



FINAL BRIEFING: HYDRAULIC ACTUATOR JTP FATIGUE TESTING

HCAT Review Meeting

15-17 March 2005

Greensboro, NC



SUBSTRATES/HT CONDITION

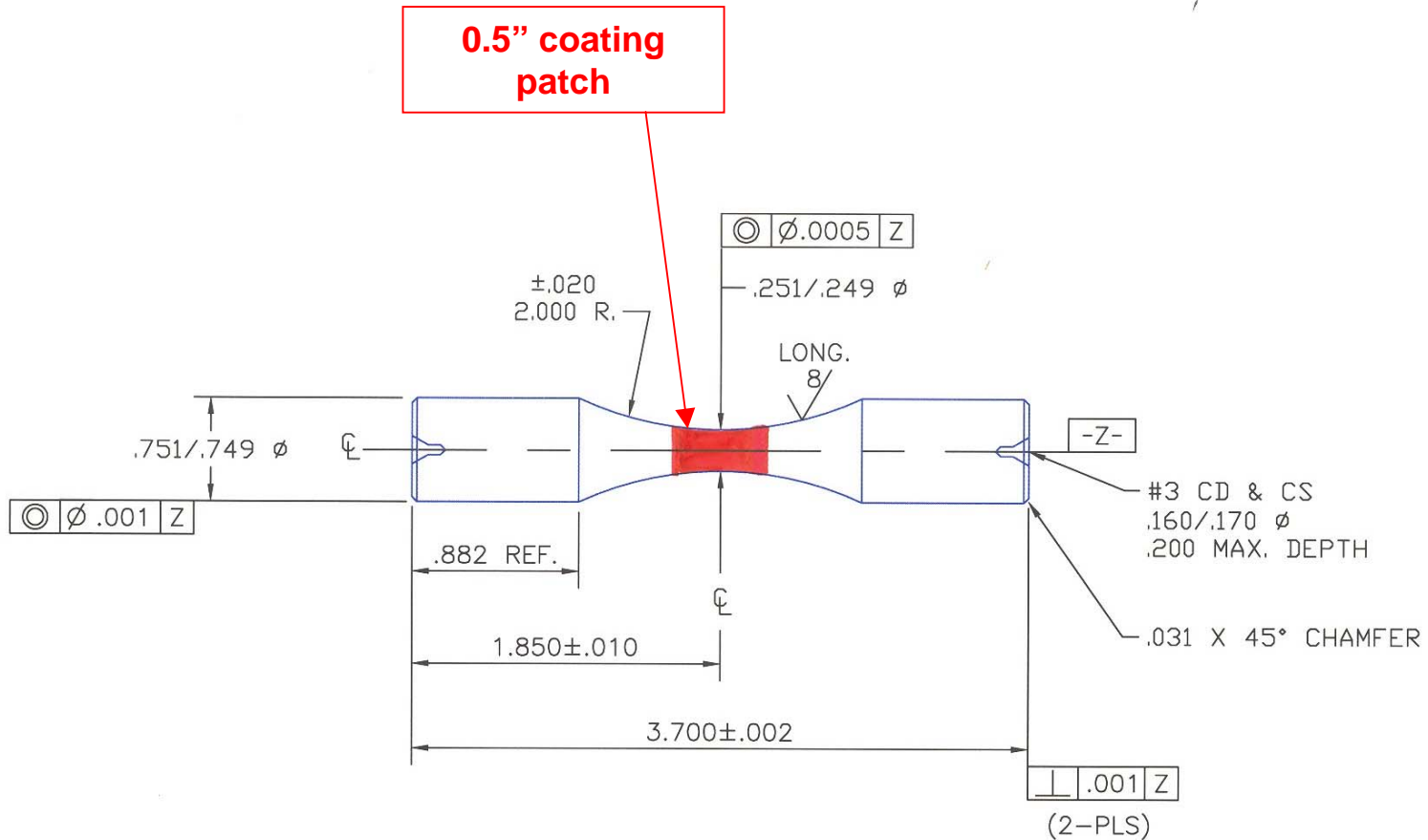
- 4340: 180-200 ksi UTS
- PH15-5: 155 ksi UTS (“1025”)
- Ti-6Al-4V: 130 ksi UTS
- All specimens peened per AMS 2432, 100% coverage, 8-10A intensity, S110 shot
(Bare specimens tested as-peened)

COATINGS

- HVOF (Hitemco)
 - WC-Co-Cr: BAC 5851, Class 2, Type XVII
 - T-400 (Co-28Mo-8Cr-2Si): BAC 5851, Class 2, Type XV, optimized per HCAT specs.
 - Cr_2C_3 -20Ni/Cr: BAC 5851, Class 2, Type XVI
 - All sprayed to 4-12 Almen
- EHC (NADEP-JAX)
 - IAW MIL-STD-1501 & QQ-C-320
 - No underlayer or sealer

COATING & FINISHING

- Gage section grit blasted prior to coating
 - HVOF: 180-220 grit Al_2O_3 or #13 glass beads
 - EHC: 54-60 mesh Al_2O_3
 - Ti-6-4 **acetone cleaned instead of grit blasting**
- Coating applied to ~0.007" thickness
- Coating ground/polished to 0.004" \pm 0.0005"
 - ❖ EHC finished at 0.0022" – 0.0045"
- Target coating finish
 - HVOF: 6-8 Ra (T-400 10-14 Ra)
 - EHC: 12-16 Ra



DRAWING NOT TO SCALE!

