

Failure mode of thermohydroscopically aged composites: case of NC2[®] carbon fibre laminates

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1. INTRODUCTION

Stitched multiaxial laminates NCF can be a new high performance preform for manufacturing complex structures by RTM or infusion processes (LRI). Nevertheless, the stitching leads to a particular morphology with resin-rich regions inside the material, as illustrated Figure 1. The latter become critical areas and a specific crack network will develop in the bulk of the laminates when they are subjected to the hygrothermal ageing cycles. To a better control of the cracking behaviour within the resin-rich regions under certain aeronautical application in service, a thermal/hygrothermal-mechanical coupling at different ageing states has been investigated by the full-field image correlation at mesoscopic level: 1/ material at initial state; material with initiated cracks 2a/ in plane (at 135° ply), 2b/ in thickness (at 90° plies) and finally 3/ material with large cracks developed in all resin-rich regions inside plies. The 0°-tensile test was applied throughout all testing configurations, strain gauges and microscopic observations helped to validate the obtained results. The typical material studied was NC2[®] (Non Crimp New Concept) - a specific family of NCF, of sequence QI [135/0/45/90]_s and stitching yarn PET 76dtex.

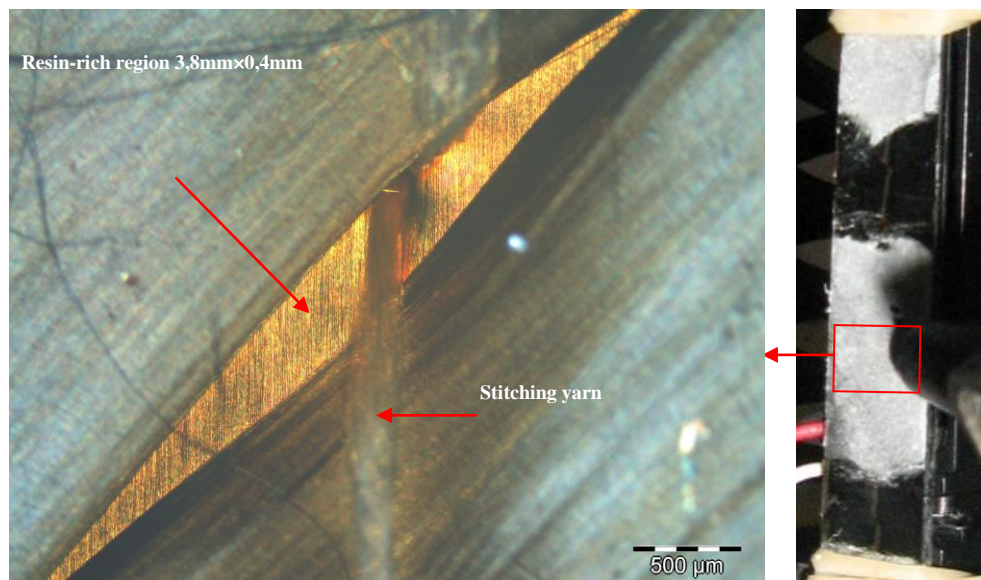


Figure 1. Perturbation of the fiber arrangement around stitching yarn.

2. METHODS

2.1. 2D digital image correlation

2D digital image correlation principle has been described already by many authors [1]. The specific implementation used here has been described in [2]. Only a brief recall is given, with a focus on original parts. Sub-pixel estimation is based on the generalization of the Grid Technique using the Windowed Fourier Transform (WFT) algorithm proposed by Surrel [3]: phase estimations are performed on a set of local Zone Of Interest (ZOI). This approach takes advantage of the mathematical background of phase processing; for example, an implementation has been proposed to extract directly the phase gradient and the strain from intensity maps [4]. Lens distortion is corrected using a 2D regular grid, as proposed in [5]; note that no camera model is necessary.

