

Fatigue life of thermoset composite materials

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Abstract This article deals with the lifetime of laminated materials produced by different production technologies (hand lamination technology, vacuum bagging technology and prepreg technology with curing in the oven) during cyclic repeated bending stress. Like tested materials composite systems were chosen composite systems with epoxy matrix and carbon reinforcement (Kordcarbon CC200T, epoxy resin with trade name L285) and second composite epoxy system with glass reinforcement (Quadra-axial glass fabric, named Saertex Q-E-820, epoxy resin Biresin CR 82 and third prepreg systems (unidirectional prepreg, trade name Deltapreg VV430U-DT860W-39% and prepreg system with glass fabric VV320P_DT806R-37%). Fatigue tests were performed by cyclic bending loads during a three-point arrangement on a universal servo-hydraulic testing machine INSTRON 8871. Experimentally the number of cycles fracture of the material was determined at 90 % and 80 % of the maximum breaking load.

1. Introduction

Increasingly, there is a need to know the behaviour of composite materials in fatigue cyclic loading in the design and development of new products. Carbon laminates are characterised by excellent fatigue resistance. The best combination is the epoxy matrix/carbon fiber. Carbon composites with epoxy resin are very suitable material for cyclic and variable stresses because they resist well. The tensile fatigue limit of these composites is usually about 70 % of the static tensile strength; the AC tensile strength is about 35 % of the static tensile strength. Because these composites have a very favourable strength-to-weight ratio, their use is very advantageous for aircraft structures. The advantage is high fatigue strength due to static strength and its slight decrease with the number of cycles to fracture, high residual strength, low notch sensitivity, low sensitivity to loading frequency, as well as a small decrease in stiffness with the number of loading oscillations performed.

Another significant advantage is the possibility of obtaining the required stiffness, strength, Poisson number or preload by the appropriate layering of the desired layers. The disadvantages include weak compressive load resistance, squeezing and corrosion sensitivity when in contact with Al alloys and steels. A significant disadvantage is the absorption of moisture and the consequent deterioration of mechanical properties. However, by making a suitable design, these disadvantages can be overcome. Compared to metallic materials, the Wöhler carbon laminate curves are very flat, and there is no fatigue limit [1]. In connection with S-N curves, high-cycle and low-cycle fatigue should be distinguished. The first term identifies a situation of long fatigue life; that is, the voltage amplitude is sufficiently low, and thus, plastic deformation is not dominant for material behaviour.

High-cycle fatigue starts from 10^2 - 10^4 cycles. In addition to the position of the Wöhler curves, which determine the number of cycles failing, the residual lifetime, based on the cumulation theory of damage, is determined for a specific voltage and several cycles. The lifetime is exhausted if the sum of the individual damages is greater than 1. The advantages of using a carbon composite are mainly in low weight, high strength, excellent shock absorption properties, high durability and very favourable



fatigue characteristics. A comparison of the fatigue behaviour of carbon composites with other materials is shown in figure 1 [2-3].

The aim of the paper is to determine the fatigue life of fiber composites produced by the method of manual lamination.

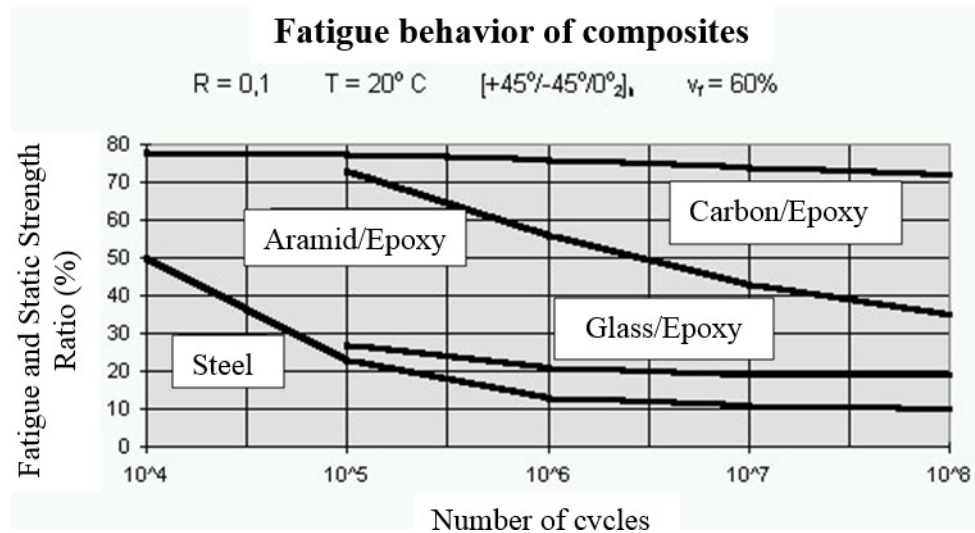


Figure 1. Fatigue behaviour of composites - comparison [3].