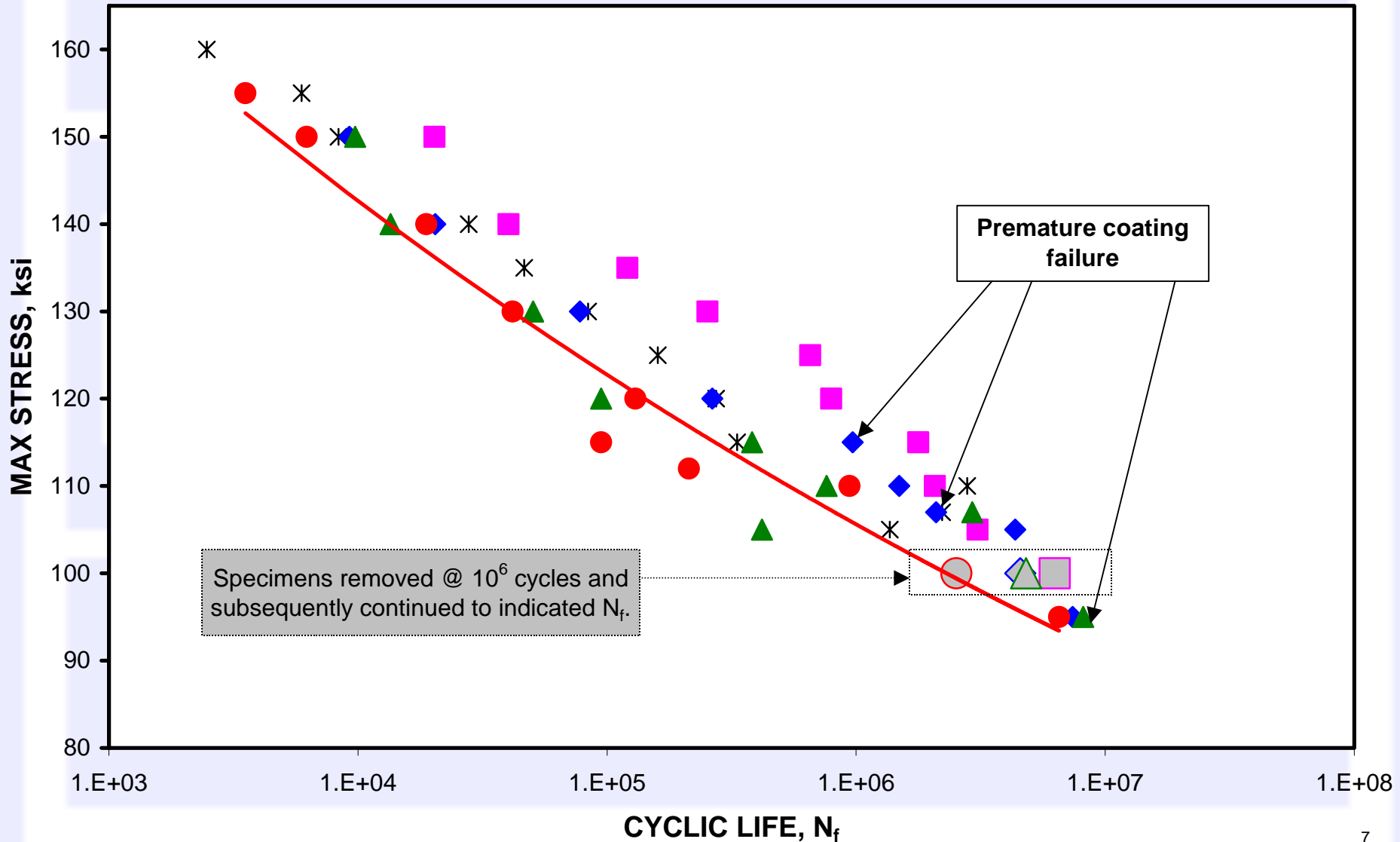
Drawn:		 Metcut Research Inc. Cincinnati, Ohio 45209-1196	Desc.: FATIGUE SPECIMEN	
Mfg.:			Cust. Dwg. #: 981105-1	
Q.C.:			Date Issued: 11/5/98	
Test:			Rev:	Dwg. #: 1288

FATIGUE TEST CONDITIONS

- Room temperature
- Stress ratio: $R = -1.0$
- Frequency: 60 Hz or as fast as possible without encountering heating above 100°F (could be as low as 1-2 Hz)
- 12 specimens/curve for bare substrate
- 10 specimens/curve for coated groups

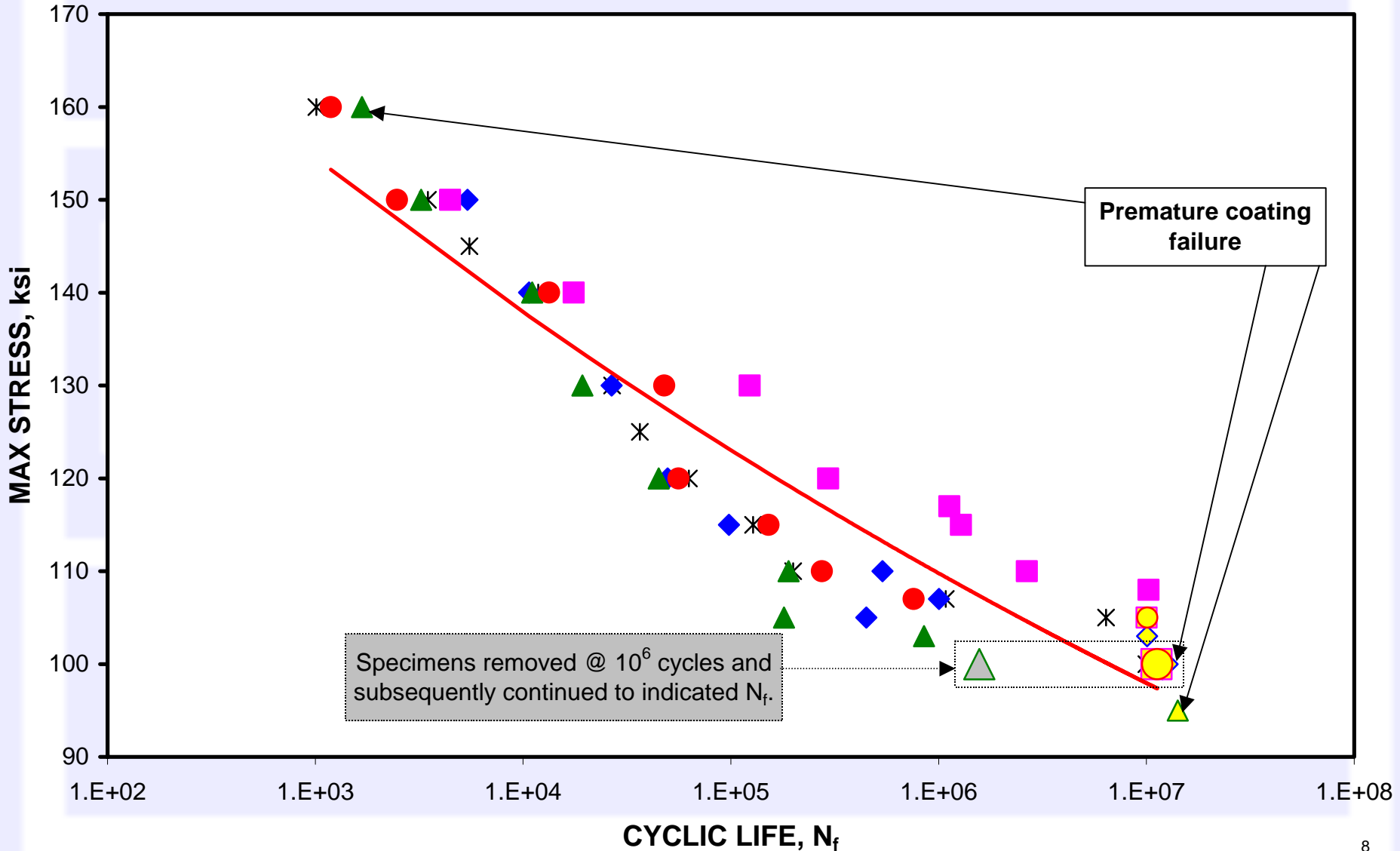
HCAT HYDRAULIC ACTUATOR FATIGUE PROGRAM PH15-5 SUBSTRATE

