GRX-810 NASA Developed Data Sheet

Principal Features

GRX-810 alloy is a nickel-Cobalt-Chromium-Tungsten oxide dispersion strengthened (ODS) alloy that combines excellent high-temperature strength, outstanding resistance to oxidizing environments up to 2400°F (1316°C). At 2000°F (1093°C) GRX-810 provides a 2x improvement in strength compared to superalloy 718 and 625. Most notably, GRX-810 provides over 1000x longer creep rupture lives in the build direction compared to 718 and 625. It is amenable to the additive manufacturing, specifically laser-powder bed fusion. Other attractive features include its stable microstructure up to its melting temperature.

Easily Fabricated

GRX-810 can be easily printed at similar build speeds compared to superalloy 718.

Heat Treatment

GRX-810 can be used in both the as-built and post HIP states. No aging or solution treatment is required.

Applications

The GRX-810 alloy was specifically designed for aerospace applications, including liquid rocket engine injectors, preburners, turbines, and hot-section components, capable of withstanding temperatures up to 1,100 °C. The objective of this alloy was to bridge the temperature gap between traditional Nickel-based superalloys and refractory alloys.

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Composition and Processing

Table 1: Nominal composition for base powder GRX-810.

Element	Nominal
Al	0.3%
C	0.055%
Cr	30%
Co	32%
Nb	0.8%
Ni	Balance
Re	1.5%
Ti	0.3%
W	3.0%

Table 2: Heat treatment used performed on GRX-810 samples used for material test data.

Heat Treatment	Temperature	Time	Stress
HIP – ASTM 3301	1163°C	3-4 hours	103 MPa

Table 3: L-PBF core process parameters for GRX-810.

Laser Power (W)	Scan Speed (mm/s)	Layer Thickness (mm)
275	1000	0.04

Physical Properties

Room Temperature Overview

All Thermal properties were measured from room temperature to 1300°C. Due to system limitations, thermal diffusivity could not be determined above 1200C, therefore, thermal diffusivity and thermal conductivity were reported to 1200C. Density was measured per ASTM B3311-22 on a Mettler-Toledo XS-205 Density Determinator. Specific heat was measured per ASTM E1269-24 using a Netzsch DSC 404 F1 Pegasus. Thermal Diffusivity was measured per ASTM E1461-13 (2022) using a TA Instruments DLF1200 laser flash. Thermal Expansion was performed per ASTM E288-22 using a Netzsch DIL402SE dilatometer.

Table 4: Room Temperature Properties for HIP GRX-810

Density (g/cm^3)	8.44
Specific Heat (J/g*K)	0.434
Coefficient of Thermal Expansion (10^{-6}/K)	10.6
Thermal Conductivity (W/m*K)	11.0
Thermal Diffusivity (Cm^2/s)	0.0299
Poisson’s Ratio	0.234
Young’s Modulus (GPa)	188.2

Table 5: Room Temperature Properties for As-built GRX-810

Density (g/cm^3)	8.44
Specific Heat (J/g*K)	0.434
Coefficient of Thermal Expansion (10^{-6}/K)	11.8
Thermal Conductivity (W/m*K)	10.55
Thermal Diffusivity (Cm^2/s)	0.0295
Poisson’s Ratio	0.24
Young’s Modulus (GPa)	190.6

Specific Heat

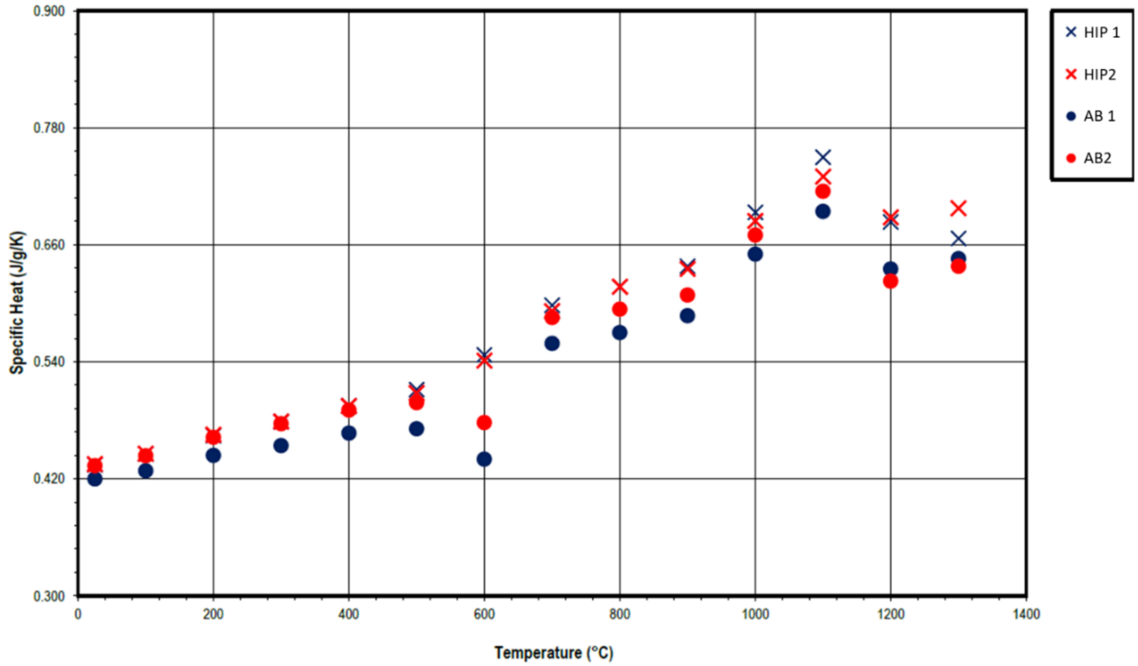

Figure 1: Specific heat as a function of temperature for AM GRX-810 in the as-built and HIP condition.

Thermal Conductivity

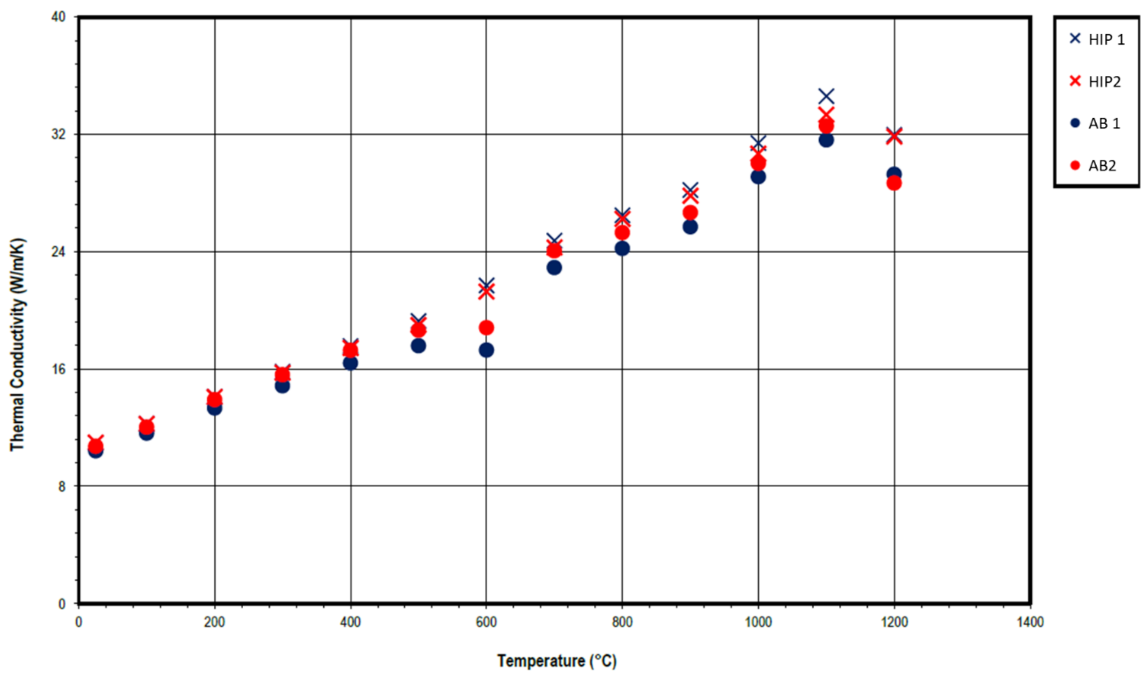

Figure 2: Thermal conductivity vs temperature curve for AM GRX-810 in the as-built and HIP condition.

