AXIAL FATIGUE AND CONSTANT LIFE DIAGRAMS OF A CARBON NANOFIBER BASED-HIERARCHICAL CARBON FIBER/EPOXY BIAx ±45° LAMINATE

Daniel R. Bortz*, César Merino† and Ignacio Martin-Gullon*†

* Department of Chemical Engineering
University of Alicante
Campus de San Vicente del Raspeig, Ap. 99 E-03080, Alicante, Spain
e-mail: bortz.d@gmail.com, gullon@ua.es, web page: http://www.ua.es

† Grupo Antolín Ingeniería
Ctra. Irún 244, E-09007, Burgos, Spain
e-mail: cesar.merino@grupoantolin.com, web page: http://www.grupoantolin.com

Key words: Fatigue, Fiber reinforced polymer, Carbon fiber, Carbon nanofibers, Hierarchical composites.

ABSTRACT

We report the results of a comprehensive characterization of the axial fatigue performance of an all-carbon hierarchical composite laminate, in which small amounts (≤1 wt.%) of a carbon nanofiber (CNF) reinforcement are utilized alongside traditional micron-sized carbon fibers. As-received CNFs (GANF, Grupo Antolín Ingeniería) were dispersed in an epoxy matrix (Resoltech 1800/1805) through three-roll calendar milling. The dispersions were subsequently infused into 300 mm² dry fabric preforms by the vacuum assisted resin transfer molding (VARTM) technique. Primary fibers were arranged as a unidirectional fabric (HexForce® 48200 TA 600). Plies were biaxially oriented [±45°]₆ to the loading direction and fiber volume fraction was approximately 0.55 for all test panels. Coupons were sinusoidally loaded at 5 Hz under load control at R = 10, -2, -1, -0.5 and 0.1 (R is the ratio of minimum to maximum load in a fatigue cycle). Data were fit to a power law model and presented as mean and 95/95 confidence level S-N diagrams. The S-N diagrams were used to construct stress based constant life diagrams in order to compare the hierarchical and similarly prepared unreinforced groups in the full range of constant amplitude loading conditions.

Results indicate that the biax CNF-reinforced composites collectively possess improved fatigue and static strengths over their unmodified counterparts. The most significant increases in fatigue life were specific to purely compressive loading, where carbon composites are traditionally very sensitive to fatigue cycling. Here, mean fatigue life was augmented by nearly an order of magnitude over the full range of experimental stress amplitudes. In all cases, fully reversed loading (R = -1) produced the shortest fatigue lives at a given stress amplitude. However, the CNF-reinforced laminates still increased the million-cycle strength
by approximately 10%. These findings are attributed to the high interface density of the CNF-reinforced matrix better controlling the multi-scale aspect of fatigue related damage. Specifically, it is the ability of the nanoscale-reinforcing phase to accept and redistribute small-scale strains from the epoxy matrix during the preservation of the CNF/matrix interface. Further strain energy absorption is expected upon CNF de-bonding and subsequent void nucleation. These mechanisms are able to delay the onset of micro-scale fatigue damage, which is a precursor to crack coalescence and ultimately catastrophic failure. The current results are both promising in their own right and should encourage further development of these high performance, all-carbon hierarchical systems for fatigue intensive applications.