

N 9 1 - 2 4 3 1 6 -

THE EFFECT OF HYDROGEN ON THE DEFORMATION BEHAVIOR OF A SINGLE  
CRYSTAL NICKEL-BASE SUPERALLOYW.S. Walston and A.W. Thompson  
Carnegie Mellon University  
Pittsburgh, PA 1521359-26  
19866I.M. Bernstein  
Illinois Institute of Technology  
Chicago, IL 60616

The major goal of this study is to determine how hydrogen affects the deformation and fracture behavior of PWA 1480. Tensile tests, hydrogen-induced crack growth and fracture toughness tests are being performed in order to meet this goal. The role of hydrogen trapping sites is also being incorporated by varying the levels of porosity and eutectic  $\gamma$ . This presentation will concentrate mainly on the effect of hydrogen on the tensile deformation behavior.

All tensile samples tested were within  $5^\circ$  of  $[001]$ . The samples were given the normal heat treatment resulting in a cuboidal  $\gamma$  size of approximately  $0.5 \mu\text{m}$ . Samples were gas-phase charged for 15 days at  $350^\circ\text{C}$  and 20 kpsi resulting in a uniform hydrogen concentration of 300 ppm by weight (17500 appm). The concentration in the samples was analyzed by vacuum hot extraction at  $900^\circ\text{C}$ . Tensile tests were interrupted at different plastic strain levels to observe the development of the dislocation structure. TEM foils were cut perpendicular to the tensile axis to allow the deformation of both phases to be simultaneously observed as well as parallel to  $[111]$  to show the superdislocations on their slip planes. TEM observations were performed on a JEOL 120 CX operating at 120 KeV.

Similar to other nickel-base superalloys, hydrogen was detrimental to the room temperature tensile properties of PWA 1480. There was little effect on strength, however the material was severely embrittled. Even without hydrogen, the elongation-to-failure was only approximately 3%. The tensile fracture surface was made up primarily of ductile voids with regions of cleavage fracture. These cleavage facets are the eutectic  $\gamma$  in the microstructure. It was shown by quantitative fractography that hydrogen embrittles the eutectic  $\gamma$  and causes the crack path to seek out and fracture through the eutectic  $\gamma$ . There was two to three times the amount of cleavage on the fracture surface of the hydrogen-charged samples than on the surface of the uncharged samples.

The effect of hydrogen can also be seen in the dislocation structure. There is a marked tendency for dislocation trapping in the  $\gamma$  matrix with and without hydrogen at all

---

This work is supported by NASA Lewis Research Center

plastic strain levels. Without hydrogen there is a high dislocation density in the  $\gamma$  matrix leading to strain exhaustion in this region and failure through the matrix. The dislocation structure at failure with hydrogen is slightly different. TEM foils cut parallel to [111] showed dislocations wrapping around  $\gamma'$  precipitates. This is in contrast to other observations on high  $\gamma' V_f$  superalloys which report long straight screw dislocations cutting through the  $\gamma'$  precipitates.<sup>1</sup> [001] foils show that there is a lower dislocation density in the  $\gamma$  matrix which can be linked to the effects of hydrogen on the fracture behavior. By seeking out the eutectic  $\gamma$  and preferentially failing through this phase, it is possible that the maximum accommodating strain in the  $\gamma$  matrix is not reached. This suggests that removing the eutectic  $\gamma$  through heat treatment would result in less hydrogen embrittlement. Preliminary results indicate that this is true and also that eliminating the eutectic  $\gamma$  results in a significantly higher ductility in all specimens.

The primary activity in the  $\gamma'$  precipitates is in the form of superlattice intrinsic stacking faults (SISFs). These faults have been reported in other ordered alloys and superalloys.<sup>2,3</sup> It is not believed that these SISFs play a large role in the deformation of this alloy. In hydrogen-charged samples, "extended Z" configurations have been observed in the  $\gamma'$  precipitates similar to those in superalloys at high temperatures.<sup>4</sup> This suggests that solute hydrogen promotes the cross-slip of superdislocation segments at room temperature. This phenomena was observed in previous work at Carnegie Mellon on a similar superalloy,<sup>1</sup> and recently room temperature cross-slip has been reported in Ni<sub>3</sub>Al.<sup>5</sup>

## References

1. M. Dollar and I.M. Bernstein, *Acta Met.*, **36**, 2369, (1988)
2. D.P. Pope and S.S. Ezz, *Int. Met. Rev.*, **29**, 136, (1984)
3. W.W. Milligan, *priv. comm.*
4. A. Huisein't Veld, et. al., *Scr. Met.*, **19**, 105, (1985)
5. A. Korner, *Phil. Mag. A*, **58**, 507, (1988)

Table I. Effect of Hydrogen on <001> Room Temperature Tensile Properties.