Thermal Diffusivity

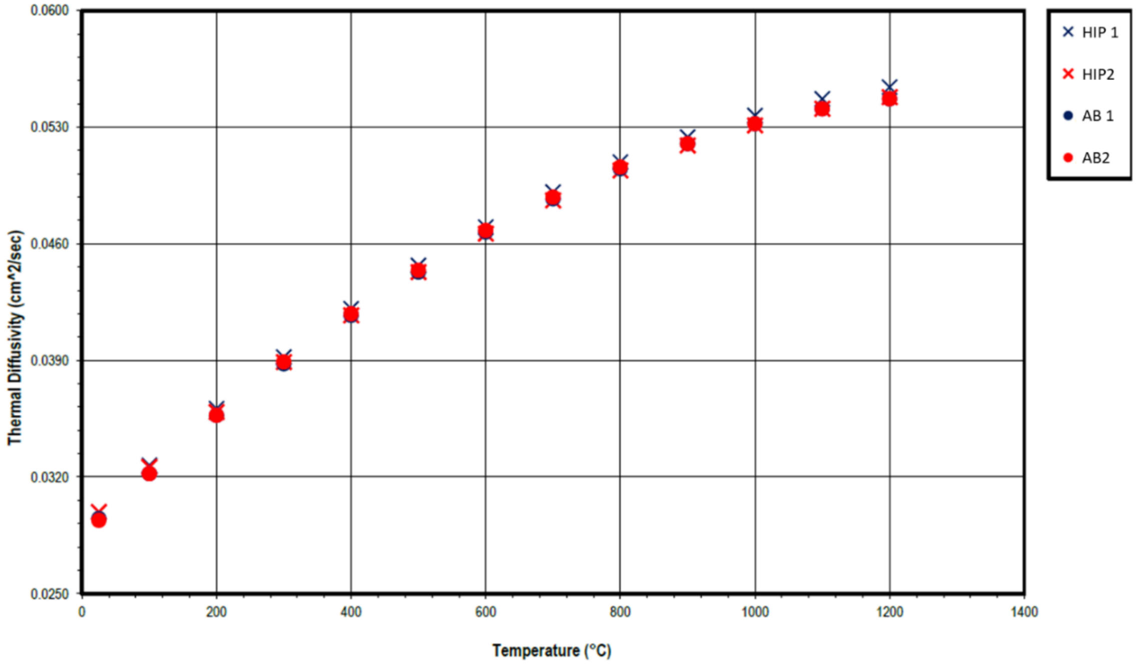

Figure 3: Thermal Diffusivity vs temperature curve for AM GRX-810 in the as-built and HIP conditions.

Table 6: Tabulated data for specific heat, thermal diffusivity, and thermal conductivity vs temperature in As-built GRX-810.

Temperature (C)	AB Specific Heat (J/g/K)	AB Thermal Diffusivity (Cm^{-2}/s)	AB Thermal Conductivity (W/m/K)
25	0.420	0.0295	10.7
100	0.428	0.0322	12.0
200	0.444	0.0357	13.9
300	0.454	0.0388	15.6
400	0.467	0.0417	17.3
500	0.471	0.0443	18.6
600	0.440	0.0467	18.8
700	0.559	0.0487	24.1
800	0.570	0.0505	25.3
900	0.587	0.0520	26.7
1000	0.650	0.0532	30.0
1100	0.694	0.0541	32.6
1200	0.635	0.0547	28.7
1300	0.646	---	---

Table 7: Tabulated data for specific heat, thermal diffusivity, and thermal conductivity vs temperature in HIP GRX-810

Temperature (C)	HIP Specific Heat (J/g/K)	HIP Thermal Diffusivity (Cm^2/s)	HIP Thermal Conductivity (W/m/K)
25	0.434	0.0299	11.0
100	0.446	0.0327	12.3
200	0.464	0.0361	14.1
300	0.479	0.0392	15.8
400	0.495	0.0421	17.6
500	0.511	0.0447	19.3
600	0.547	0.0470	21.7
700	0.598	0.0491	24.7
800	0.617	0.0509	26.5
900	0.638	0.0524	28.2
1000	0.693	0.0537	31.4
1100	0.750	0.0547	34.6
1200	0.683	0.0554	32.0
1300	0.666	---	---

Thermal Expansion

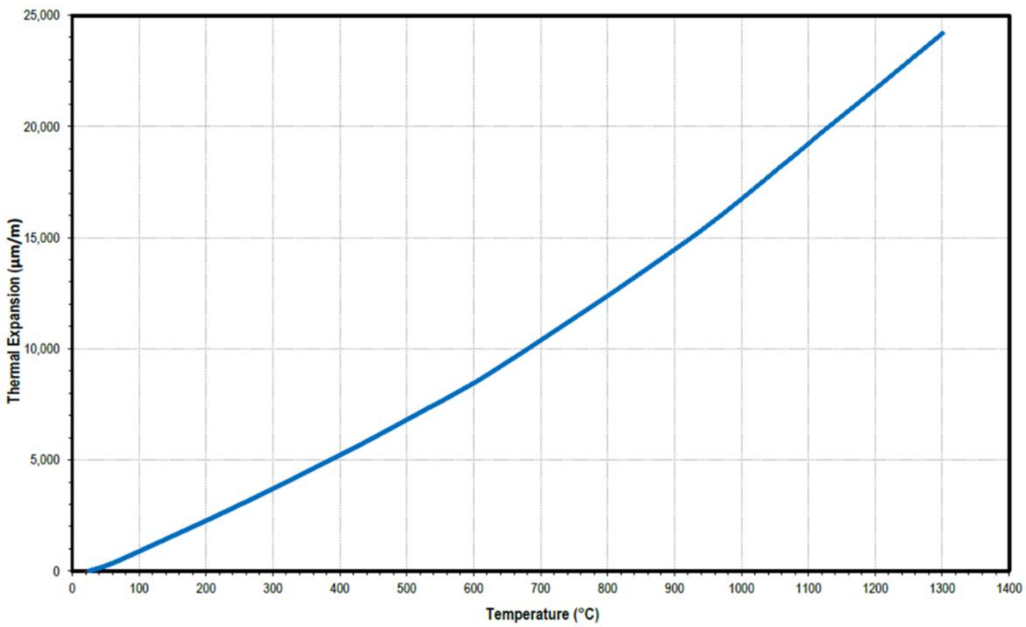

Figure 4: Thermal displacement as a function of temperature for AM HIP GRX-810

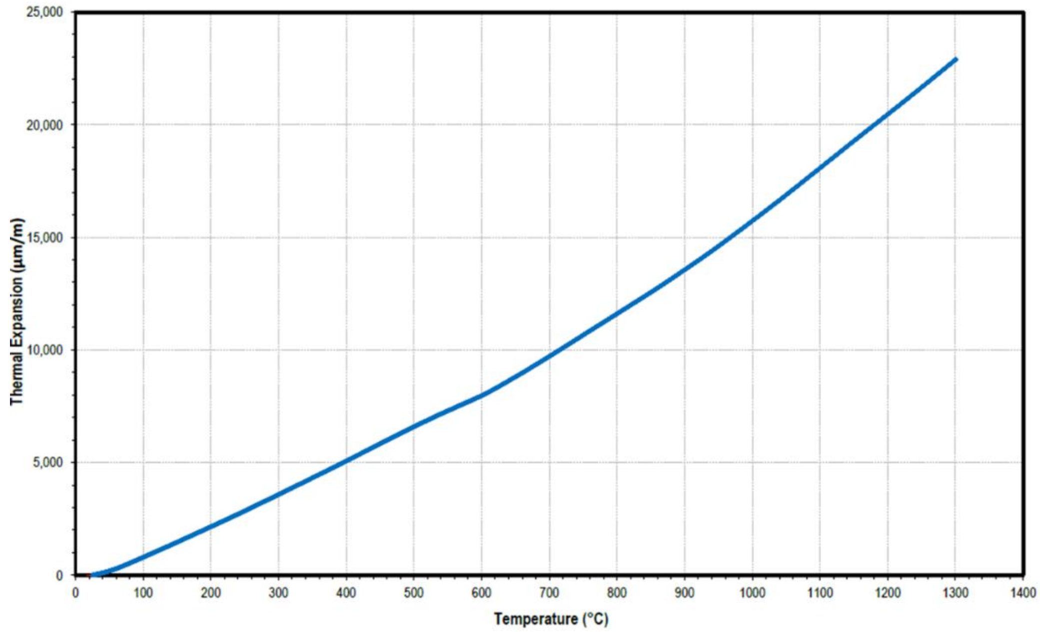

Figure 5: Thermal displacement as a function of temperature for AM As-built GRX-810

Table 8: Tabulated thermal expansion data vs. Temperature in HIP and as-built AM GRX-810

Temperature (C)	HIP CTE (10^{-6} m/m/°C)	AB CTE (10^{-6} m/m/°C)
100	11.8	10.6
200	12.9	12.3
300	13.5	13
400	13.9	13.5
500	14.3	13.9
600	14.7	13.9
700	15.4	14.4
800	16	15
900	16.5	15.5
1000	17.2	16.1
1100	17.9	16.8
1200	18.5	17.4
1300	19	17.9

Elastic Modulus:

Table 9: Elastic modulus for AM GRX-810 produced using a single-laser AM printer (1) measured from tensile tests.

Temp (C)	Modulus (Gpa)
-196	182.0
21	158.6
427	115.8
649	106.2
871	82.1
1093	42.7

Microstructure and Characterization

Polish Procedure:

Table 10: GRX-810 polishing procedure.

