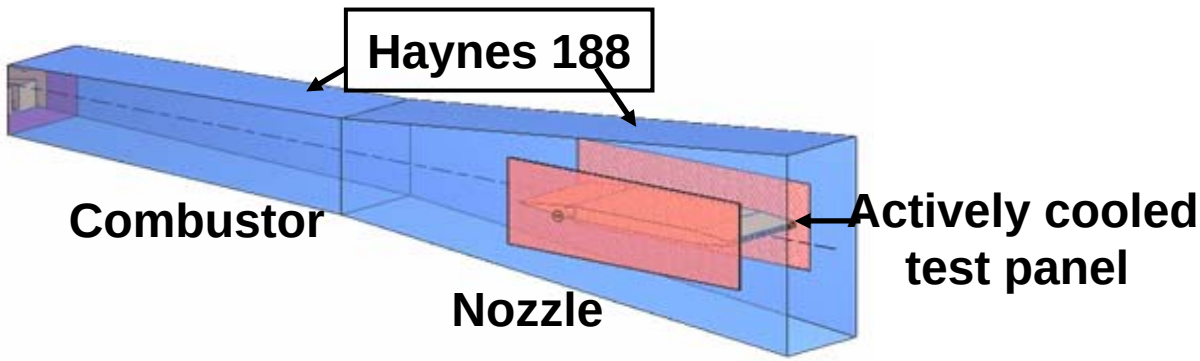
Fatigue Life of Haynes 188 Superalloy in Direct Connect Combustor Durability Rig

Tim Gabb[1], John Gayda[1], Henry Webster[2], Greg Ribeiro[2]

1. NASA Glenn Research Center
2. ATK GASL

Fundamental Aeronautics 2007 Annual Meeting
Hypersonics Materials and Structures
November 1, 2007

- The Direct Connect Combustor Durability Rig (DCR) provides a flexible and efficient test bed to demonstrate the durability of actively cooled scramjet engine structure, static and dynamic sealing technologies, and thermal management techniques.
  - DCR shall be hydrogen fueled and cooled
  - Flight-like structural test panels shall be hydrogen cooled
  - Tests planned for Mach 5 and 7 at NASA Langley Research Center

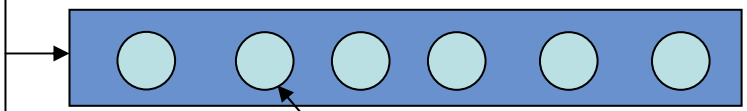


Statement of Problem:

Actively cooled Haynes 188 superalloy DCR panels shall encounter severe conditions that could challenge low cycle fatigue durability

Haynes 188 Panel Cross-section

- **Temperatures up to 650°C**
- **High thermal gradients**
- **Hydrogen/air high pressure environments**
- **Surface finish variations**



Electro-discharge machined (EDM) hydrogen cooling passages

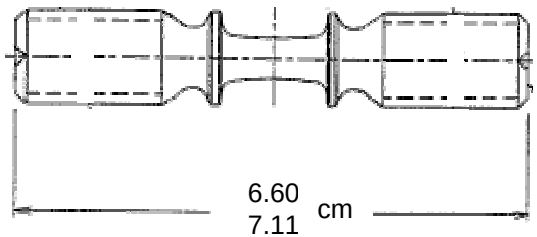
Objective:

Assess low cycle fatigue capability of Haynes 188 for DCR application

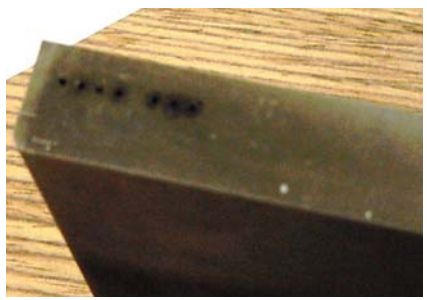
- 25 and 650°C
- Hydrogen and helium environments
- Low stress ground (LSG) and electro-discharge machined (EDM) finish

- Progress:
  - Specimens machined from dropoffs of actual Haynes 188 DCR panels
  - EDM finish of cooling holes simulated on specimen surfaces
  - Initial fatigue tests in helium and hydrogen completed
  - Failure initiation modes compared