2. Testing methodology

Cyclic fatigue tests were performed on servo-hydraulic universal test machine INSTRON 8871, shown in figure 2. This machine is designed primarily for cyclic fatigue testing but it can be used also for static tests. The machine base is equipped with a T-groove, where a wide range of test components can be clamped for different types of tests. Fatigue tests were performed by a cyclic bending load in a three-point configuration. The distance between the supports was set the same as for the static test, 80 mm. The static bending test was carried out according to the CSN EN ISO 14 125 standards [4].

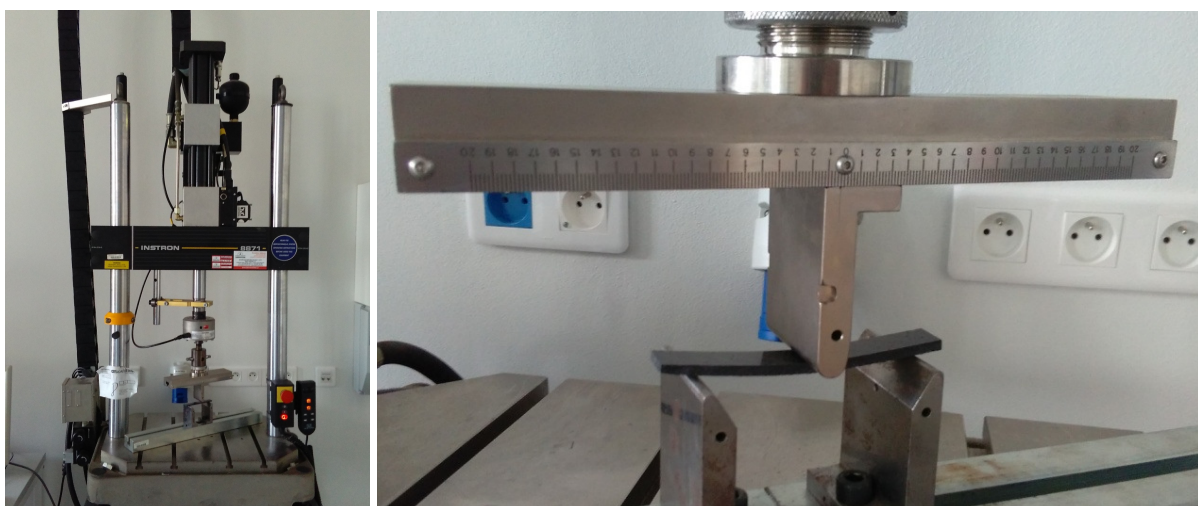


Figure 2. Cyclic bending test arrangement.

Several test measurements were made before performing the test itself. Subsequently, a load frequency of 6 Hz and two load sizes were selected - 80 % and 90 % of the maximum bending force found in the static test. Furthermore, the mean oscillation force F_s and the load amplitude F_a were selected. The load curve was sinusoidal, see figure 3.

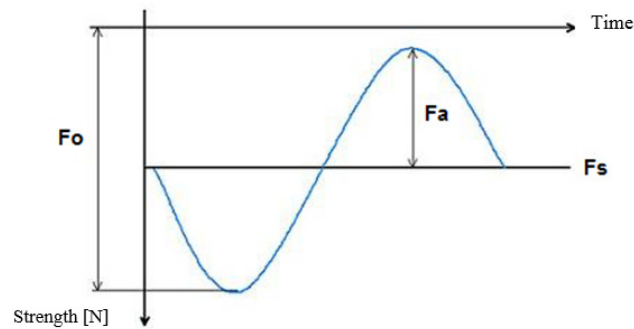


Figure 3. Cyclic loading.

3. Materials tested

Three types of materials were selected for testing, which differed in the reinforcement component and the production technology.

For fabric no. 1, carbon fabric was used as a reinforcing component from Kordárna Plus a.s., which is a direct manufacturer of these fabrics. The fibers are supplied by TORAY and bear the designation FT300B - 3000 - 40B. This fiber has a tensile strength of 3805 MPa and a tensile modulus of 232 GPa [5]. The carbon fabric used for the production of test specimens has the designation CC200 T - 100 KORDCARBON, weight 200g / m², twill weave, see figure 4.