Polishing Step	Grit Size	Lubricant	Time (min)	Load (N)	RPM
1	220	H_2O	1-2	150	300
2	9um Diamond suspension	60% HUDOIL Extender + 40% ethanol	7	150	150
3	6 um Diamond suspension	60% HUDOIL Extender + 40% ethanol	7	150	150
4	3 um Diamond suspension	60% HUDOIL Extender + 40% ethanol	3.5	150	150
5	3 um Diamond suspension	60% HUDOIL Extender + 40% ethanol	3.5	150	150
6	1 um Diamond suspension	60% HUDOIL Extender + 40% ethanol	3.5	150	150
7	1 um Diamond suspension	60% HUDOIL Extender + 40% ethanol	15	150	150
8	.05	60% Colloidal Silica + 40% H_2O	120-240	N/A	N/A

Etchant

Electrolytic etching in 5g Oxalic, 95mL HCl at 25C. Stainless steel cathode, carbon cathode at 6V with 1-2s contact. (Etch until blue film covers specimen surface evenly)

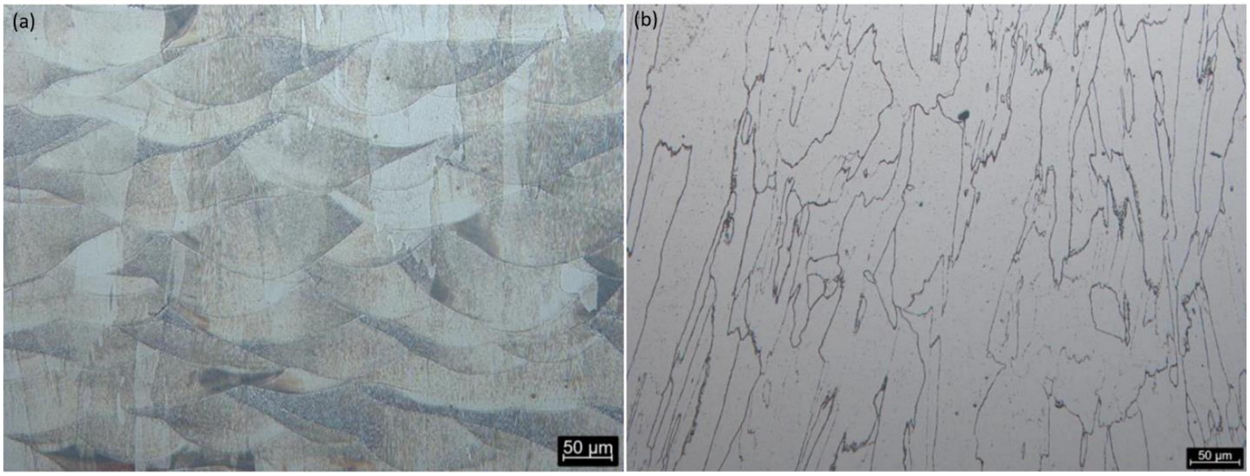

Figure 6: Typical as-built microstructure of AM GRX-810 in the XZ plane for (a) as-built and (b) HIP after etching.

Grain Structure

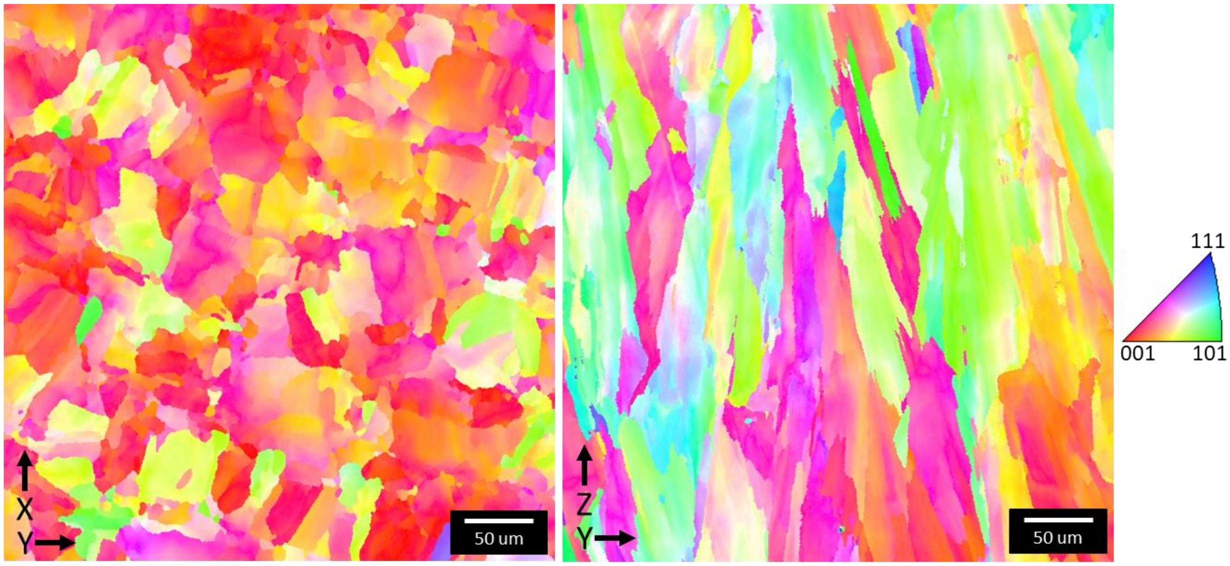

Figure 7: Typical grain structure of HIPed AM GRX-810 in the XY plane (left) and XZ plane (right).

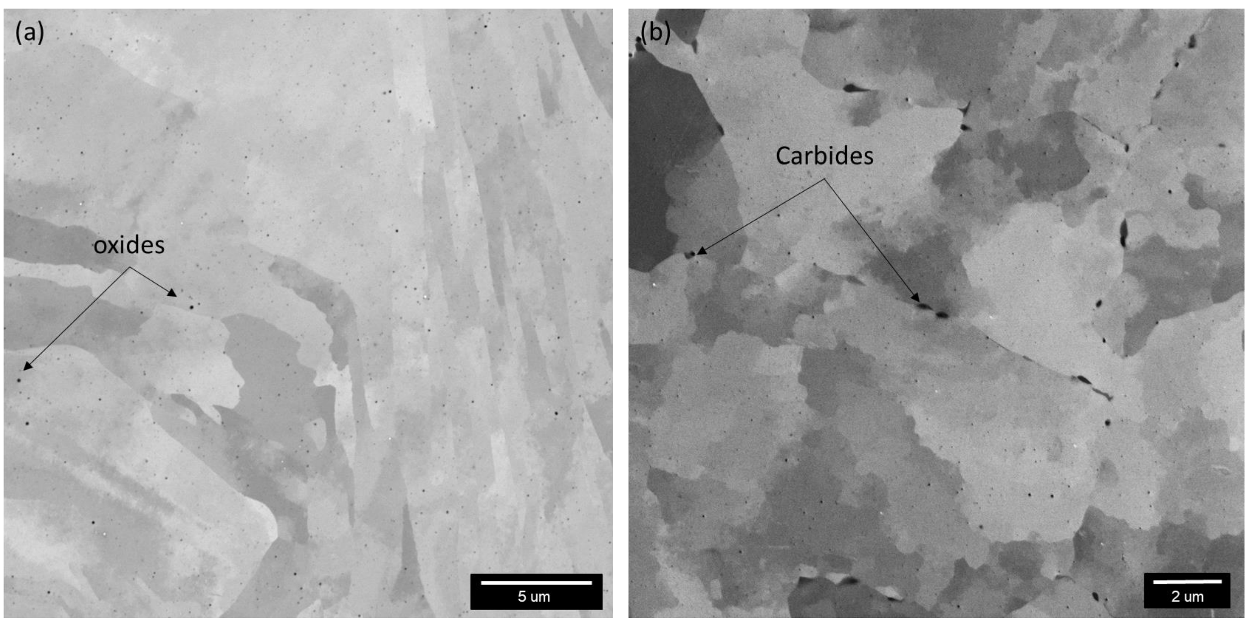

Figure 8: Typical SEM microstructure of (a) as-built and (b) HIP AM GRX-810.

Mechanical Properties

Multiple printers were employed to print and test GRX-810 specimen. The data from each AM printer has been separated to convey printer-to-printer variation typical for GRX-810.

Tensile

Table 11: Average tensile behavior vs temperature for as-built AM GRX-810 loading in Z direction with respect to AM machine.