DCR Panel Remnants



Fatigue Test Specimens



Trial EDM Cooling Holes

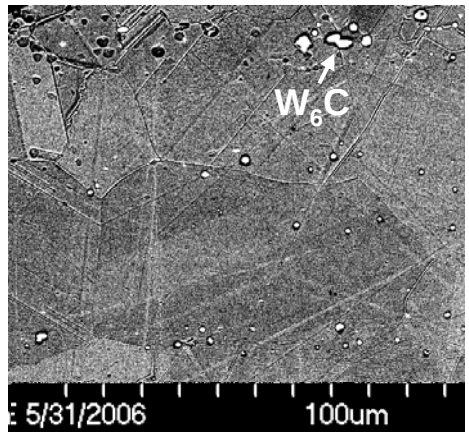
Haynes 188

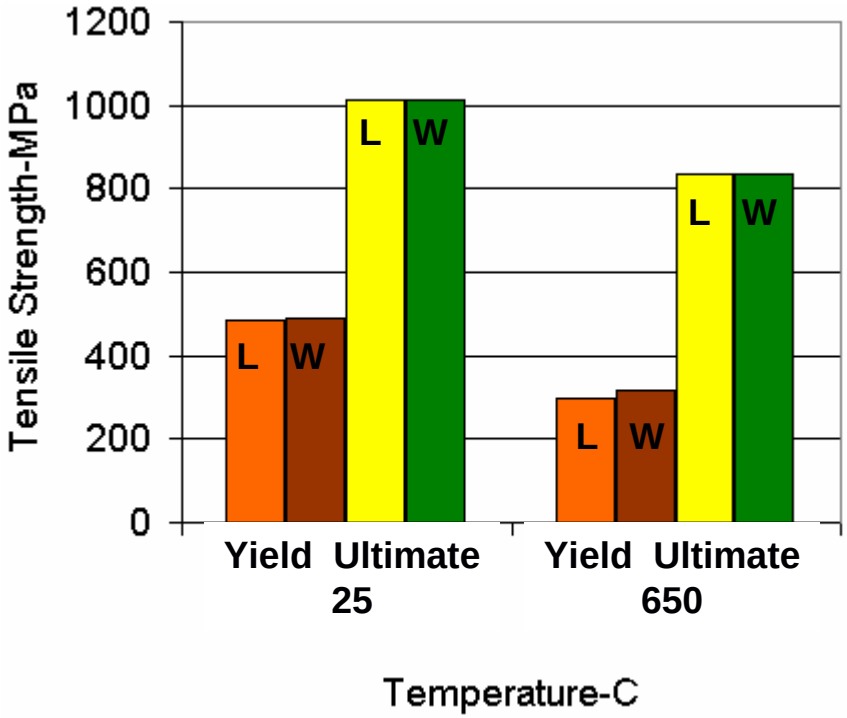
Element	B	C	Cr	Fe	La	Mn	Ni	Si	W	Co
Weight %	0.015*	0.10	22.0	3.0*	0.03	1.25*	22.0	0.35	14.0	39 (bal.)

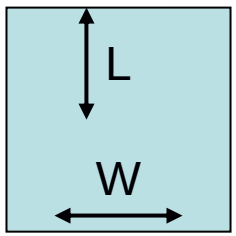
* Maximum

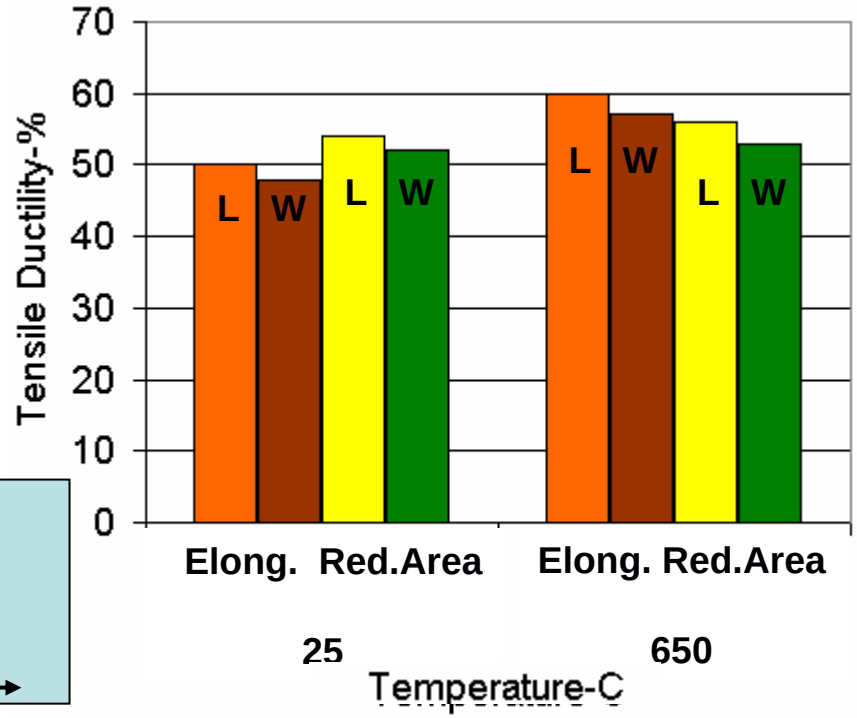
Haynes 188 Panel Sections

- Microstructure is γ FCC matrix, with scattered W_6C carbides
- Mean grain size is about 40 μm
- Tensile properties are not L-W directional, show considerable ductility for tests in air



