# EXPERIMENTAL ASSESSMENT OF FATIGUE DAMAGE MECHANISMS IN $[0_4/90_n]_s$ LAMINATES USING CARBON-EPOXY ULTRATHIN PLIES

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The damage mechanisms of cross-ply laminates under fatigue loading have been deeply studied during last years ([1]–[5]). Transverse cracking, delaminations and fibre breakage are the main fatigue damage mechanisms which occur in cross-ply laminates ($[0_4/90_n]_s$), appearing mainly in this order. In a recent publication, París et al. [6] have explained physically the *scale effect* based on the quasi-static damage mechanisms involved in failure. Hence, the objective of this experimental work has been to observe the fatigue damage mechanisms appearing in cross-ply laminates with the 90º layer for both conventional and ultrathin thicknesses to explore if there is any effect on them due to the thickness of the 90º layer.

To reach this purpose, two different $[0_4/90_n]_s$ laminates have been manufactured using the carbon/epoxy prepreg TP402/T700 with both 30g/m$^2$ and 150g/m$^2$. The two selected stacking sequences have been $[0_4/90_3/0_4]$ and $[0_4/90/0_4]$. Whereas all 0º plies have been manufactured with 150g/m$^2$ prepreg for both laminates, 150g/m$^2$ prepreg has been used for the 90º plies in the former and 30g/m$^2$ prepreg for the 90º ply in the latter. In what follows, $[0_4/90_3/0_4]$ is referred to as CP-450 and $[0_4/90/0_4]$ as CP-30.
Both laminates have been manufactured in a clean room and cured in an autoclave using a vacuum bag. Once cured, glass-epoxy tabs have been bonded to both panel sides in the gripping zones and, afterwards, the panels have been cut into the specimens as recommended in [7]. The specimen dimensions are shown in Figure 1, with $L_s$=180mm, $w$=25mm, $L_t$=55mm. All coupons have been sanded and polished to observe the damage on their free edge by means of an optical microscope.

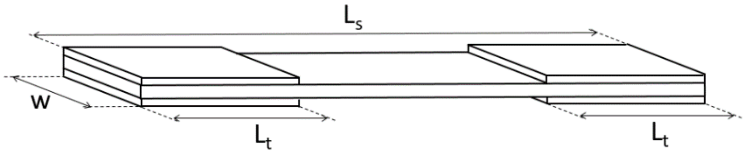

**Figure 1.** Scheme of specimen and its dimensions.

Both laminates have been tested quasi-statically, obtaining their ultimate tensile force ($F_u$): 67.54kN for CP-450 with a coefficient of variation of 4.67%, and 64.02kN for CP-30 with a coefficient of variation of 6.71%.
The cyclic tests have been performed in an Instron 8801 hydraulic testing machine, controlling the load by means of a sinusoidal function with a force ratio of 0.1 and a frequency of 1Hz. CP-450 samples have been tested at 60, 40 and 30% of its ultimate tensile force and CP-30 ones at 60 and 30%.

In relation with CP-450, the experimental results have been analysed through the transverse crack density ($\rho_{TC}$) for each number of cycles in which a stop has been done, defining $\rho_{TC}$ as the number of transverse cracks divided by the total gauge length in mm. Figure 2 shows an example for 40% of $F_u$. In this thick laminate transverse cracks have appeared since the first cycle for every force level.

