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

Shindo, Y., Ikeda, K., Kokawa, H., Kawasaki, A., Ueda, S., Horiguchi, K., Sanada, K., Mano, Y. (Dept. of Mater. Processing, Graduate School of Engineering, Tohoku Univ.)
Satoh, S., Nishimura, A., Tamura, H.

i) Cryomechanics of Insulating Materials

(a) In order to evaluate the cryogenic compressive properties of G-10CR and SL-ES30 glass-cloth/epoxy laminates for superconducting magnets in fusion energy systems, compression tests as specified in JIS K 6911 were performed at room temperature, liquid nitrogen temperature (77K) and liquid helium temperature (4K)[1]. The specimens, a length (L) and a width (W), were cut in the warp, fill and normal directions, respectively. Compression specimens of G-10CR were tested in the normal direction. Figure 1 shows the influence of specimen geometry on the compressive strength of G-10CR at 4K. For comparison, the experimental data of Kasen et al.[2] for G-10CR are also superimposed here. The results clearly demonstrate the dependence of compressive strength on the cross-sectional area although the scatter of results at a given L/W^2 is very large. Further increase in cross-sectional area leads to a reduction in compressive strength. The compressive strength in the fill direction of SL-ES30 depends on specimen geometry, and decreases with an increase in L/W^2, but the compressive strengths in the warp and normal directions are nearly independent of L/W^2 variations. The compressive strength in the normal direction depends on cross-sectional area.

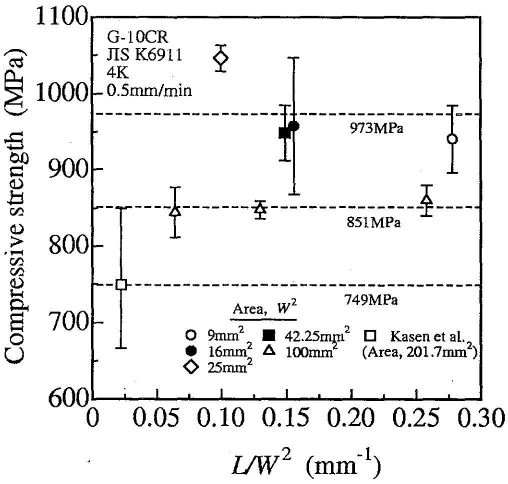

Fig. 1. Effect of L/W^2 on compressive strength of G-10CR at 4K

(b) The tension tests as specified in JIS K 7054 were carried out at room temperature and 77K to evaluate the cryogenic tensile properties in the warp and fill directions of SL-ES30. Using the stress - strain curves obtained from the tension tests of SL-ES30, the damage parameters are determined to predict the cryogenic tensile behavior through a finite element analysis coupled with damage.

(c) An analytical procedure, using a finite element method, was developed to calculate the dissipative energy and temperature rise associated with crack extension in a glass-cloth/epoxy laminate at low temperatures. The amount of energy dissipated during fracture of the compact tension specimen is calculated as a function of crack speed using a dynamic strain energy release rate.

(d) The cryogenic interlaminar fracture toughness properties of SL-E glass-cloth/epoxy laminate were measured under Mode II loading using end notched flexure (END) tests as specified in JIS K 7086. The tests were performed at room temperature, 77K and 4K. Contact and friction along the crack surfaces is taken into account in the finite element modeling of the delamination crack growth.

ii) Cryogenic Fracture Toughness of Structural Alloys and Weldments

(a) The use of the small punch test to estimate the elastic-plastic fracture toughness J_{IC} of SUS316 type austenitic stainless steel electron-beam weld was studied. The tests were performed with thin plate specimens of 10×10×0.5mm at 4K. Correlations between equivalent fracture strain and J_{IC} were assessed. A finite element analysis was also performed to convert the experimentally measured load - displacement data into useful engineering information.

(b) The small punch and notch tensile tests were performed in magnetic fields at 4K to evaluate the fracture toughness of austenitic stainless steel welds.

References

1) Shindo, Y. et al. : Cryogenic Engineering, 34(1999)15.
2) Kasen, M. B. et al. : Adv. Cryog. Eng., 26(1980)235.