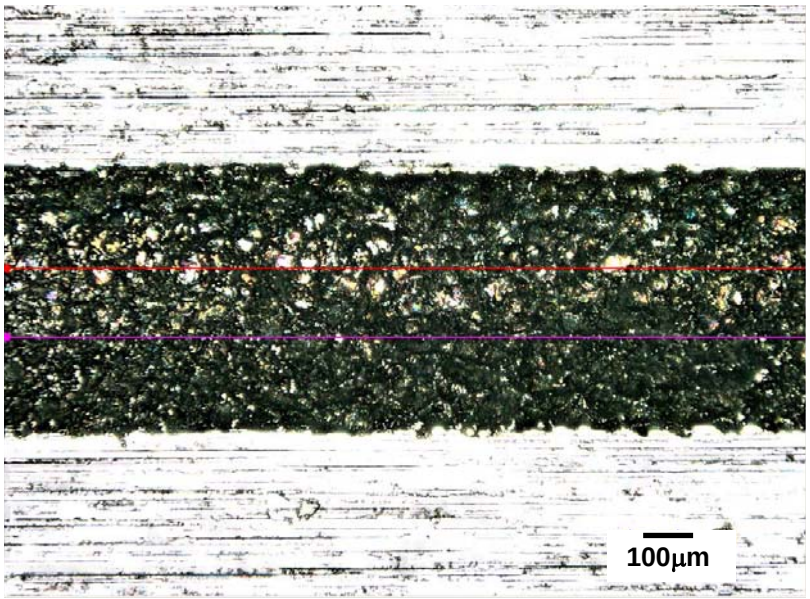


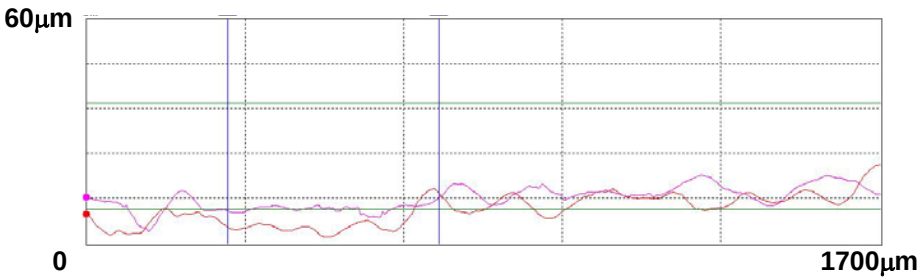




EDM Cooling Hole Roughness Was Reproduced on the Surfaces of Selected Specimens

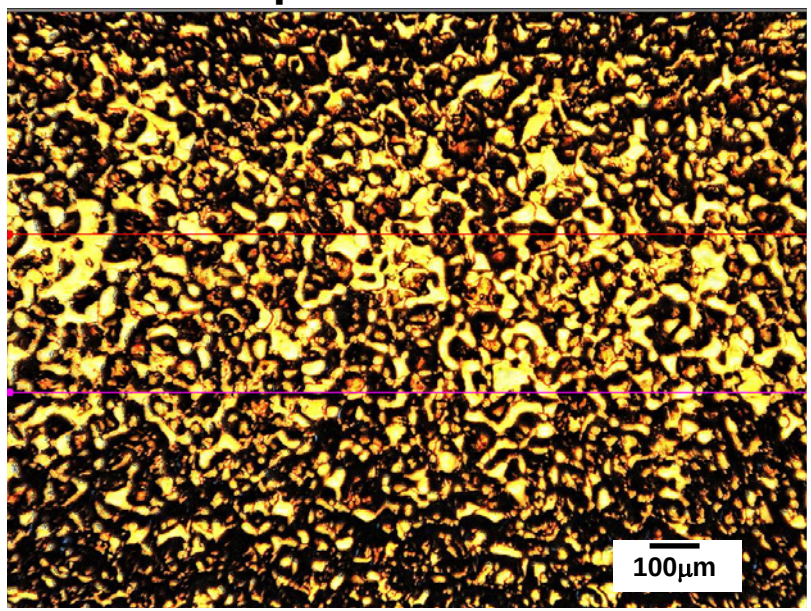
Trial EDM Cooling Hole

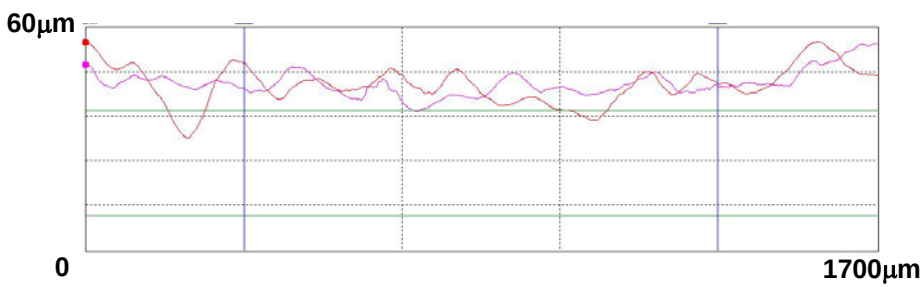




Hole Roughness Profile

EDM Specimen Surface



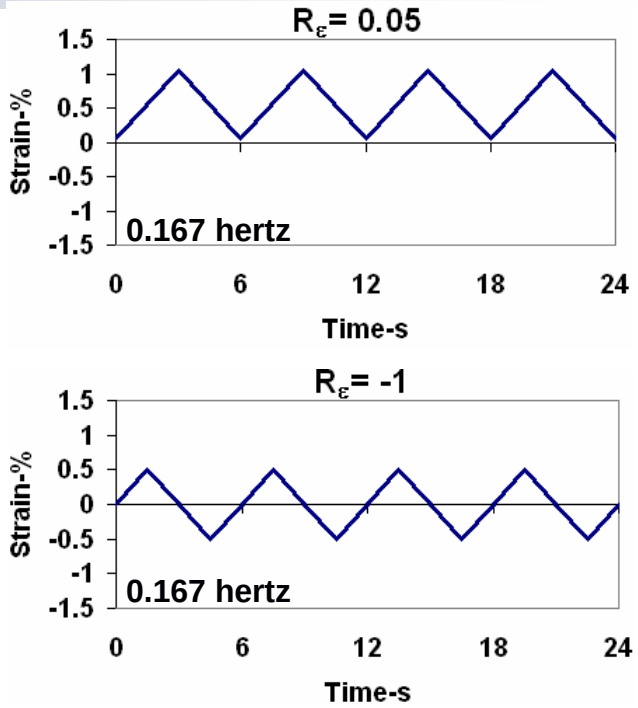


Specimen Roughness Profile

Fatigue Testing:

Performed at NASA Marshall Space Flight Center, hydrogen test facility

- 25 and 650°C, hydrogen and helium gas environments at 34.5 MPa pressure
- Low stress ground (LSG) and EDM finish specimens
- Constant total strain range ($\Delta\varepsilon_t$) tests, min./max. strain ratios (R_ε)=0.05 and –1