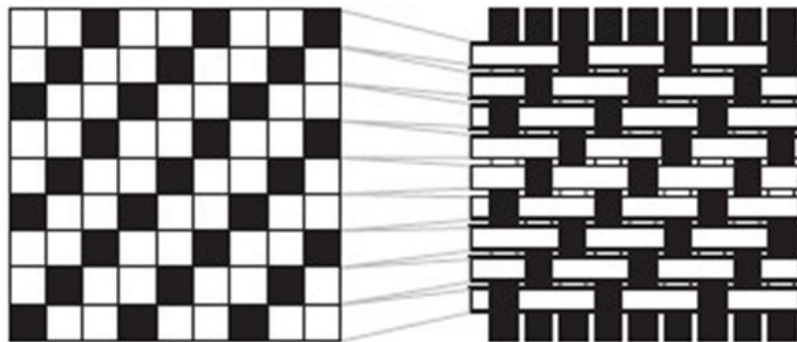


Figure 4. Twill weave pattern.

HAVEL L285 epoxy resin was used as a matrix together with H285 hardener in a 100:40 mixing ratio. This low viscosity epoxy system is designed to produce high static and dynamic load parts. It is suitable for hand lamination in combination with glass, carbon or aramid fibers.

A thin layer of the epoxy mixture was applied to the cleaned and separated form, and then the first layer of fabric was placed thereon. Subsequently, the fabric was soaked with an epoxy mixture using a brush (figure 5). A plastic spatula was used to displace any bubbles.



Figure 5. Production of the board by the method of manual lamination.

For the production of material no. 2, a 4-axial Saertex glass fabric was used. Q-E-820 samples consist of eight layers. The matrix was a Biresin CR 82 resin with a CH 80-1 hardener at a ratio of 100:27. These specimens were made by hand lamination as well as Kordcarbon specimens, but also vacuum compression was used, see figure 6. Test specimens for static and fatigue bending tests were machined from prepared cured plates to 20 mm × 100 mm.

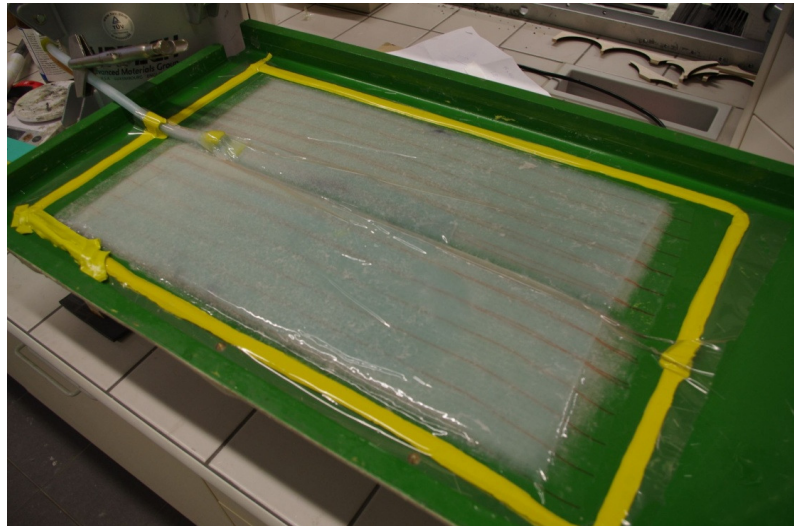


Figure 6. Vacuum pressing.

For the production of material no. 3, glass preregs (Deltapreg canvas VV320P and unidirectional UD Deltapreg VV430U) of the Italian manufacturer Delta were used. The sample plate produced consists of two types of reinforcing glass preregs - one-way prepreg with a density of 430g / m² and a prepreg screen with a density of 320 g/m². The UD prepreg is oriented in the axis of the test specimens; the canvas prepreg is oriented at an angle of 45°. The arrangement of the individual layers is shown in figure 7. The manufacturer used Deltatech DT806 epoxy resin as the prepreg matrix.

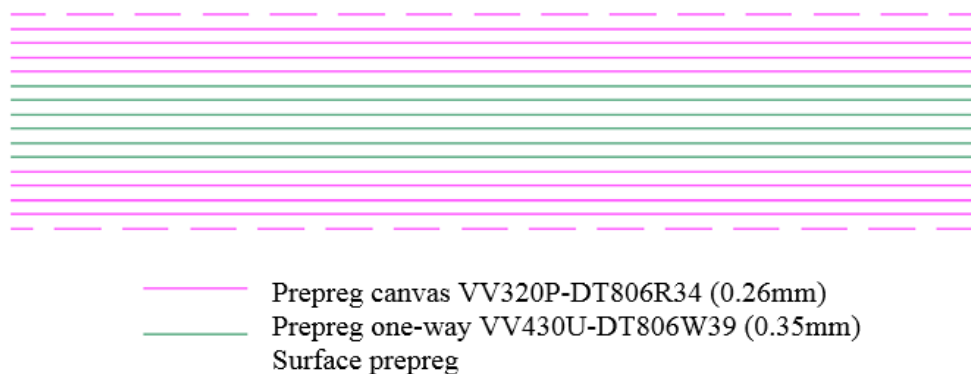


Figure 7. Arrangement of individual layers of fibreglass board

4. Results

The main result is the number of refractive cycles that the tested composites withstand the 80 % and 90 % of the static flexural strength, respectively.

