

## **Study of the effect of frequency on composite laminates under uniaxial fatigue loads**

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### **ABSTRACT**

Composites are nowadays widely used in primary structures. For safety reasons, the characterization of these materials under fatigue loads is being a very important task. The main advances in this field have been made in glass fiber composites, due to their use in turbine blades, where the fatigue is a crucial factor.

The characterization of a unidirectional carbon fibre composite material under fatigue loads is presented in this paper. The objective of the study is to obtain the S-N curve of the material at several frequencies and for different fibre orientation angles.

For this purpose, fatigue tests under tension-tension at 0, 15 and 45 degrees for several frequencies (10 Hz, 15 Hz and 18 Hz) have been carried out.

**KEY WORDS:** Composite materials, fatigue, frequency, testing.

### **1. INTRODUCTION**

The present use of composite materials in aircraft primary structures causes that knowing of fatigue behaviour becomes an important task. The effect of frequency on fatigue behaviour of graphite-epoxy composites has been reported by Kawai and Taniguchi [1] for fabric laminates. These authors observe different fatigue behaviour associated to different frequency values in off-axis tension-tension tests, and pointed out that high frequency values can cause overheating of the resin during tests. Aircraft structural components under realistic service conditions are subjected to complex fatigue a load spectrum that involves changes in frequency, amplitude, mean and waveform. Therefore the effect of frequency is a factor to consider in the fatigue behaviour of composite laminates.

The characterization of a unidirectional carbon fibre composite material under fatigue loads is presented in this paper. The objective of the study is to obtain the S-N curve of the material at several frequencies and for different fibre orientation angles, in order to allow to observe the influence of frequency. For this purpose, fatigue tests under tension-tension at 0, 15 and 45 degrees for several frequencies (10 Hz, 15 Hz and 18 Hz) have been carried out. Finally, results for different orientations have been compared using a non-dimensional representation (Kawai [2]).

### **2. COUPONS AND TEST PREPARATION**

Two kinds of tests have been done: static and dynamic tension tests. In both cases, the

dimensions of the coupons are the same, i. e., 1 cm width, 20 cm length and 1 mm thickness, according to the standards ASTM D3039 [3] for the static tests and ASTM D3479 [4] for the dynamic tests.

To obtain these coupons of a graphite/epoxy (AS4/8552) material, three panels of 4 layers each have been done, one for each fibre orientation (0°, 15° and 45°). Two coupons have been tested for each orientation and for each kind of test.

The manufacturing of the panels have been done using a vacuum bag for compaction of layers and autoclave for the curing process.

Once cured, the panels have been machined in a diamond disc saw to obtain the coupons at the correct dimensions. Previously to this step, tabs have been adhered to the sides of the panel to improve the grip of the clamps to the coupons during the test.

In the case of the static test, the objective is to obtain the maximum strength that the coupons are capable to resist, for each fibre orientation.

Once obtained the ultimate strengths, these values are used to obtain the stress levels for the dynamic tests, as a percentage of the maximum strengths. The dynamic tests will show the number of cycles that the material is capable to resist at each stress level. The curve that approximate this values is called the S-N curve of the material.

The static tests have been done in an Instron 4483 electromechanical testing machine controlling the displacement at a speed of 0.5 mm/min.

The dynamic tests have been done in an Instron 8801 hydraulic testing machine controlling the load, using a sinusoidal function with a parameter  $R$  of 0.1, being

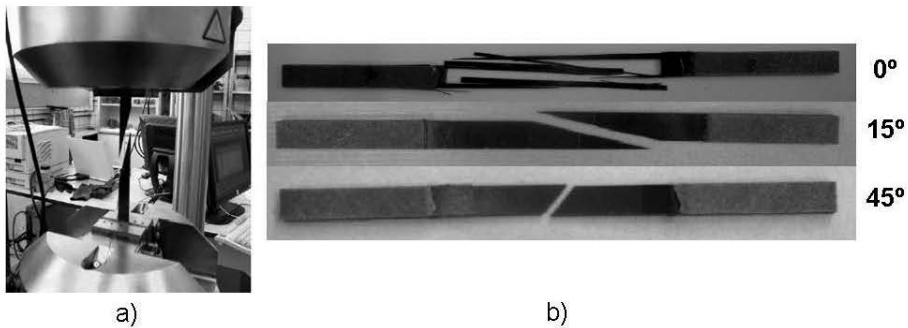
$$R = \frac{\sigma_{\min}}{\sigma_{\max}} \quad (1)$$

As said before,  $\sigma_{\max}$  is calculated as a percentage of the maximum tensile static strength.

