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

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Abstract:

The tie plate structure for the ITER Central Solenoid (CS) is required to have high strength and good fatigue and fracture behavior at both room temperature and 4 K. A super-austenitic stainless steel - UNS 20910, commonly referred to by its trade name, Nitronic 50 (N50) - has been chosen for consideration to fulfill this task, due to its good room temperature and cryogenic yield strengths and weldability. Although N50 is often considered for cryogenic applications, little published data exists at 4 K. Here, a full series of tests have been conducted at 295 K and 4 K, and static tensile properties of four forgings of commercially-available N50 are reported along with fatigue life, fatigue crack growth rate (FCGR), and fracture toughness data. This study makes a significant contribution to the cryogenic mechanical properties database of high strength, paramagnetic alloys with potential for superconducting magnet applications.

Materials:

Nitronic 50 is a super-austenitic stainless steel that is also known as UNS 20910, (F)XM-19, and its more descriptive designation Fe-21Cr-12Ni-5Mn. It is known for its excellent corrosion resistance, high strength across a broad temperature range, and paramagnetism even after straining to failure.

Table 1: Composition and grain size of all heats tested. Grain size was not tested in heats A11371 and A11399.

Heat No.	ASTM Grain Size	Composition (%)																		
		C	Mn	P	S	Si	Ni	Cr	V	Mo	Co	Cu	N	Cb	Al	Ti	W	B	Sn	Ta
A11371	N/A	0.043	4.74	0.024	0.002	0.24	11.97	21.25	0.15	2.20	0.04	0.26	0.29	0.15	N/A	N/A	N/A	N/A	N/A	N/A
A11399	N/A	0.039	4.81	0.023	0.006	0.33	11.88	20.80	0.16	2.23	0.07	0.23	0.27	0.15	N/A	N/A	N/A	N/A	N/A	N/A
G16529 Slab	4	0.035	5.18	0.024	0.004	0.27	12.09	21.16	0.15	2.12	0.07	0.37	0.28	0.15	<.01	<.01	<.05	0.002	0.005	<.01
G16529 Head	1	0.035	5.18	0.024	0.004	0.27	12.09	21.16	0.15	2.12	0.07	0.37	0.28	0.15	<.01	<.01	<.05	0.002	0.005	<.01