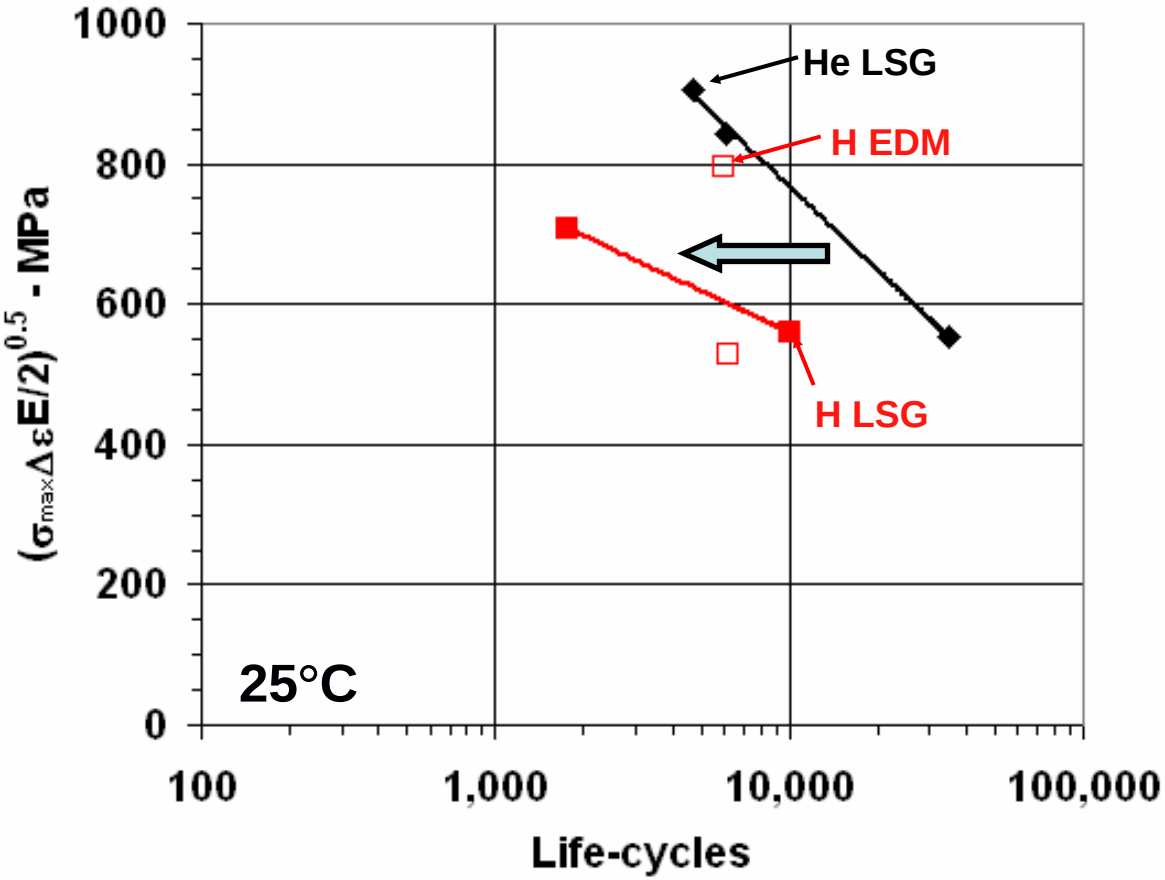


- Lives compared using the Smith-Watson-Topper stress parameter, **SWT= $(\sigma_{max}\Delta\varepsilon_t E/2)^{0.5}$**
- Accounts for variations in:
  - Total strain range $\Delta\varepsilon_t$
  - Maximum stress σ_{max}
  - Elastic modulus **E**
- NASA GRC has successfully used this in past Haynes 188 fatigue work (1)