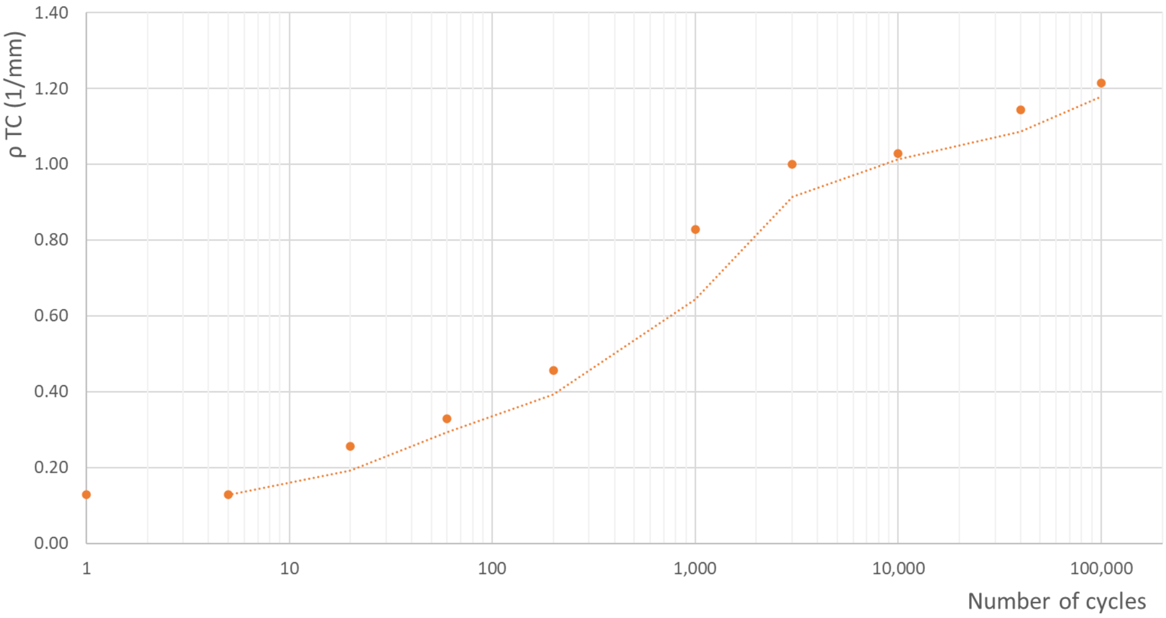

**Figure 2.** Transverse crack density evolution versus number of cycles at 40% of $F_u$ and 1Hz.

According to the presence of the second damage mechanism, delaminations induced at the transverse crack tips, which appears under fatigue loading, CP-450 specimens have noticeable shown it after different number of cycles at each force level.

In relation with CP-30, the experimental results have been treated as the number of damages for each number of cycles. In this case, different types of damage have been observed and they have been classified as: isolated debonds (ID), isolated-continued debonds (I-CD) for a path of debonds which have not kinked, and generalised transverse damage (GTD) for a path of debonds which have not kinked and have progressed from one 0º/90º interphase to another. A damage can develop from ID to I-CD and finally to a GTD. The results at 30% of Fu are shown in Figure 3.

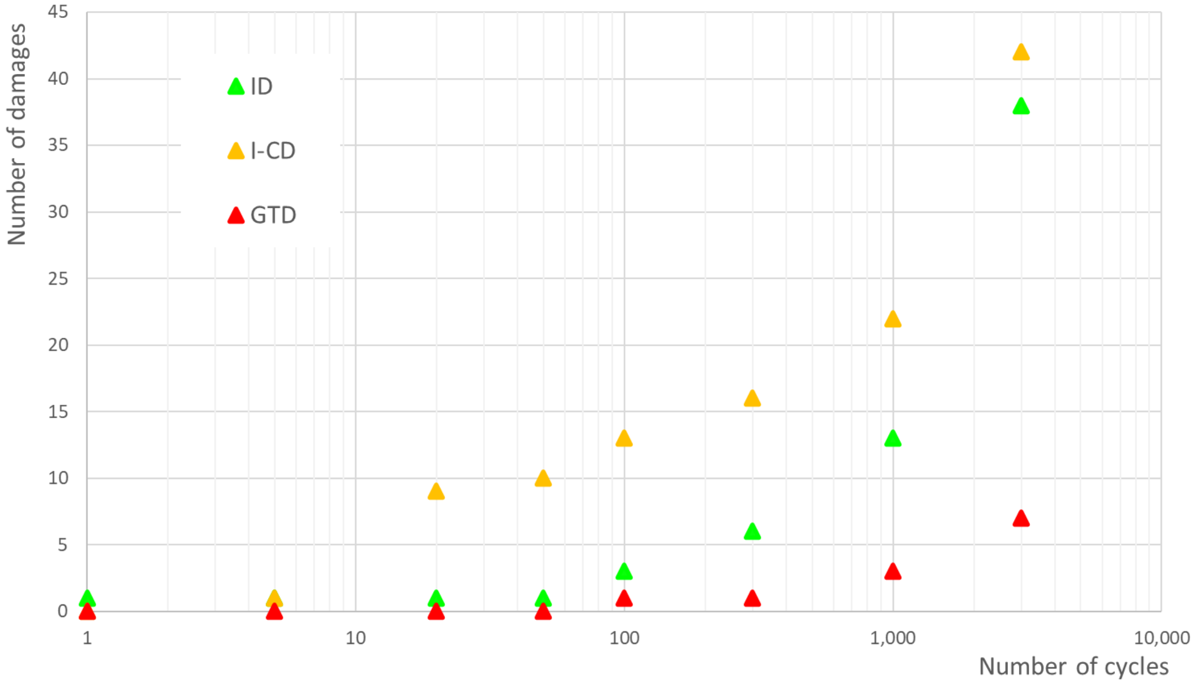

**Figure 3.** Number of damages versus number of cycles at 30% of $F_u$ and 1Hz for CP-30.

From Figure 3, it can be observed how the different damages evolve without triggering neither transverse cracks nor delaminations at the maximum number of cycles tested ($3 \cdot 10^3$ cycles). At 60% of $F_u$, the same situation has been produced.

The main difference found between both cross-ply laminates tested under cyclic loading for the number of cycles explored is the different level of damage observed in relation with the thickness of the 90º layer. These experimental observations correlate well with [6]. More experimental work needs to be done to comprehend profoundly how fatigue damage mechanisms initiate and propagate up to the final failure when ultrathin plies are used.

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