Fatigue and Fracture Properties of a Super-Austenitic Stainless Steel at 295 K and 4 K

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Introduction

Since 2007 the US-ITER program has collaborated with the NHMFL for structural and superconductor materials characterization, recognizing our capabilities for qualifying materials for use in superconducting magnets. ITER's Central Solenoid will be an assembly of six separate coils stacked to reach a height of 14 m and must remain adequately compressed at all times, from room temperature down to 4 K. Because of space limitations, the pre-compression structure must be made of a non-magnetic material that is appreciably stronger than conventional stainless steels at room temperature, yet must remain ductile at 4 K. A high strength austenitic steel known as "Nitronic 50" (N50) has been chosen due to its high strength across a broad temperature range, but very little cryogenic temperature data exists [1]. We have completed mechanical properties characterization for US-ITER of three different heats of this attractive candidate alloy to qualify it for use in such applications [2].

Experimental

TABLE 1 - Testing Summary

Test Type	Test Standard	Test Temperature	Properties Obtained
Tensile	ASTM E 1450	295 K and 4 K	Yield Strength, Ultimate Tensile Strength, Elongation and Reduction of Area
S-n Fatigue	ASTM E 466	4 K	Qualitatively assess cyclic stress with respect to number of cycles to failure
Fatigue Crack Growth Rate	ASTM E 647	4 K	Rate at which a crack propagates with pre-existing flaw
Fracture Toughness	ASTM E 1820	4 K	Energy absorbed during failure

Results and Discussion

When evaluating Fatigue Crack Growth Rate (FCGR) and Fracture Toughness of a material, orientation of the load and crack plane has a large effect on the results. A test with a crack plane that runs parallel to the forging direction yields more conservative design data. However, the crack plane runs transverse to the forging direction in these tests to simulate in-service stress. Figure 1 shows Fracture Toughness vs. Yield Strength of N50 compared with most austenitic steels. The austenitic SS reference data [1] have crack planes running in the longitudinal direction, hence the discrepancy. Regardless, N50 shows remarkably high toughness and yield strength. Comparing FCGR and S-n fatigue data to a 316LN study previously performed at NHMFL [3] reveals that N50 crack growth rate and fatigue life is superior.

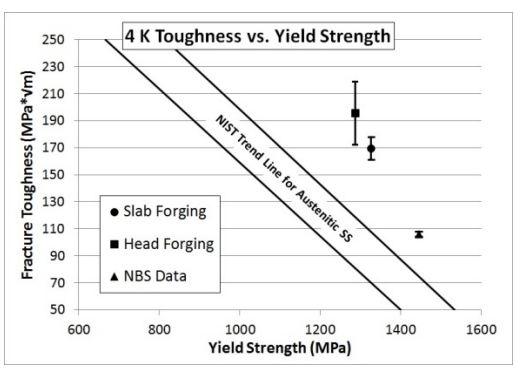

Figure 1 – Fracture Toughness vs. Yield Strength

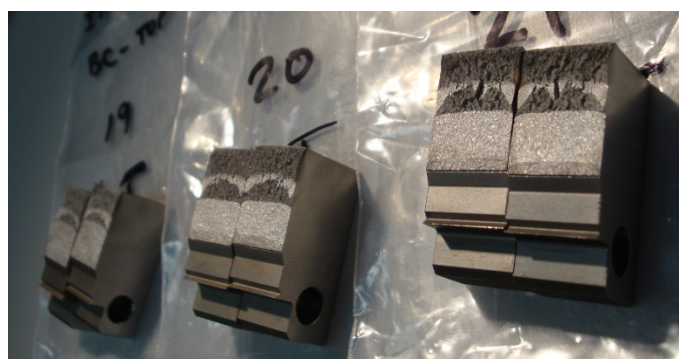

Figure 2 – FCGR-J specimens, post-test

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References

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2. McRae, Walsh, Dalder, Litherland, Trosen, and Kuhlmann, "Fatigue and Fracture Properties of a Super-Austenitic Stainless Steel at 295 K and 4 K", Advances in Cryogenic Engineering Materials, Vol. 60, 2013.
3. Toplosky, Walsh, and Han, "Fatigue Properties of Modified 316LN Stainless Steel at 4 K for High Field Cable-In-Conduit Applications", Advances in Cryogenic Engineering Materials, Vol. 56, 2010.