1. S. Kalluri, M. A. McGaw, G. R. Halford, "Fatigue Life Estimation Under Cumulative Cyclic Loading Conditions", ASTM STP 1389, ASTM, West Conshohocken, PA, 2000, pp. 94-109.

Results: Room Temperature

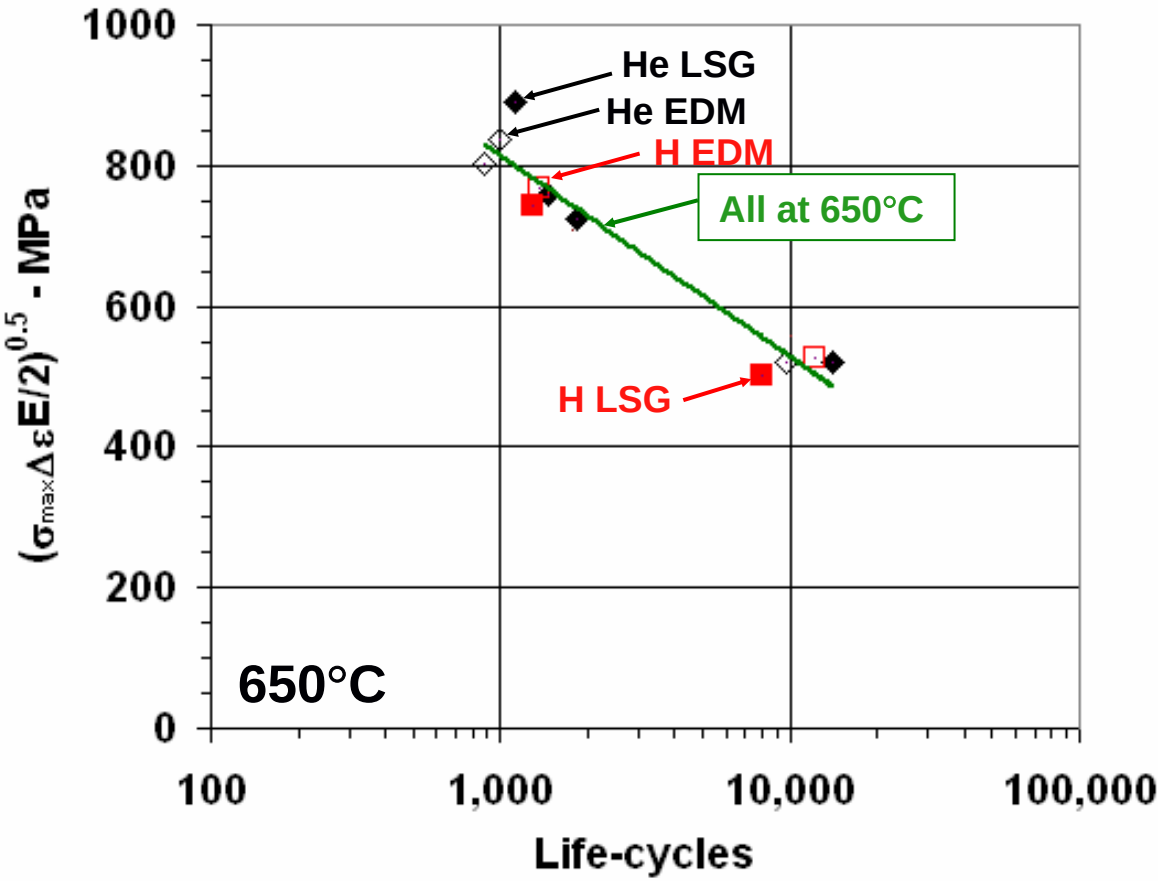
Initial Fatigue Tests Indicate Hydrogen Reduces Fatigue Life At Room Temperature