Machine	Test Temperature		Avg. 0.2% Yield Strength		Avg. Ultimate Tensile Strength		Avg. Elongation	Tested Samples
Single-Laser	°F	°C	ksi	Mpa	ksi	Mpa	%	#
AM Printer 1	-320	-196	118.3	815.3	183.5	1265.2	49.0	4
	75	24	83.1	573.3	127.9	881.5	44.6	7
	800	427	68.0	468.8	99.0	682.6	40.0	2
	1200	649	61.5	424.0	94.8	653.3	43.0	2
	1600	871	33.1	227.9	40.3	277.5	62.0	2
	1832	1000	21.8	150.3	23.2	159.6	45.5	2
	2000	1093	15.9	109.9	16.7	115.0	21.6	9
Machine	Test Temperature		Avg. 0.2% Yield Strength		Avg. Ultimate Tensile Strength		Avg. Elongation	Tested Samples
Single-Laser	°F	°C	ksi	Mpa	ksi	Mpa	%	#
AM Printer 2	75	24	76.0	524.0	115.2	794.0	45.5	18
	400	204	55.1	380.1	95.3	656.7		4
	800	427	52.0	358.5	87.4	602.4		4
	1000	538	59.0	406.7	88.1	607.2	41.9	8
	1200	649	46.4	319.9	82.9	571.4		4
	1600	871	27.2	187.2	36.4	250.6		4
	1800	982	19.2	132.2	22.8	157.0		4
	1900	1038	19.0	131.0	19.3	133.1		4
	2000	1093	14.9	103.0	15.6	107.7	39.6	17
	2100	1149	13.0	89.8	13.2	91.3	23.9	10
	2200	1204	10.7	73.6	11.1	76.3	13.2	6
	2300	1260	8.7	59.9	9.4	64.5	13.0	6
	2400	1316	6.1	41.8	7.1	49.1	6.6	6
Machine	Test Temperature		Avg. 0.2% Yield Strength		Avg. Ultimate Tensile Strength		Avg. Elongation	Tested Samples
Single-Laser	°F	°C	ksi	Mpa	ksi	Mpa	%	#
AM Printer 3	75	24	90.0	620.5	114.0	786.0	56.5	3
	1000	538	67.2	463.3	90.5	624.2	55.8	3
	2000	1093	13.4	92.2	14.9	103.0	40.8	3
Machine	Test Temperature		Avg. 0.2% Yield Strength		Avg. Ultimate Tensile Strength		Avg. Elongation	Tested Samples
Multi-Laser	°F	°C	ksi	Mpa	ksi	Mpa	%	#
AM Printer 1	75	24	75.5	520.7	115.5	796.3	48.0	16
	400	204	62.7	432.3	96.2	663.5	47.9	16
	800	427	58.4	402.4	89.6	618.0	48.7	16
	1000	538	56.5	389.6	84.8	584.3	48.5	6
	1200	649	53.1	365.9	84.8	584.9	50.2	16
	1400	760	48.3	332.7	61.3	422.9	102.2	6
	1600	871	30.1	207.7	37.3	257.0	98.8	16
	1800	982	20.3	140.0	22.4	154.2	81.4	16
	1900	1038	16.6	114.5	17.8	122.7	68.0	10
	2000	1093	13.7	94.7	14.5	100.0	53.5	19
	2100	1149	12.1	83.1	12.3	84.9		6
	2200	1204	9.3	64.3	9.5	65.7		6
	2300	1260	7.4	50.9	7.7	52.9		7

Table 12: Average tensile behavior vs temperature for HIP AM GRX-810 loading in Z direction with respect to AM machine.

Machine	Test Temperature		Avg. 0.2% Yield Strength		Avg. Ultimate Tensile Strength		Avg. Elongation	Tested Samples
Single-Laser AM Printer 1	°F	°C	ksi	Mpa	ksi	Mpa	%	#
	-320	-196	105.0	723.9	178.0	1227.3	49.0	2
	75	24	69.7	480.3	129.3	891.7	51.5	3
	800	427	59.5	410.2	95.0	655.0	40.0	1
	1200	649	53.5	368.9	91.5	630.9	43.0	1
	1600	871	29.9	206.2	38.1	262.7	62.0	1
	1832	1000	21.8	150.3	23.2	159.6	45.5	2
	2000	1093	15.8	108.9	16.9	116.3	32.5	3
Machine	Test Temperature		Avg. 0.2% Yield Strength		Avg. Ultimate Tensile Strength		Avg. Elongation	Tested Samples
Single-Laser AM Printer 2	°F	°C	ksi	Mpa	ksi	Mpa	%	#
	75	24	69.7	480.7	114.5	789.4	48.2	12
	400	204	55.1	380.1	95.3	656.7		4
	800	427	52.0	358.5	87.4	602.4		4
	1000	538	51.6	355.9	85.5	589.3	46.1	4
	1200	649	46.4	319.9	82.9	571.4		4
	1600	871	27.2	187.2	36.4	250.6		4
	1800	982	19.2	132.2	22.8	157.0		4
	1900	1038	19.0	131.0	19.3	133.1		4
	2000	1093	14.9	102.8	15.5	107.0	37.1	10
	2100	1149	13.0	89.6	13.3	91.7	21.8	7
	2200	1204	10.2	70.4	11.0	76.0	13.2	3
	2300	1260	8.6	59.5	9.6	66.1	15.0	3
	2400	1316	5.5	37.8	6.6	45.8	4.3	3
Machine	Test Temperature		Avg. 0.2% Yield Strength		Avg. Ultimate Tensile Strength		Avg. Elongation	Tested Samples
Single-Laser AM Printer 3	°F	°C	ksi	Mpa	ksi	Mpa	%	#
	75	24	67.6	466.3	107.4	740.7	62.8	3
	1000	538	49.3	339.9	84.2	580.5	59.2	3
	2000	1093	13.2	90.8	14.6	100.4	40.6	3
Machine	Test Temperature		Avg. 0.2% Yield Strength		Avg. Ultimate Tensile Strength		Avg. Elongation	Tested Samples
Multi-Laser AM Printer 1	°F	°C	ksi	Mpa	ksi	Mpa	%	#
	75	24	65.9	454.4	111.9	771.7	51.0	8
	400	204	54.1	373.1	92.5	637.5	51.4	8
	800	427	50.9	351.0	86.5	596.5	52.7	8
	1000	538	48.5	334.4	81.8	564.2	52.7	3
	1200	649	45.4	312.8	81.4	561.3	58.2	8
	1400	760	43.5	299.9	58.8	405.6	109.0	3
	1600	871	27.7	190.8	35.2	242.5	104.1	8
	1800	982	19.0	131.0	21.8	150.2	88.2	8
	1900	1038	16.1	111.1	17.4	120.2	68.5	5
	2000	1093	13.6	93.9	14.4	99.0	58.5	11
	2100	1149	11.6	80.3	11.9	82.0		3
	2200	1204	9.5	65.2	9.7	66.7		3
	2300	1260	7.7	52.8	7.9	54.7		3

Table 13: Average tensile behavior vs temperature for as-built AM GRX-810 loading in X direction (horizontal) with respect to AM machine.

Machine	Test Temperature		Avg. 0.2% Yield Strength		Avg. Ultimate Tensile Strength		Avg. Elongation	Tested Samples
Multi-Laser	°F	°C	ksi	Mpa	ksi	Mpa	%	#
AM Printer 1	75	24	85.3	587.8	129.0	889.4	37.5	10
	400	204	70.7	487.3	109.2	753.2	37.3	10
	800	427	65.7	452.6	99.9	688.6	36.8	10
	1200	649	58.8	405.2	92.8	640.0	34.2	10
	1600	871	32.5	223.9	40.9	282.2	38.1	10
	1800	982	21.2	146.2	24.1	165.9	23.0	10
	1900	1038	16.8	115.5	18.6	128.0	17.0	10
	2000	1093	13.3	91.8	14.3	98.7	14.3	16
	2100	1149	11.6	80.0	11.7	80.8		6
	2200	1204	8.6	59.3	8.9	61.2		6
	2300	1260	6.3	43.6	6.6	45.6		6

Table 14: Average tensile behavior vs temperature for HIP AM GRX-810 loading in X direction (horizontal) with respect to AM machine.

Machine	Test Temperature		Avg. 0.2% Yield Strength		Avg. Ultimate Tensile Strength		Avg. Elongation	Tested Samples
Multi-Laser	°F	°C	ksi	Mpa	ksi	Mpa	%	#
AM Printer 1	75	24	74.2	511.6	127.0	875.6	42.6	3
	400	204	58.4	402.8	105.9	730.2	41.5	5
	800	427	54.3	374.4	96.9	668.0	40.5	5
	1200	649	49.4	340.7	89.8	619.0	38.0	5
	1600	871	28.8	198.3	39.3	270.7	41.5	5
	1800	982	19.6	134.9	23.5	162.2	25.8	5
	1900	1038	16.2	111.6	18.6	128.2	16.1	5
	2000	1093	13.1	90.4	14.3	98.4	14.1	8
	2100	1149	10.6	73.0	10.7	74.0		3
	2200	1204	8.9	61.3	9.1	62.7		3
	2300	1260	6.4	44.2	6.7	46.0		3

Table 15: Average tensile behavior vs temperature for AM GRX-810 loading in 45° from the build direction (Z)

Machine	Condition	Test Temperature		Avg. 0.2% Yield Strength		Avg. Ultimate Tensile Strength		Avg. Elongation	Tested Samples
Single-Laser	N/A	°F	°C	ksi	Mpa	ksi	Mpa	%	#
AM Printer 3	As-built	75	24	98.8	681.0	132.6	914.2	34.2	3
	HIP	75	24	74.2	511.6	127.0	875.6	42.6	3
	As-built	800	427	77.4	533.4	105.1	724.4	33.6	3
	HIP	800	427	55.6	383.3	99.7	687.4	38.2	3
	As-built	1200	649	70.2	484.0	100.0	689.2	29.9	3
	HIP	1200	649	50.6	349.1	94.5	651.6	38.8	3

