§2. Mechanical Properties of Candidate Materials for the Large-Scale Superconducting Magnets at Cryogenic Temperatures

Shindo, Y., Horiguchi, K., Narita, F., Mano, Y., Kumagai, S. (Dept. of Mater. Processing, Graduate School of Engineering, Tohoku Univ.), Satoh, S., Nishimura, A., Tamura, H.

i) Cryomechanics of Insulating Materials

(a) The cryogenic damage and fracture behaviors of G-11 woven glass-epoxy laminates were discussed[1]. In conjunction with the cryogenic fracture toughness test, a finite element analysis was conducted to predict the fracture and deformation for models of the compact tension specimens. The strain energy method was adopted to calculate strain energy release rate which leads to determination of stress intensity factor. In order to verify the model, correlations between experimental and analytical results were made, in terms of the load-displacement response and the extent of damage growth. At room temperature and 77 K, good agreements were found between the calculations and the experimental data. The predictions showed that the fracture behavior was influenced by temperature rises associated with individual damage events at 4 K. An apparent fracture toughness (K_i) was calculated for each specimen using the load (P_i) at which a significant change of slope in the damage zone size versus load curve was observed. The K_i value was independent of notch length but increased with specimen size.

(b) An experimental and analytical investigation in cryogenic Mode II interlaminar fracture behavior and toughness of SL-E woven glass-epoxy laminates was conducted[2]. The end notched flexure (ENF) tests were performed at room temperature (R.T.), liquid nitrogen temperature (77 K) and liquid helium temperature (4 K) to evaluate the effect of temperature and geometrical variations on the Mode II interlaminar fracture toughness (G_{IIC}). No dependence of G_{IIC} values on geometrical variations was observed. G_{IIC} increased with decreasing temperature over the interval R.T. to 77 K. The G_{IIC} value at 4 K was slightly lower than that at 77 K. In order to verify the failure mechanisms, fracture surface examinations were performed on a scanning electron microscope. The dominant failure mode was fiber/matrix interfacial failure with relatively little matrix deformation and failure. A finite element model was used to perform the delamination crack analysis. The results of the finite element analysis were utilized to supplement the experimental data. It can be concluded that for the delamination cracks in Mode II ENF tests the finite element analysis must be used.

ii) Cryogenic Fracture Toughness of Structural Alloys and Weldments

(a) The use of the small punch (SP) test to estimate the elastic-plastic fracture toughness (J_{IC}) of structural alloys and weldments for superconducting magnets in fusion energy systems was studied[3]. SP tests were performed with thin plate specimens of 10×10×0.5 mm at 4 K. Correlations between SP energy, equivalent fracture strain, and J_{IC} were assessed. All J_{IC} data were obtained using 25-mm-thick compact specimens that followed standard test method for J_{IC}. There was a linear correlation between equivalent fracture strain and J_{IC} at 4 K. A finite element analysis was also performed to convert the experimentally measured load-displacement data into useful engineering information. The maximum strain energy density was calculated and correlated with J_{IC}. The correlation between the maximum strain energy density and J_{IC} showed a reasonably good agreement.

(b) Notch tensile tests were performed with small cylindrical notched bar specimens at 4 K[4]. Correlations between notch tensile strength (σ_{NTS}), failure energy absorption (E_{NT}), and J_{IC} were assessed. The best data fit was found between the ratio σ_{NTS}/J_{IC} and J_{IC}. A finite element analysis was also performed to compute directly the J-values. Comparisons of the predicted J_{IC} with results obtained from conventional JIS Z 2284 standard tests were made. Results of structural alloy weldment with a representatively wide range of J_{IC} indicate that fracture toughness prediction accuracy is roughly equal to ±25%.

References

1) Sanada, K. et al. : J. Japan Inst. Metals, 63(1999)221.
2) Shindo, Y. et al. : J. Japan Inst. Metals, in press.
3) Shindo, Y. et al. : Cryogenic Engineering, 34(1999)729.
4) Shindo, Y. et al. : J. Japan Inst. Metals, 64(2000)56.