Effect of EDM finish on fatigue life at 25°C not yet clear, potentially modest

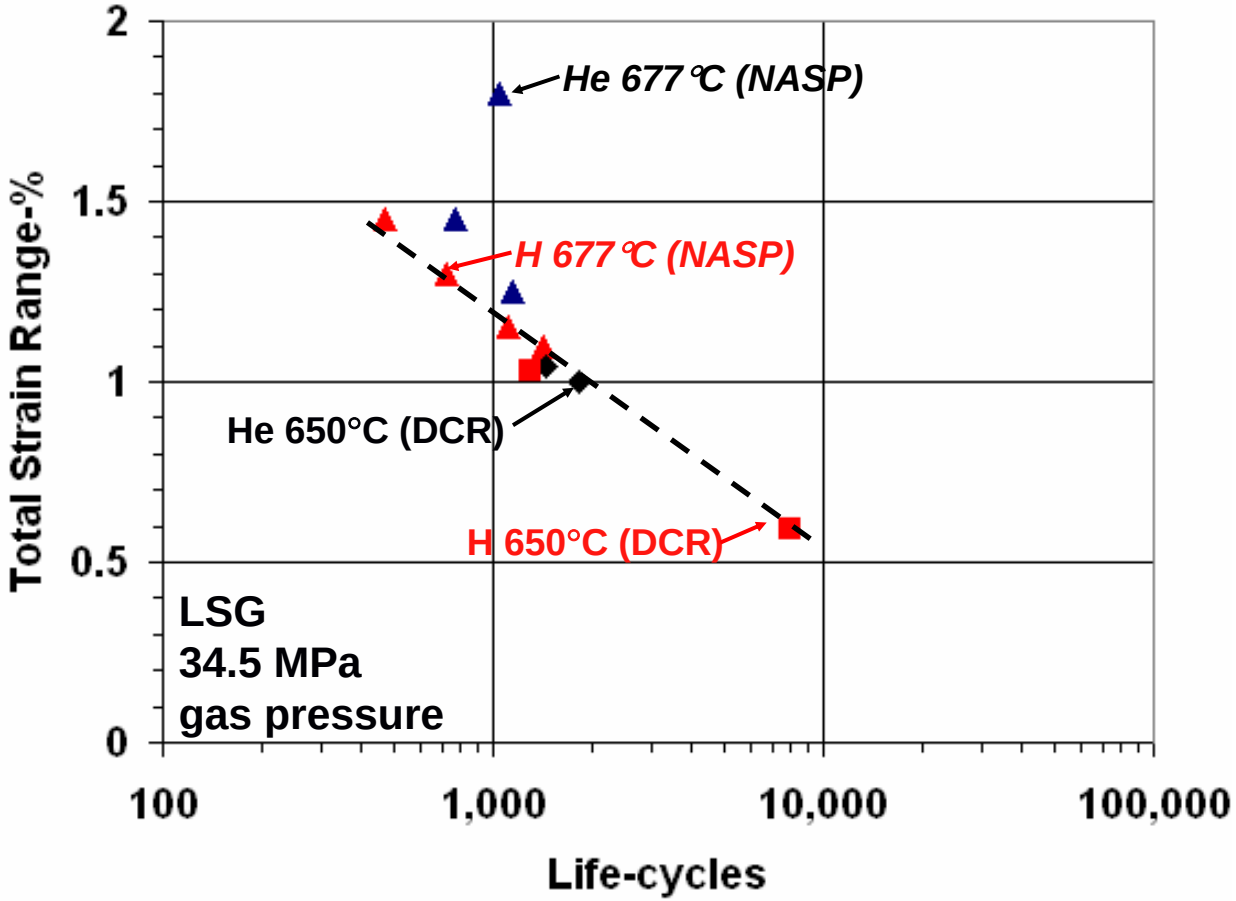
650°C

Current Results Indicate Hydrogen Does Not Reduce Fatigue Life At 650°C



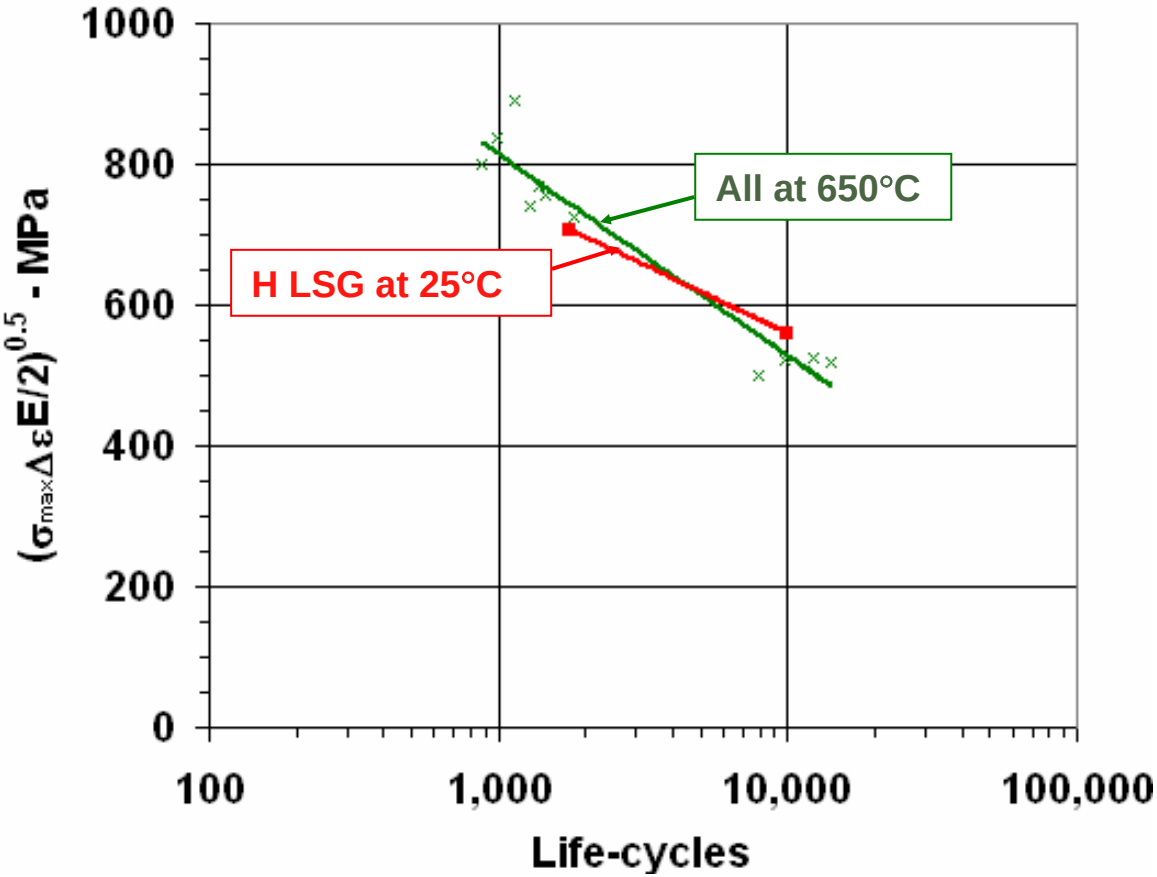
Effects of EDM finish do not appear substantial at 650°C

These Promising Fatigue Results are Consistent With Earlier National Aerospace Plane (NASP) Tests of Haynes 188



