Shear Tests of Conduit Insulation for the ITER Central Solenoid

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Introduction

The Central Solenoid (CS) modules for ITER will utilize a system of epoxy-impregnated glass tape and cloth, combined with Kapton, for electrical insulation between windings and layers of cable-in-conduit conductors (CICC). This insulation will experience a combination of compressive and shear stresses as the layers compress axially and the conduit strains at different rates due to the hoop stress gradient from inside to outside of the coils. The NHMFL's Mechanical and Physical Properties Lab has the capability to test these prototype insulation systems under combined loading conditions at cryogenic temperatures. Three combinations of compressive/shear stress ratios are tested on nine different candidate insulation configurations at 77 K and 4 K to assess their strength in each condition as well as their failure modes. This test series further supports the development of the CS insulation system and bolsters the database of insulation properties for CICC applications.

Experimental

Square sandwich-style specimens were cut via water-jet from AISI 316 steel plates that were bonded to each other according to each candidate insulation system configuration, which simulate insulation bonded to the conduit alloy. Figure 1 shows the angled test fixtures that were used to apply the desired shear and compressive stress components. The 45° fixture is shown, and specimens were also tested at 15° and 60° for static tests (loading to failure). Specimens were also loaded in a cyclic condition at 45° to assess fatigue life at different stress levels. These fixtures are mounted in a test machine that applied axial compression as shown. Note that two specimens are needed per test. This design facilitates unconstrained shear motion of the insulation when compressed axially by the machine, as lateral translation of the center fixture is allowed to occur freely.

Results and Discussion

Figure 2 depicts the minimum results obtained during static testing of the best-performing systems, which are each designed for different orientations in the CS modules. Data from a previous insulation system configuration [1] is also shown for comparison. Fatigue life is illustrated in Figure 3, in which the stress oscillated from that shown on the graph, down to 10% of that stress. Since fatigue was only tested at 45°, the shear stress component is the same as the compressive component.

Conclusions

The fatigue strength after 10^5 cycles is reduced by 43-55% from static data for turn insulation, and by 28-40% for ground insulation. The majority of failures that occurred between layers of insulation ("cohesive") in the turn insulation occurred at the quench detection tape that is wound between glass cloth layers. Additionally, all cohesive failures in the ground insulation occurred at the Kapton-glass interface, and increasing Kapton thickness is suspected to decrease interlaminar shear strength.

Acknowledgements

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References

[1] Simon, N.J, *et al.*, Advances in Cryogenic Engineering Materials, **38**, 363 (1992).

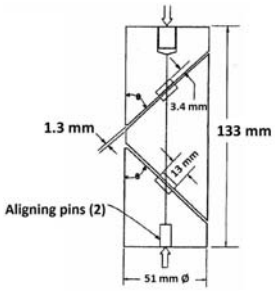

Figure 1 – Angled Test Fixture

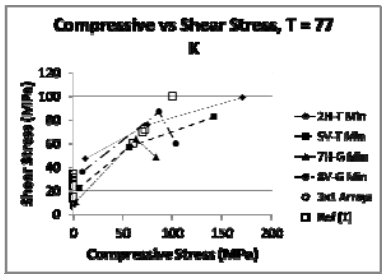

Figure 2 – Minimum shear/compression results and reference data [1]

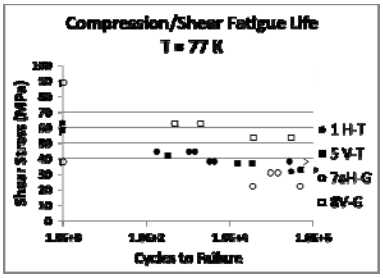

Figure 3 – Fatigue life of 45° compression/shear specimens, load ratio R = 0.1