§19. Cryogenic Fatigue Delamination Growth in Material Systems for Superconducting Fusion Magnets

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1. Purpose

Glass fiber reinforced polymer (GFRP) woven laminates are widely used for the insulation of superconducting magnet coils in future fusion reactors. The study of composite laminates actually involves many topics, such as, for example, manufacturing processes, anisotropic elasticity, micromechnics, and fracture and damage mechanics. Delamination is a primary mode for failure of composite laminates. Therefore, the susceptibility of composite laminates to initiation and growth of delaminations must be considered already at the design phase. The resistance to delamination is normally characterized by fracture toughness, and test standards have been developed to measure delamination fracture toughness under various modes of loading at room temperature (RT). However, prediction of initiation and growth of delaminations is complicated and the success of the predictions relies on accurate interlaminar toughness data for the material under both static and fatigue loading and at different environmental conditions. Furthermore, few data are available on composite laminates at low temperatures. This study presents experimental and numerical results on the fatigue delamination growth behavior of GFRP woven laminates at low temperatures[1]. A previous study[2] deals with the translaminar crack growth behavior in woven laminates, whereas the present work focuses on research to understand the interlamilar crack growth.

2. Procedure

The composite laminate sample was cut into rectangular specimens for double cantilever beam (DCB) testing. All the tests were conducted using a 30 kN axial loading capacity servo-hydraulic testing machine at RT, liquid nitrogen temperature (77 K), and liquid helium temperature (4 K). The constant force amplitude tests were performed in sinusoidal load control at a frequency of 2 Hz and a constant load ratio, $R = 0.1$. A scanning electron microscopy was also used in observations of fatigue delamination growth mechanisms for each environment.

A three-dimensional finite element analysis was made, and the *J*-integral range was calculated. The failure criteria (Hoffman criterion and maximum strain criterion) were incorporated into the model to study the damage distributions within the DCB specimen.

3. Results

(1) Fatigue delamination growth rates of the GFRP woven laminates at low temperatures were much lower than that at RT. The Mode I cyclic fatigue delamination growth rate da/dN in SL-EC woven laminates is shown in Fig. 1 as a function of the *J*-integral range ΔJ at RT, 77 K and 4 K. (2) The dominant fatigue delamination growth mechanisms were different at RT and low temperatures. At RT, fiber/matrix debonding was the main fracture mechanisms. However, at low temperatures, both fiber/matrix debonding and brittle fracture of matrix were the dominant fatigue delamination growth mechanisms. (3) The finite element method coupled with damage can be used to predict the damage zone within the woven laminates DCB specimen. The cryogenic fatigue delamination behavior is not significantly affected by the damage.

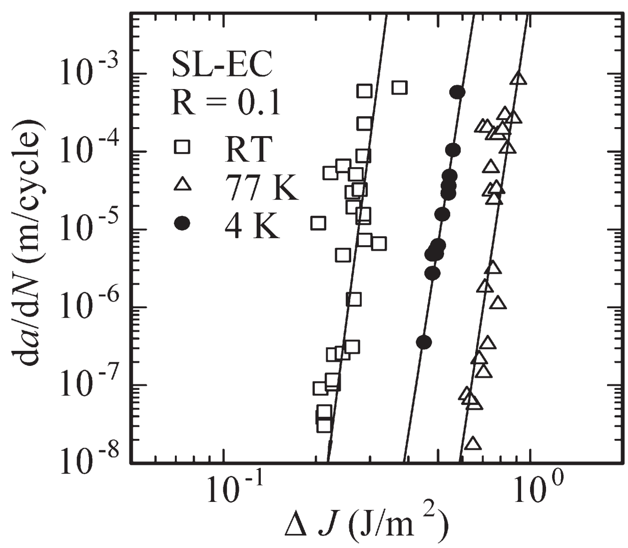

Fig. 1 Cyclic fatigue delamination growth rate in SL-EC woven laminates at RT, 77 K and 4 K (load ratio R=0.1, frequency 2 Hz).

References
1) Shindo, Y., Inamoto, A., Narita, F. and Horiguchi, K.: Eng. Fract. Mech., in press.
2) Shindo, Y., Inamoto, A. and Narita, F., Acta Mater., 53 (2005) 1389.