EVALUATION OF THE EFFECT OF SURFACE FINISH ON HIGH-CYCLE FATIGUE OF SLM-IN718

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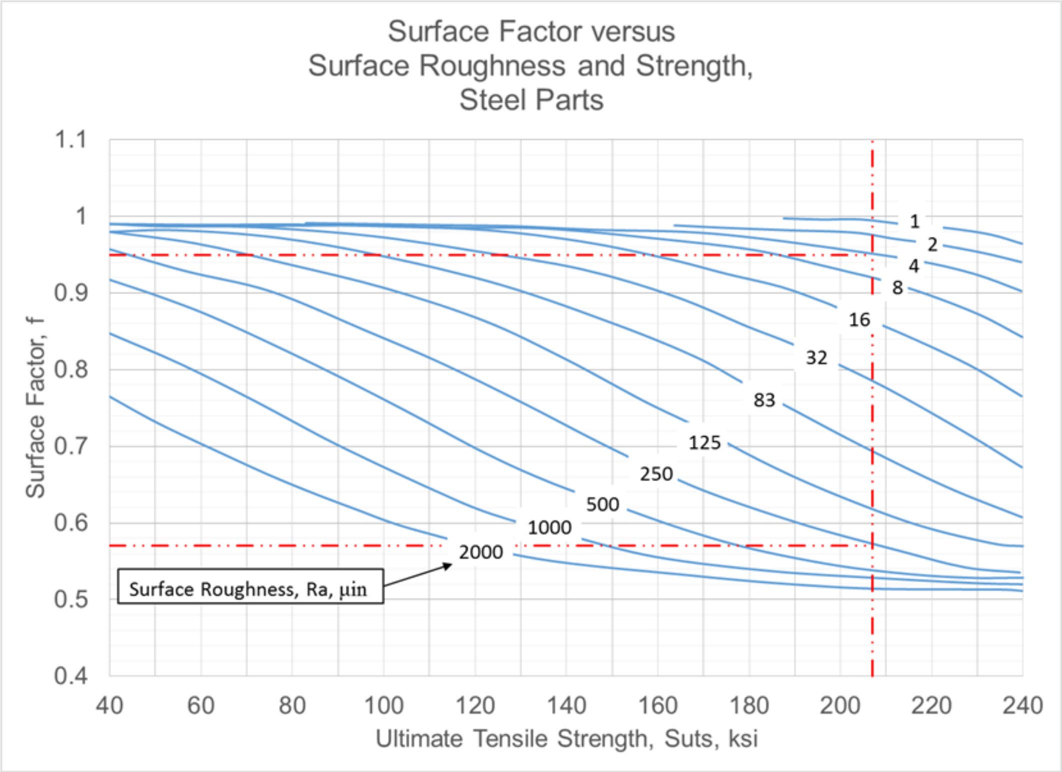
Introduction

- The as-build surface finish of an SLM part is much rougher than the surface finish generated by machining processes
- A rougher surface can reduce the fatigue strength of a part.
- Question: what is an appropriate “knock-down” factor for selective laser melted (SLM) Inconel 718 with an “as-built” surface finish relative to a low-stress ground (LSG) surface which is normally used for fatigue applications?
- Previous work characterizing the effect of surface finish on endurance limit showed good promise.
- Some surface finish data was available.