Haynes 188 is showing sustained fatigue life in gaseous hydrogen near 650°C

Current Indications Are That Fatigue Life Capability in Hydrogen is Not Decreasing With Temperature or Surface Finish

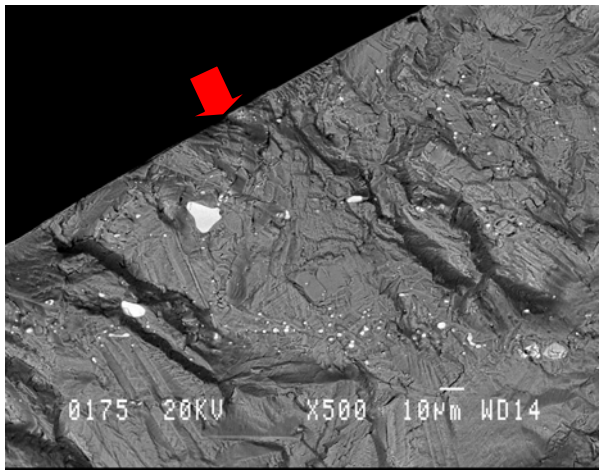


Additional tests are necessary to reaffirm these positive trends

Room Temperature:

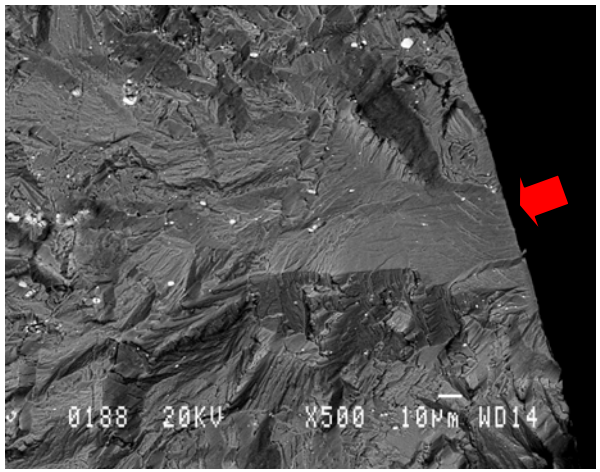
Fatigue Failure Initiation Sites Varied At Room Temperature