✱ Uncoated Baseline
◆ WC-Co-Cr
■ T-400
▲ Cr2C3
● EHC
— Power (EHC)



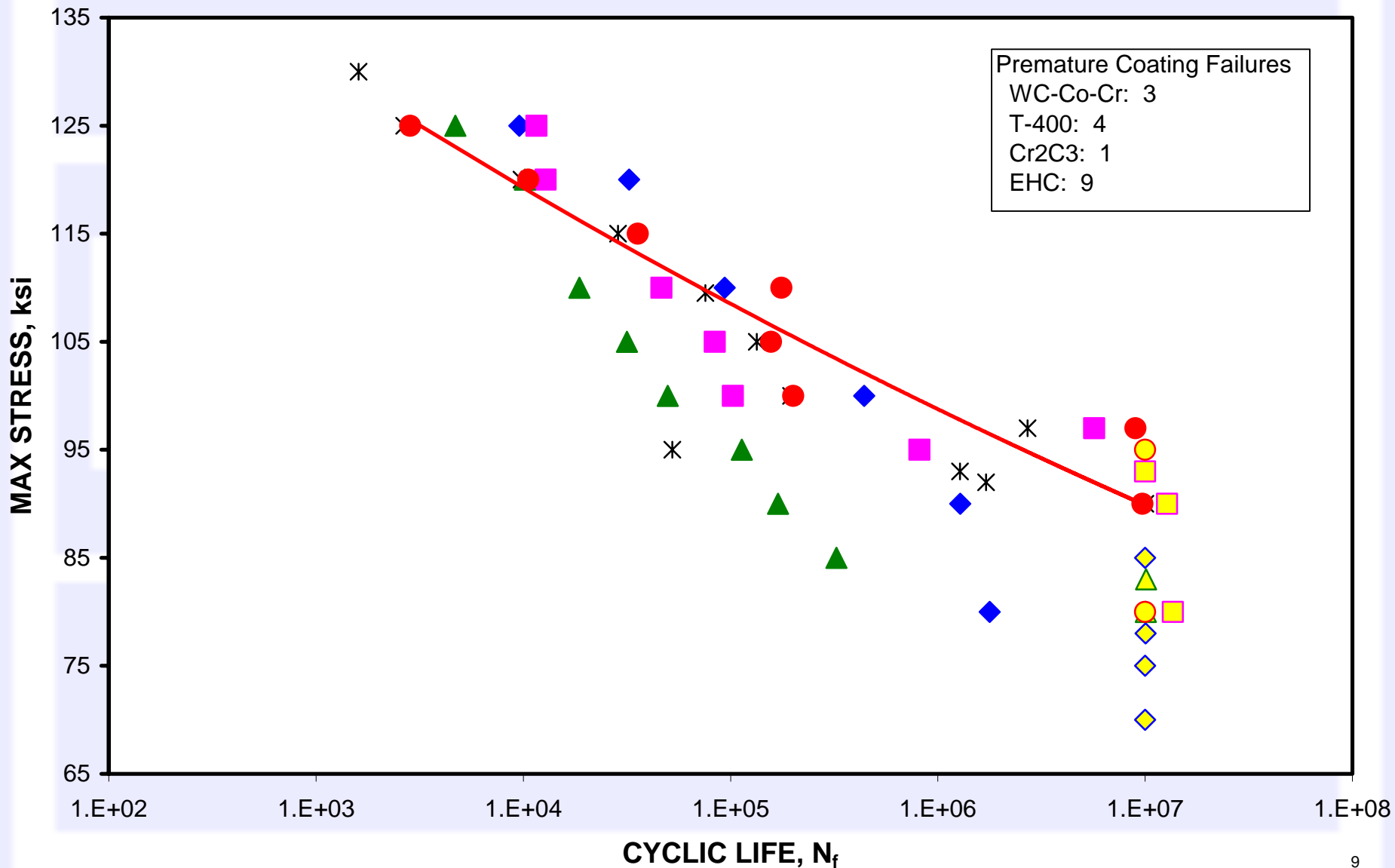
HCAT HYDRAULIC ACTUATOR FATIGUE PROGRAM 4340 SUBSTRATE

✱ Uncoated Baseline
◆ WC-Co-Cr
■ T-400
▲ Cr2C3
● EHC
— Power (EHC)