Characterization of the Current Data

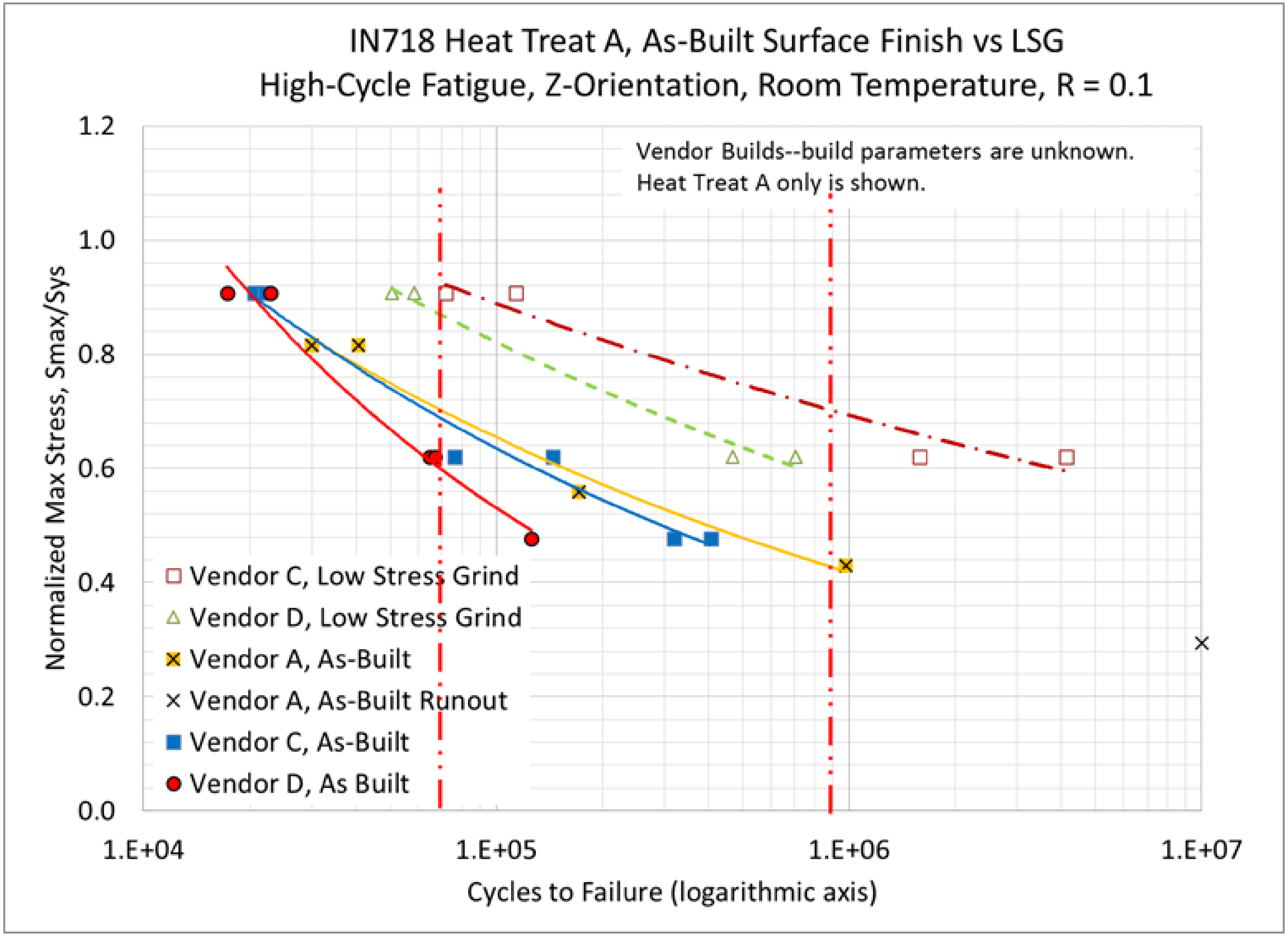
Table I: Average Surface Finishes, As-Built, µin, RMS				
	Room	**800F**	**1000F**	**1200F**
Mean	247	267	243	245
Standard Deviation	39	43	42	67

