§3. Development of Strength Evaluation Methods of Cryogenic Material Systems

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1. Purpose

Superconducting magnets for use in fusion reactors may use large quantities of nonmetallic composite materials. There are a variety of applications where GFRP (glass fiber reinforced polymer) woven laminates can provide thermal insulation, electrical insulation and structural support. The reliability and safety of the fusion reactor are entirely dependent on good design which in turn rely heavily on predictable materials performance. However, a great deal of confusion has arisen in recent years surrounding the general topics of fracture and fatigue of the composites. Due to heterogeneity in fiber reinforced composites, fracture and fatigue processes emanating from crack tip are far more complicated than those occurred in metals. The composite materials made from woven-fabric glass/epoxy laminates have poor through-thickness properties, poor impact damage tolerance, and low interlaminar fracture toughness. Depending on the microstructural details of the composite and the magnitude of the cyclic stress concentration, fatigue crack growth and subsequent fracture of the composite materials can be very complicated in nature. The purpose of the present study is to characterize the fatigue crack growth behavior of woven fiber reinforced epoxy composites at low temperatures. The study was undertaken using both experimental and simulation work in an effort to contribute to the understanding of the basic mechanisms governing cyclic fatigue crack growth in these composites[1]. This combined numerical-experimental study used CT (compact tension) specimens.

2. Procedure

Fatigue crack growth rate tests were performed with CT specimens at room temperature (RT), liquid nitrogen temperature (77 K), and liquid helium temperature (4 K) in accordance with ASTM (American Society for Testing and Materials) E 647-00[2]. The fracture surfaces were also examined by SEM (scanning electron microscopy) to correlate with the fatigue properties. A finite element method coupled with fatigue damage was adopted for the extensional analysis. The effects of temperature and loading condition on the fatigue crack growth rates are examined.

3. Results

(1) Fatigue crack growth rates for the CT specimens of GFRP woven laminates decrease with decreasing temperature from RT down to 77 K but the values at 4 K are higher than those at 77 K. Cyclic fatigue crack growth rate da/dN in G-11 woven laminates for the CT specimens is plotted in Fig. 1 as a function of the J-integral range ΔJ at 77 K and 4 K. (2) The fiber/matrix adhesion of fracture surfaces for the CT specimens is increased with decreasing temperatures. (3) Fiber/matrix debonding and fiber pull-out are the main fracture mechanisms of the CT specimen at high J-integral range levels, while matrix cracking is the dominant fatigue crack growth mechanism at low J-integral levels. (4) The finite element analysis with damage is an efficient way to predict the J-integral range and damage zone for the CT specimens at low temperatures.

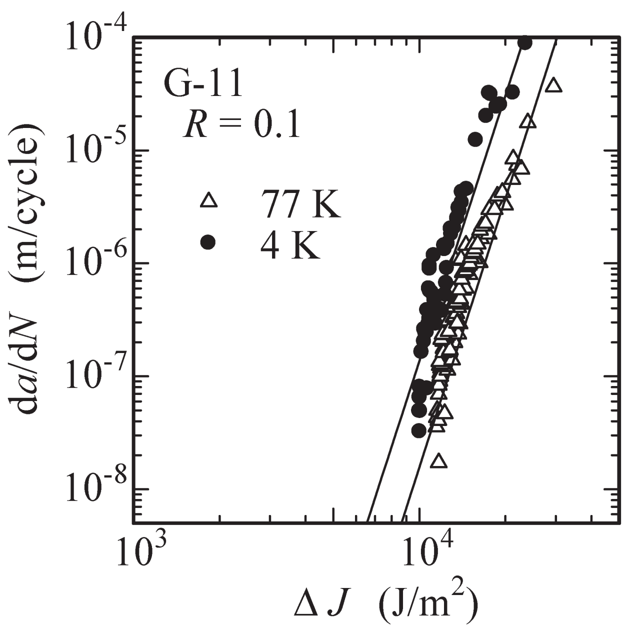

Fig. 1. Fatigue crack growth rate in G-11 woven laminates at 77 K and 4 K (load ratio R = 0.1, frequency 3 Hz)

References

1) Y. Shindo, A. Inamoto and F. Narita, Acta Materialia, **53**, (2005) 1389
2) ASTM E 647-00, Standard test method for measurement of fatigue crack growth rates, ASTM (2000)