|           | $\sigma_{ys}$ (MPa) | $\sigma_{UTS}$ (MPa) | $e_t$ (%) | R.A. (%) |
|-----------|---------------------|----------------------|-----------|----------|
| uncharged | 1001                | 1120                 | 2.9       | 3.1      |
| charged   | 1014                | 1060                 | 0.38      | 2.7      |

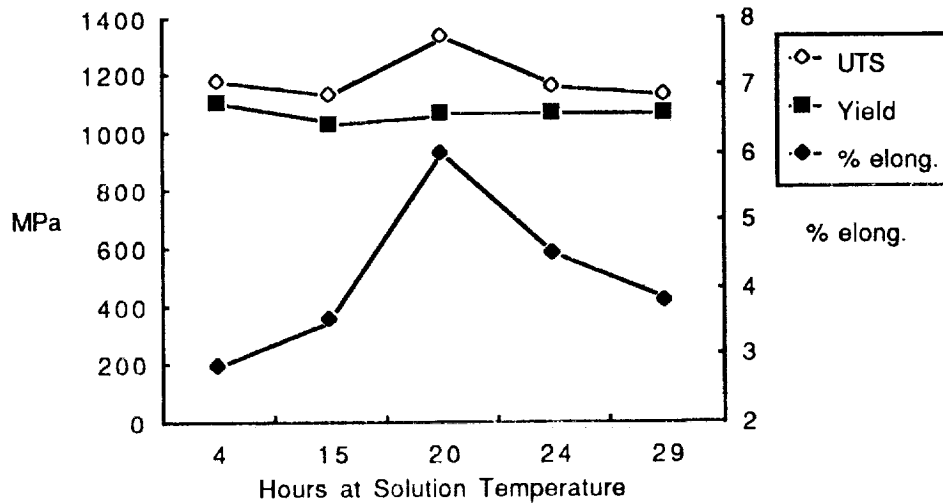
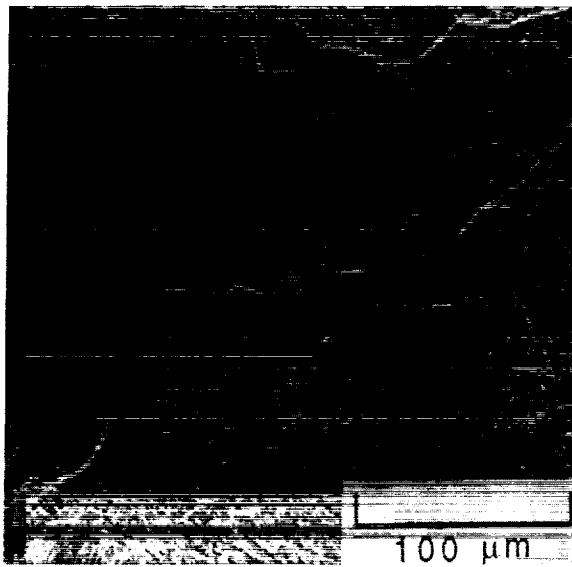
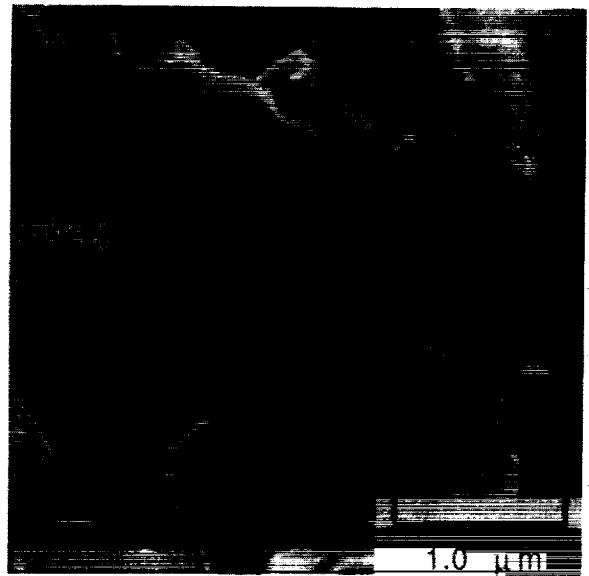


Figure 1. Effect of heat treatment solutionizing time on tensile properties. At 20 hours all of the eutectic  $\gamma$  is removed, and at longer times incipient melting becomes a factor. This shows that removing the eutectic  $\gamma$  can significantly increase ductility.



