

THE EFFECT OF POROSITY AND γ - γ' EUTECTIC CONTENT ON THE LOW CYCLE FATIGUE BEHAVIOR OF HYDROGEN-CHARGED PWA 1480

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7-4-76
725103

Single crystal superalloys such as PWA 1480 are being considered for turbopump blades in the main engines of the space shuttle. As fatigue resistance in a hydrogen environment is a key issue in this application, a study of the effect of porosity and γ - γ' eutectic content on the fatigue life of a hydrogen-charged PWA 1480 single crystal was performed. Porosity and eutectic have been linked to fatigue initiation in previous studies, and therefore reduction of either or both may be one means to improve fatigue life of PWA 1480 when hydrogen is present.

To reduce levels of porosity and eutectic alone or in combination, [001] single crystals of PWA 1480 were given various thermomechanical treatments. A eutectic solution treatment at 1290 °C was employed to reduce eutectic content, while porosity was reduced by hot isostatic pressing (HIP). To reduce porosity and eutectic content, a duplex thermomechanical treatment was used in which PWA 1480 was first given a eutectic solution at 1290 °C and then HIPed. After processing, fatigue specimens were machined, heat treated, and subsequently charged in high-pressure gaseous hydrogen. The hydrogen level increased from less than 5 to 400 ppm by weight after charging.

Room temperature, strain-controlled fatigue tests were run on all material conditions in an air environment. Hydrogen charging was found to reduce the fatigue life of PWA 1480 containing normal levels of porosity and eutectic (standard microstructure) by more than one order of magnitude. Initiation sites in hydrogen charged PWA 1480 were easily identified by (001) facets on the fracture surface. Each facet usually initiated at a central pore which was often closely associated with a γ - γ' eutectic. Material given the eutectic solution treatment was found to have a significant decrease in eutectic content; however, a small amount of incipient melting occurred producing an appreciable increase in the number of large pores. This microstructure showed a greater life degradation than the standard microstructure in the presence of hydrogen. HIPing at 1280 °C was found to reduce the size and frequency of larger pores and also halved the amount of γ' eutectic. The HIPed material showed a slight improvement in fatigue life over material with the standard microstructure in the presence of hydrogen.

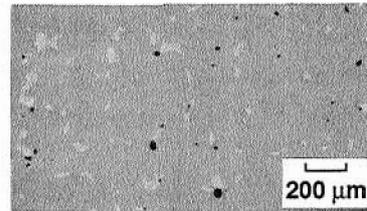
The longest fatigue life of hydrogen-charged PWA 1480 was obtained with material given the eutectic solution and then HIPed. The porosity and eutectic content of this material was significantly lower than any of the other conditions tested. Further, the degree of facet formation on the fracture surface of tested specimens was also greatly reduced. The reduction in porosity level achieved by this duplex thermomechanical treatment suggests that closure of porosity is more readily achieved if eutectic content is minimized before HIPing.

Objective and Material

PWA 1480 single-crystal superalloy

- Orientation, [001]
- Fine aging γ' , 60 vol. %
- Coarse eutectic, 2 vol. %
- Porosity, 0.3 vol. %

Study the effect of $\gamma-\gamma'$ eutectic and porosity on the fatigue life of a single-crystal, nickel-base superalloy in the presence of hydrogen

