INFLUENCE OF PROCESS CONDITIONS ON THE FATIGUE BEHAVIOUR OF AUTOCLAVE MOULDED LAMINATES

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Abstract

In the present work, three glass/epoxy $[0/90_2]_S$ laminates were manufactured in autoclave following different process conditions to study the influence of the microstructure and defect content on the long-term performances of composite laminates.
The first panel was cured at a pressure of 5 bars using a non-perforated release ply. Given the low fibre vlume fraction of the prepreg, the second panel was cured at a pressure of 5 bars using a perforated release ply to increase the resin drainage, and moving ain the same direction the third panel was cured at 7 bars using a perforated release ply. The three processes lead to laminates characterized by different fibre volume fraction and porosity contents.
Specimens extracted from all the panels were tested under uniaxial tension-tension fatigue at four load levels. The damage evolution, consisting of initiation, propagation and multiplication of cracks in the off-axis plies, was monitored throughout all the tests and found to be sensibly affected by the fibre and void content, thus highlighting the need to account for the actual microstructure in the design of composite structures.

1. Introduction

Manufacturing-induced defects, and in particular the presence of voids, have a large detrimental influence on the mechanical properties of composite materials, under both static [1-6] and fatigue [7-12] loadings.

To quantify the effect of porosity on the performances of composites is then necessary to increase the safety of the structure, and, together with the relations between process parameters and porosity content, to develop *cost-effective* production processes.

In this direction, a recent work by the authors [12] dealt with the influence of micro-sized voids on the fatigue behaviour of glass/epoxy laminates made by infusion, showing a large detrimental effect of porosity on the fatigue performance of $[0/90_2]_S$ and $[0/45_2/0/-45_2]_S$ laminates.

To observe the influence of voids on composite laminates made with a different manufacturing process than infusion, in this work an experimental campaign is carried out on glass/epoxy $[0/90_2]_S$ laminates made by autoclave moulding, to analise the influence of process conditions on the microstructure and the defect content, and on their long-term behaviour.

2. Materials and methods

Three $[0/90_2]_S$ composite panels were produced with UE400/REM glass/epoxy prepregs, following different processing conditions, and characterized by the fibre volume fraction V_f and the porosity content (void area fraction A_v and the void equivalent diameter D_v).

The first panel ("Panel 1") was cured at a pressure of 5 bars using a non-perforated release ply, thus not allowing any resin bleeding. It was characterized by a fibre volume fraction $V_{f1} = 0.38$, a void area fraction $A_{v1} = 0.44\%$ and a void equivalent diameter $D_{v1} = 67$ μm. The second panel ("Panel 2") was produced keeping the same curing pressure (5 bars) but using a perforated release ply, allowing the resin to bleed. For the second panel, $V_{f2} = 0.58$, $A_{v2} = 0.73\%$ and $D_{v2} = 40.8$ μm. Finally, the third panel ("Panel 3") was produced with a pressure of 7 bars and a perforated release ply, resulting in $V_{f3} = 0.60$, $A_{v3} = 1.56\%$ and $D_{v3} = 40$ μm.

The three laminates were tested under tensile-tensile fatigue with a MTS 858 Mini Bionix testing machine, at a frequence of 10 Hz. Four global stress levels were used: 50, 60, 70, and 80 MPa.

To monitor the damage evolution (initiation and propagation of multiple transverse cracks, see Figure 1), a linear camera was placed in front of the specimen and connected with the testing machine, so that scans of the specimen could be done automatically at regular intervals during the tests [12]. To help the crack detection, a light source was placed behind the specimen. To monitor the stiffness drop due to the damage evolution, an extensometer was used in all the tests. The whole experimental setup is shown in Figure 2. To automatically detect the transverse cracks from the pictures, a previously developed Matlab® tool was used [12].

The influence of the microstructure on the fatigue behaviour was quantified in terms of life to first crack initiation, crack growth rate, crack density evolution and stiffness drop.

