§21. Cryogenic Mode II Interlaminar Fracture Toughness of Composite Insulation Systems for Superconducting Magnets

Shindo, Y., Narita, F. (Dept. of Mater. Processing, Graduate School of Engineering, Tohoku Univ.),
Sanada, K. (Dept. of Mechanical Systems Engineering, Faculty of Engineering, Toyama Prefectural Univ.),
Nishimura, A., Tamura, H.

1. Purpose

GFRP woven laminates have wide applications in many branches of engineering. They are used mainly as electrical insulation, thermal insulation, and permeability barriers, which provide minimal structural support in superconducting magnets at cryogenic temperatures. In recent years, considerable efforts have been concentrated on the investigation of the mechanical properties of GFRP woven laminates at cryogenic temperatures.

Delamination is one of the most essential failure modes for composite laminates[1]. These delaminations may initiate at stress singularities, such as holes, free edges, and matrix cracks, or they may occur during manufacture or from in service damage. Typically, delamination growth is predicted by comparing the energy release rate G to its critical value, interlaminar fracture toughness, G_c. Characterizations of the mode II delamiantion toughness of GFRP woven laminates have primarily utilized the end notched flexure (ENF) test. However, as a result of the three point bend configuration of the ENF, there is a vertical shear force acting within the delamianated regions and at the delamination tip. This shear force causes friction that may affect the interlaminar fracture toughness. This work describes the evaluation of a four point bend end notched flexure (4ENF) test for determining the mode II interlaminar fracture toughness of GFRP woven laminates at room temperature (RT), 77 K and 4 K[2].

2. Procedure

The composite laminate sample was cut into rectangular specimens for 4ENF testing. All the tests were conducted using a 30 kN axial loading capacity servo-hydraulic testing machine. The specimens were loaded until the crack grew and unloaded to zero load. The mode II interlaminar fracture toughness G_{IIC} was reduced from 4ENF test data using an experimental compliance calibration method.

A three-dimensional finite element analysis (FEA) was performed to represent the interlaminar fracture and damage of G-11. In order to predict fiber-dominated failure and matrix cracking associated with damage in the 4ENF specimens at cryogenic temperatures, we used the Hoffman failure criterion with maximum strain criterion

3. Results

(1) Stable mode II crack propagation can be obtained with 4ENF specimens at cryogenic temperatures, and the R curves obtained are nearly flat, although the data show some scatter. Fig. 1 shows results of a mode II interlaminar fracture toughness versus crack length Δa curve (R curve) for G-11 at 4K. Solid and open circles are the values obtained from beam theory (BT) and linear FEA, respectively. Open triangles denote the values from FEA coupled with damage. (2) The values of G_{IIC} at cryogenic temperatures are affected by damage within the specimen and higher than those at RT. (3) Matrix microcracking develops on the upper crack surface and underneath the load point on the specimen bottom, and the fiber-dominated failure occurs near the crack tip. These predictions are qualitatively consistent with the observed trends in damage pattern, and the finite element model coupled with damage can be used to predict the matrix microcracking and fiber dominated failure zones of the 4ENF specimens.

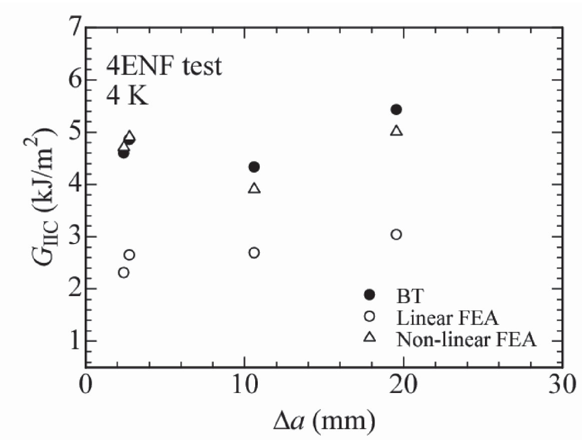

Fig. 1 G_{IIC} resistance curves for the 4ENF specimen at 4K.

1) Shindo, Y. Narita, F., Sato, T.: Acta Mechanica **187** (2006) 231.
2) Shindo, Y., Sato, T., Narita, F., Sanada, K.: Journal of Composite Materials, in press.