CYCLING BEHAVIOUR OF STITCHED COMPOISTE SANDWICH STRUCTURES

B. Lascoup [a], Z. Aboura [b], K. Khellil [b], M. Benzeggagh [b]

[a] ESTACA Campus Ouest – Parc Universitaire Laval Changé
BP 76121 - 53061 Laval Cedex 9
[b] Université de Technologie de Compiègne, Laboratoire de Mécanique Roberval UMR CNRS 6066
Dept GM - Polymères et Composites BP 20529 - 60206 Compiègne Cedex, France

Abstract The aim of this work is to apprehend the effect of stitching on the mechanical behavior under cycling loading. Thus a four-points flexural testing is conducted at 5Hz until failure or 10^6 cycles. Loading level is deduced from the failure in case of static loading. Rigidity evolution under cycling remains classical even for the stitched structure. After a first phase of fast loss of rigidity where degradations settle, damages remain present but are not propagated any more. In this zone, an apparent stability of the resistance of the structure appears. However the rupture intervenes by decay of the microscopic cracks. Stitches presence enables reaching definitely higher loads while preserving a good resistance to the repeated loadings. A particular attention is given to the specific ruin of such a stitched structure. The weak point of this material already highlighted by static studies is the stitches points of anchoring. Moreover, the relative positioning of the two stitching yarns is studied. Under loading, the additional degree of freedom of non-dependant stitches allows a better distribution of the efforts by relieving the points of anchoring of the seams or the rupture intervenes classically. Maximum number of cycling could be multiplied by a 2 factor.

1 INTRODUCTION

Sandwich structures are a good example of the potential offered by composite materials. Their major advantage is its high flexural stiffness per weight ratio. The lightweight foam core serves to place the stiffer face sheet material further away from the neutral axis where its resistance to flexural loads is amplified. Nevertheless, the weakness of this association is the interface that is susceptible to delaminate and in general has limited strength since there are no reinforcements bridging the foam and the skins. In the case of the monolithic composite materials, the introduction of reinforcement through the thickness has shown its own interest [1, 2, 3]. To date, the stitching of sandwich structures has received minimal attention.

In this study, the stitches are used as a strong complement to bond the two skins and the core. The purpose of this reinforcement is not only to ensure a good link between the sandwich components but also to increase the mechanical properties of this material.

. MATERIAL PRESENTATION

The studied sandwich results from a traditional sandwich composed of a 35 kg/m^3 polyurethane foam core and two thin skins in woven glass fiber. Stitches are added binding these three components transversely. These stitches, made up of a glass yarn, are not vertical, they form an 45° angle with horizontal. The "pattern" thus created, is a cross (figure 1) and the stitching step is 25mm. Due to the stitching process, the spacing between the rows is 25 mm.

"X" axis is defined as the direction of the rows of the stitches and "Y" axis as the perpendicular direction. "Z" axis represents the thickness.

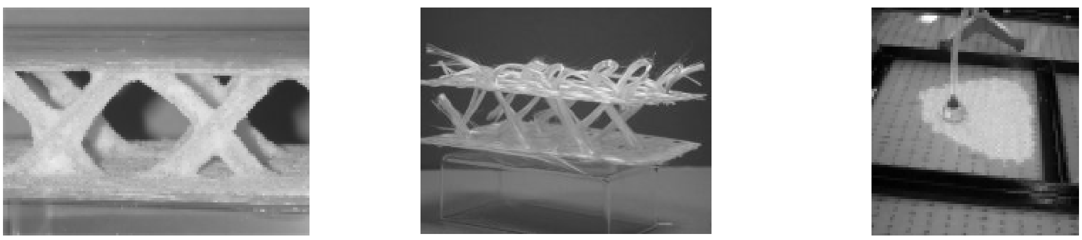
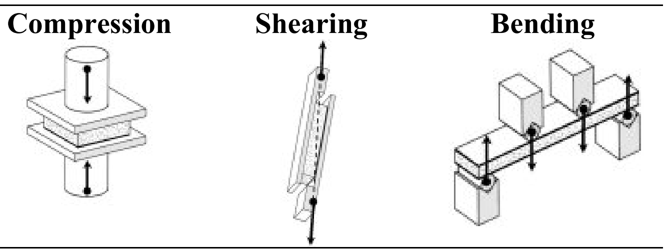


Figure 1. stitched sandwich : (a) without foam, (b) without foam and resin, (c) injection.