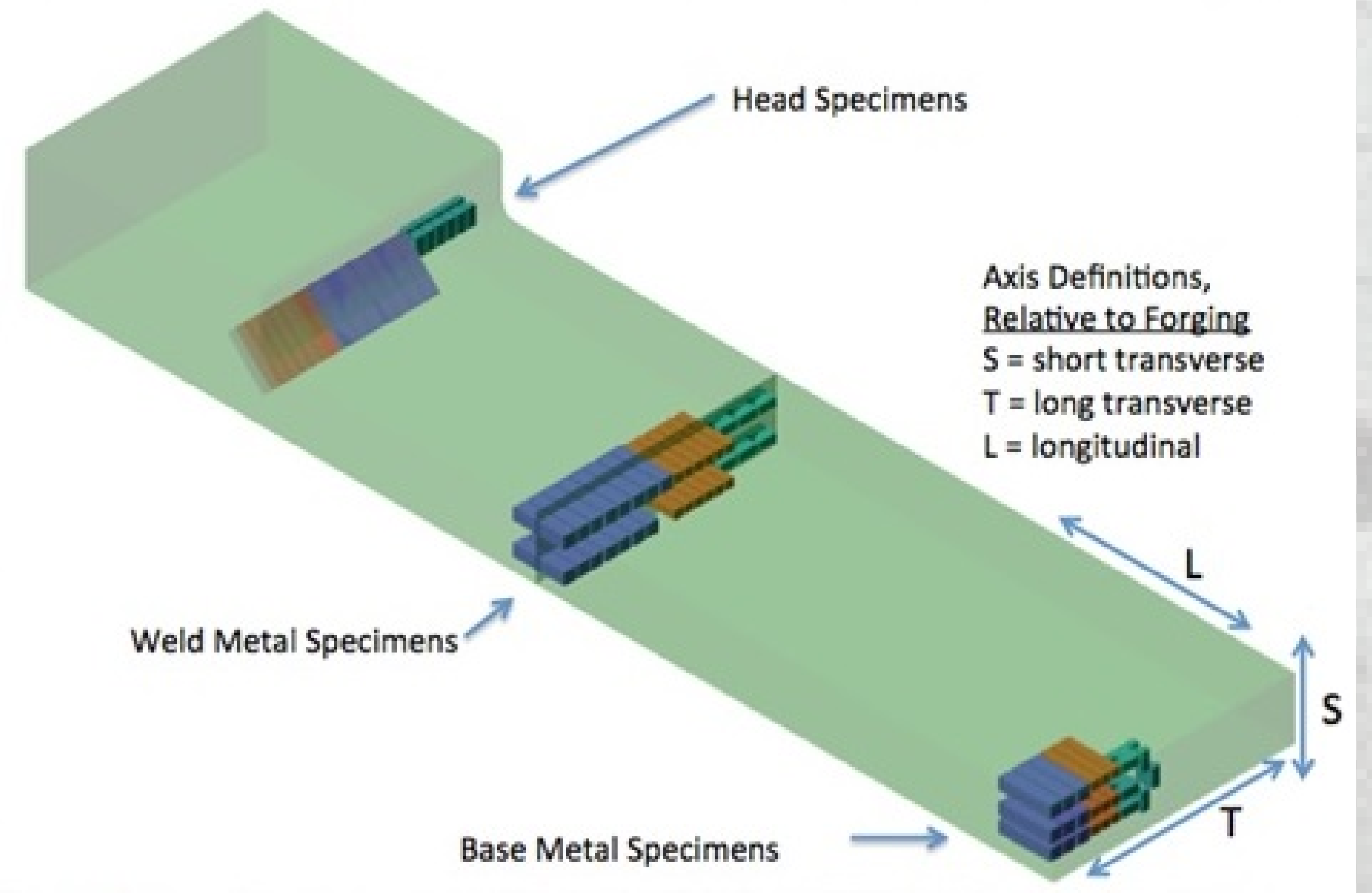


Image courtesy: Major Tool and Machine, Inc.

Specimens were oriented as shown. Tensile and fatigue specimens were taken from the head forgings tangent to, and near the surface of the fillet, in the interest of ensuring that there exist no adverse effects of possible grain direction change due to the forging process at this corner.

Tensile Test Results:

Table 2: Tensile test results with specimen heat no. and orientation.

Heat No. and Material ID	Specimen Orientation	No. of tests	Temp K	Yield Strength (MPa)	Tensile Strength (MPa)	Elong. (%)	Red. Area (%)
A11371 Slab	L	1	295*	482	779	47	72
A11399 Slab	L	1	295*	527	804	47	76
G16529 Slab	L	4	295	408	766	40	68
G16529 Head	45°	4	295	357	746	49	72
A11371 Slab	L	1	4	1540	1862	8	11
	T	1	4	1525	1837	11	12
A11399 Slab	L	1	4	1620	1893	12	16
	T	1	4	1395	1738	9	11
G16529 Slab	L	6	4	1326	1742	26	42
G16529 Head	45°	6	4	1264	1695	30	36