LSG / 1% Strain / He



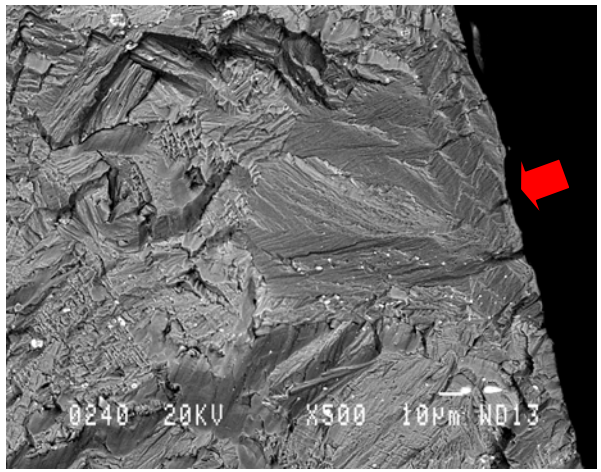
Normal to Load Axis

LSG / 1% Strain / H



Crystallographic

EDM / 1% Strain / H



Crystallographic

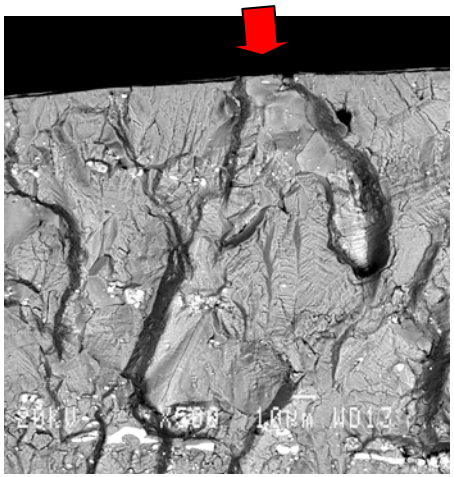
- Subsequent crack growth was also transgranular, did not appear brittle

Crystallographic grain failures initiated cracks in hydrogen

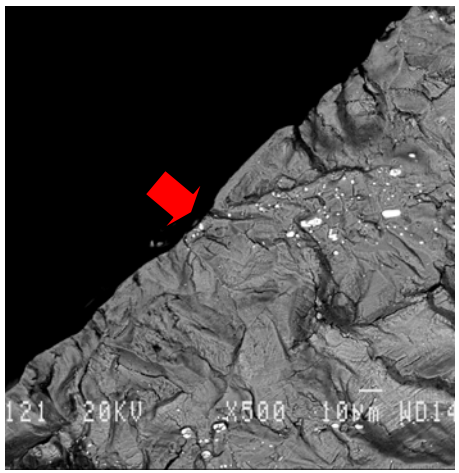
650°C:

Fatigue Failure Initiation Sites Also Varied At 650°C

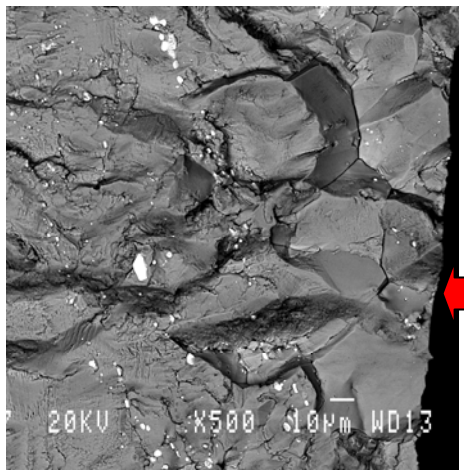
LSG / 1% Strain / He



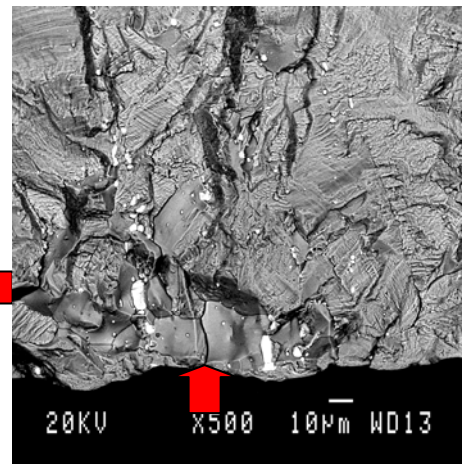
EDM / 1% Strain / He



LSG / 1% Strain / H



EDM / 1% Strain / H



More Grain Boundary Cracking

- Subsequent crack growth was predominantly transgranular, did not appear brittle

Proportion of initial grain boundary cracking increased in hydrogen

Summary:

Low cycle fatigue capability of Haynes 188 being assessed for DCR application, with good progress

- 25 and 650°C
- Hydrogen and helium environments
- Low stress ground (LSG) and electro-discharge machined (EDM) finish

Conclusions:

Low cycle fatigue life capability of Haynes 188 in hydrogen looks quite satisfactory for DCR application

- Capability not decreasing with temperature
- Capability not decreasing with EDM surface finish
- Failures indicate retention of ductility during crack growth

Future Work:

More fatigue tests are planned

- Run additional tests at intermediate strains
- Perform multiple tests at strains of two selected life-limiting locations of the DCR
  - Drilled bolt hole in combustor sidewall, in air
  - EDM cooling hole, in hydrogen
- Conduct fractography on these failed specimens
- Generate life lines and finalize life estimates
- Use specimen test data to correlate analytical models and refine overall structural life analysis
- Finalize inspection intervals and procedures to monitor critical areas