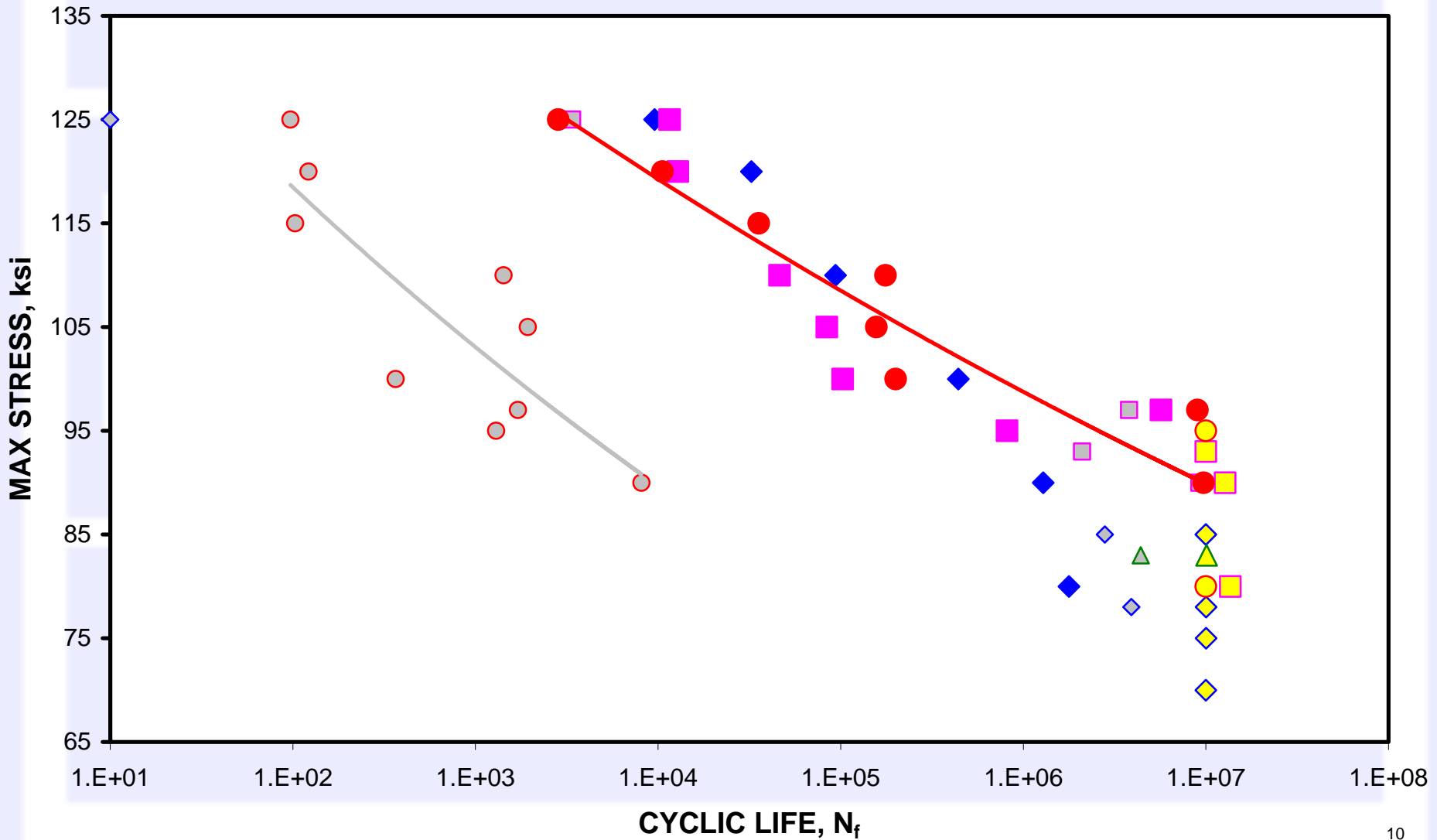
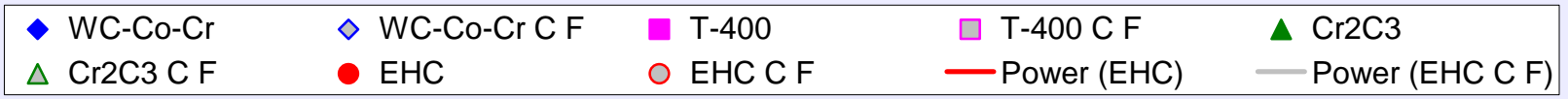


HCAT HYDRAULIC ACTUATOR FATIGUE PROGRAM Ti-6Al-4V SUBSTRATE

✱ Uncoated Baseline ◆ WC-Co-Cr ■ T-400 ▲ Cr2C3 ● EHC — Power (EHC)



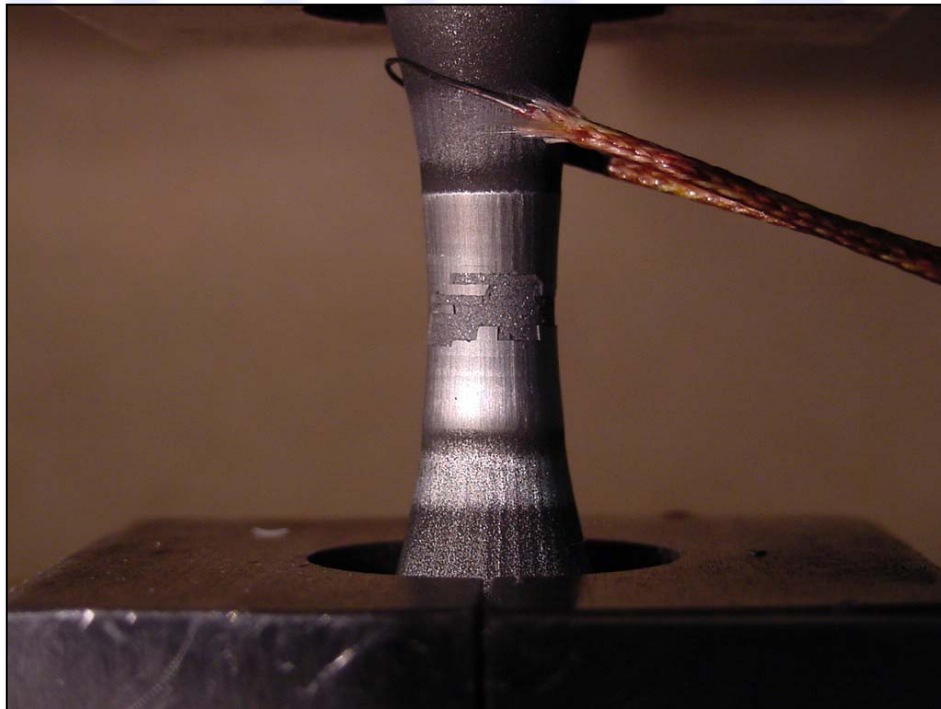
PREMATURE COATING FAILURES Ti-6-4 SUBSTRATE



PREMATURE COATING FAILURE FREQUENCY

	WC-Co-Cr	T-400	Cr₂C₃	EHC
4340	1	0	2	0
PH15-5	2	0	1	0
Ti-6-4	3	4	1	9

Specimen 4340-F10. WC-Co-Cr on 4340
Stress = 103 ksi. Removal at 10,082,265 cycles
Ring cracking at ~ 9.5M cycles