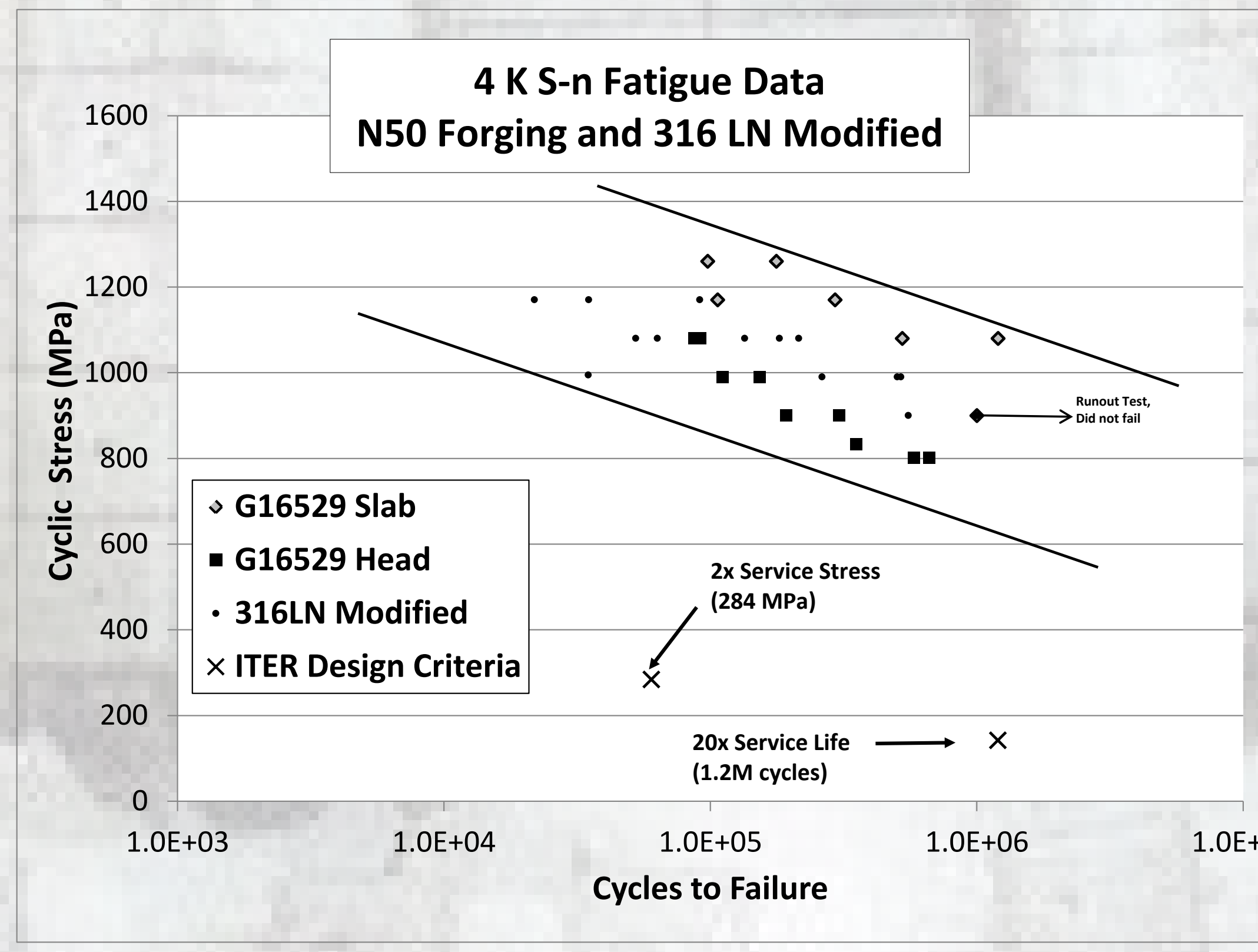
* Data from mill certification sheet on billet prior to forging

Observations:

- Either grain size or specimen loading axis with respect to forging direction appear to have measurable effect on tensile properties within same heat.
- G16529 was annealed after forging, but no documentation exists to ascertain whether A11371 and A11399 were as well. Higher yield strengths and lower ductility in those two heats may be explained by having not been annealed after forging.

Fatigue:

Tension-tension fatigue tests were run at 20 Hz in load control, constant load amplitude (R = 0.1). Fig. 1 compares results with a modified 316LN[1]. N50 has fatigue life comparable to that of 316LN, and sometimes greater.