4.1. Carbon Laminate Kordcarbon CC200T

At a load corresponding to 80 % of the static strength of the body, it was 150,000 cycles without failure and was subsequently subjected to a static test for residual strength.

Table 1. Comparison of average values of cyclically unloaded bodies and bodies after 150,000 cycles.

Kordcarbon CC200T	E [MPa]	σ_{fM} [MPa]
A cyclically unloaded test specimen	38600	597
150000 Cycles 80 % σ_{fM}	32450	572

After 150,000 cycles at 80 % strength, the test specimens showed a slight decrease in elastic modulus, or more specifically, 15 %. There was also a slight decrease in the strength limit, but this decrease is at the limit of measurement error.

Table 2. Number of cycles for Kordcarbon test specimens.

test specimen number	Number of cycles	
	load 80 % σ_{fM}	load 90 % σ_{fM}
1.1	150 000*	46 250
1.2	150 000*	78 541
1.3	150 000*	23 122

In table 2, significant differences in the number of cycles that the test specimens could withstand at 90 % strength were observed. These differences can be caused by defects in the structure of the material, such as bubbles or insufficient resin saturation at some points in the sample. The quality not only of carbon but also of other composites is very dependent on the careful production.

4.2. Fiberglass 4axial fabric Saertex Q-E-820

The number of cycles after which the specimens were broken are shown in table 3.

Table 3. Number of cycles for test specimen from 4-axial glass fabric.

test specimen number	Number of cycles	
	load 80 % σ_{fM}	load 90 % σ_{fM}
1.1	12 326	3 749
1.2	11 343	2 534
1.3	15 032	-

As can be seen from table 3, 4-axial fibreglass test specimens did not withstand many cycles for such high load levels.

4.3. Glass prepreg Deltapreg VV320P + VV430U

The number of cycles after which the specimens were broken are shown in table 4.

Table 4. Number of cycles for test specimen from glass prepreg.

test specimen number	Number of cycles	
	load 80 % σ_{fM}	load 90 % σ_{fM}
1.1	85 821	12 073
1.2	108 249	20 487
1.3	102 460	19 452

Glass prepreg specimens withstood relatively high cycles compared to 4 axial glass fabric specimens. Prepreg products have a high proportion of fiber reinforcement, thus achieving excellent mechanical properties. Compared to the standard lamination technology, the fiber reinforcement is evenly saturated here, which improves fatigue resistance many times over.

5. Discussion

Deltapreg glass prepreg specimens withstood much more cycles than Saertex 4-axial fiberglass specimens. A comparison of the number of cycles is shown in figures 8 and 9.

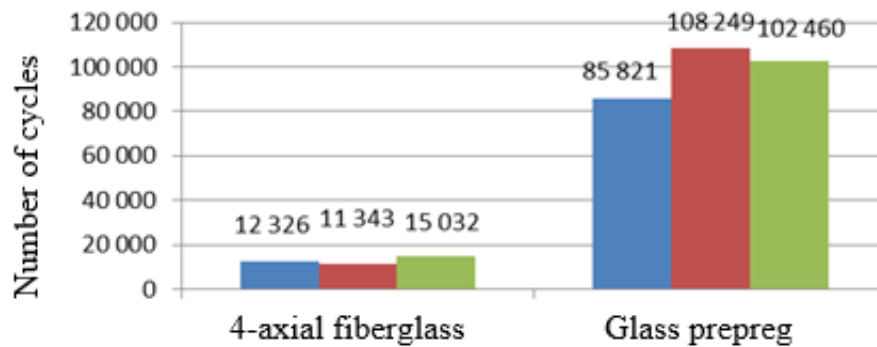


Figure 8. Comparison of the number of cycles of fiberglass under a load of 80 % σ_{fm} .