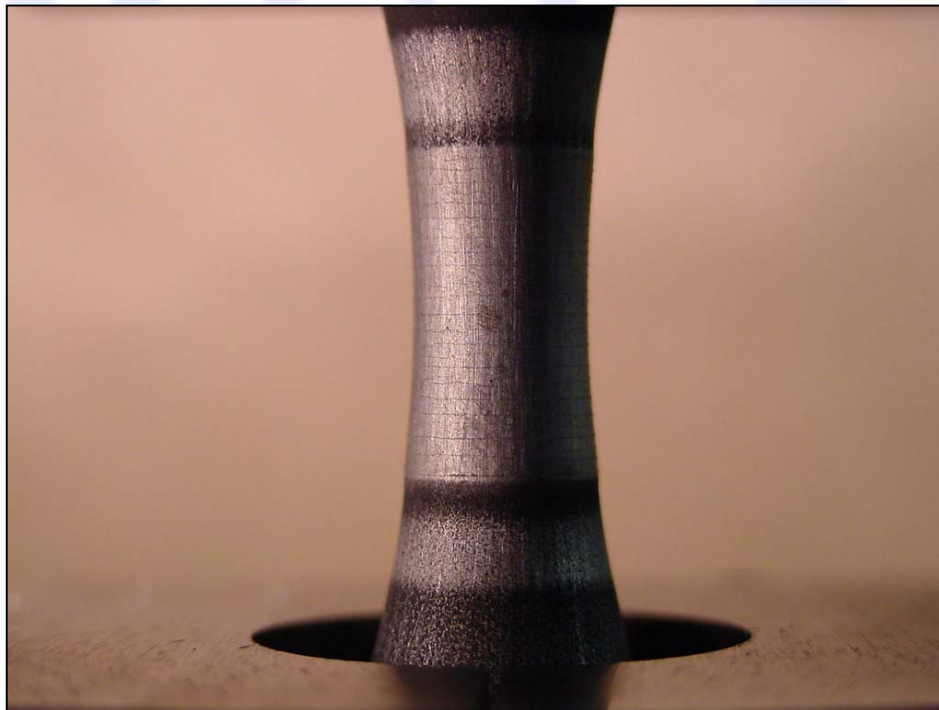
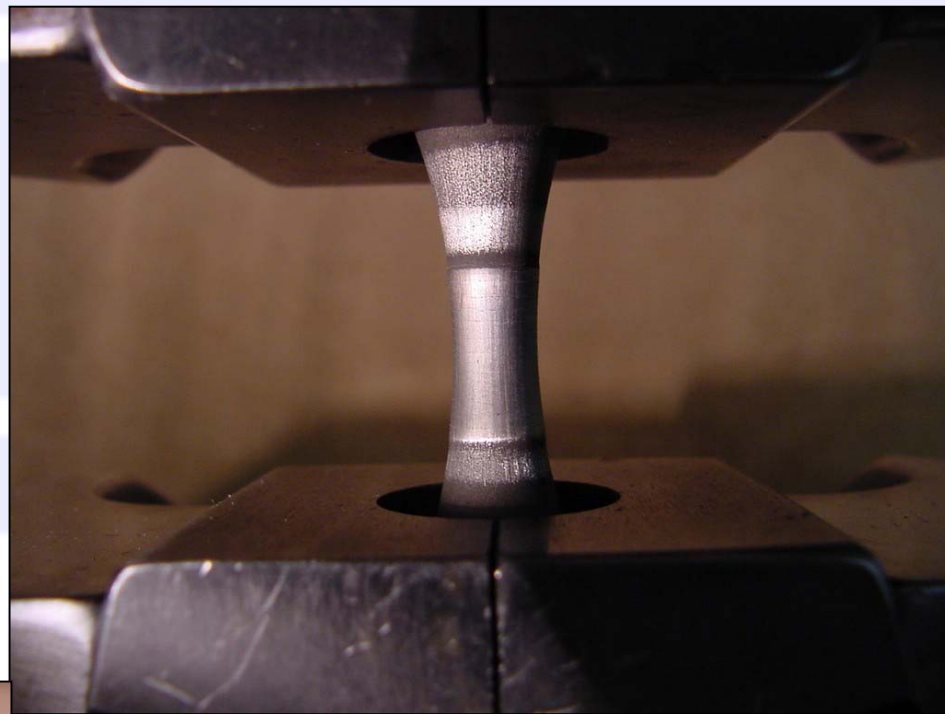


Specimen 4340-F27. Cr_2C_3 on 4340
Stress = 160 ksi. $N_f = 1,679$ cycles
Spalling at 1,630 cycles