Early Work

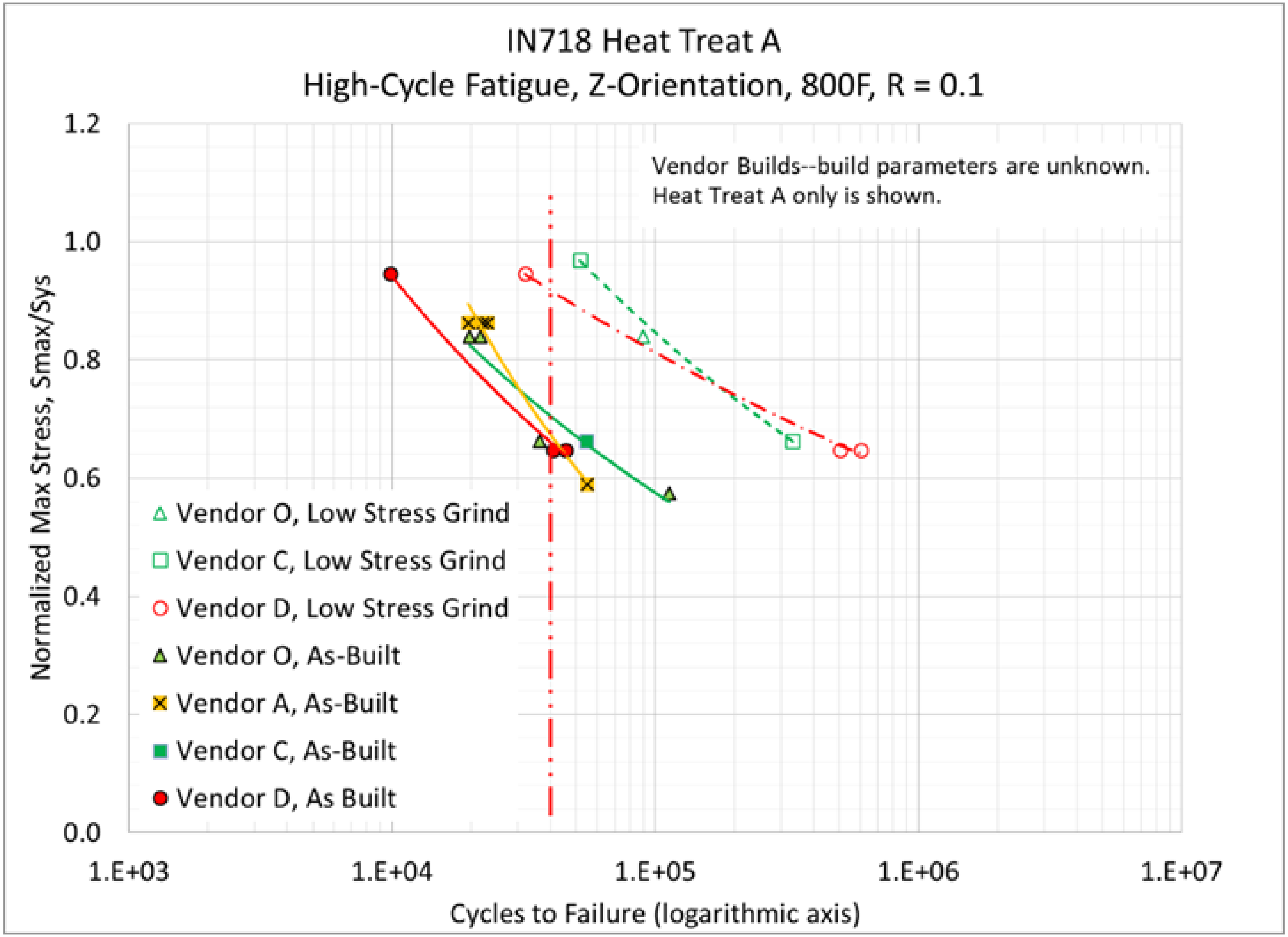


- <u>For steel parts</u>, the endurance limit is a function of tensile strength and surface factor.
- From the graph:
  - 250 µin → 0.57
  - 4 µin → 0.95
- Surface factor → 0.57/0.95 = 0.60
- Knock-down = 1 – surface factor = 0.40

