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CRACK DENSITY GROWTH OF HIGH TEMPERATURE CROSS-PLY LAMINATES SUBJECTED TO ELEVATED TEMPERATURES

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ABSTRACT

In aircraft industries, current efforts includes extending use of long fiber reinforced Polymer Composites (PC) in aero-engine structures towards temperatures up to 200°C or above. In such use, the PC experiences long term exposures to high temperatures, thermal cycling, static and fatigue loading. These loadings may introduce damage in the PC and consequently degrades the stiffness [1]. Hence it is important to understand and predict the damage growth in PC. The damage in this work refers to transverse crack density (= number of transverse cracks per unit length) growth. The scope is to predict the transverse crack density growth for as-built as well as thermally cycled high temperature PC when subjected to quasi-static tensile loading at room temperature (RT) and Elevated Temperatures (ET). For that purpose, using resin transfer molding technique, Uni-Directional (UD) laminate and three cross-ply laminates $[0/90_2]_s$, featuring Carbon Fiber (CF) made of UD fabric with sparsely woven yarns in both warp and weft direction reinforced in heat resistant resin, were manufactured. The thicknesses of the manufactured cross-ply laminates i.e., Plate1, Plate2 and Plate3 are 1.21mm, 1.09mm and 0.96mm respectively. The thermo-elastic constants were experimentally determined from the UD laminate. Coupon sized specimens were prepared from cross-ply laminates with edges grinded and polished to facilitate optical microscopic observation of the damage state in 90° layers. Selected specimens from Plate2 and Plate3 were isothermally heat treated at 150°C in air for 500 hours (during which specimens were removed 7 times from oven for weight measurements) and 1000 hours (where specimens were removed 10 times from oven for weight measurements).

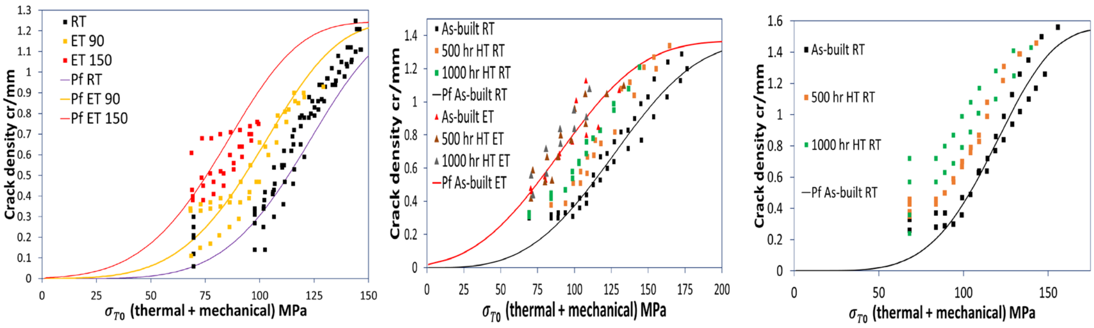
When observing the edges of the as-built cross-ply laminates under microscope, it was found that the bundle structure of the carbon fabric remained intact despite highly compacted during manufacturing. Also resin rich regions, incorporating warp and weft yarns, were observed surrounding the bundles. In addition to that, several manufacturing induced transverse cracks were observed in the edges, which probably developed due to the residual stress built up during cooling down from manufacturing temperature. Also, these cracks were observed to pass through or in the vicinity of warp yarns. The warp yarns acted as a weak region which influenced the initiation and path of the transverse cracks' growth along thickness direction in the edges. The influence of warp yarns in crack growth was observed upon continuous loading. After heat treatment, the crack density was observed to increase. From an additional experiment, where a specimen was thermally cycled between RT and 150°C for 40 times, it was confirmed that the thermal cycling has caused the increase in crack density from heat treatment. Quasi-static tensile tests were performed in the as-built (from Plate1-3) and thermally cycled (heat treated) specimens (from Plate2 and Plate3) with a constant displacement rate of 2 mm/min. In RT tests, specimens were loaded to predetermined strain levels to introduce damage in 90° layers and then unloaded. The strain was measured within 50mm from the middle of the specimens using an extensometer. Stiffness was measured and crack density was quantified from edges, before and after every damage inducing loading step. Likewise at ET tests, the specimens were

preheated to 150°C in environmental chamber attached to tensile testing machine while holding at 2N, until specimens reach thermal equilibrium. Later they were loaded to predetermined strain level to introduce damage. After unloading, the specimens were exposed to ambient temperature. Then specimens were tested for stiffness and crack density was quantified from edges by optical observation.

Plate1 specimens were static tested at RT, 90°C and 150°C. The crack density growth versus applied thermo-mechanical transverse stress in 90° layers were already discussed in [2] and are given in Figure 1a. The similar test results of Plate2 specimens were described in [3] and are given in Figure 1b. As-built and thermally cycled Plate3 specimens were static tested at RT and the corresponding test results are given in Figure 1c. From the Figure 1, it can be observed that when both as-built and thermally cycled specimens static tested at RT and ET, there was a steady increase in crack density upon continuous loading. Also, the crack density in as-built specimens tested at ET and thermally cycled specimens tested at RT and ET were higher at the same applied thermo-mechanical transverse stress as in the as-built specimens tested at RT. This could be probably due to the decrease in resistance to transverse cracking in specimens when thermally cycled and when tested at 150°C. Based on Weibull distribution model described in [3], the Probability of Failure (P_f) approach was developed to predict the transverse crack density growth in specimens tested at RT and ET. The Weibull distribution model is described using shape parameter m, scale parameter σ_0 and location parameter σ_c. σ_c incorporates the effect of test temperature. The P_f at an applied thermo-mechanical transverse stress σ_T is,

$$P_f = 1 - exp\left(-\left(\frac{\sigma_T - \sigma_c}{\sigma_0}\right)^m\right), \qquad (1)$$

The predictions based on (1), had good agreement with the test results, see in Figure 1a-c. The current work is being done on incorporating thermal cycling effect in Weibull distribution model by assuming the cyclic (fatigue) effect as monotonic degradation of the scale parameter. The expected prediction model could possibly address the transverse cracking resistance in PC when they are subjected to static tensile loading after several thermal cycles or after several flight mission cycles in realistic scenario.



a) b) c)

Figure 1: Transverse crack density growth versus applied thermo-mechanical transverse stress in 90° layer in a) plate1 specimens b) plate2 specimens c) plate3 specimens; HT refers to thermally cycled specimens; Continuous lines are prediction results based on P_f.

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