§ 24. Cryogenic and Magnetic Fracture Mechanics for Structural Integrity Assessment of Large Scale Superconducting Magnets

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1. Cryomechanics of Insulating Materials

Woven-fabric glass/epoxy laminates have received increased attention for application in thermal insulation, electrical insulation, structural support, and permeability barrier in superconducting magnets at cryogenic temperatures. This study presents the thermal-mechanical response of multi-layered woven glass/epoxy laminates with cracks and temperature-dependent properties under tension at cryogenic temperatures [1]. The composite material is assumed to be under generalized plane strain. Cracks are located in the fill fiber bundles whose fibers are oriented perpendicular to the mechanical load. Also, these cracks are assumed to span the width of the fill fiber bundles. Finite element model is employed to study the influence of residual thermal stresses on the mechanical behavior of multi-layered woven laminates with cracks.

The following conclusions can be drawn from this study. (1) The Young's modulus of the two-layered woven laminates becomes large as the temperature decreases. The influence of a crack can decrease the Young's modulus. The stress distributions near the crack tip are found to depend on the temperature and mechanical mean stress. (2) The Young's modulus of multi-layered woven laminates without cracks is almost independent of the number of layers. Cracks in the fill fiber bundles decrease the Young's modulus. In particular, the existence of surface cracks causes significant degradation of the Young's modulus. The stress distributions near the tip of the central crack are found to depend on the number of layers and mechanical mean stress, and be strongly influenced by the neighboring crack. The influence of the number of layers on the stress becomes small as mechanical mean stress increases.

2. Cryogenic and Magnetic Fracture Properties of Structural Alloys

To design superconducting device and applications it is necessary to consider the possible influence of the magnetic field on mechanical properties of cryogenic structural materials. The main purpose of the study is to investigate the effect of magnetic field on the cryogenic fracture properties in the structural alloys. First, the use of notch tensile and small punch specimens for the measurement of elastic-plastic fracture toughness of a nickel-iron superalloy is investigated [2]. The tensile, notch tensile and small punch tests are employed at liquid helium temperature (4 K) in magnetic fields of 0 and 6 T (T; tesla). The specimens are oriented such that the axis of the solenoid field is parallel to the specimen load direction, and are loaded at constant stroke rate of 0.2 mm/min. A finite element analysis is also performed to convert the experimentally measured load-displacement data into useful engineering information. Next, metastable austenitic stainless steels are examined to help further clarify the role of alloy stability on the direction and magnitude of fracture toughness change in an applied magnetic field. The small punch tests are performed in a 6 T magnetic field at 4 K in the bore of a superconducting magnet and without an applied magnetic field.

The following conclusions can be drawn from this study. (1) The fracture toughness of the nickel-iron superalloy is not significantly affected by magnetic fields. (2) Notch tensile and small punch specimens are preferred for fracture tests conducted for the purpose of laboratory materials evaluation in cryogenic high magnetic field environments. (3) Metastable austenitic stainless steels show a decrease in the measured fracture toughness at 4 K with the application of magnetic field. (4) The magnitude of change in 4-K fracture toughness with the application of magnetic field is a function of the stability of the alloy.

References

1) Takeda, T., Shindo, Y., Narita, F. and Kumagai, S. : Cryogenics **42** (2002) 451.
2) Yamaguchi, Y., Horiguchi, K., Shindo, Y., Sekiya, D. and Kumagai, S. : Cryogenics, in press.