Fracture Toughness of Thin Walled Conduit Alloys in a CICC Application

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Introduction

The Series-Connected Hybrid Magnets being designed and built here use Cable-in-Conduct-Conductor (CICC) technology, and the properties of the conduit are extremely important to the performance and reliability of the magnets. The results reported here are from tests of two conduit alloys (Haynes 242 and modified AISI 316LN) whose properties strongly depend on manufacturing variables, especially the Nb_3Sn superconductor reaction heat treatment (aging at 650C for 48 hrs) and the numerous welds to join conduit tubes. Since the rectangular tube conduit has dimensions (~1.5 mm wall, 13.7 mm X 16 mm) not suitable for conventional test specimens, non-standard specimens removed directly from the conduit are used. In summary, after procurement of near-net shape tube, in-house manufacturing steps occur that affect the final product properties. They are; shaping, welding, winding into a coil, Nb_3Sn heat treatment, and in-service operation at 4 K. Verification of the conduits' properties is performed with test samples removed directly from the finished product.

Experimental

The plane strain fracture toughness (K_{IC}) typical test specimen is a Compact Tension (CT) with dimensions > the conduit. Therefore an alternative specimen design is used, a Middle-Tension (MT) test specimen with an electro-discharge-machine (EDM) notch 2 mm long by 0.2 mm wide, shown in Figure 1.

The following classic fracture-mechanics equation, modified to take into account geometry effects, can be used to calculate the stress intensity K_I as a function of applied load in the plane strain regime.

$$K_I = P^* (f(a/w) / (B * W^{0.5}) \qquad [1]$$

where P is force, a is crack length, B is thickness, W is Width, and $f(a/w)$ is the compliance factor. A material with low toughness will fracture in the linear elastic region and higher toughness material (such as 316LN and H242) will yield and fail due to tensile overload.

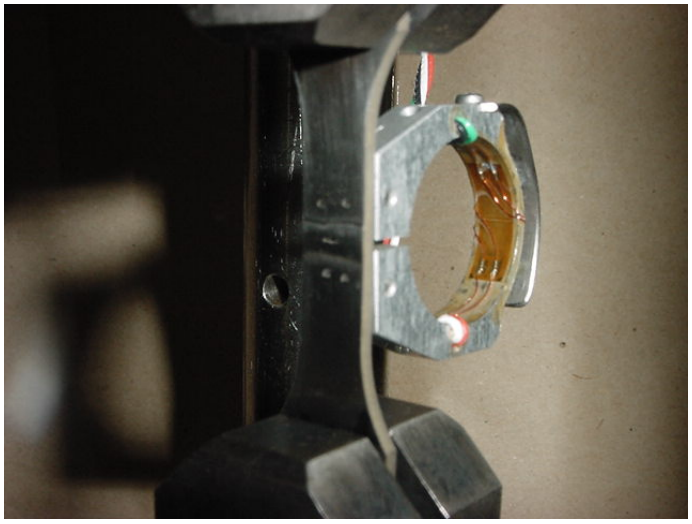

FIGURE 3. Photo of a MT specimen with notch in weld region and COD gage clipped on.

Conclusions

The conduit alloys of performed well in the areas of concern (welds and heat affected zones). The MT fracture toughness measurements have been determined to be conservative (40 to 50% lower than conventional CT specimen) and show that both the conduit alloys have a K_{IC} > 130 MPa*m$^{0.5}$ which is in excess of the design requirement (100 MPa*m$^{0.5}$).