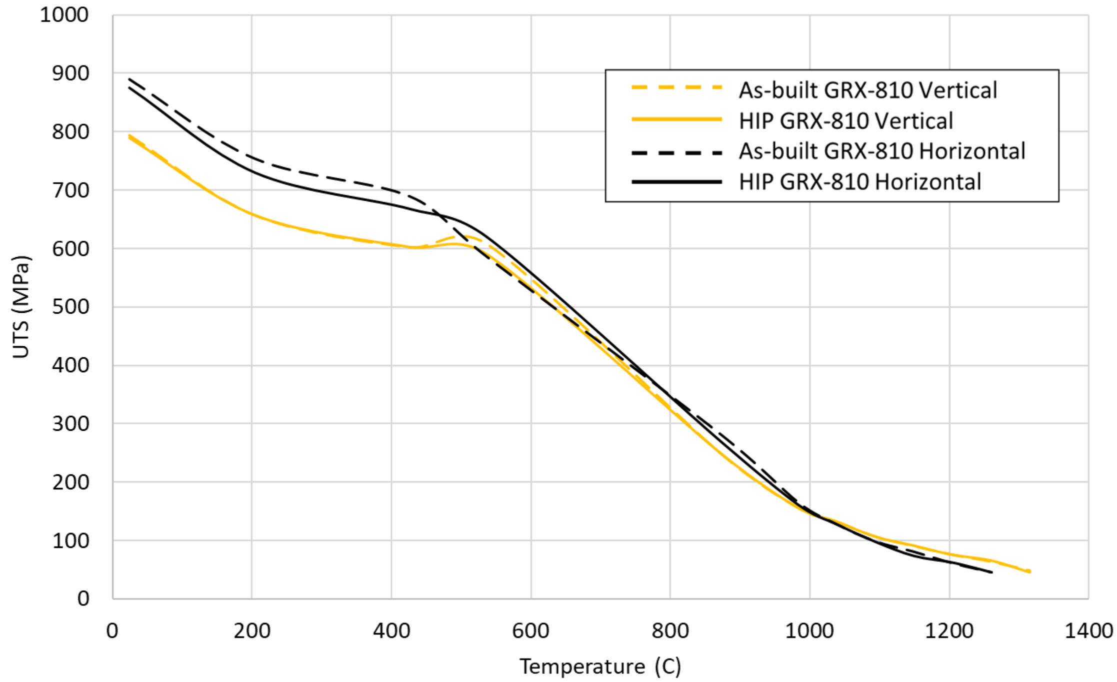

Figure 9: Ultimate Tensile Strength vs. temperature for AM GRX-810

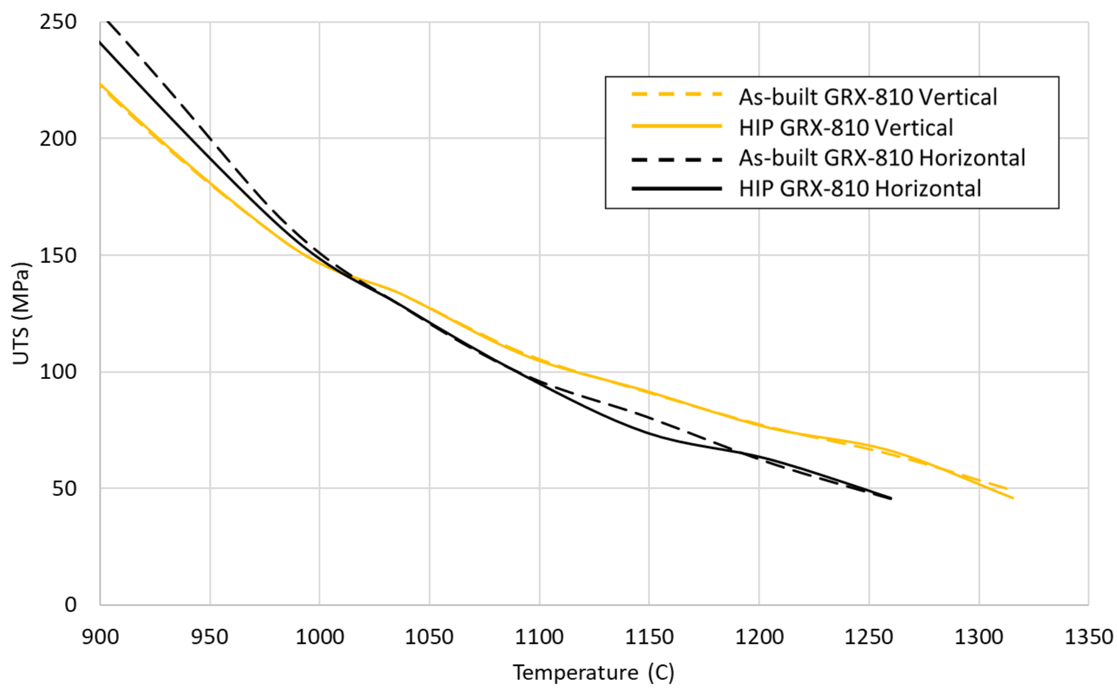

Figure 10: Ultimate Tensile Strength vs. temperature for AM GRX-810 at elevated temperatures

Low Cycle Fatigue

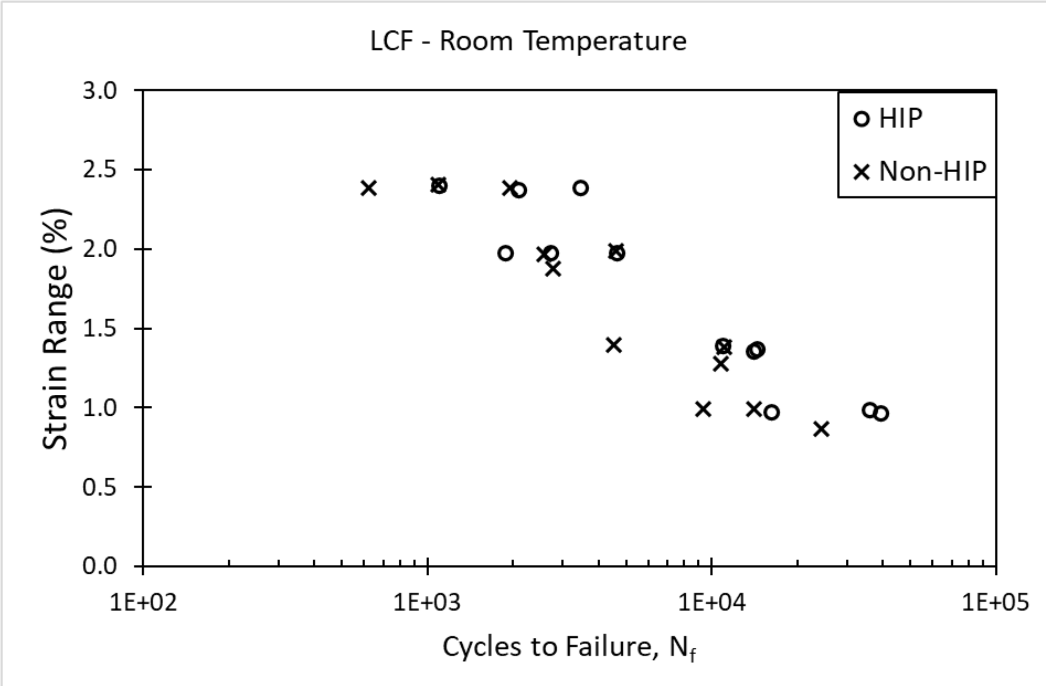

Figure 11: Low cycle fatigue life vs strain amplitude (R=-1) at room temperature for AM GRX-810 loading in the Z direction

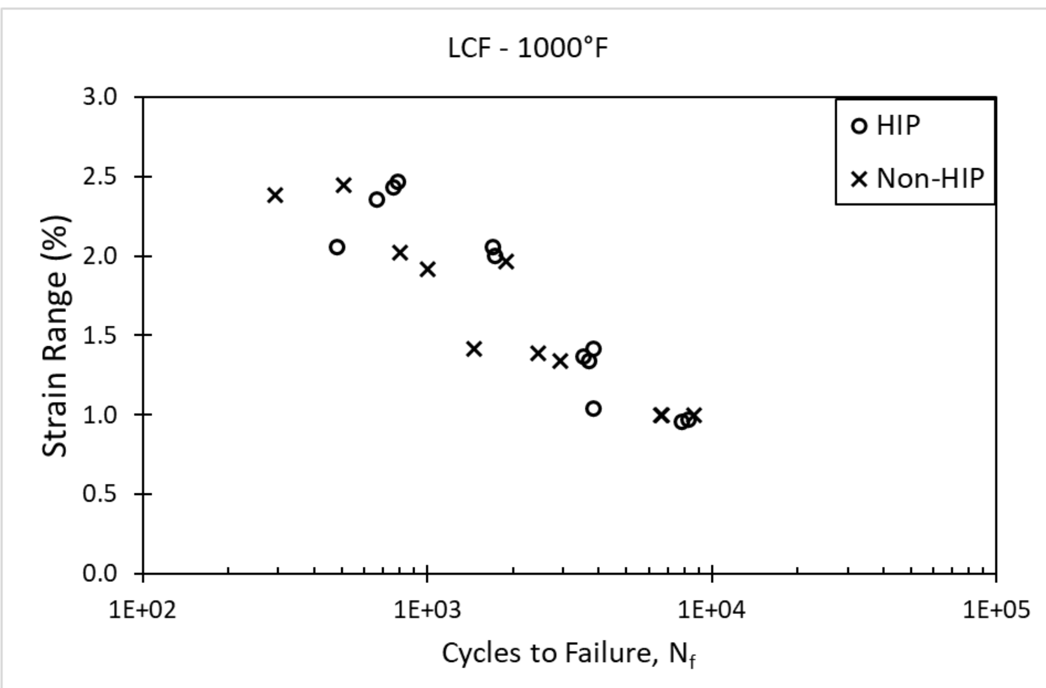

Figure 12: Low cycle fatigue life vs strain amplitude (R=-1) at 1000°F (537.8°C) for AM GRX-810 loading in the Z direction