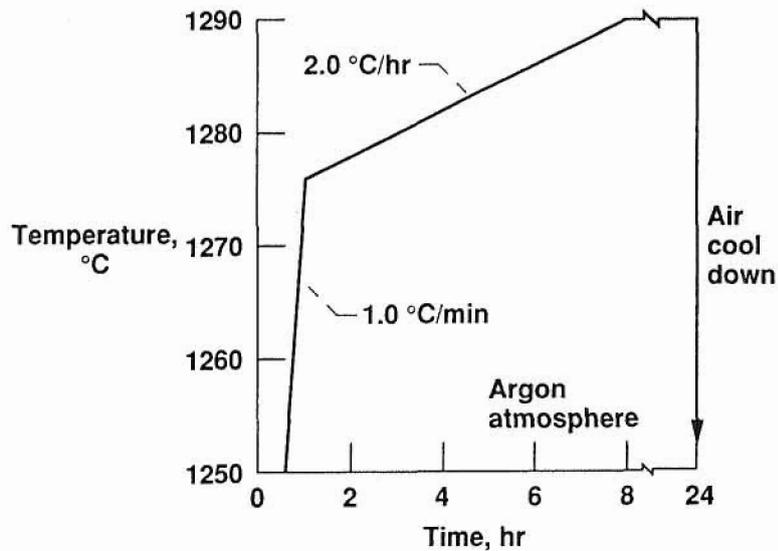


Chemical composition by weight

9.4 Cr	11 Ta
4.7 Al	5.2 W
1.0 Ti	4.8 Co
Balance Ni	

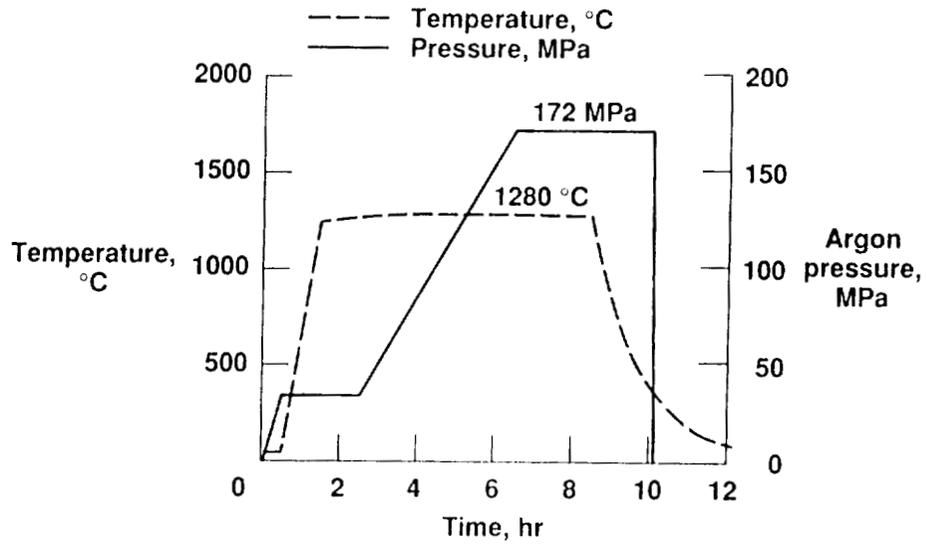
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1290 °C Eutectic Solution Treatment Used to Reduce γ' Eutectic Content



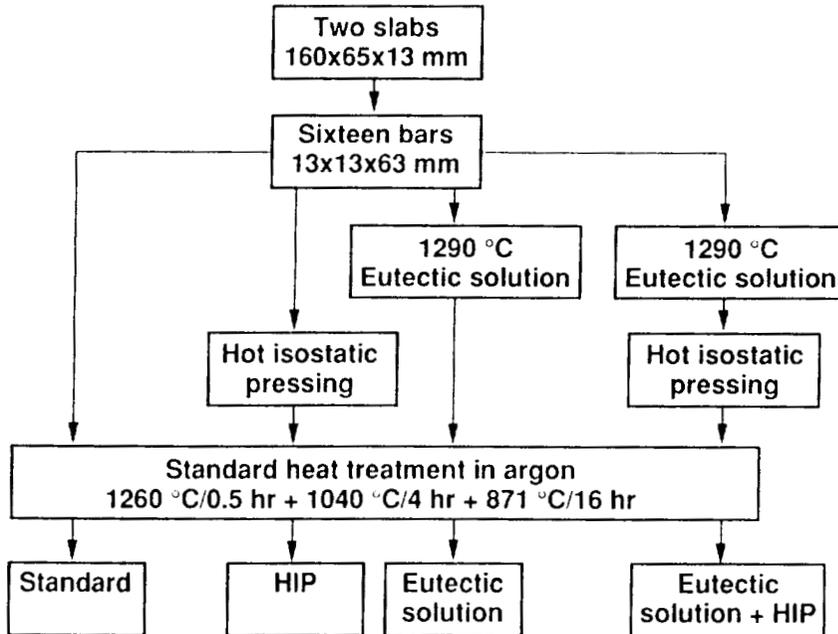
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Hot Isostatic Pressing (HIP) Used to Reduce Porosity



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Processing Flowchart

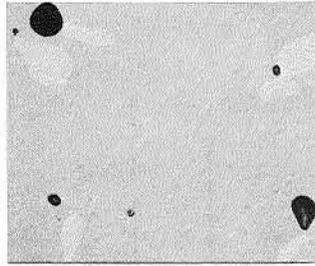


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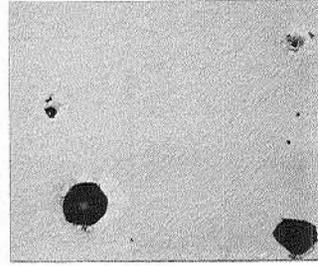
γ - γ' Eutectic Morphology After Processing

Standard treatments (2.3 vol. % eutectic)