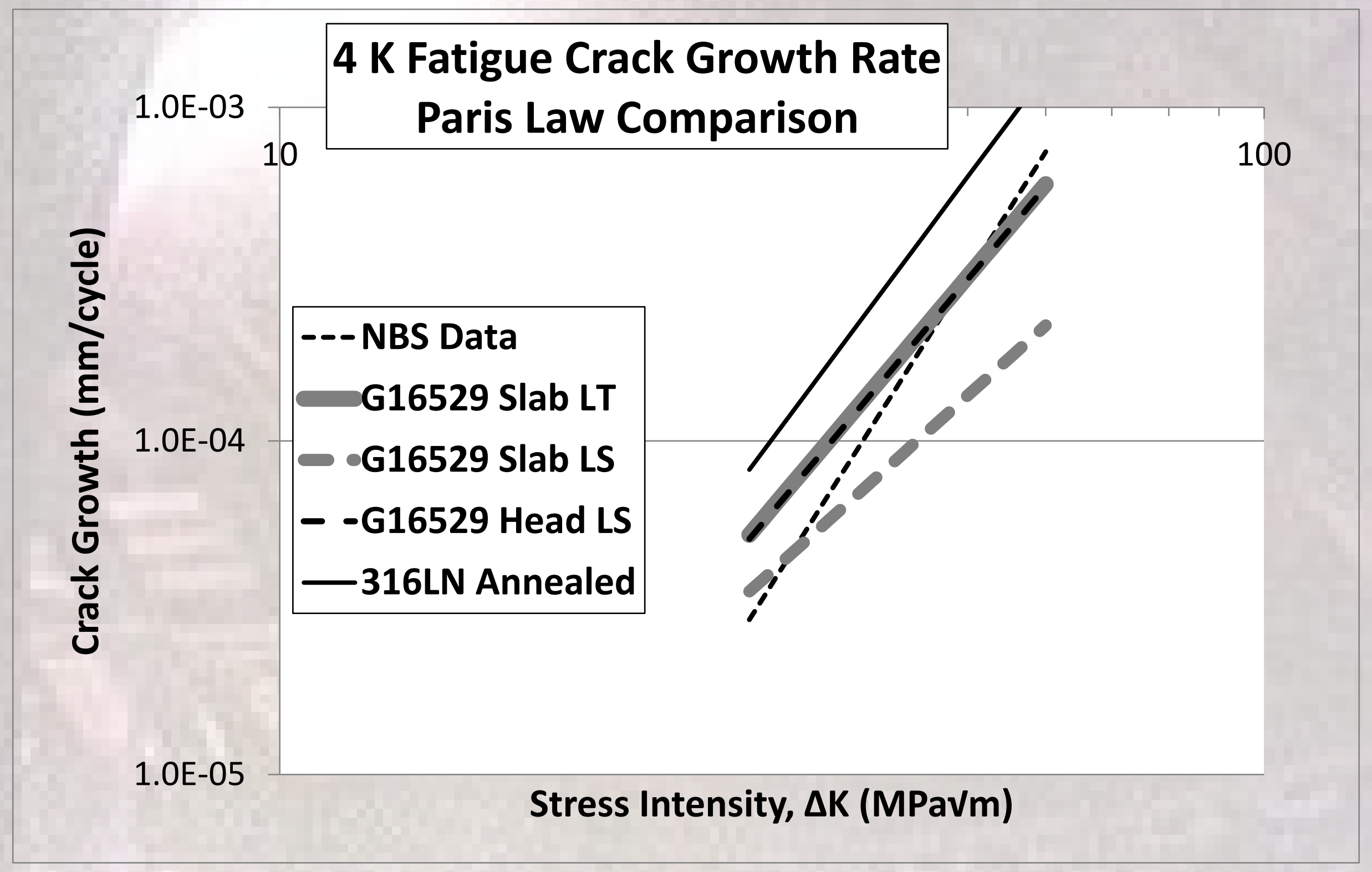
FCGR and Fracture Toughness:

Dual-purpose compact tension (CT) specimens were made for testing both FCGR and toughness from the same specimen. Fracture toughness was tested via J-integral methods, and K_{IC} is calculated from J_{IC}. Three specimens were tested for each orientation.