The frequencies used in the tests have been 10 Hz for the reference configuration and a higher frequency (15 Hz in the case of the 0° coupons and 18 Hz in the case of the 15° and 45 ° coupons) to observe the effect of the frequency increase. The difference in the higher frequencies has been caused due to the limits of the testing machine.

During fatigue tests, a thermocouple has been placed on the coupons to measure the temperature of the material.

A view of a dynamic test and three coupons after testing is shown on figure 1.



**Fig. 1. a) View of a dynamic tests. b) Three coupons after testing, one of each orientation**

### 3. TEST RESULTS AND ANALYSIS

The results of the tests are presented next.

#### 3.1 Static tests

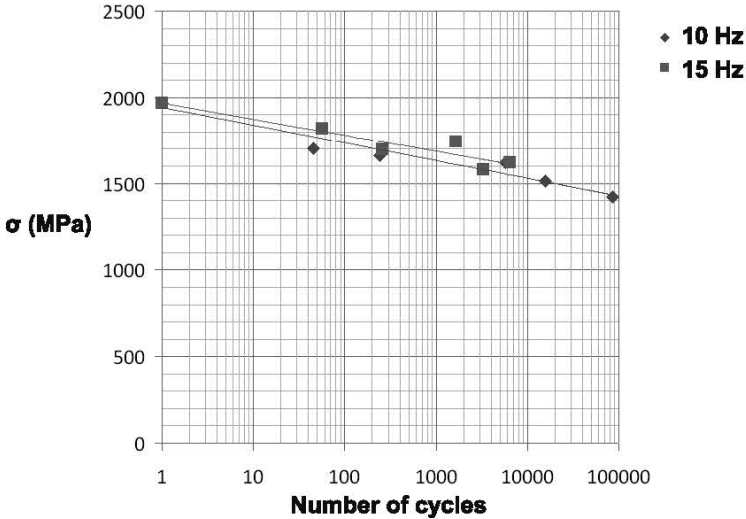
The mean values obtained from the results of static tests are shown in table 1. These values have been used to obtain the loads for the dynamic tests.

<b>Orientation angle (deg)</b>	<b>Tensile strength (MPa)</b>
0°	1948
15°	369
45°	95

**Table 1. Mean values of the static tensile strength for on-axis and off-axis orientations.**

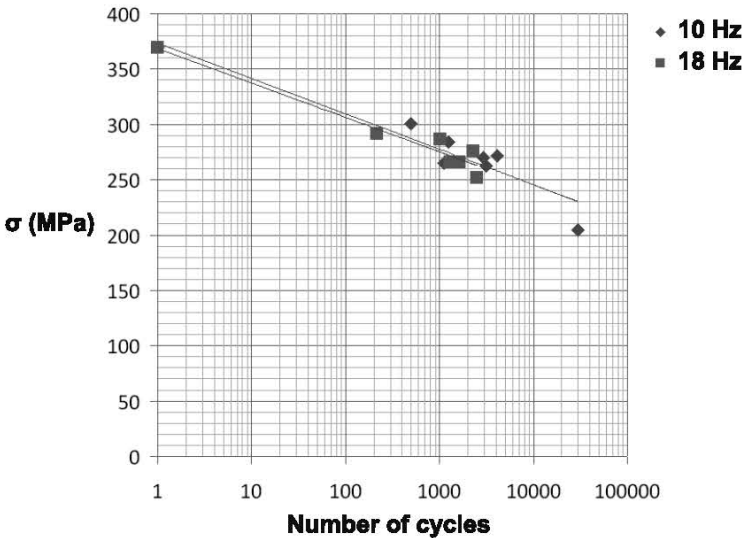
#### 3.2 Dynamic tests

The 0° coupons have been tested at 90, 85, 75 and 70% (for the frequency of 10 Hz) and 90, 85, 82 and 80% (for the frequency of 15 Hz) of the maximum strength. The values of the cycles needed to reach the failure in the coupons at these stress levels were obtained. All these values for the two frequencies tested (10 Hz and 15 Hz) and the trend curves that approximate best these points are shown in figure 1. The differences in the load levels were due to technical problems in the testing machine.



**Fig. 1. S-N curves for the 0° coupons at 10 Hz and 15 Hz**

As in the previous case, the values and the trend curves for the 15° coupons are presented in figure 2, for load levels of 85, 75, 70 and 65% (for the frequency of 10 Hz) and 80, 75, 70 and 65% (for the frequency of 18 Hz) of the maximum strength.



**Fig. 2. S-N curves for the 15° coupons at 10 Hz and 18 Hz**

As in the previous case, the values and the trend curves for the 45° coupons are presented in figure 3, for load levels of 85, 80, 75 and 70% (for the frequency of 10 Hz) and 90, 85, 80, 75, 70 and 65% (for the frequency of 18 Hz) of the maximum strength.

