§16. Development of Nonmetallic Materials for LHD Superconducting Magnet

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Glass fiber reinforced plastics(GFRP) have been used as insulating materials or spacers in LHD superconducting magnet. Compressive elastic modulus and thermal contraction in laminated direction of GFRPs were increased. However, the improvement of mechanical properties have upper limitation caused by polymeric matrix. Ceramics material have the advantage of higher mechanical properties and they deserve to research the applicability of the partial alternatives as structural material. But there are few fundamental data of mechanical properties of ceramics, refractory material, at cryogenic temperature.

The objective of this study is to obtain the basic mechanical properties of some typical ceramics and to choose the ceramics which show high mechanical strength and/or high fracture toughness, which enable them to apply to structual material for superconducting magnet.

Mechanical properties such as flexural strength and fracture toughness were measured at room temperature(RT), liquid nitrogen temperature (LNT) and liquid helium temperature(LHeT). Three point bending test was carried out by the specimens whose size of approximately 4 x 3 x 40 mm. Span length was 30 mm. Fracture toughness were measured by the single edge notched beam (SENB) method. Monolithic alumina, silicon nitride and zirconia were selected in this study. Especially zirconia, three types of zirconia which contain in the range of 2.5, 3 and 6.0 mole% yttria stabilizer were prepared.

Figures 1 and 2 show the temperature dependency of flexural strengths and fracture toughness, respectively. Compared with alumina and silicon nitride, zirconia showed higher flexural strengths and fracture toughness. Especially the fracture toughness of zirconia doped 3mole% yttria(3Y-ZrO_2) were remarkably increased at 13 $MPam^{1/2}$ down to LHeT, which is larger than the value expected from the increase of Young's modulus. One of the main reason of this toughening is explained as the stress-induced phase transition from tetragonal to monoclinic. It is considered that certain plastic behaviors in phase transition region contribute to the increase of fracture toughness. This non-linear increase of fracture toughness towards temperature could not explain only the increase of Young's modulus and it is needed to clarify the mechanism and theory of this behavior.

Considering the applicability of zirconia as structural material for superconducting magnet, zirconia has more similar thermal contraction coefficient to metals than other ceramics and thermal conductivity is lower than stainless steel. Consequently, it is found that zirconia is the promising material for structural and/or insulating material for cryogenic use.

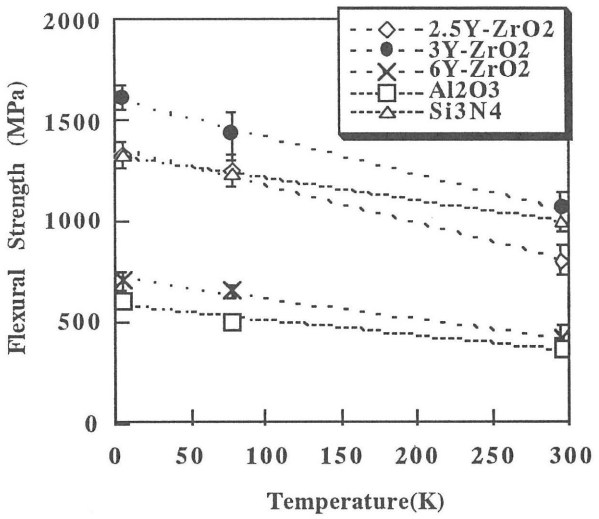

Fig.1 Temperature dependency of flexural strength of various ceramics.

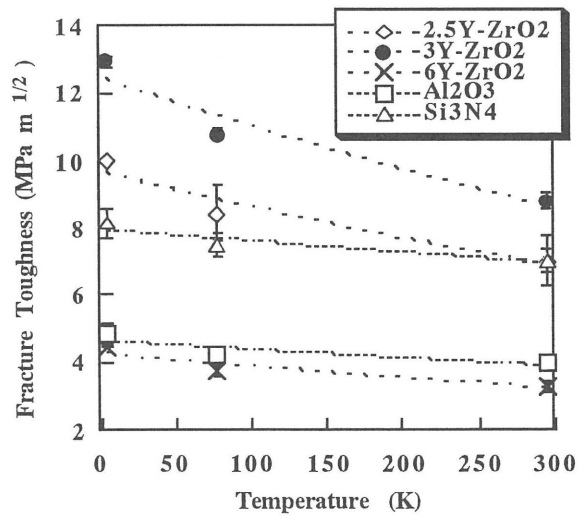

Fig.2 Temperature dependency of fracture toughness of various ceramics.