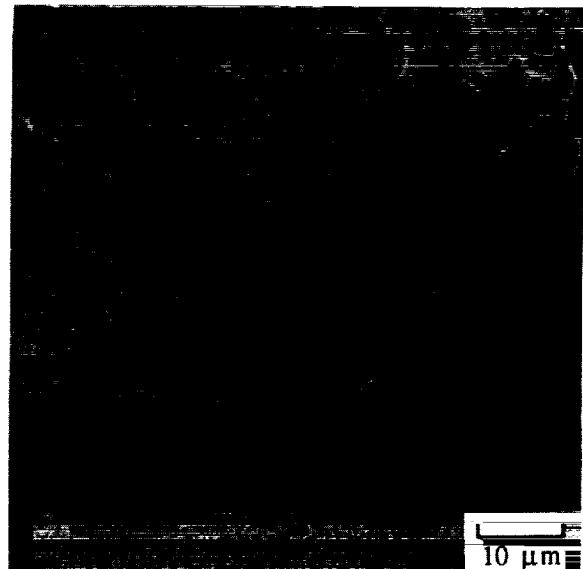
a



b



c

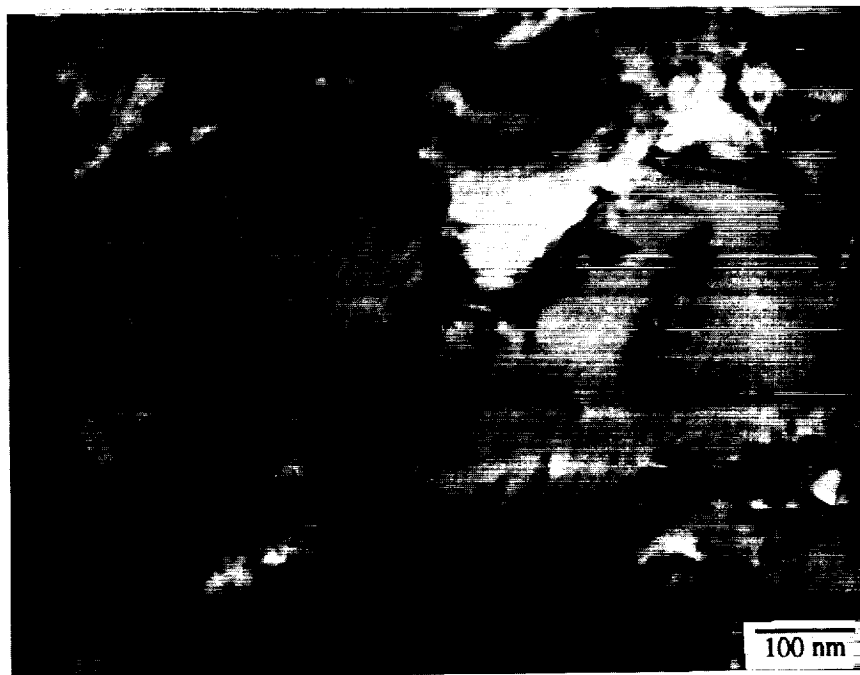


d

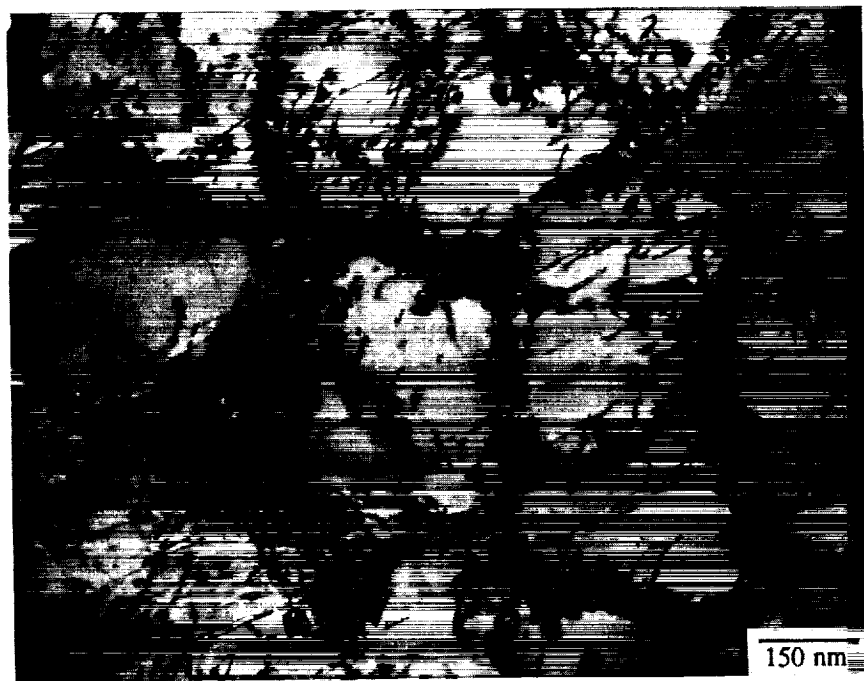
Figure 2. (a) Overall [001] tensile fracture (b) small ductile voids (c) cleavage facet (d) plateau etch showing cleavage on fracture surface and eutectic  $\gamma$  in microstructure.