2.3. Mesoscopic scale crack propagation

Application here requires a high spatial resolution and low noise level. Specific studies were made to evaluate noise level and spatial resolution, using procedures described in [6]. Using a 32x32 ZOI, the spatial resolution, defined as the radius of the autocorrelation function of noise at 50% attenuation, is 4.26 pixels. But, the microscopic level (1 pixel \Leftrightarrow

4.7 μm) increases the displacement noise: the resolution is 0.123 pixel which is 10 times higher than usual. Here we developed a specific temporal filtering: each pixel is filtered using a set “previous” and “posterior” values at the same location. Displacement is monotone, and 20 images are taken for a displacement corresponding to 1 pixel. But the filter must take into account the nature of the image encoding, a random pattern of mean size 3 pixels. Then, intensity level for a given point is a polynomial interpolation of values along time. Limits of the filtering window has to be discussed: it has been established that using 8 images i.e. 0.4 times the number of images inducing a 1 pixel shift, noise is reduced by a factor of 3, and no blur appears if at least a 4th order interpolation is used.

3. RESULTS AND DISCUSSION

At the initial state, it has been shown that the presence of resin rich regions doesn't induce a specific damage mode, and that the material failure cannot be related to local crack initiation at the surface of the specimen. Then, after hygrothermal cycling, cracks in resin rich regions are completely developed. Experimental tests anyway show that even if cracks open during the loading process, the displacement values remain small, and can be related to the sub-surface deformation. Again failure seems to be disconnected to stitching perturbations. Now, if hygrothermal cycles are such that only an incomplete cracking situation is achieved, does mechanical loading makes cracks propagate? For the chosen quasi-isotropic sequence, no propagation could be detected in plane. During, all the experiments, even if the tensile test has been carefully controlled (and in particular the clamp alignment), the first failure appears in the mid-plane of the specimen. Displacement and strain measurements were made on the specimen thickness (Figure 2). In a first step, an initial crack due to aging is active. But a 2nd vertical crack appears and develops whilst the 1st one remains of the same size. Last, the 2nd crack continues to spread but still do not reach the 1st till the specimen failure. It is worth noting that the laminate is made of two stitched NC2 parts, linked together by continuous resin layers due to stitching lines at the inter-layer; failure happens as if these two parts were strongly cohesive and glued together as long as the resin layers break. Finally, no indication is found that the failure is related to the hygrothermal cracking in the local resin rich region of the NC2. It seems that the failure is more related to the laminate arrangement.

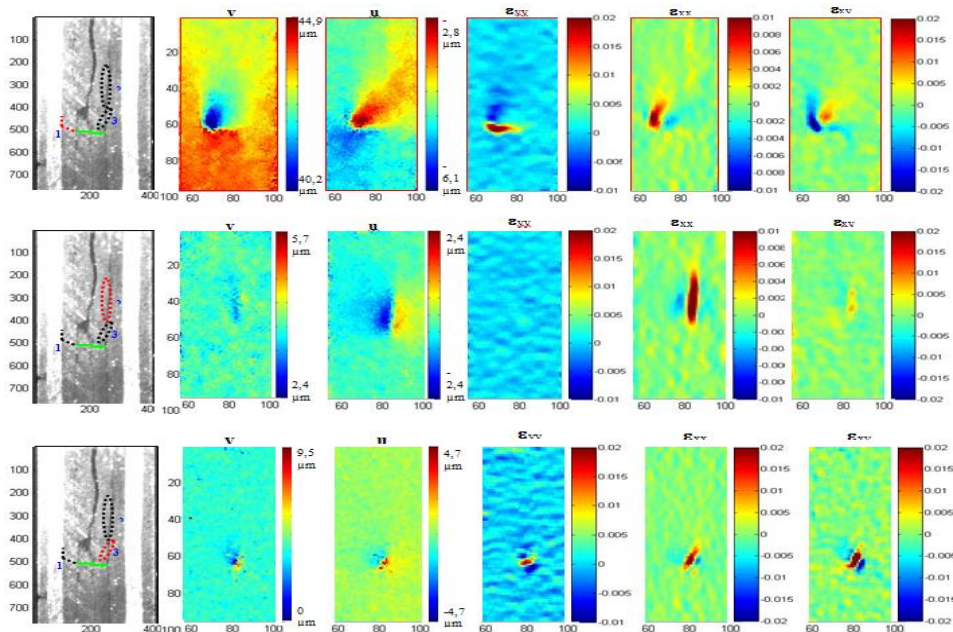


Figure 2. Iterative crack propagation through the thickness on a hygrothermally cycled [135 90 45 0]_s NC2 composite.

References

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