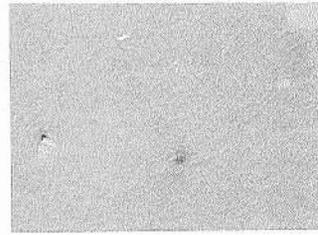
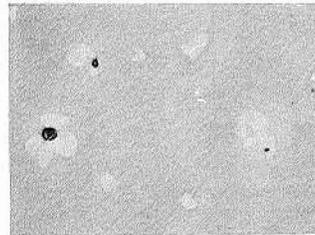
Eutectic solution (0.5 vol. %)



HIP (1.0 vol. %)

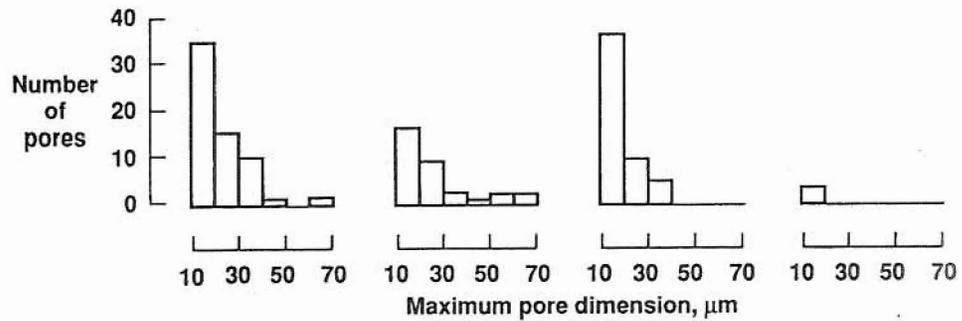
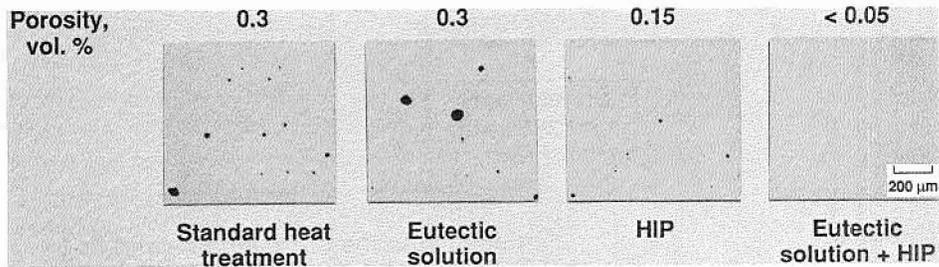


Eutectic solution + HIP (< 0.1 vol. %)



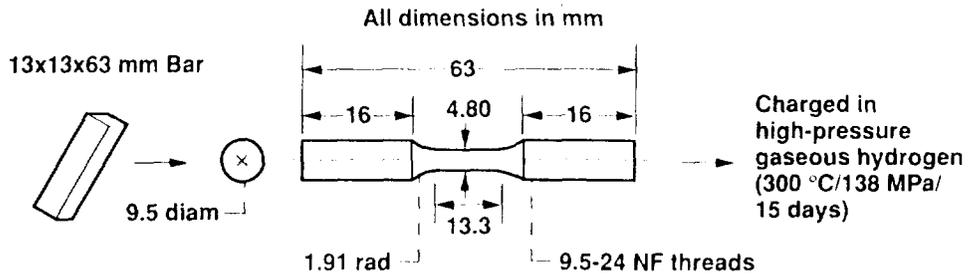
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Porosity Distributions After Processing



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Machining, Charging, and Testing Procedures



Tensile test

- Room temperature
- Strain rate, 0.1 %/sec

Or

Fatigue test

- Room temperature
- Strain control
- Sine wave, 0.1 Hz
- Maximum strain/minimum strain = -1

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Tensile Properties of PWA 1480

Uncharged (< 5 ppm by weight of hydrogen)

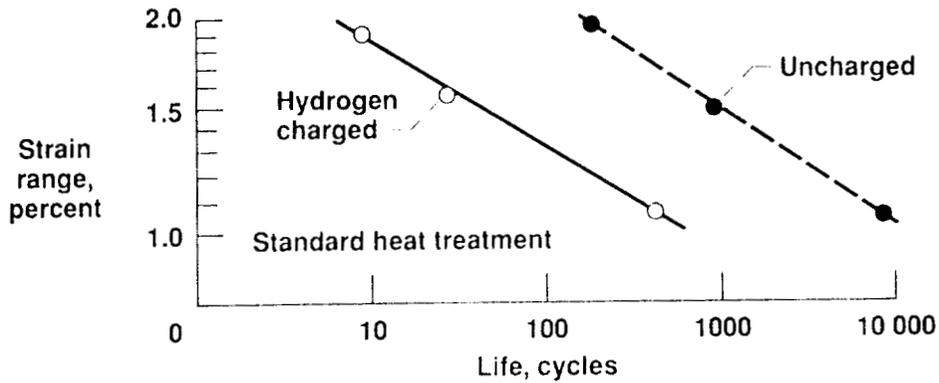
Heat treatment	Yield strength, MPa	Ultimate strength, MPa	Elongation, percent	Reduction in area, percent
Standard	1041	1241	7.6	8.4