Table 3: FGCR and Fracture Toughness Results at 4 K

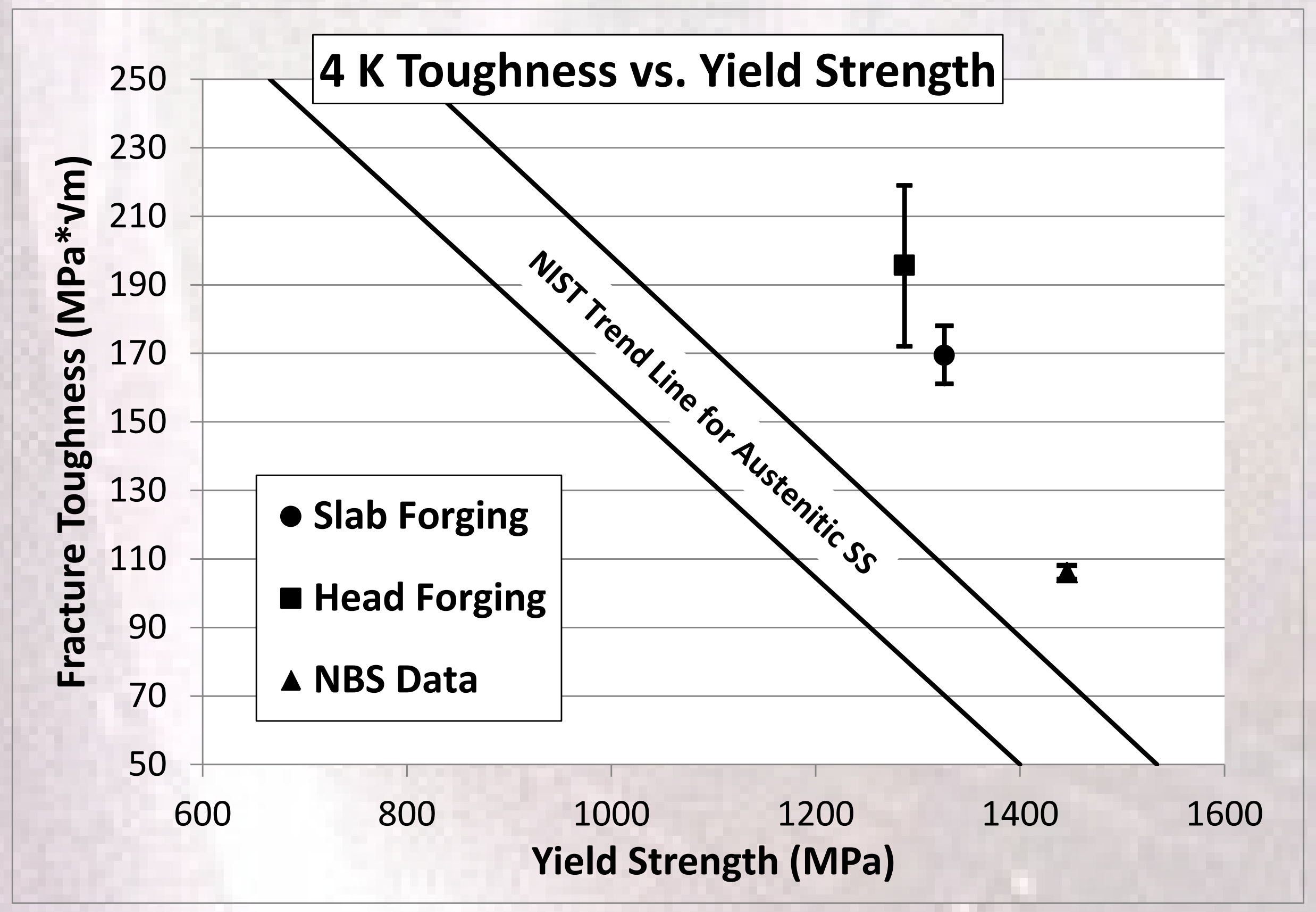
	$K_{IC}(J)$ MPa√m	Paris Law Constants C	Paris Law Constants m	ΔK Range MPa√m
G16529 Slab LT	167	3.624E-10	3.493	26 to 78
G16529 Slab LS*	N/A	4.326E-09	2.649	23 to 58
G16529 Head LS	191	3.313E-10	3.511	27 to 93
G16529 Head LT	200			

* Out-of-plane crack propagation during J-test



Above: Paris Law lines are plotted with previously-tested N50[2] and 316LN data. Those two were tested in the TL direction.

Below: N50 exhibits good fracture toughness for an Austenitic SS with high yield strength. Trend shown is for TL direction, so it is not directly applicable



Future Research:

Further investigation will be made on another head forging in the region from where the 45° tensile specimens were machined, along with more qualification in the same manner of a different forging process. Grain size of heats A11371 and A11399 will be measured, and hardness of all heats will be tested to help indicate whether the suspect heats were annealed after forging.

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References:

1. V. J. Toplosky, R. P. Walsh, and K. Han, “Fatigue Properties of Modified 316LN Stainless Steel at 4K for High Field Cable-In-Conduit Applications”, *Advances in Cryogenic Engineering- Materials*, Vol. 56 (2010) pp.9-16.
2. D. T. Read and R. P. Reed, *Toughness, Fatigue Crack Growth, and Tensile Properties of Three Nitrogen-Strengthened Stainless Steels at Cryogenic Temperatures*, NBSIR 78-884, pp. 93-154, National Bureau of Standards, Boulder, Co, 1978.