Specimen PH15-5-F10. WC-Co-Cr on PH-15-5

Stress = 107 ksi. $N_f = 2,096,472$ cycles

Ring cracking at 1,758,000 cycles

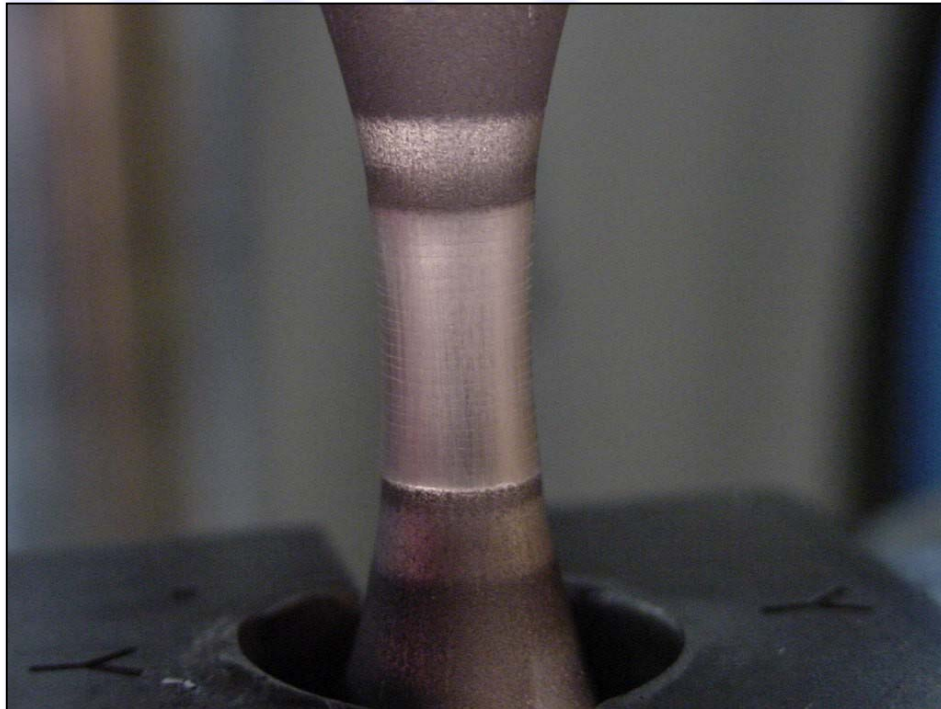
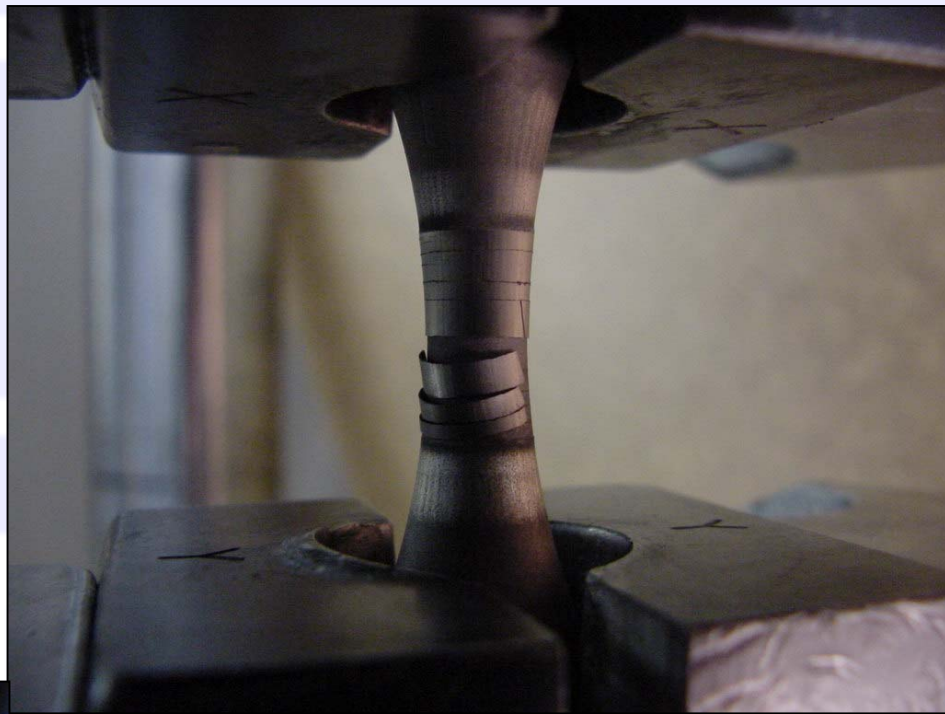


Specimen PH15-5-F27. Cr₂C₃ on PH15-5

Stress = 95 ksi. $N_f = 8,162,621$ cycles

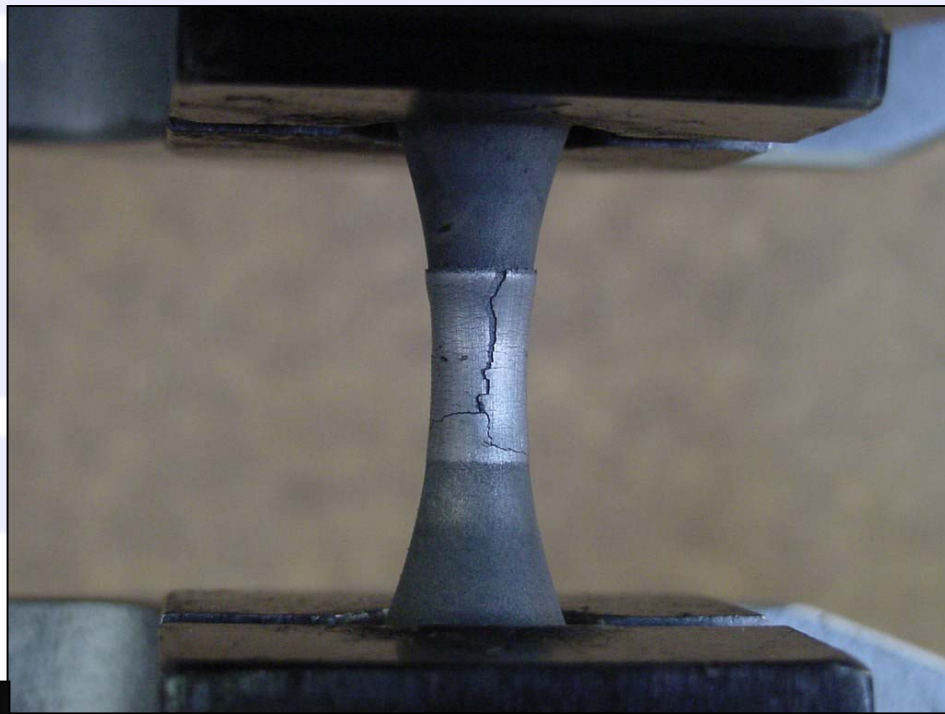
Ring cracking at ~ 6M cycles

Specimen Ti-F9. WC-Co-Cr on Ti-6-4
Stress = 85 ksi. Removal at 10,000,075 cycles
Coating spalled at ~ 2.8M cycles