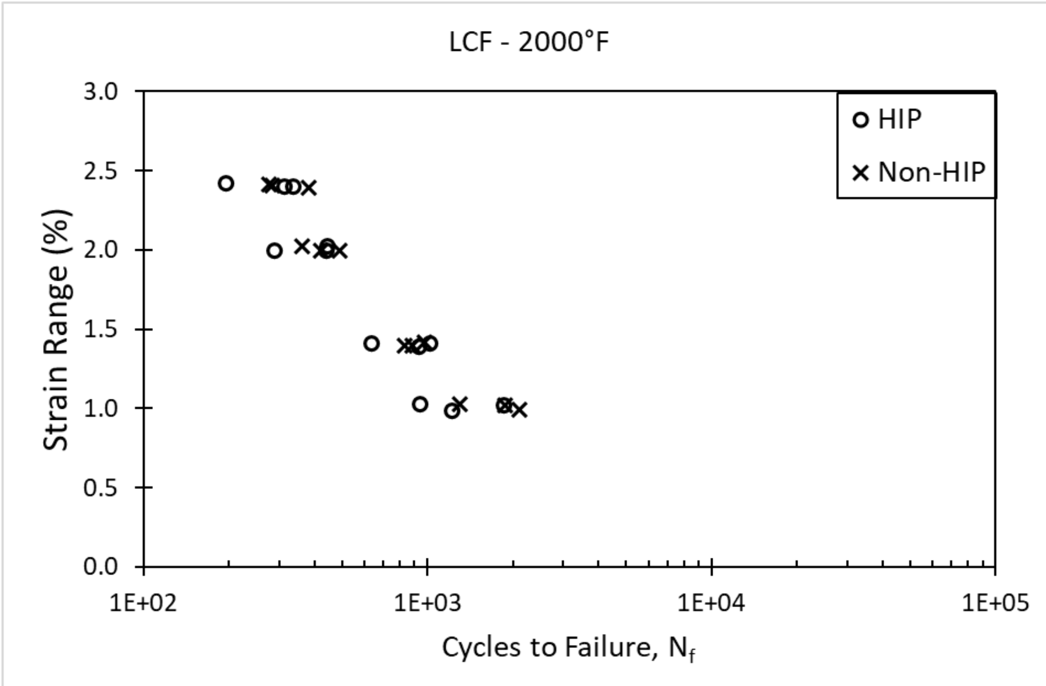

Figure 13: Low cycle fatigue life vs strain amplitude (R=-1) at 2000°F (1093°C) for AM GRX-810 loading in the Z direction

High Cycle Fatigue

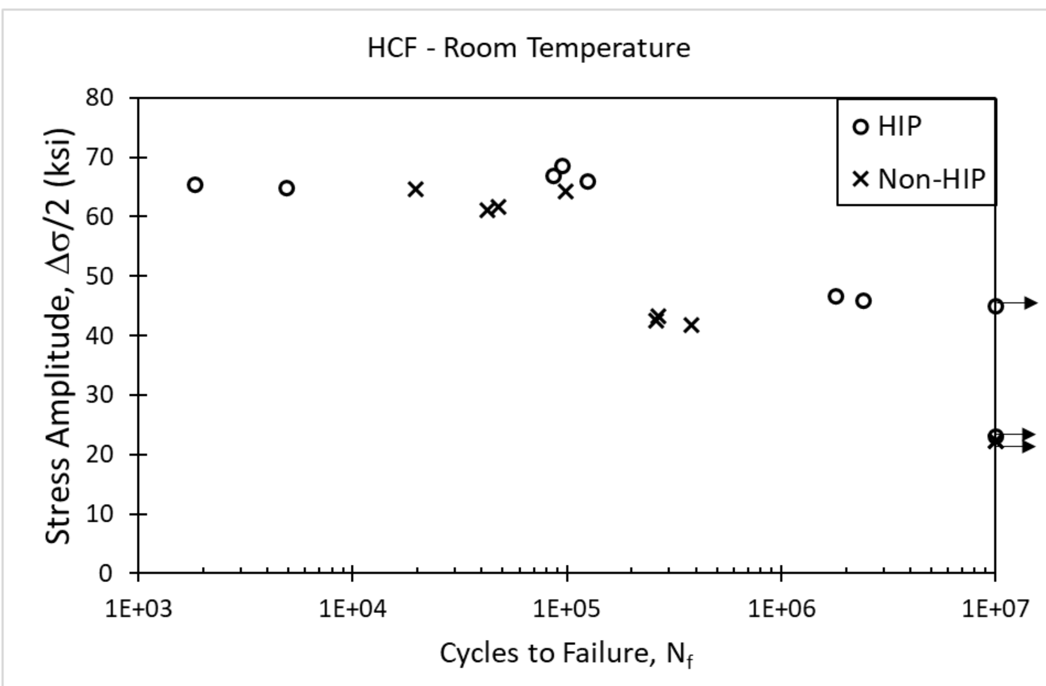

Figure 14: Stress controlled high cycle fatigue life vs stress amplitude (R=-1) for GRX-810 loading in the Z direction at room temperature.

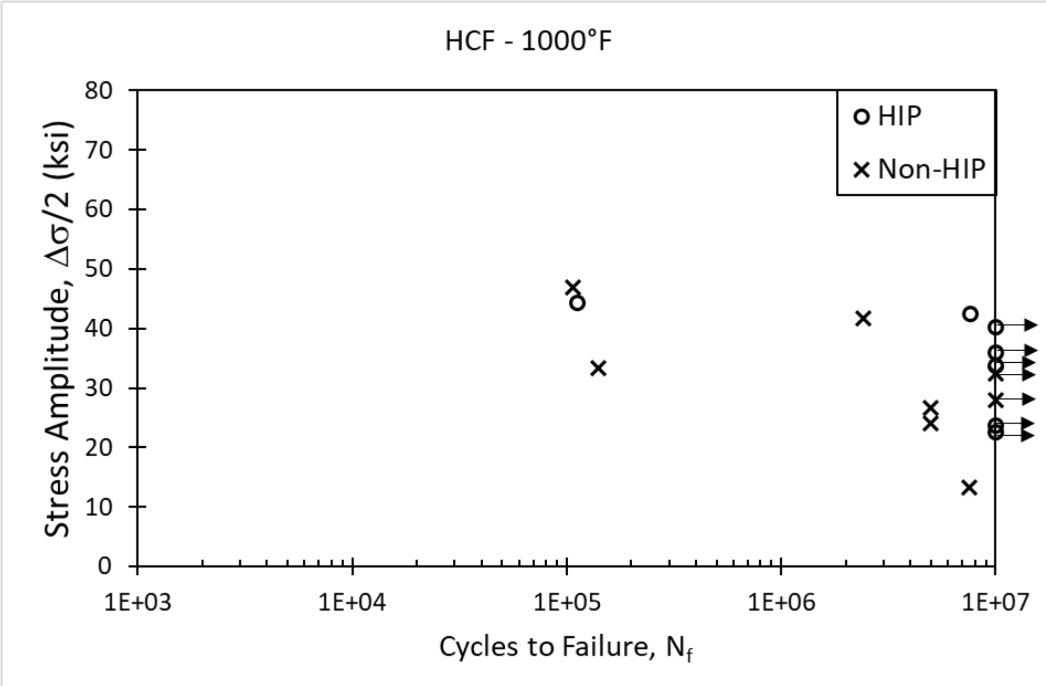

Figure 15: Stress controlled high cycle fatigue life vs stress amplitude (R=-1) for GRX-810 loading in the Z direction at 1000°F (537.8°C).

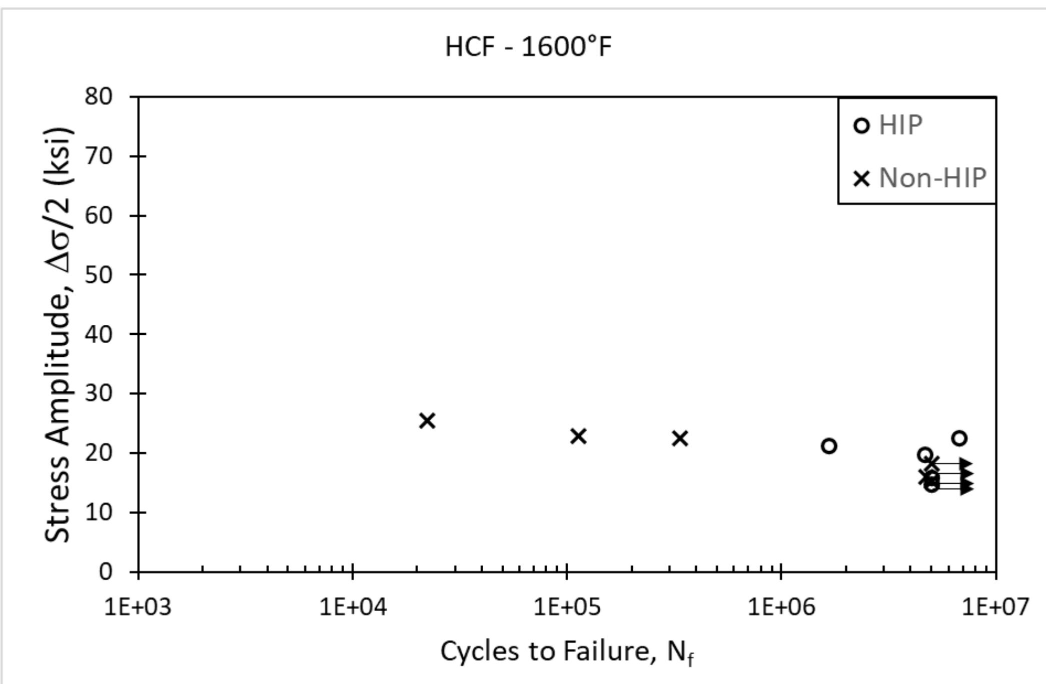

Figure 16: Stress controlled high cycle fatigue life vs stress amplitude (R=-1) for GRX-810 loading in the Z direction at 1600°F (871.1°C).