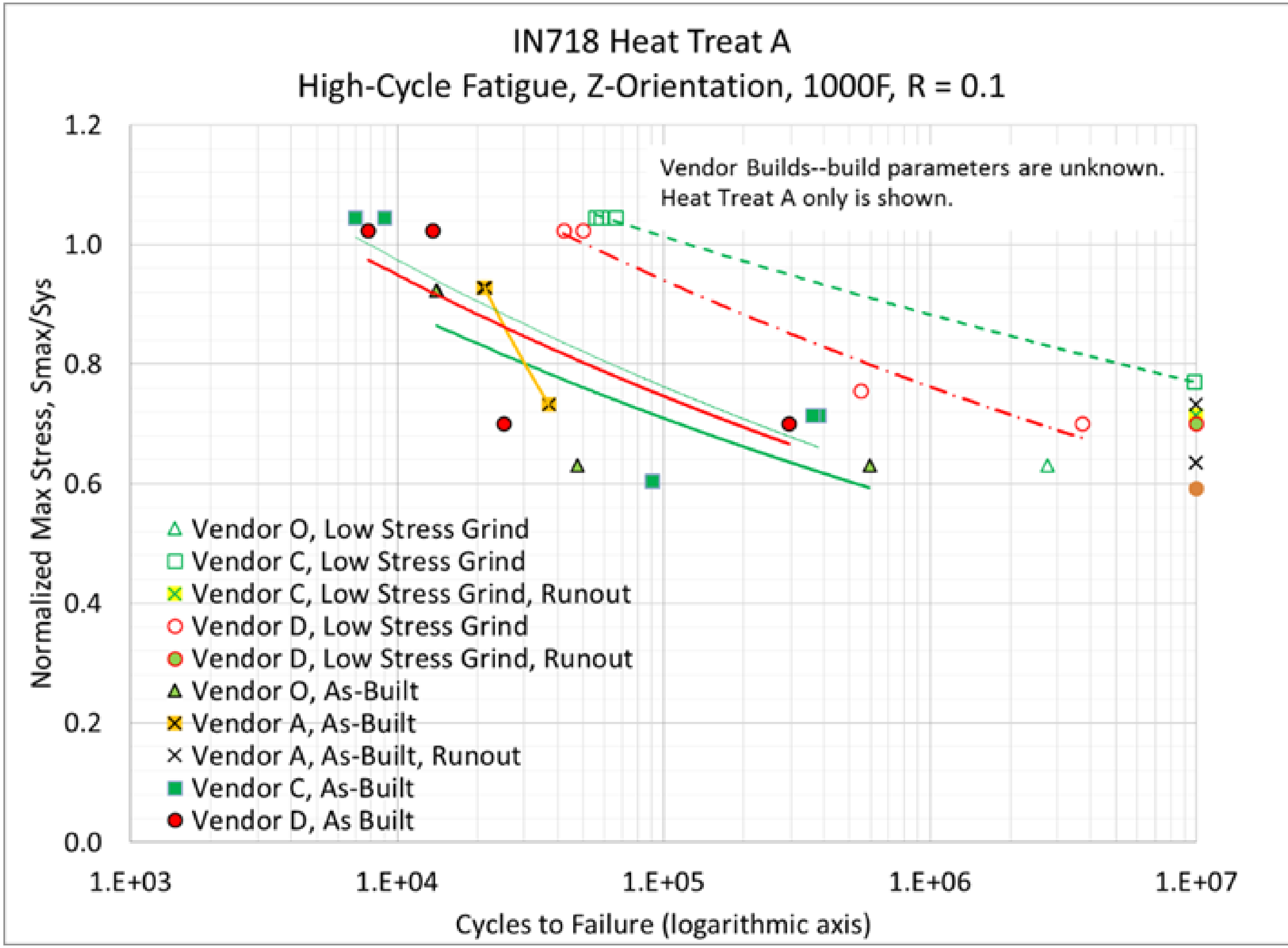
ESTIMATION FROM STRESS-LIFE (SN) CURVES



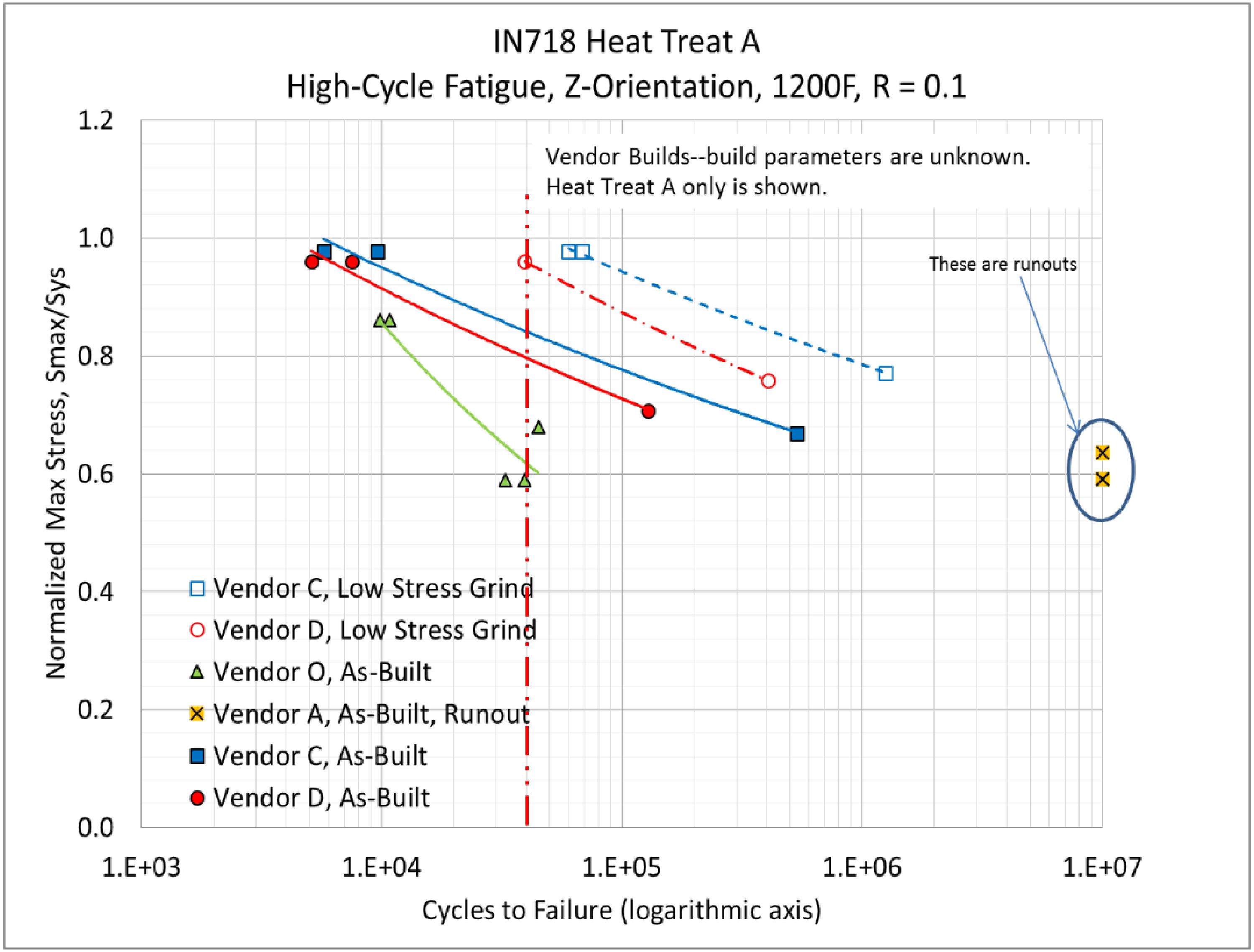
ESTIMATION FROM STRESS-LIFE (SN) CURVES



ESTIMATION FROM STRESS-LIFE (SN) CURVES



ESTIMATION FROM STRESS-LIFE (SN) CURVES



Analysis

Table II: Knockdown Factors for As-Built versus Low-Stress Grinding			
Room Temperature			
N (cycles)	Smax,norm(as built)	Smax, norm(LSG)	Knockdown = 1 - Smax,norm(as built)/Smax,norm(LSG)
80,863	0.62	0.91	32%
1,574,926	0.43	0.62	31%
800F			
N (cycles)	Smax,norm(as built)	Smax, norm(LSG)	Knockdown = 1 - Smax,norm(as built)/Smax,norm(LSG)
43,551	0.66	0.96	32%
1200F			
N (cycles)	Smax,norm(as built)	Smax, norm(LSG)	Knockdown = 1 - Smax,norm(as built)/Smax,norm(LSG)
47,505	0.62	0.97	36%

- 1000F was omitted in the analysis due to sparse data and wide variance.
- A rough estimate of the knockdown is 1/3.
- Subject to gross approximations.
- Limited life range of about 1-million cycles.

Abdulrahim (1988)

- Surface finish included
  - maximum depth of surface features
  - radius of curvature of the root.

$$N = A(S_r)^B$$

$$A = P_1(v_D^* * \sigma_3^*)$$

$$B = P_2(v_D^* * \sigma_3^*)$$

  - v^*_D is the depth of the surface features.
  - σ^*_3 is the root curvature of the surface features.
- Good correlation with fatigue data.
- Slightly conservative where it differed.

KNOCK-DOWN FACTOR—KP Method

$$K_p \equiv S_{max,norm} * \sqrt{f}$$

- K_p was defined as the “pseudo-stress intensity factor.
  - Incorporated stress and surface finish
  - Similar to stress-intensity factor, where a defect size is introduced into the calculation along with stress.
  - An empirical development.