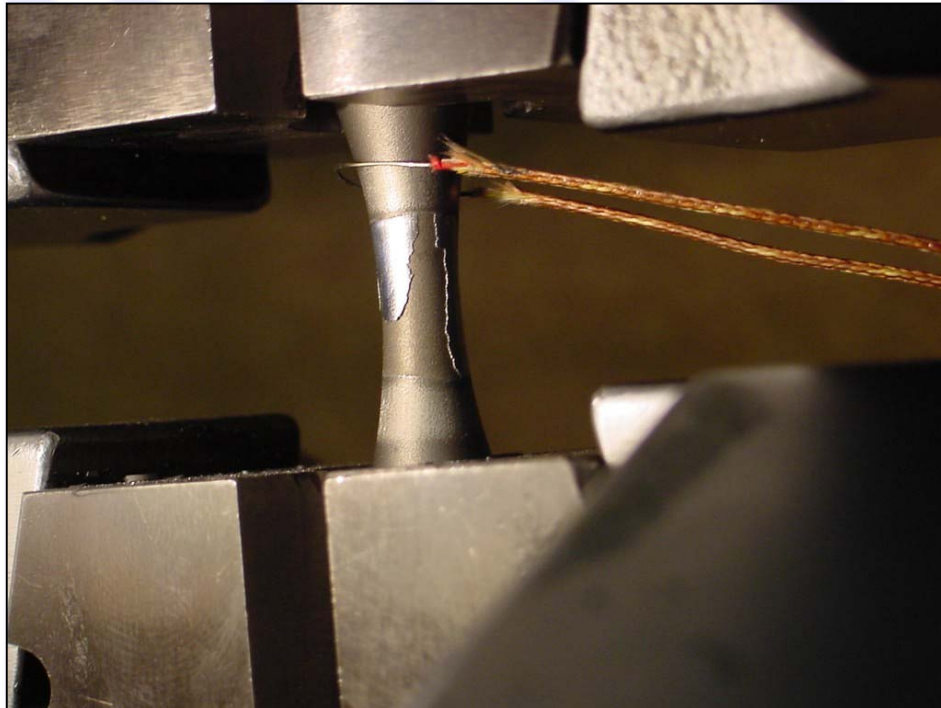
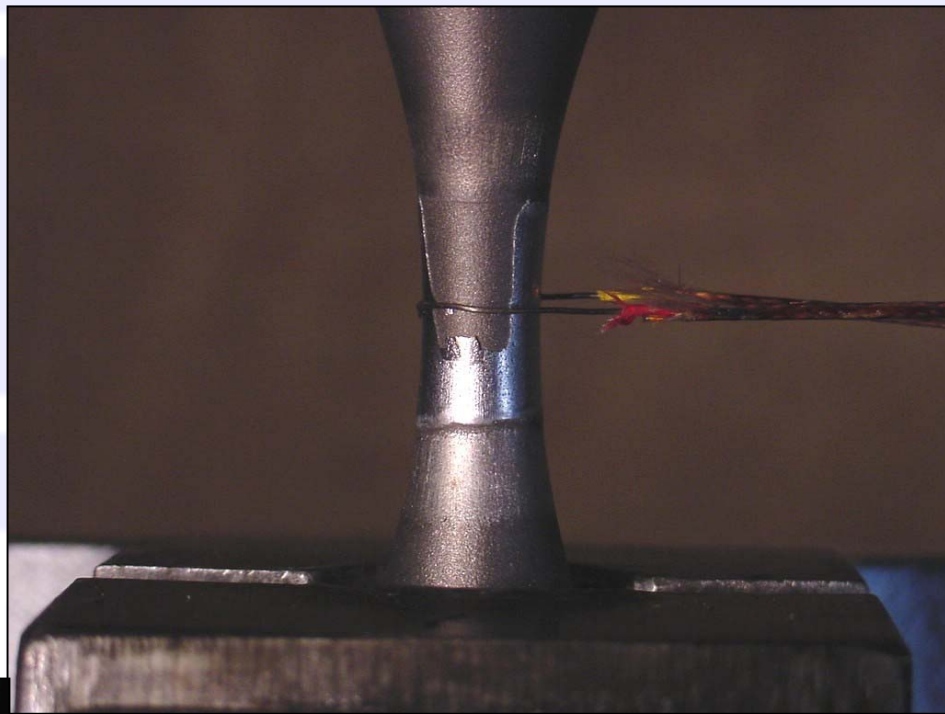
Specimen Ti-F30. Cr_2C_3 on Ti-6-4
Stress = 83 ksi. Removal at 10,096,664 cycles
Ring cracking at ~ 4.4M cycles

Specimen Ti-F14. T-400 on Ti-6-4
Stress = 90 ksi. Removal at 12,741,786 cycles
Coating cracked at ~ 9.2M cycles



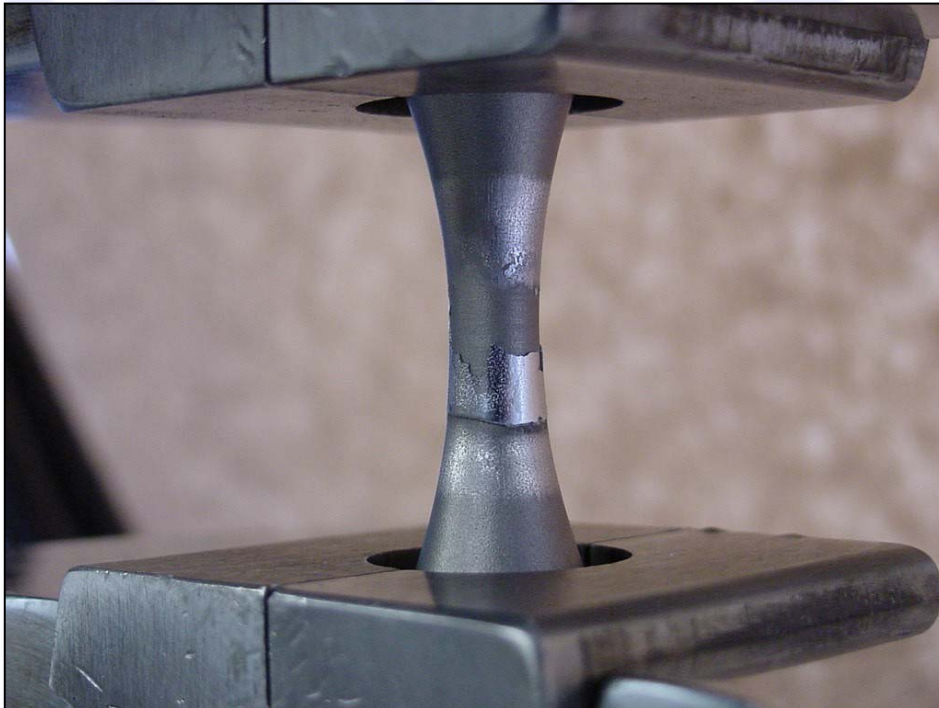
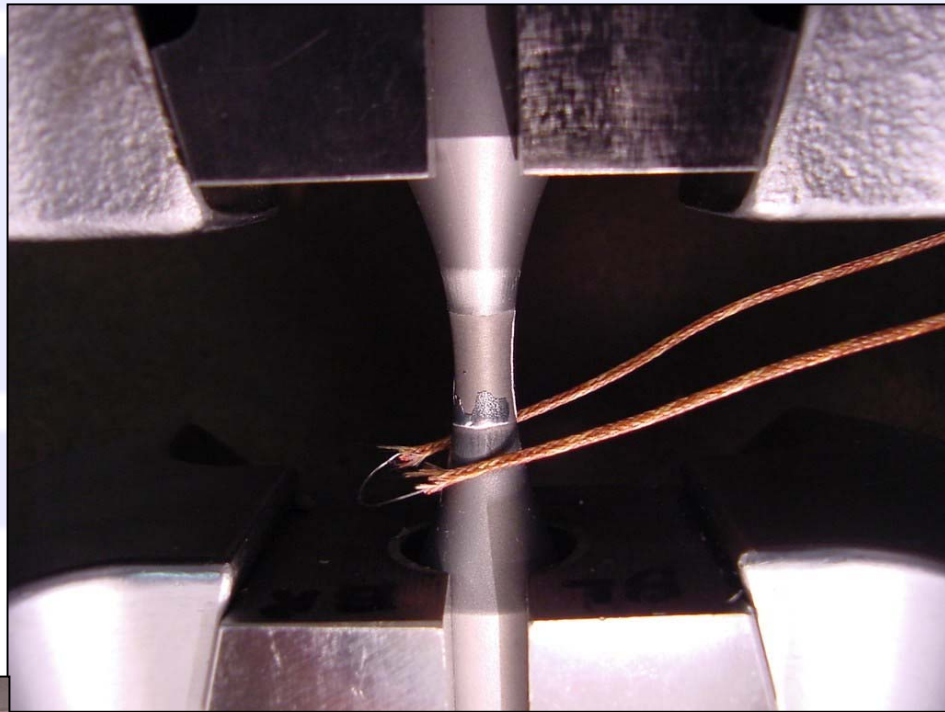
Specimen Ti-F20. T-400 on Ti-6-4
Stress = 125 ksi. $N_f = 11,562$ cycles
“Diffuse” ring cracking at 3,380 cycles