The total thickness of the panels, after injection of polyester resin (RTM process of the laboratory) is 22 mm : 20 mm core thickness and each skin has a 1 mm thickness. During the injection process, the stitches act like channels and allow the out-flow of the resin towards the lower face.
The glass fiber ratio of the skins is 23% for the unstitched sandwich and 25% for the stitched one : the dimension of the air-gap chosen for the thickness of the skins (1mm for 2 plies) involves an accumulation of resin during the impregnation explaining the quite lower fiber ratio. Concerning the stitches, this ratio is 15%; this value is controlled by the ratio between the diameter of the yarn of glass (2400 tex) and the diameter of the needle. After its passage, the needle leaves a print in the shape of a hollow roll and the resin fills in the space between the two diameters during the injection.
After injection, a significant mass improvement is observed due to stitches implementation. Indeed this mass increase from 5.45 kg/m² for an unstitched sandwich to 6.38 kg/m² for a stitched one.

2 MECHANICAL BEHAVIOR UNDER STATIC LOAD

To determine the improvement involved by adding stitches, typical mechanical tests are performed : 4 points bending test, core shear test and flatwise compression test. A particular attention is given to the failure mode due to the presence of the stitches.
The tests are carried out on a INSTRON 1186 universal tensile testing machine in accordance with the EN 14125 ISO, ASTM C365-03 and ASTM 273 standards. Figure 2 presents mechanical result obtained from this tests.



	Ez	Max. Stress	Gxz	Max. Stress	Ef	Max. Stress
Unstitched	14.6 $^{\pm 0.8}$	0.28 $^{\pm 0.01}$	3.1 $^{\pm 0.1}$	0.20 $^{\pm 0.03}$	1532 $^{\pm 78}$	7.6 $^{\pm 0.2}$
Stitched sandwich	95.5 $^{\pm 2.1}$	2.27 $^{\pm 0.14}$	19.4 $^{\pm 2.9}$	1.26 $^{\pm 0.19}$	4667 $^{\pm 188}$	30.4 $^{\pm 3.9}$

Figure 2. mechanical improvement involved by stitching

Compared to an unstitched sandwich, the benefit of the stitch introduction is considerable. Rigidity and ultimate stress are quite higher. But, while being rigidified, the material becomes more brittle and the rupture gets more fragile.

3 CYCLING BEHAVIOR

3.1 Experimental protocol

The fatigue tests were carried out on a multipurpose testing machine INSTRON 1341. The configuration of the test is the same as the static test of 4points bending (440mm between supports external) and a 150mm large sample. It is controlled by imposed load; the stresses cyclic are represented by figure 3.
The frequency of the stress of input was fixed at 5Hz.

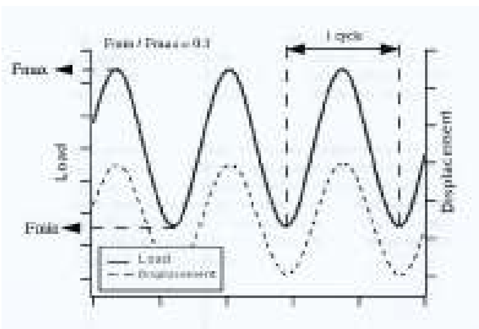


Figure 3. load control during cycling 4points bending test

The average charge around whose the load will oscillate and the amplitude are directly related to the values of the maximum loading (Fmax) and the minimal load (Fmin). The value R is defined as

R = Cmin/Cmax = 0.1

Fixing the value of the maximum loading allows determining the entirety of the experimental parameters. From the load diagrams obtained during the quasi-static tests, the level of Cmax is selected like a percentage of the maximum loading reached.
Thereafter, the tests concerning the same material will be indicated by this percentage (% Cmax).
It is important to keep in mind which this value strongly depends on material and the comparisons of the results will have to take account either of the value expressed as a percentage of Cmax or of the value of the Fmax load.
During the test, a sensor LVDT positioned in the center of the supports will allow to determine the arrow of the specimen. Since the test is controlled in load, this value will inform us about the evolution of the rigidity of material according to the number of cycle.
The end of the test is fixed at the first of the two criteria reached:

- 10^6 cycles
- the value of the arrow reached corresponding to the rupture for the quasi-static test.