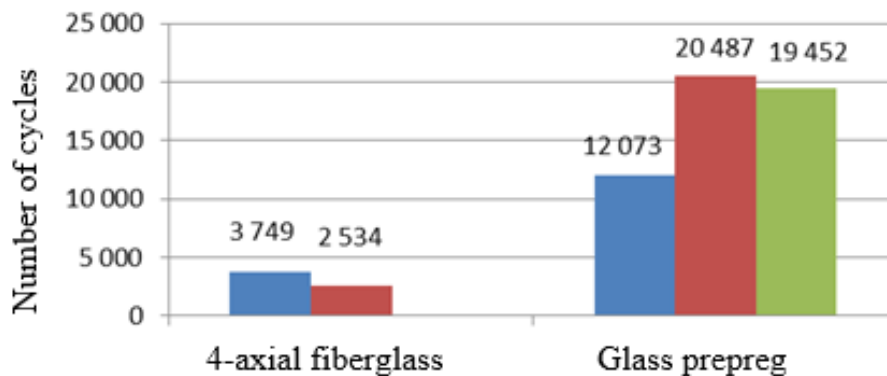


Figure 9. Comparison of the number of cycles of fiberglass under a load of 90% σ_{fm} .

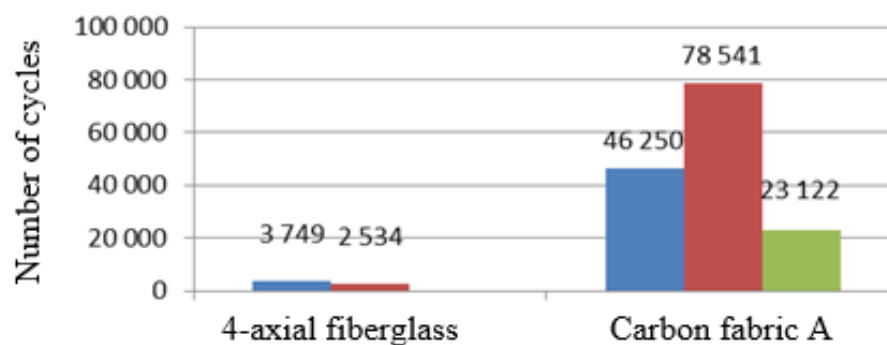


Figure 10. Comparison of the number of cycles of glass and carbon laminates under load 90 % σ_{fm} .

Glass prepreg specimens have shown a relatively good fatigue life not only against 4-axial fiberglass specimens but also compared to carbon fabric specimens. At a load of 80% of the flexural strength, these test specimens withstood on average 98.800 cycles, while the Kordcarbon CC200T carbon fabric housings withstood this load of 150.000 cycles without breaking the specimen, see figure 11. The comparison of the number of cycles at 90 % stress limit for Kordcarbon CC200T and Saaxtex 4axial fiberglass is shown in figure 10.

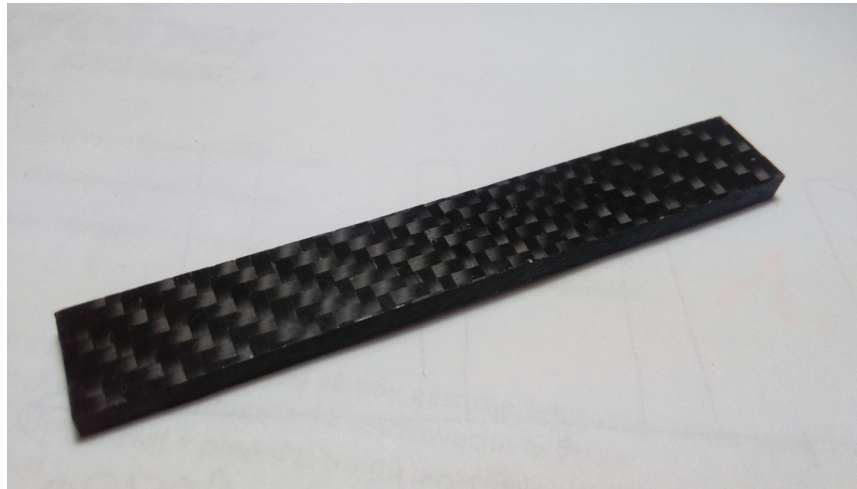


Figure 11. Kordcarbon CC200T carbon fabric test specimen after 150,000 cycles without damage.

6. Conclusion

The results of the experiments show that the carbon composite Kordcarbon CC200T achieves the highest durability. The second place in terms of durability under cyclic loading is the material made of a combination of glass prepreg Deltapreg. On the contrary, the worst material of durability under cyclic loading was the composite made of four axial glass fabric Saertex Q-E-820, produced by the method of manual lamination followed by vacuum pressing.

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