Surface Finish Data

- The as-built surface finish data were used in each case.
- The LSG surface finish data was only listed as < 4 μin.
- Data was graphed and at convenient fatigue lives, data was extracted.

Surface Factor

$$S_{fraction} \equiv \frac{K_p(AB)}{K_p(LSG)} * \sqrt{\frac{f_{avg}(LSG)}{f_{avg}(AB)}}$$

- The radical on the right returns the factor to stress space.

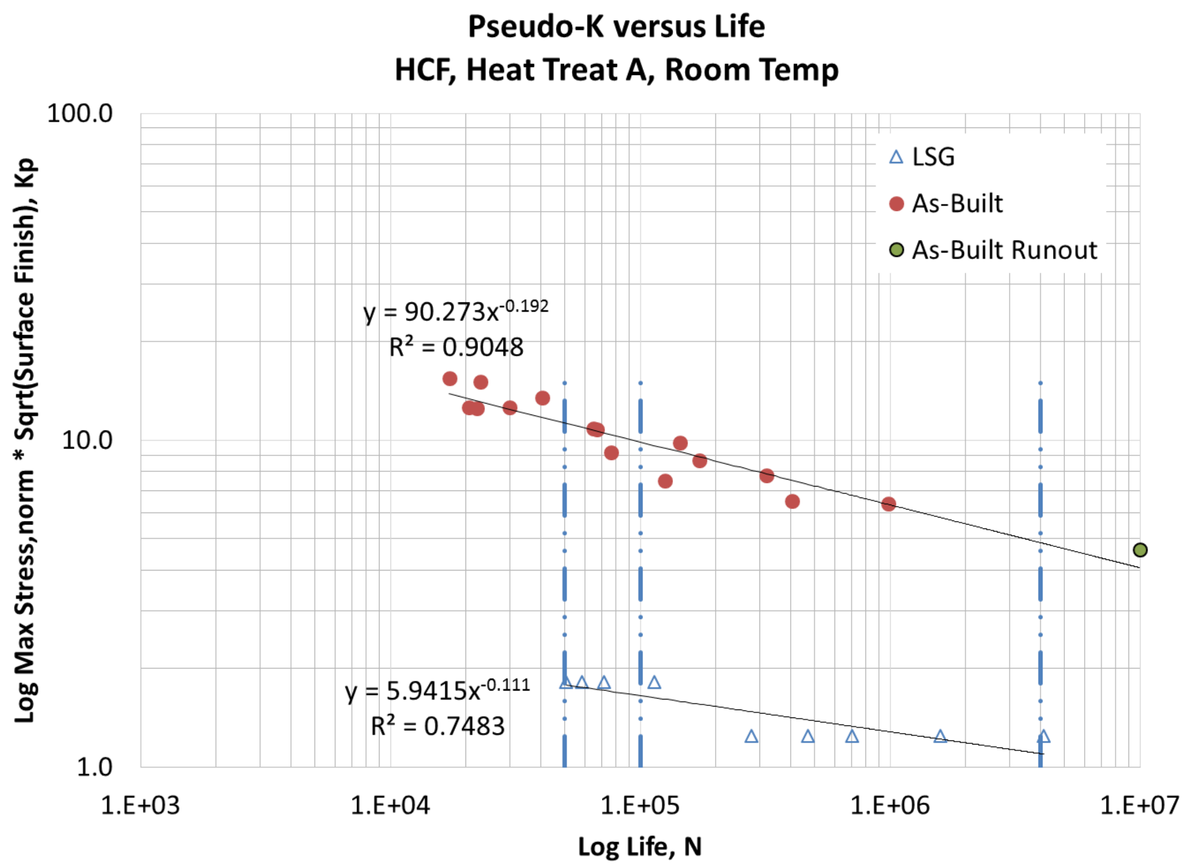


Table III: Knockdown for HT A at RT				
N	Kp(LSG)	Kp(AB)	Sfraction	Knockdown = 1 - Sfraction
50,000	1.8	11.4	0.81	19%
100,000	1.7	9.9	0.76	24%
1,000,000	1.3	6.4	0.63	37%
4,000,000	1.1	4.9	0.57	43%