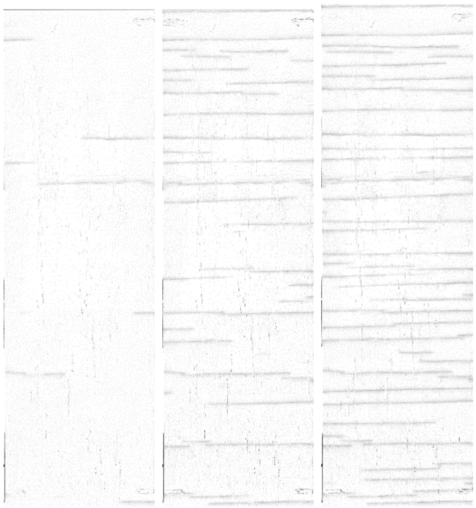

Figure 1. Example of fatigue damage evolution in $[0/90_2]_S$ laminates.

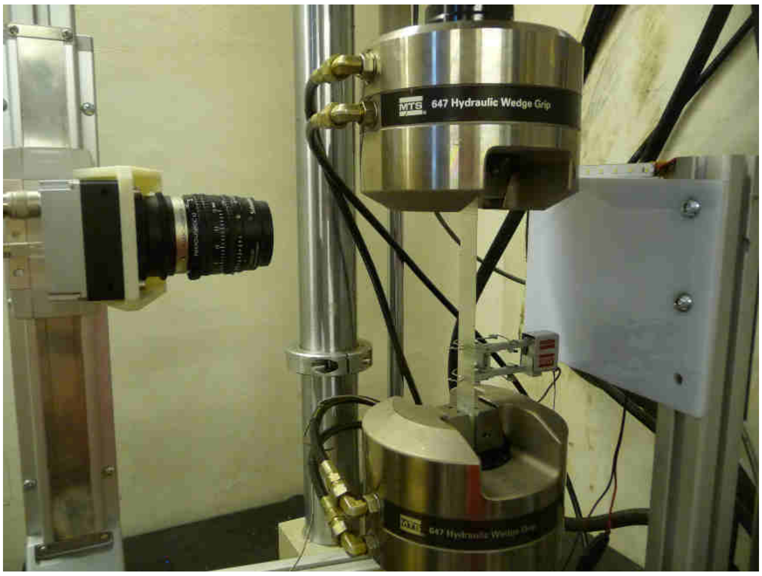

Figure 2. Experimental test setup. A linear camera is mounted in front of the specimen and a light source is place behind it to monitor the transverse crack evolution during the tests [12].

3. Fatigue test results

The preliminary results of the fatigue tests are reported in Figures 3 and 4 for Panels 2 and 3. The effect of a larger void content is clear on the life to crack initiation of the two panels, that appears to be around a decade smaller for Panel 3 compared to Panel 2. The slope of the S-N curve does not appear to be influenced by the void content, as found also in Ref [12] for infused laminates.

