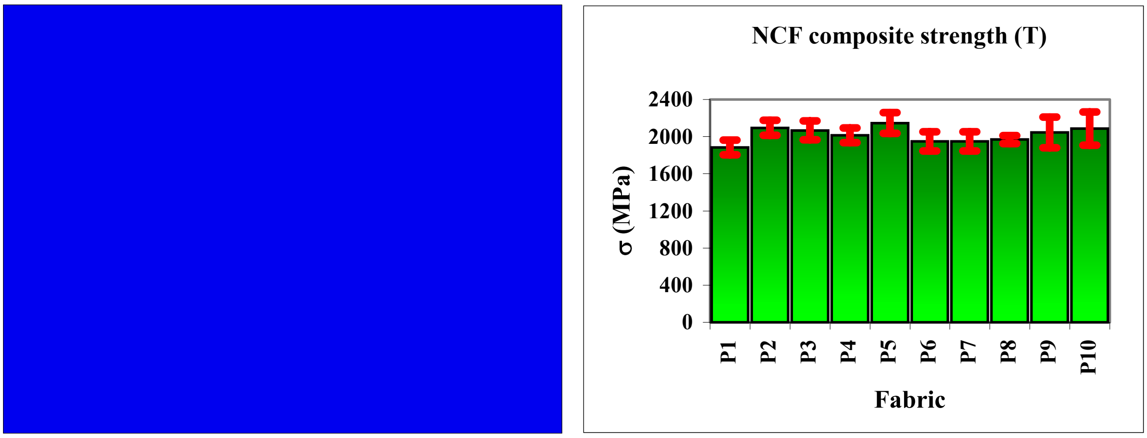


Fig. 3. Results from tensile tests, scatter in data is indicated by scatter bars.

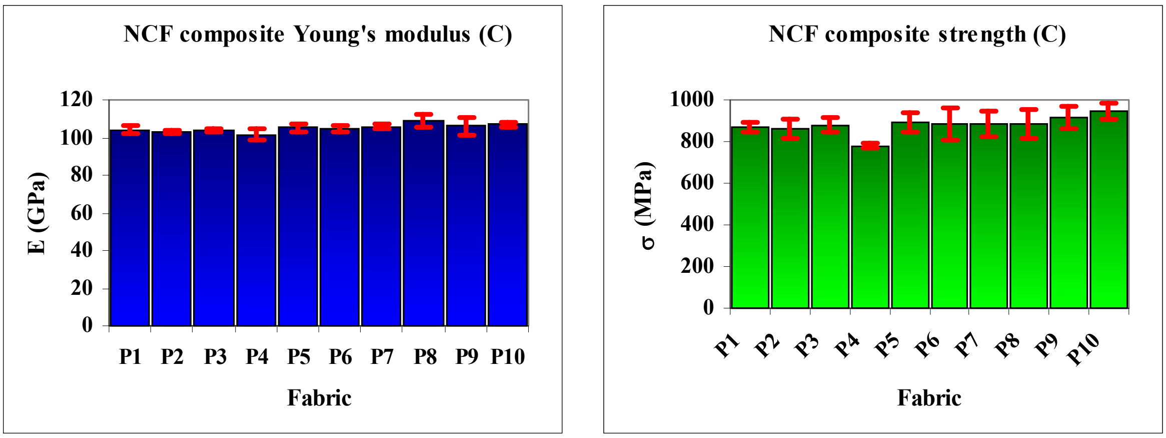


Fig. 4. Results from compression tests, scatter in data is indicated by scatter bars.

Poisson's ratio for the composite materials was also measured. The results for Poisson's ratio are presented in Table 2. As shown in Table 2, Poisson's ratio is affected by the stitch pattern. The results indicate that the Poisson's ratio, ν_{xy}, is reduced if a small stitch gauge and stitch length is combined.

Table 2. Effect of stitch pattern on Poisson's ratio (from static tensile tests) on the NCF composites P1-P10.

Fabric	Stitch style	Stitch gauge (bundles/inch)	Stitch length (mm)	Poisson's ratio
P1	Zig-zag	10	3.5	0.305±0.022
P2	Mixed zig-zag	10	3.5	0.336±0.028
P3	Mixed zig-zag	10	2.5	0.329±0.028
P4	Zig-zag	10	2.5	0.341±0.030
P5	Zig-zag	5	2.5	0.267±0.039
P6	Mixed zig-zag	5	2.5	0.300±0.036
P7	Mixed zig-zag	5	3.5	0.316±0.046
P8	Zig-zag	5	3.5	0.299±0.043
P9	Straight	5	5.0	0.332±0.019
P10	Straight	10	5.0	0.309±0.021

The fatigue life was only measured for the fabrics designated P1, P2, P5 and P8. Results from the fatigue tests are presented in Fig. 5. Included in the figure are also fatigue properties of a HTA/6376C UD-prepreg laminate.

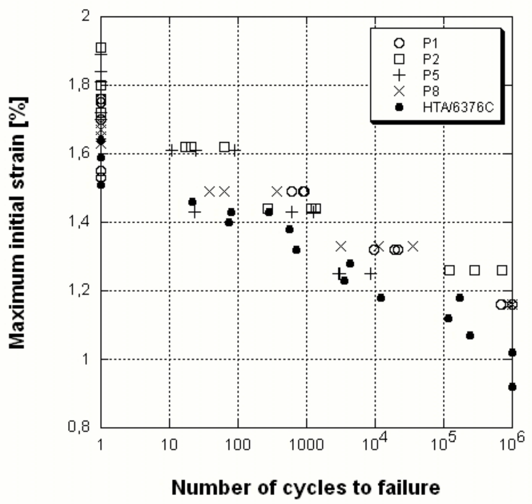


Fig. 5. Fatigue life diagram

Based on the results presented in Fig. 5 it appears as if a small stitch gauge in combination with a small stitch length can have a detrimental effect on the fatigue life (cf. effect on Poisson's ratio, above). More data is, however, needed to verify this finding. Interesting to notice is that the fatigue life of the NCF composites is well on par with the fatigue life of the HTA/6376C prepreg laminate, which of course is an advantage if NCF composites shall be used for e.g. aircraft components. However, the relatively poor compression strength will most likely lead to very poor tension-compression fatigue properties, and future work should therefore focus on improving the compression strength of NCF composites to enable competitive design with this type of material.

3. CONCLUSIONS

This paper presents an experimental investigation on the effects of stitch pattern, i.e. stitch style, gauge and length, on the mechanical properties of unidirectional NCF composite materials.

The results imply that the strength and stiffness is insensitive to the stitch pattern for tensile and compressive loading, respectively. However, a small effect on the Poisson's ratio is reported where combined small stitch gauge and short stitch length promote reduction of Poisson's ratio. In addition, comparing strengths in tension and compression the compressive strength is generally less than half of that in tension. A small difference in stiffness between the compression and tensile load cases is also noticeable, where the stiffness in tension is approximately ten percent higher than that in compression.

Fatigue (tension-tension) properties of the tested unidirectional NCF composites are better than those of a comparable prepreg laminate. In addition, only small effects of the stitch pattern on the fatigue life are observed.

ACKNOWLEDGEMENTS

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