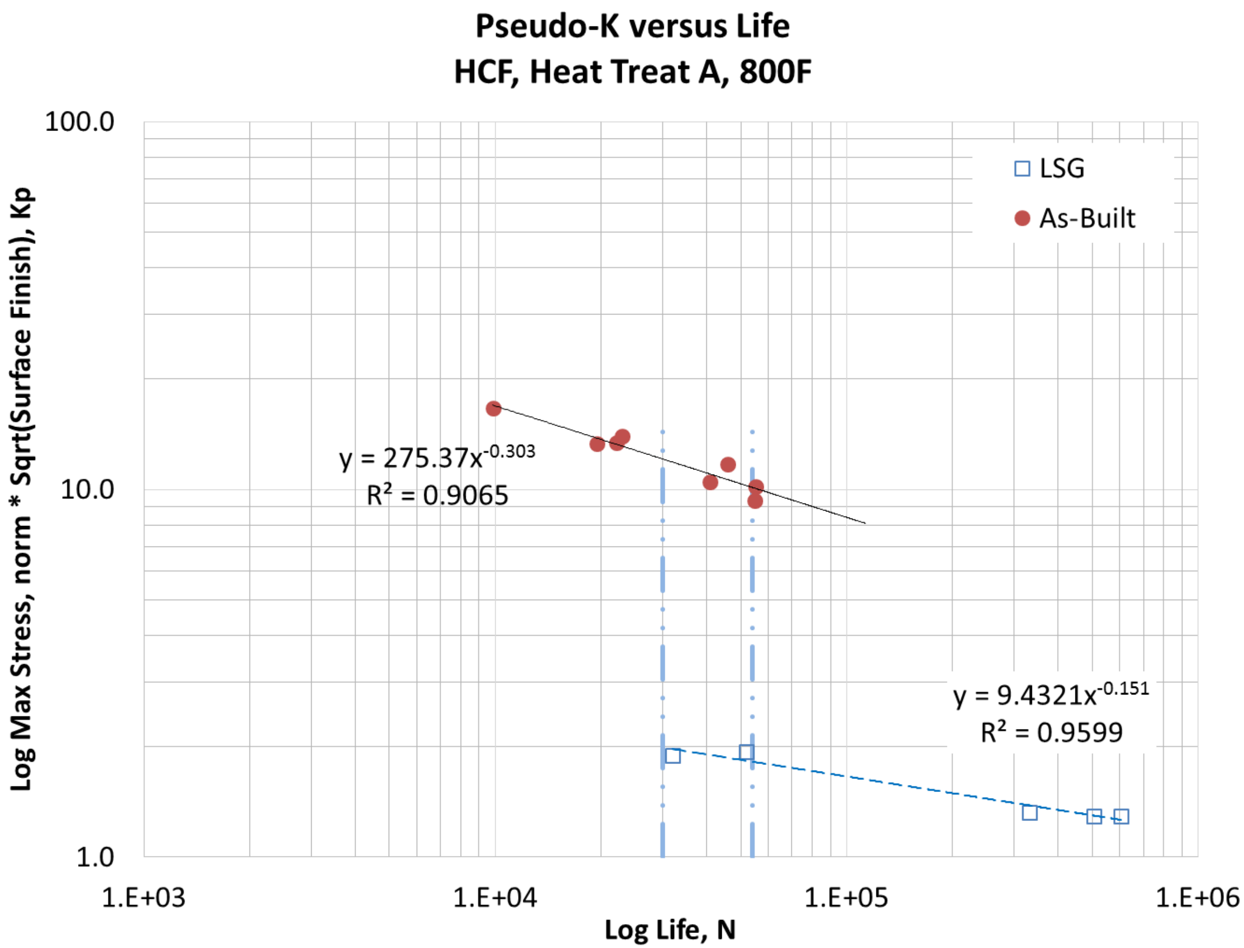


Table IV: Knockdown for HT A at 800F				
N	Kp(LSG)	Kp(AB)	Sfraction	Knockdown = 1 - Sfraction
32,000	2.0	12	0.74	26%
54,000	1.8	10	0.68	32%