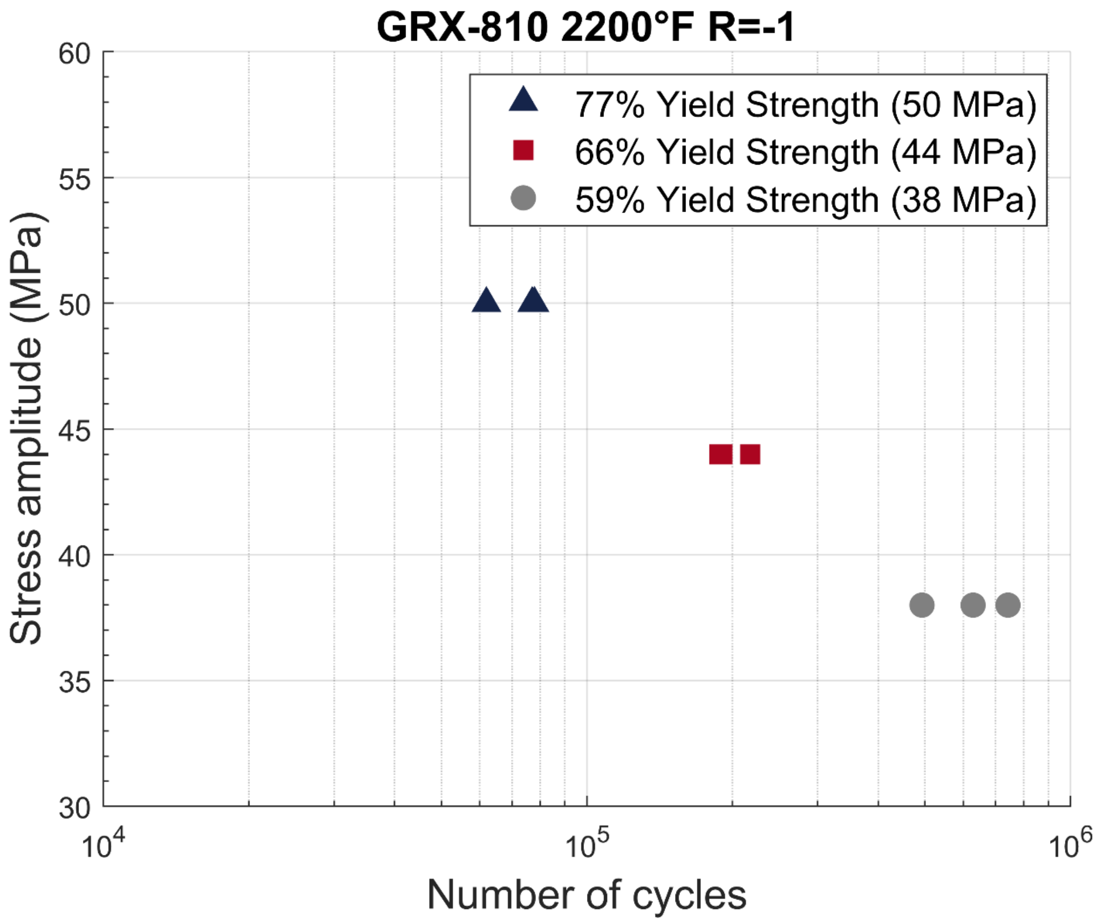

Figure 17: Stress controlled high cycle fatigue life vs stress amplitude (R=-1) for GRX-810 loading in the Z direction at 2200°F (1204°C).

Creep

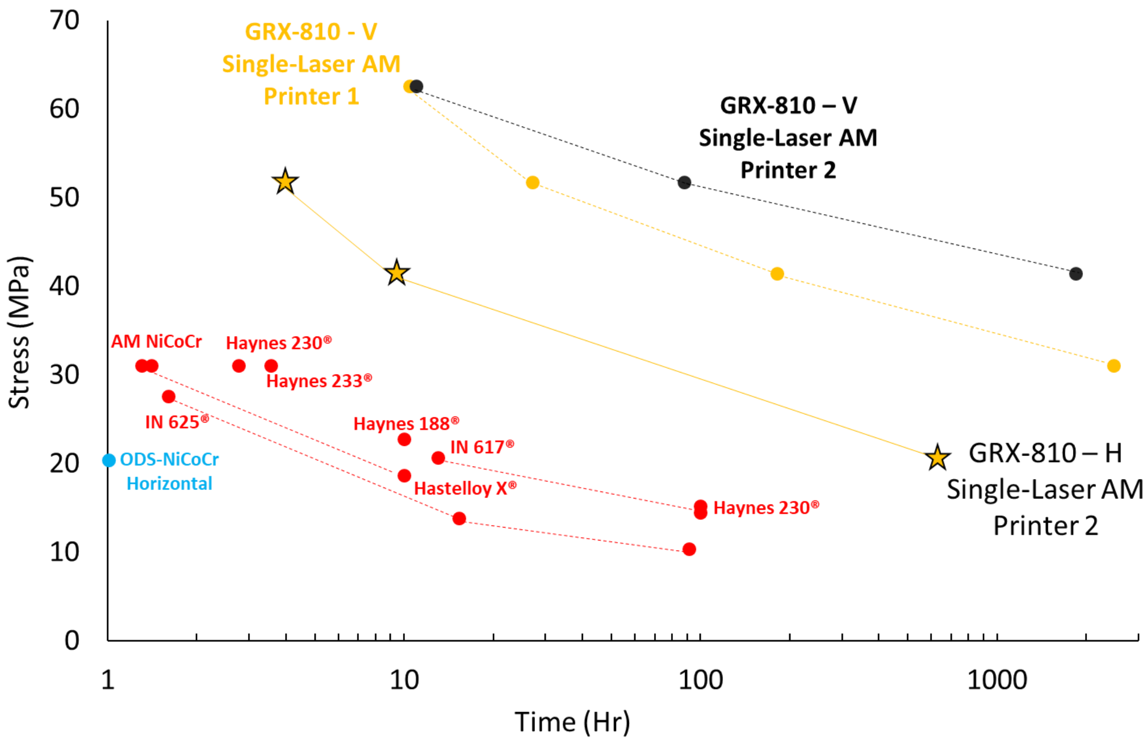

Figure 18: Creep overview at 2000°F (1093°C) for AM GRX-810.

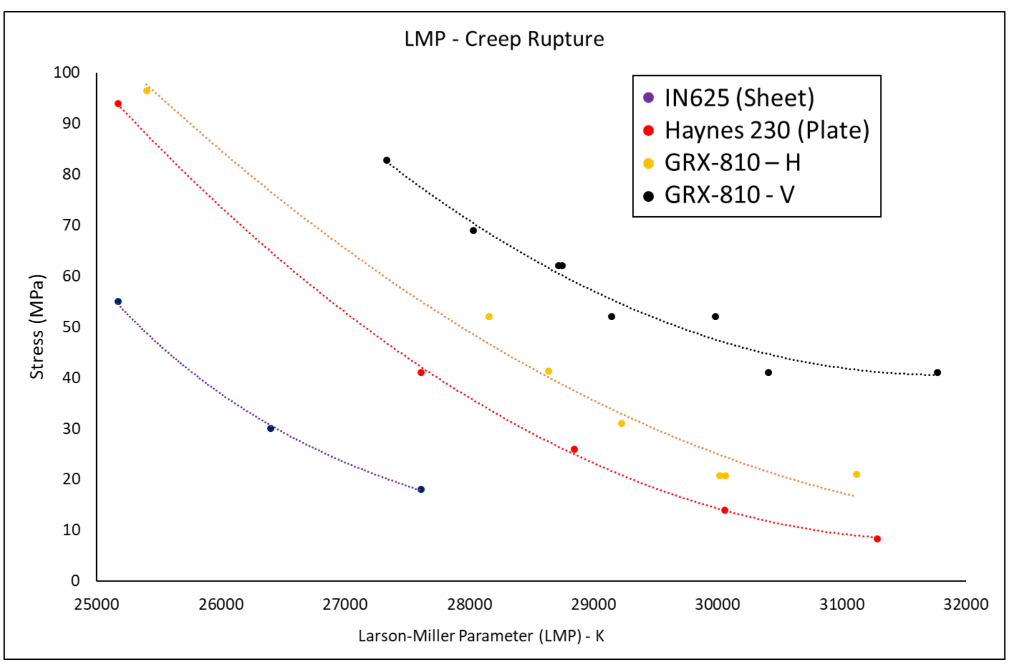

Figure 19: The Larson Miller Parameter vs. stress for creep rupture in GRX-810 in the horizontal (H) and vertical (V) build directions compared to plate Haynes 230 and sheet Superalloy 625.

