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SELF-HEATING ANALYSIS OF HYBRID THIN-PLY LAMINATES SUBJECTED TO CYCLIC MECHANICAL LOADING

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ABSTRACT

Development of thin-ply composites in the last decade has opened up new possibilities for designing high-performance lightweight and flexible structural components with increased damage resistance, ductility and multifunctionality [1,2]. In addition to improved mechanical properties thin-ply hybrid laminates can be simultaneously utilized as multifunctional materials owing to beneficial physical properties of constituents. For example, glass fibers have good electrical insulation properties and carbon fibers have good thermal conductivity properties. Such multifunctional hybrid composites have great potential for application in structural electronics [2], structural batteries [3], aerospace and automotive industry among others. In the present work carbon/glass thin-ply laminates with various lay-ups and different layer thicknesses were studied experimentally. Laminate specimens were subjected to cyclic mechanical loading with relatively high frequency, which causes self-heating of composite and accelerates the fatigue failure [4-5]. A detailed investigation of self-heating within the laminate was performed in the present work using high-resolution thermal imaging camera.

Carbon/glass thin-ply laminates were manufactured using Textreme carbon fiber plain weave fabrics from Oxeon (Sweden) with areal weight of 100g/m^2 and glass fiber plain weave fabrics from Interglas (Germany) with an areal weight of 80g/m^2. Epoxy resin LY1564 from Huntsman (USA) with XB 3404-1 hardener was used as the matrix. Fabrics were hand stacked into 6 different lay-ups and two reference materials (purely carbon fiber/epoxy and purely glass fiber/epoxy composites). Vacuum infusion technique was used for epoxy infusion into the stacked dry fabrics. Composite plates were cured in an oven at 80°C temperature for 8 hours. Hybrid carbon/glass laminates with various combinations of single, double and quadruple carbon and glass fiber layers were manufactured for the purpose of parametric analysis regarding their self-heating and heat transfer behavior. All plates including the reference material plates consisted of 16 layers.

The main objective of the present work is to parametrically investigate self-heating of hybrid carbon/glass thin-ply laminates subjected to cyclic mechanical loading. Mechanical loading was performed on Instron E10000 dynamic testing machine, equipped with a ±10 kN load cell. The tests were carried out in tension-tension cyclic loading regime with fixed maximum and minimum strain levels. In order to observe a clearly measurable self-heating effect during the cyclic loading, relatively large loading frequencies (20 – 30Hz) were applied. Maximum applied tensile strain levels were in the range from 0.4% up to 0.9%. Heat generation and temperature distribution within laminate layers were measured using a high-performance and high-resolution thermal imaging camera FLIR A6752sc. In order to perform a detailed temperature change monitoring in thin laminate layers, the camera was equipped with FLIR 1X microscope lens. All cyclic loading tests were started at room temperature and the cyclic loading of specimens was conducted until reaching steady state thermal conditions at which no significant further temperature increase was observed. After reaching the steady state temperature (typically within 7-8 minutes) the cyclic loading was stopped but the specimen was kept in the tensile machine grips until complete cool-down back to room temperature. The temperature distribution and change in the force was also recorded during the cool-down step.

The results for reference carbon/epoxy laminates (CR) were analyzed first. As expected, it was found that higher applied maximum strain level leads to larger self-heating and higher temperatures recorded during the test. The effect of loading frequency (20-30 Hz) on self-heating for CR laminates was found to be relatively small (see Fig.1a). Results for glass fiber reference laminates (GR) subjected to 20 Hz cyclic loading frequency at different maximum strain levels are shown in Fig.1b. In Fig.1 relative increase of average temperature (ΔT) in test specimens with respect to initial (room) temperature is plotted on the vertical axis. In general, Fig.1b shows that self-heating increases significantly with increased maximum strain level. Compared to CR laminates, results indicated higher self-heating of GR laminates when subjected to equal loading conditions. Finally, the work also investigated and compared the self-heating of various carbon/glass hybrid laminates. A clear dependency of self-heating on laminate lay-up and maximum strain level was observed. Notably, the hybrid laminate lay-up with the most distributed layer configuration and with carbon/epoxy external layers demonstrated the highest self-heating compared to other studied hybrid laminate lay-ups.

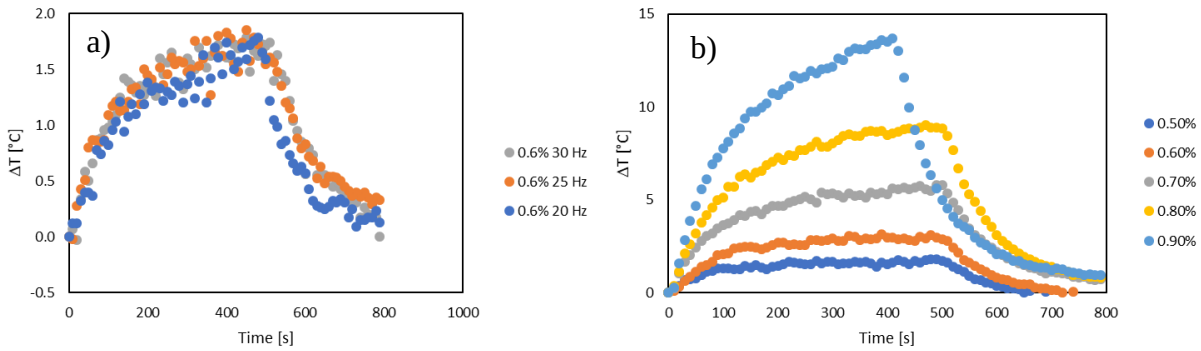

Figure 1: Change of average temperature during cyclic loading followed by unloading in: a) carbon epoxy (CR) reference laminates at various loading frequencies; b) glass/epoxy (GR) reference laminates at 20Hz loading

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