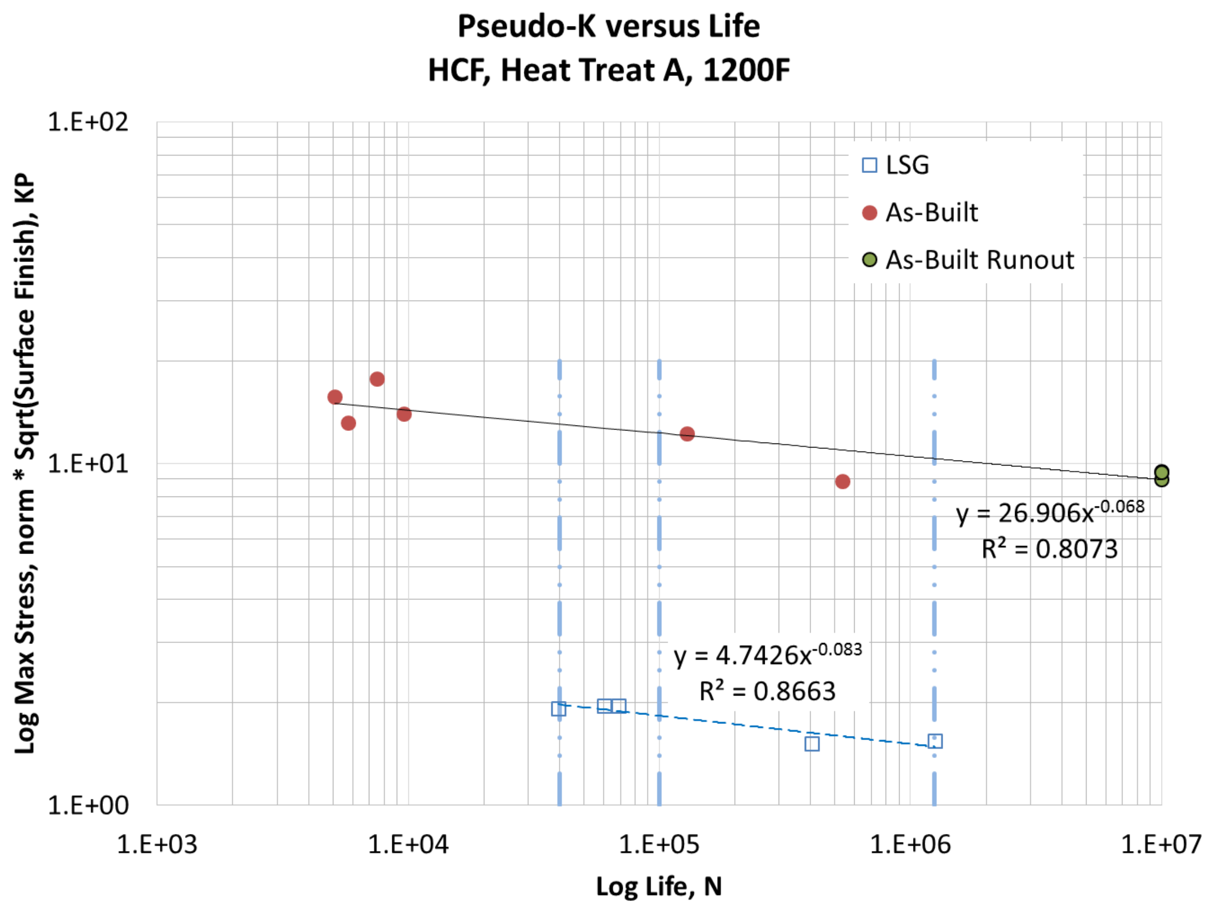
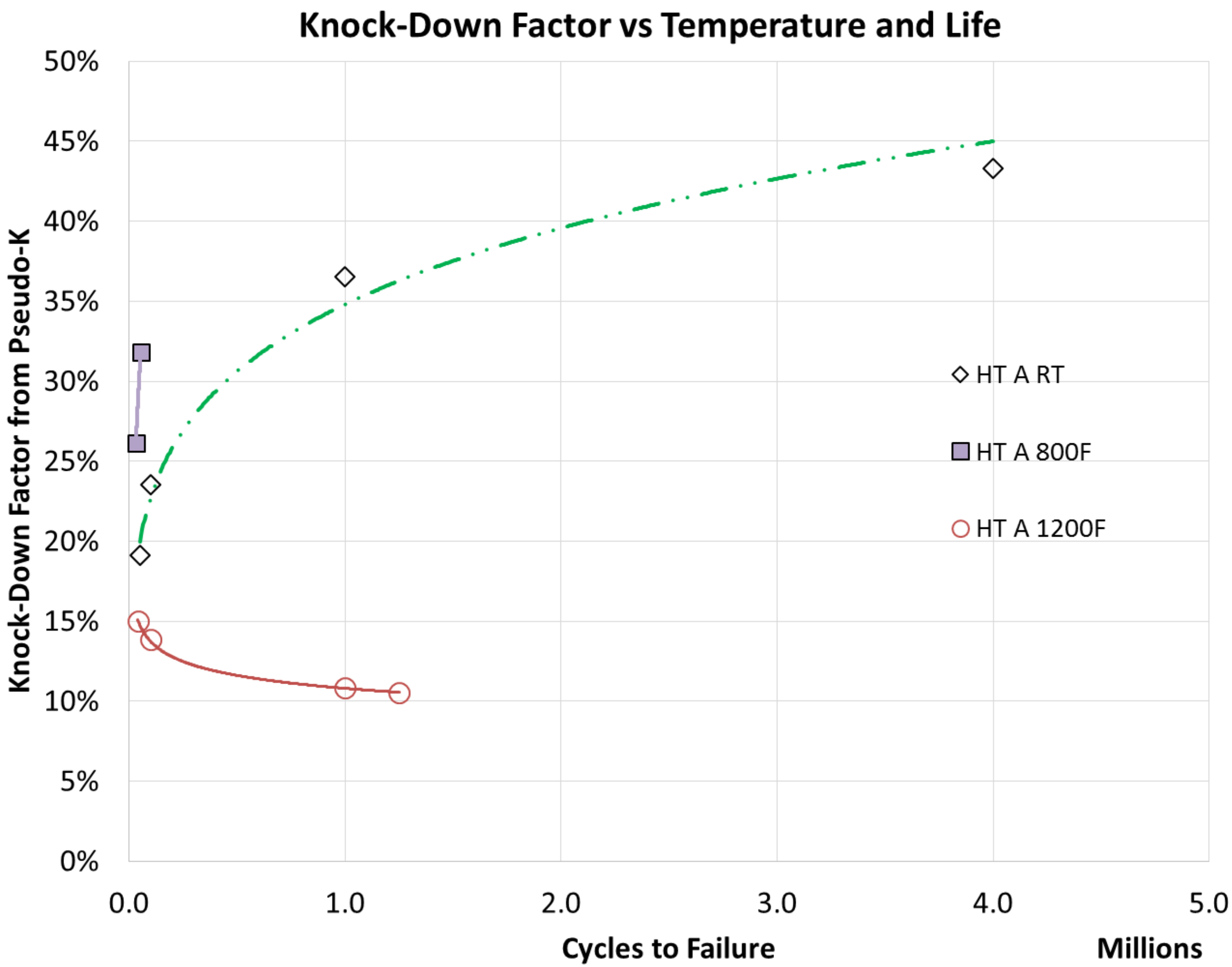
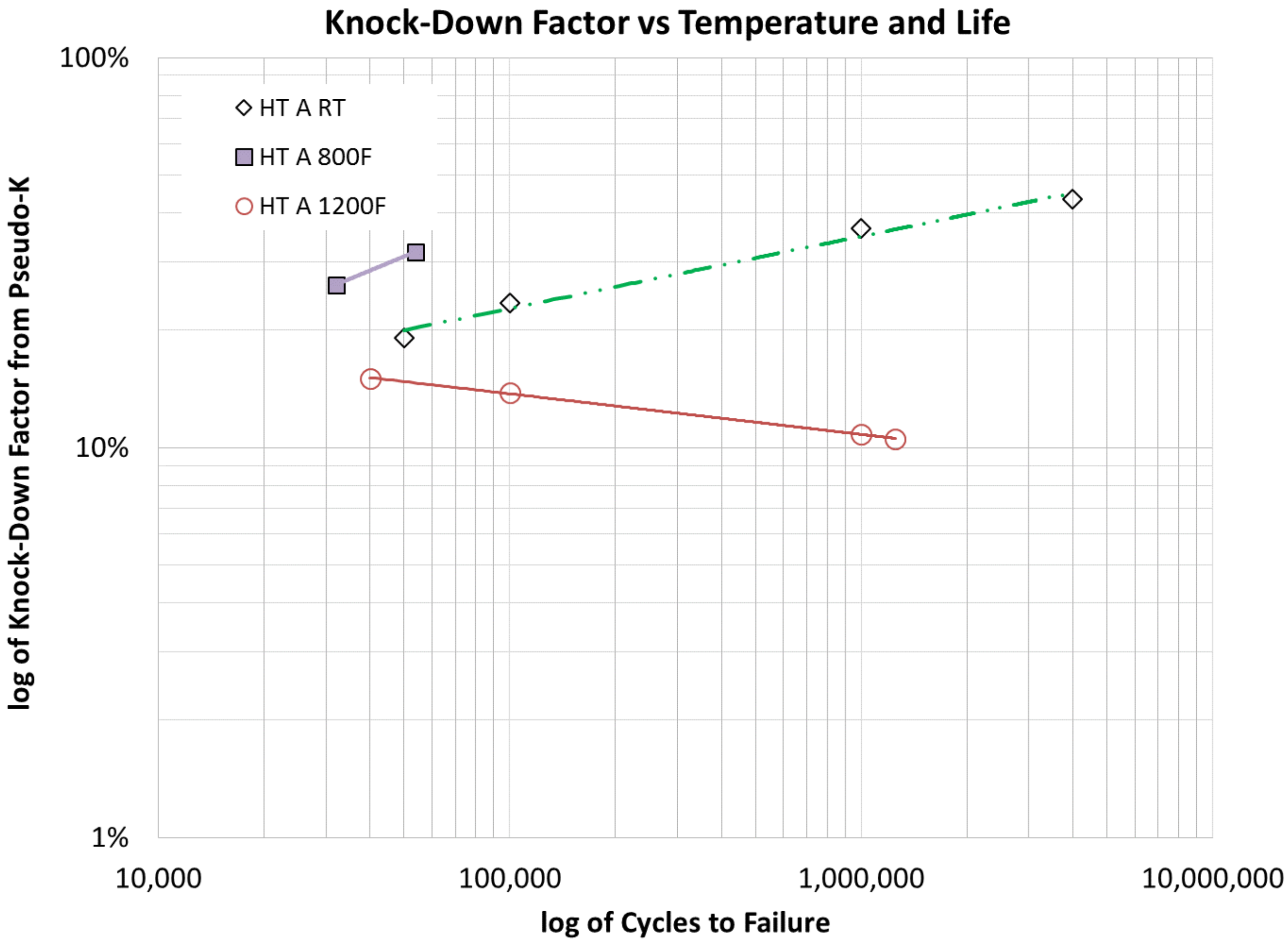