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Oxidation Resistance

Cyclic Oxidation

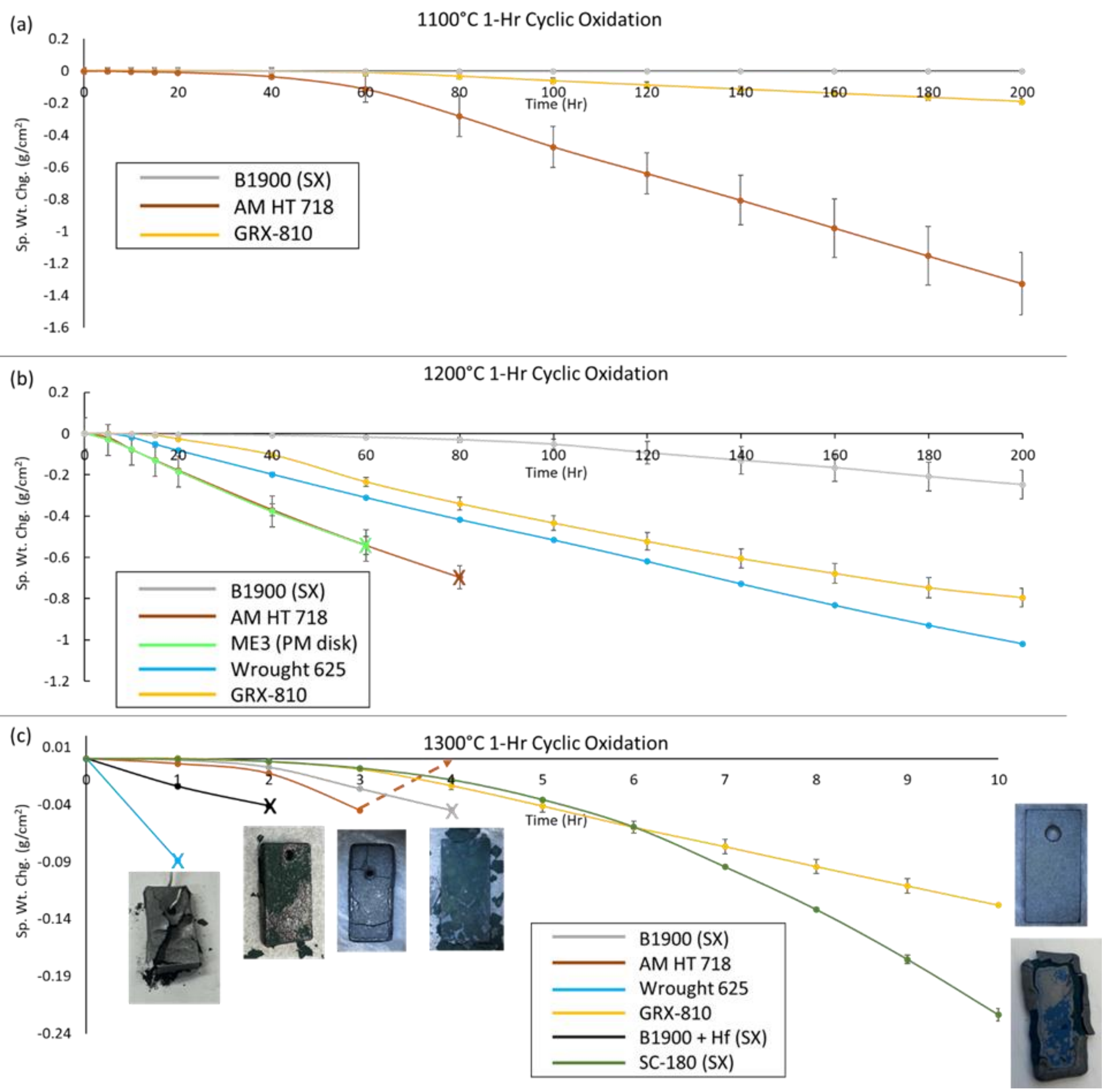

Figure 20: Cyclic Oxidation Results at 1100°C, 1200°C, and 1300°C. Cyclic oxidation results for (a) GRX-810, 718, and single crystal B1900 at 1100°C, (b) GRX-810, 718, ME3 (powder metallurgy (PM) disk alloy), 625, and B1900 at 1200C, and (c) GRX-810, 625, 718, single crystals B1900+Hf, B1900, and SC180 at 1300°C. Images of the samples were taken after the final cycle measured to highlight the state of the alloy at that point. Note: the 718 sample produced runaway oxidation gain after cycle 3 which has been denoted with the dashed arrow. "x" denotes a test ending due to catastrophic oxidation (sample weight < 1 gram or severe microstructure degradation).

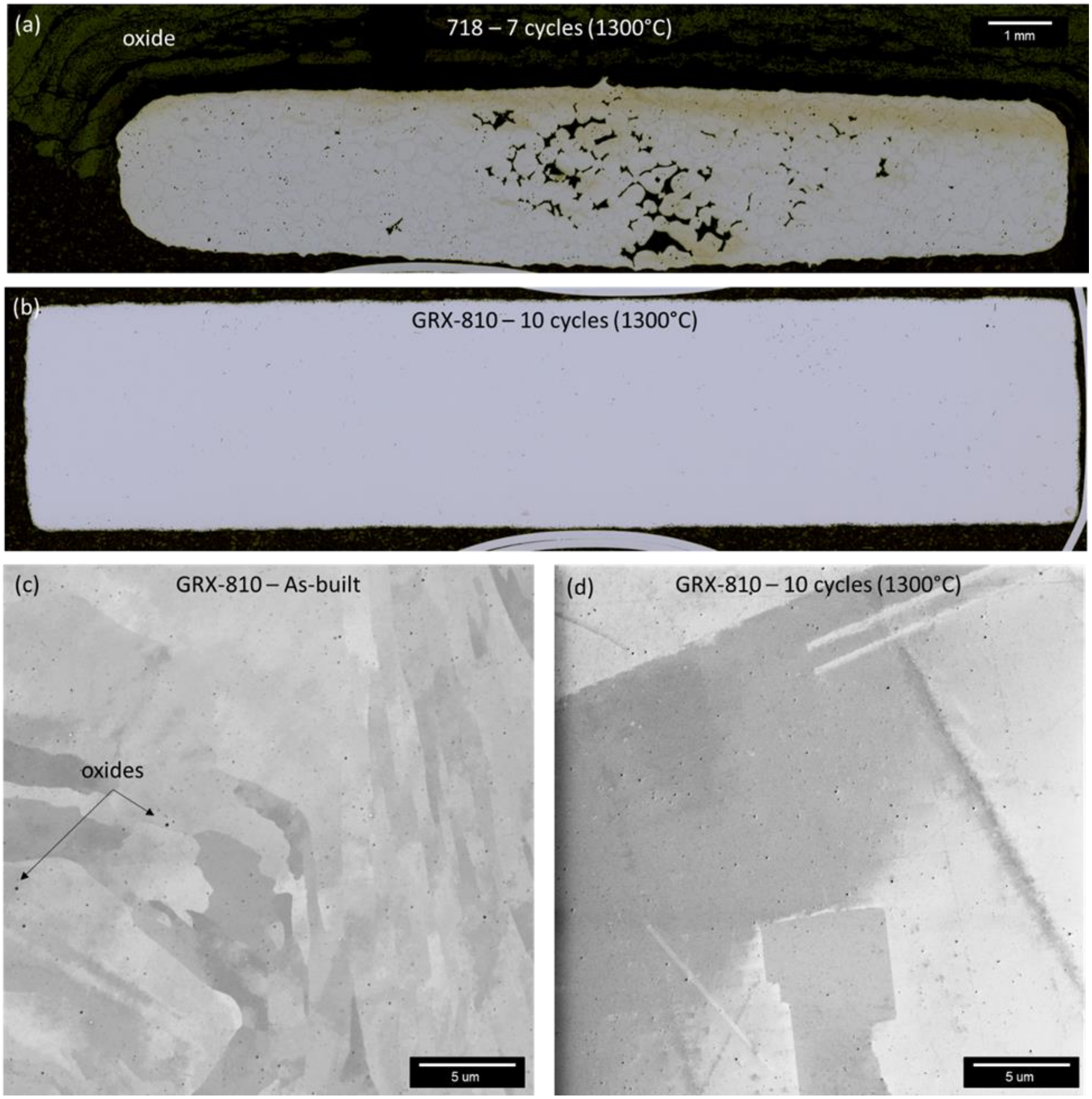

Figure 21: Microstructural stability at 1300°C. metallography cross-sections of (a) superalloy 718 after 7 cycles and (b) GRX-810 after 10 cycles. SEM micrographs of the oxide (fine dark circular features) size and morphology of (c) as-printed GRX-810 and (d) GRX-810 after ten 1300°C 1-hour cycles.

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