During these tests, the evolution of experimental rigidity (N/mm) is determined, i.e. the slope of the load according to the arrow represented by the figure 4.

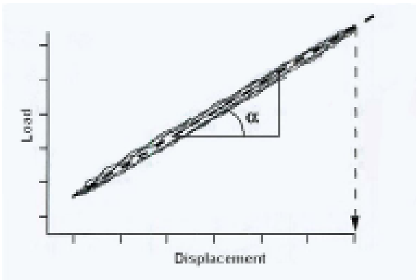


Figure 4. flexural rigidity

The evolution of this rigidity according to the number of cycles can either be expressed in raw data (N/mm) or expressed as a percentage of rigidity obtained at the time of the first cycles corresponding to initial rigidity which could be obtained during a quasi-static test (% Cmax).
The fatigue tests will be thus carried out to 25%, 50% and 75% of the maximum loading obtained during the quasi-static tests.

3.2 Unstitched material

The unstitched structure presents of the relatively weak performances compared to the stitched ones. The value of the maximum loading for a quasi-static deflection test 4 points is of 1300N and the deflection reached is of 15mm.

The results of the fatigue tests carried out to 25%, 50% and 75% of this maximum loading shows a very flexible behavior where the structure strongly becomes deformed and there is no really bending deformation between the central supports. The main part of the efforts is shearing in the external parts where the interface core/skin is requested.
Nevertheless the core/skin interface shearing failure is visible only for the strong loadings (75% Cmax). For the lower loading, no failure is noted.

The curve of Wöhler is made difficult to determine with precision by the lack of data of lifespan. Nevertheless the value with 75% of Cmax and the fact that the lifespan to 100% of Cmax is 1 cycle (quasi-static test) make it possible to give a tendency for the determination of lifespan according to the loading.
This type of material is not very sensitive to stresses of fatigue and the failure is principally due to interface core/skin breaking without skin failure.

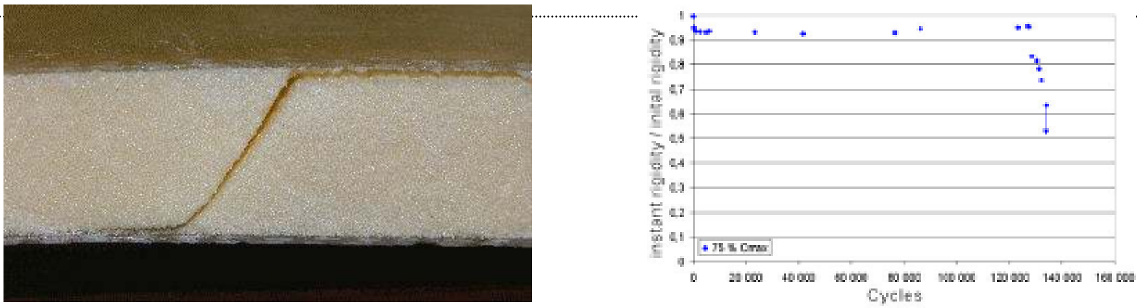


Figure 5. unstitched sandwich fatigue behavior (75% Cmax)

The first cycles make fall rigidity (figure 5) by micro cracking of the skins and the interface in a non-destructive way. After a stability phase during 100 000 cycles approximately, the failure starts in the interface and propagates by cracking of foam at45° (figure 5). The loading fall is then very fast.