Specimen Ti-F49. EHC on Ti-6-4
Stress = 125 ksi. $N_f = 2,843$ cycles
Coating spalled at 97 cycles



Specimen Ti-F46. EHC on Ti-6-4
Stress = 110 ksi. $N_f = 175,958$ cycles
Coating spalled at 1,425 cycles

Specimen Ti-F42. EHC on Ti-6-4
Stress = 100 ksi. $N_f = 200,320$ cycles
Coating spalled at 336 cycles



Specimen Ti-F45. EHC on Ti-6-4
Stress = 95 ksi. Removal at 10,000,114 cycles
Coating spalled at ~ 1300 cycles

σ/ϵ CONSIDERATIONS

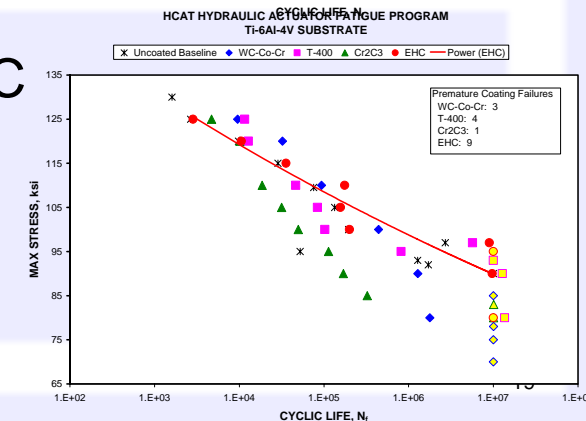
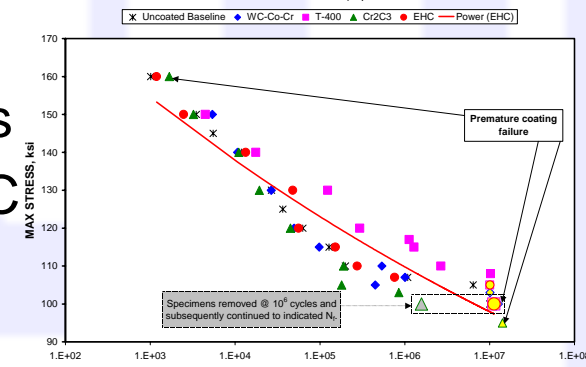
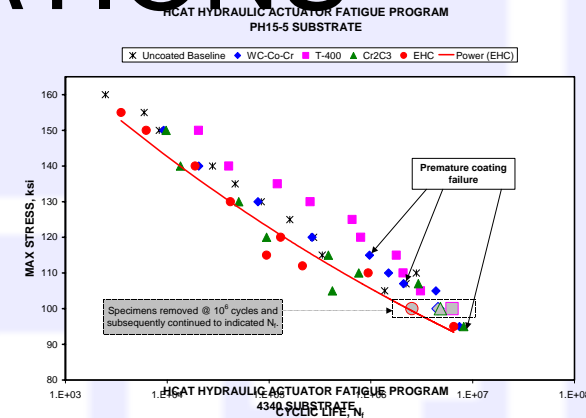
$$\begin{aligned}\epsilon_{\text{Ti}} / \epsilon_{\text{steel}} &= E_{\text{steel}} / E_{\text{Ti}} \\ &= 29/17 = 1.7\end{aligned}$$

\therefore Strains in Ti are 70% higher than in 4340 and PH15-5 at the same stress level.

SUMMARY OBSERVATIONS

Fatigue Performance

- On PH15-5
 - T-400 outperforms EHC
 - WC-Co-Cr and Cr₂C₃ are equivalent to EHC
- On 4340
 - T-400 outperforms EHC at lower stress levels
 - WC-Co-Cr and Cr₂C₃ are ~ equivalent to EHC
- On Ti-6-4
 - EHC outperforms Cr₂C₃
 - WC-Co-Cr and T-400 are ~ equivalent to EHC



SUMMARY OBSERVATIONS

Coating Behavior

- Coating durability on Ti-6-4 was significantly worse than on the other substrates, particularly for EHC
- For HVOF coatings, premature coating failure primarily was due to ring cracking
- For T-400, ring cracking was less well-defined than for the other HVOF coatings
- EHC on Ti-6-4 exhibited severe spalling at all stress levels