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

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1. Cryomechanics of Insulating Materials

The purpose of this study is to demonstrate the effect of temperature and mixed-mode ratio on the interlaminar fracture toughness of glass-cloth/epoxy laminates. The double cantilever beam (DCB)[1)], end notched flexure (ENF)[2)] and mixed mode bending (MMB)[3)] tests were performed at room temperature (R.T.), liquid nitrogen temperature (77K) and liquid helium temperature (4K). In order to evaluate the interlaminar fracture toughness of glass-cloth/epoxy laminates, a three-dimensional finite element analysis was carried out for each specimen type for each type of loading. Critical load levels, and the geometric and material properties of the test specimens were input data for the analysis. The total energy release rate and its mode I and mode II components were evaluated using the global energy method. Effective elastic moduli were determined under the assumption of uniform strain inside the representative volume element. The fracture mechanisms were analyzed by means of post-failure scanning electron microscopy (SEM).

(1) The specimen tested at room temperature is characterized by stable crack propagation. In contrast, the specimens tested at 77 K and 4 K are characterized by load peaks, at which unstable fracture occurred. (2) Figure 1 shows the strain energy release rate G_T ($G_T = G_I + G_{II}$; mode I energy release rate G_I, mode II energy release rate G_{II}) versus mixed mode ratio G_{II}/G_T. In the figure, the solid lines represent mixed mode failure criterion $G_T = G_{IC} + G_{IIC}(G_{IIC} - G_{IC})(G_{II}/G_T)^m$ (critical energy release rate obtained from DCB test G_{IC}, critical energy release rate obtained from ENF test G_{IIC}, characteristic parameter m). G_{IC} increases between R.T. and 77 K, further cooling to 4 K produces a toughness decrease. Mixed mode interlaminar fracture toughness increases with increasing G_{II}/G_T. The G_{IIC} value increases with decreasing temperature over the interval R.T. to 4 K. (3) For the DCB specimens tested at room temperature, the dominant failure mode is fiber/matrix interfacial failure, but matrix materials are stuck on the surface of fibers at 77 K and 4 K. (4) For the ENF and MMB specimens, hackles can be observed on the fracture surface. An increasing amount of hackles is observed with increasing G_{II}/G_T and decreasing temperature. Temperature dependence of mode II and mixed mode interlaminar fracture toughness arises because of the energy required for the additional fracture surface creation.

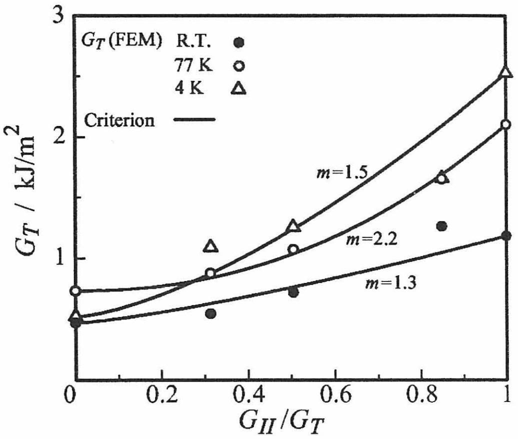

Fig. 1 G_T versus G_{II}/G_T modal ratio.

2. Cryogenic and Magnetic Fracture Properties of Fe-Ni Superalloy

The effect of magnetic fields on the cryogenic fracture properties in a nickel-iron superalloy is investigated. Tensile and notch tensile tests were performed at 4 K in magnetic fields of 0 and 6 T(T:tesla). The specimens were oriented such that the axis of the solenoid field was parallel to the specimen load direction. The stroke rate was 0.2 mm/min. The magnetic field decreases the modulus of longitudinal elasticity and strain-hardening exponent, and increases the yield strength. In order to evaluate the fracture properties of nickel-iron superalloy, a three-dimensional finite element analysis was carried out for notch tensile test specimen. In this analysis, the J-integral was evaluated via its analytical basis using the path independent integral form[4)]. The magnetic field significantly affects the J value.

References

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