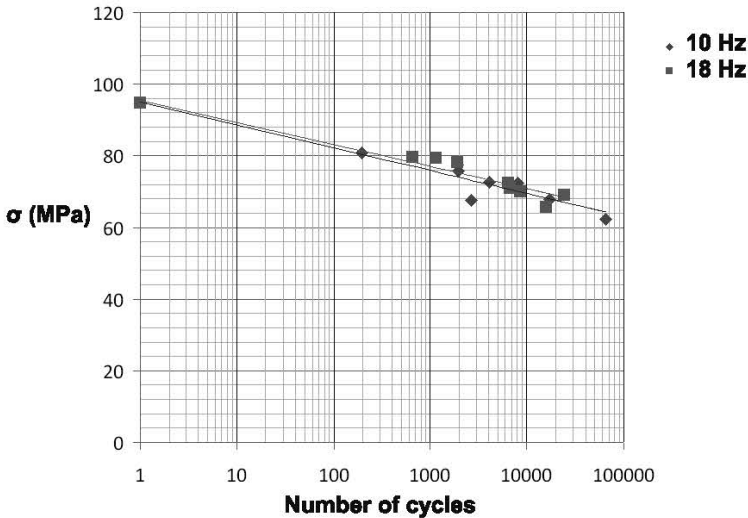


Fig. 3. S-N curves for the 45° coupons at 10 Hz and 18 Hz

### 3.3 Analysis of the results

It can be seen that the results follow a law like

$$\sigma = A \log N + B \quad (2)$$

being  $A$  and  $B$  constant values. There is a little dispersion from this trend.

The evolutions presented in figures 1-3 show that there is almost no effect of the frequency in the S-N curve of the unidirectional laminates. Only in the case of the 0° coupons can be appreciated a little influence of the frequency.

As said before, a thermocouple was used to measure the temperature of the coupons during the tests. After completing the test campaign, it can be asserted it wasn't appreciated any rise in the temperature of the coupons in the unidirectional composite parts under fatigue loads in the range of life studied.

To compare the several frequencies, a dimensionless parameter (Kawai [2]) has been chosen, given by the stress ( $\sigma$ ) divided by the maximum strength ( $\sigma_{\max}$ ) for the different orientations. The evolution of the fatigue life with this dimensionless parameter is presented in figure 4. Due to the distribution of the experimental results when representing them with the dimensionless parameter, it can be drawn a safety band that cover all of these values, as shown on figure 4. This way, the fatigue behavior of unidirectional laminates can be deduced, for any orientation, from the knowledge of the fatigue behavior of a 0° orientation laminate.

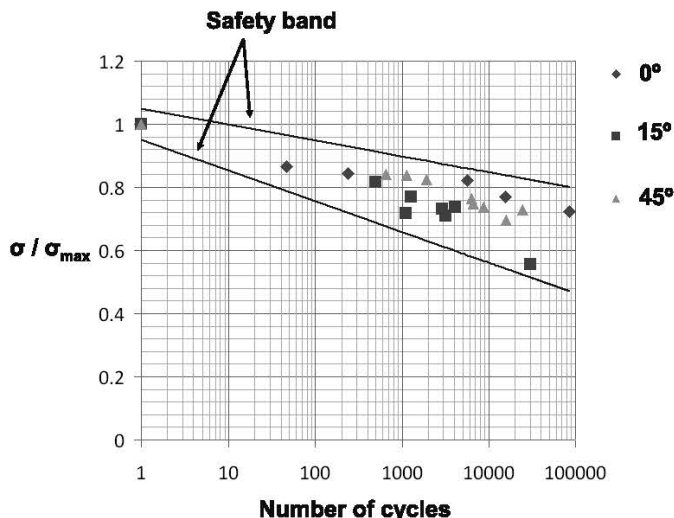


Fig. 4. Dimensionless comparison of the S-N curve for the  $0^\circ$ ,  $15^\circ$  and  $45^\circ$  coupons

#### 4. CONCLUSIONS

The objective of this work has been to study the influence of the frequency at different orientations of the fibres in the life of composite unidirectional laminates.

The results have shown that frequency has a little influence in fatigue behavior of unidirectional composite laminates. This fact has been confirmed by controlling the temperature of the coupons during the tests, haven't shown relevant variations.

The main consequence of this work is that, for  $0^\circ$  fatigue characterization tests, these tests can be done at higher frequencies than the usual ones, finishing the tests in less time.

#### ACKNOWLEDGEMENTS

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