3.3 Stitched material

With a 5000N maximum loading and a 18mm maximum deflection in static tests, the performances of the stitched structure are more important than the unstitched ones. To reach one lifespan of 10^6 cycles, a loading lower than 50% Cmax is necessary whereas the loading can reach 70% Cmax for the stitched sandwich.
The failure of this type of sandwich is involved not by the rupture of the interface core/skin but by the rupture of the skin. During cycles, rigidity does not cease decreasing synonym of a continuous propagation of degradations throughout the test (figure 6).

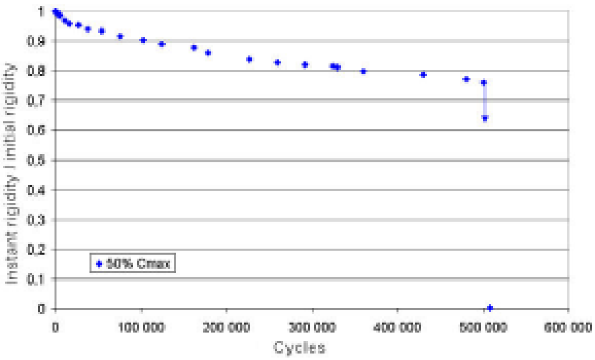
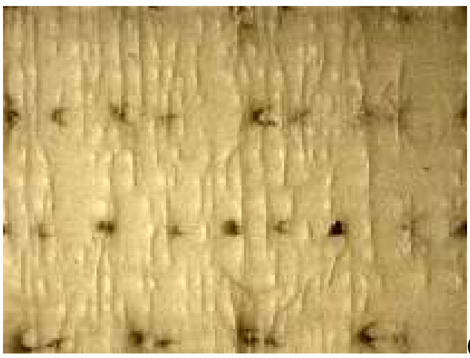


Figure 6. stitched sandwich fatigue behavior (50% Cmax)

Degradations of the skin are clearly visible during the test on the two faces of the sandwich (figure 7a): perpendicular cracks to the directions of stress (direction of the stitches) are uniformly distributed on all the surface of the specimen as well in the pure flexing area as in those presenting an association of bending and shearing.


(a)

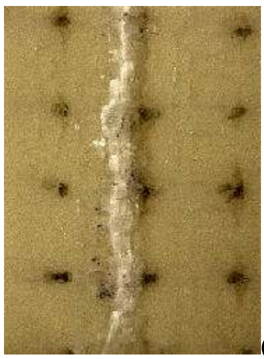

(b)

Figure 7. stitched sandwich degradations

The ruin of the material intervenes when a line of anchoring point of the stitches cracks over all the width of the specimen under the load noses (figure 7 b). The area of anchoring of the stitches concentrates the compressive stresses due to the supports and is weak by the stitches piercing through the skins.

3.4 Influence of the stitches presence

Although the unstitched structure seems more interesting in the case of cyclic stresses thanks to its relative insensitivity in term of lifespan, it is important to compare the two behaviors either while speaking in term about percentage about loading with static rupture but in absolute value about loading. Figure 8 gathers the two tendencies by giving the real values of load applied during the test.

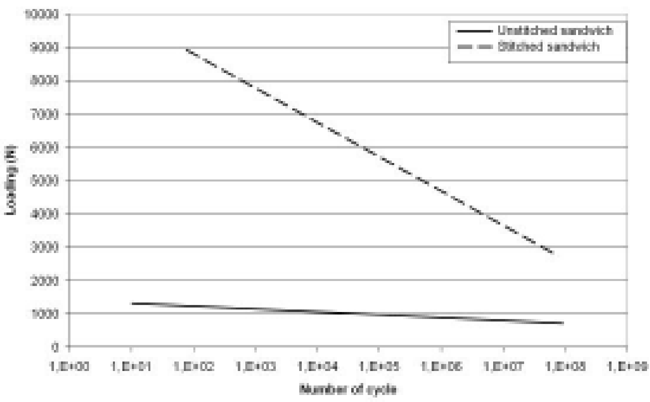


Figure 8. comparison of rigidity evolution according to lifespan

3.5 Influence of the stitches inter-penetration

The static tests revealed a critical importance of the interpenetration on the mechanical behavior of the total structure in particular at the time of the compressive forces.
In order to quantify the influence of this parameter on the fatigue behavior, a comparative study dealt with structure showing a strong rate of interpenetration versus a structure showing a weak rate. The material selected is the 12.5mm step stitched sandwich. With this type of material, a high rate of points of contact between the stitches can be obtained.