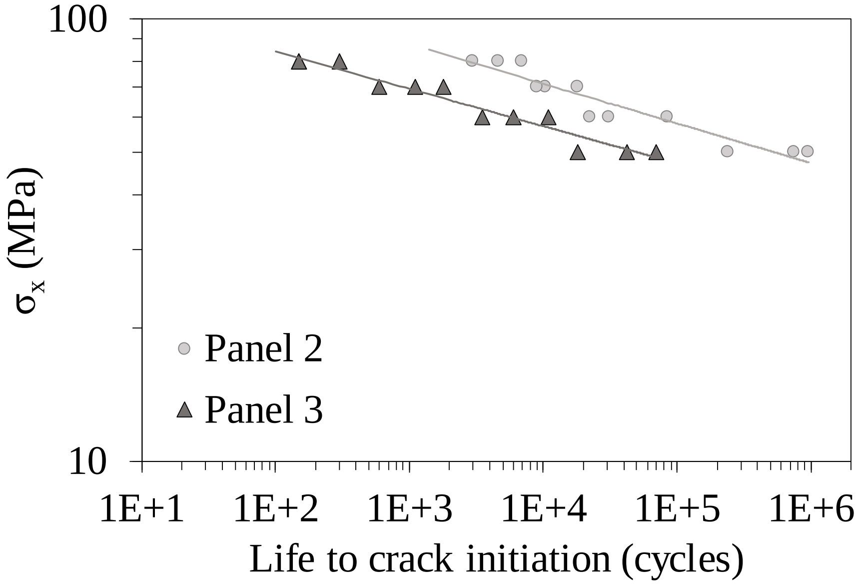

Figure 3. Life to crack initiation for the three laminates.

Also the crack propagation rate was found to be higher for Panel 3 compared to Panel 2, thus resulting in a faster evolution of the *weighted* crack density, defined as [13]

$$\rho_w = \frac{\sum_{i=1}^{n} c_i}{w \cdot L} \tag{1}$$

The faster damage evolution reflects in a faster stiffness drop of Panel 3 compared to Panel 2. In Figure 4 the stiffness trends of the two panels during their fatigue life are reported for a global applied stress of 70 MPa.

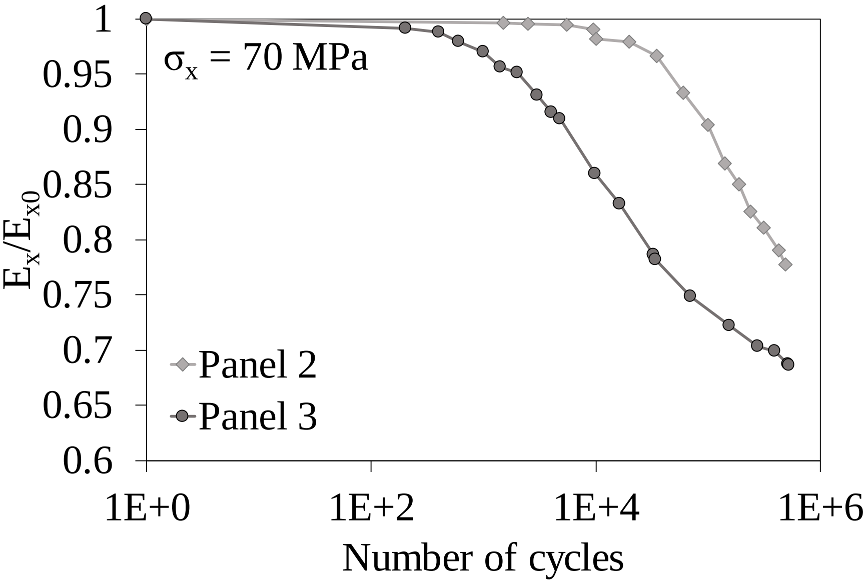

Figure 4. Stiffness drop for the three laminates under σ_x = 70 MPa.

4. Conclusions

In the preent work, three laminates were produced in autoclave by varying the curing pressure and the possibility for the resin to bleed, to study the influence of manufacturing conditions on the microstructure and on the long-term performances of composite materials.

At a pressure of 5 bars, the fibre volume fraction was seen to increase when the resin was allowed to bleed, but also the void content increased by a small amount (Panel 2). On the contrary, when 7 bars of pressure were used while allowing the resin to bleed, the fibre volume fraction increased by a small amount, while the void content increased more sensibly, due to an excessive bleeding (Panel 3).

Preliminary fatigue test results showed that voids have a large detrimental influence on the fatigue The life to crack initiation for Panel 3 was found to be a decade smaller than that of Panel 2. For Panel 3, also, the crack growth rate was found to be higher, leading to a faster damage evolution and consequently faster global stiffness drop.

The experimental results shows first that the autoclave processing conditions largely affect the fibre volume fraction and porosity content, and, in turn, the fatigue behaviour of the laminate, thus highlighting the need to properly account for the actual microstructure for the advanced design of composite structures.

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