Table V: Knockdown at 1200F				
N	Kp(LSG)	Kp(AB)	Sfraction	Knockdown = 1 - Sfraction
40,000	2.0	13	0.85	15%
100,000	1.8	12	0.86	14%
1,000,000	1.5	11	0.89	11%
1,250,000	1.5	10	0.89	11%



- Linear axes.
- Power-law trend lines were added to suggest a fit.
- RT and 800F data follow a similar trend, increasing with increasing cycles.
- The 1200F data follows a different trend, decreasing with increasing cycles.



- Log-log plot of the data.
- RT and 800F data seem similar, although not the same.
- RT and 800F follow a different trend from 1200F.
- Log-log plots collapse data dramatically, and this is, perhaps, an overstatement of the observations.

Conclusions and Recommendations

- For the first analysis, the knock-down factor was estimated at one-third
  - Consistent across all temperatures and all fatigue lives where data was available.
  - The result was weakened due to the lack of usable data above 1-million cycles.
- The pseudo-stress intensity factor, KP method, showed promise for improving correlation of roughness with a fatigue strength knockdown factor.
  - Knockdown factor of about one-third at lives below about one-million cycles.
  - Knockdown appears to increase with increasing life.
  - Results should probably not be used beyond one-million cycles.
- The data available was incomplete relative to the data used in reference [2].
- Redo evaluation with surface roughness characterized by
  - Traditional surface roughness.
  - Root radius.
- Remove variabilities arising from multiple vendor processes.
- Use a different material, e.g., Inconel 625, that does not age.

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    - Metallic Materials Engineering Branch
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  - Propulsion Lab
  - Office of Strategic Analysis and Communication
  - Advanced Development Office at MSFC
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