During the tests where the loading is average (50% Cmax), dispersion is very important while going from 300.000 cycles to 800.000 cycles as regards the lifespan. With a such important variation, it does not act any more dispersion but a sign of two phenomena (figure 9).

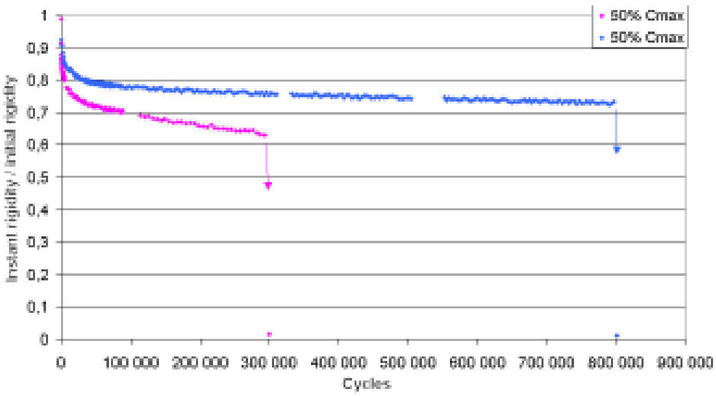


Figure 9. comparison of rigidity evolution according to lifespan

The loss of rigidity is carried out very quickly for the specimens with interpenetrate stitches and there is no plate phase but rather a slow continuous descent. The damages were initiated very early and are propagated quickly with the whole of the structure and involve its ruin.

For the test on material with shifted stitches, the initial loss is relatively fast and then it is stabilized in the form of the plate; the damages are propagated less quickly and are less penalizing for the structure.

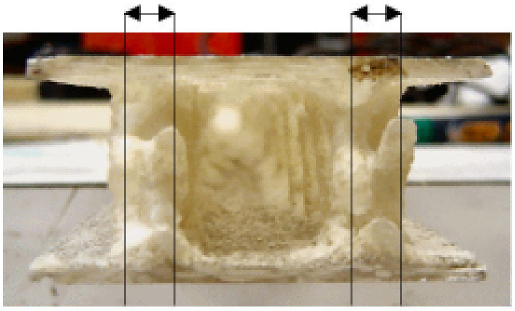


Figure 10. relative position of the stitches

The specimen presenting of the juxtaposed stitches represented by figure 10 has an important lifespan. On the other hand that which has one weak lifespan has strongly interpenetrated stitches.
The juxtaposition allows a better relative mobility of the stitches during test. The initiation of the damages observed in this case corresponds to the ruptures of the resin links between these stitches. The plate phase corresponds to the solicitation of the independent stitches. The complete rupture shows that in this configuration the relative movements of these stitches involve degradations in fatigue. Moreover, an interpenetration of the seams will tend to initially weaken the structure which will have a decreased lifespan thus.

4 CONCLUSION

The introduction of the stitches allows obtaining maximum efforts definitely more important than for classical unstitched sandwich structures. Moreover, these loadings can be supported for a greater period. Nevertheless the failure mode is clearly modified; the ruin intervenes thus by a failure of the skin in the case of a stitched sandwich whereas it intervenes by core/skin interface failure in the case of the conventional structures.
Lastly, the phase of stitching will generate substantial differences on the fatigue behavior. Thus, it is necessary to control the rate of interpenetration of the stitches yarns in order to be able to ensure one optimal lifespan.

5 REFERENCES:

1 : Z. Aboura, M.L Benzeggagh, F. Billaut, B. Dambrine "Mode I interlaminar failure of stitched textile composites materials: proposition of predictive reinforcement model", *ICCM 10 Vancouver* (august 1995)

2 : Z. Aboura, Y. Lamaa, M.L Benzeggagh “On the effect of the nature of three-dimensional preforms on the mechanical properties of CFRP”, *Composite Testing and Model Identification Châlon-en-Champagne*, 28-30 Janvier 2003