Hydrogen charged (400 ppm by weight)

Heat treatment	Yield strength, MPa	Ultimate strength, MPa	Elongation, percent	Reduction in area, percent
Standard	936	1048	2.6	7.3
Eutectic solution	1060	1083	1.7	6.9
HIP	960	1069	3.0	6.8
Eutectic solution + HIP	952	1117	3.2	4.2

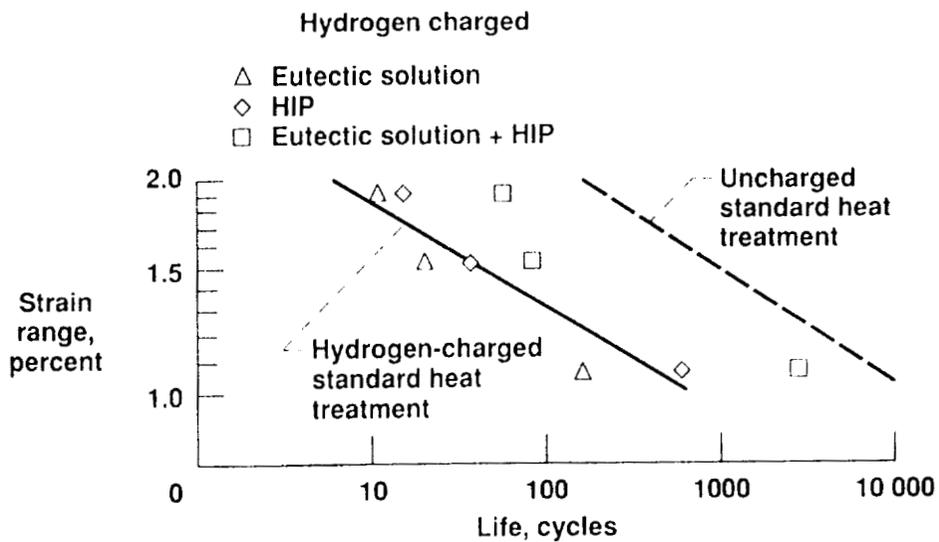
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Hydrogen Charging Severely Degrades Fatigue Life of [001] PWA 1480



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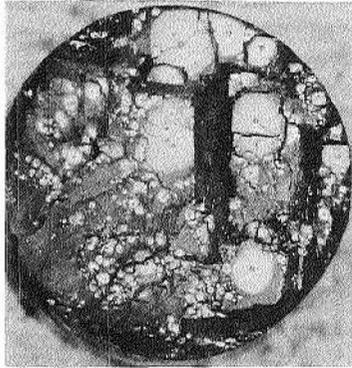
The Microstructure With the Least Amount of Porosity and Eutectic Exhibits the Best Fatigue Life When Hydrogen is Present



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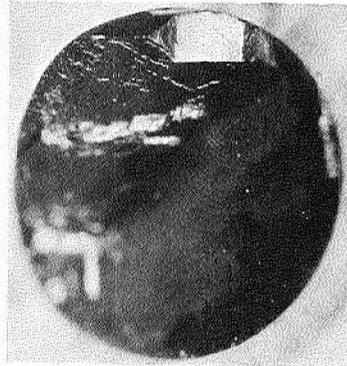
Fracture Surfaces of Fatigue Tests Run at $\Delta\varepsilon = 1\%$ of Hydrogen-Charged PWA 1480

Eutectic Solution



Multiple (001) facet initiations at
10 - 100 μm pores
Shortest life ($N_F = 166$)

Eutectic Solution + HIP



Single (001) facet initiation at
15 μm pore
Longest life ($N_F = 2750$)

Uncharged PWA 1480 Does Not Exhibit Any (001) Facets on
Fracture Surface of Fatigue Specimens

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Summary and Conclusions

- Hydrogen charging greatly reduces the fatigue life of PWA 1480.
- The reduction of fatigue life in the presence of hydrogen was minimized by a duplex thermomechanical treatment consisting of a eutectic solution at 1290 °C, followed by hot isostatic pressing. This treatment produced the greatest reduction in size and amount of eutectic and porosity.
- It is suggested that the 1290 °C eutectic solution treatment preconditions PWA 1480 such that pores are more easily closed by hot isostatic pressing.

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