ORIGINAL PAGE  
BLACK AND WHITE PHOTOGRAPH

ORIGINAL PAGE  
BLACK AND WHITE PHOTOGRAPH

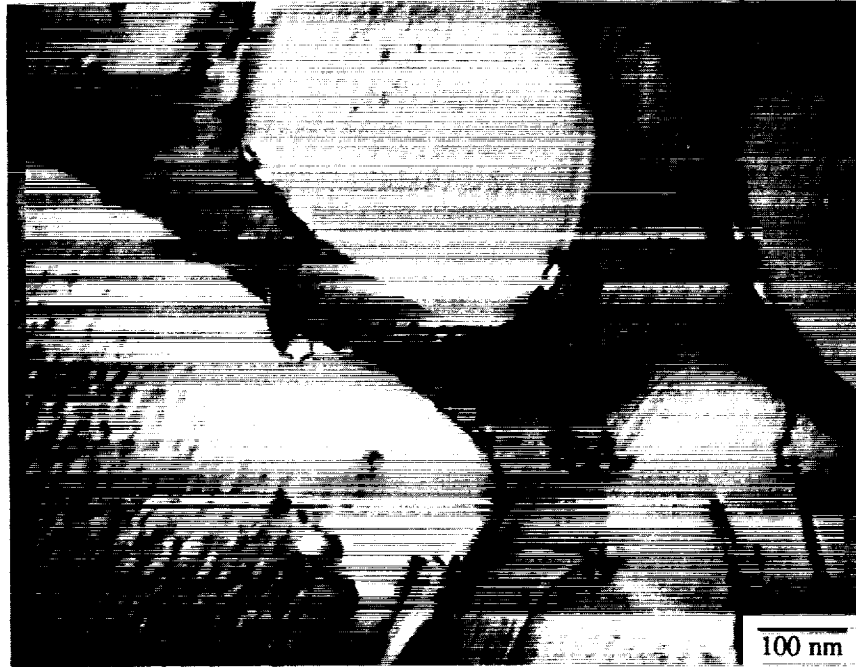


a

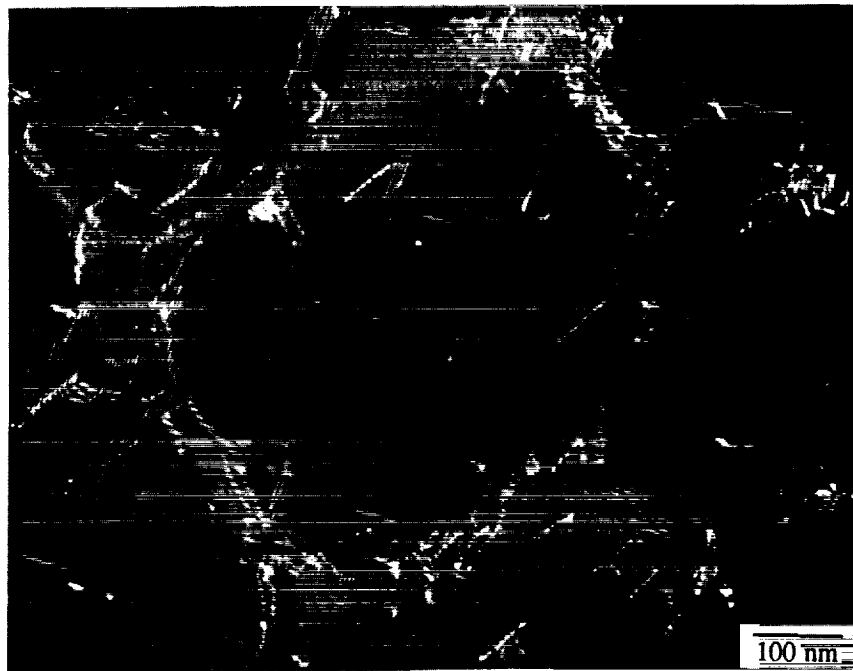


b

Figure 3. [001] micrographs of uncharged sample (a)  $\epsilon_p = 1.2\%$  (b)  $\epsilon_f = 3.0\%$ .



a



b

Figure 4. [001] micrographs of charged sample (a)  $\epsilon_p = 0.15\%$  (b)  $\epsilon_f = 0.4\%$ , weak-beam dark field (WBDF).



Figure 5. WBDF of superlattice intrinsic stacking faults (SISFs) in  $\gamma$  precipitate.



Figure 6. Room temperature cross-slip in hydrogen charged samples.

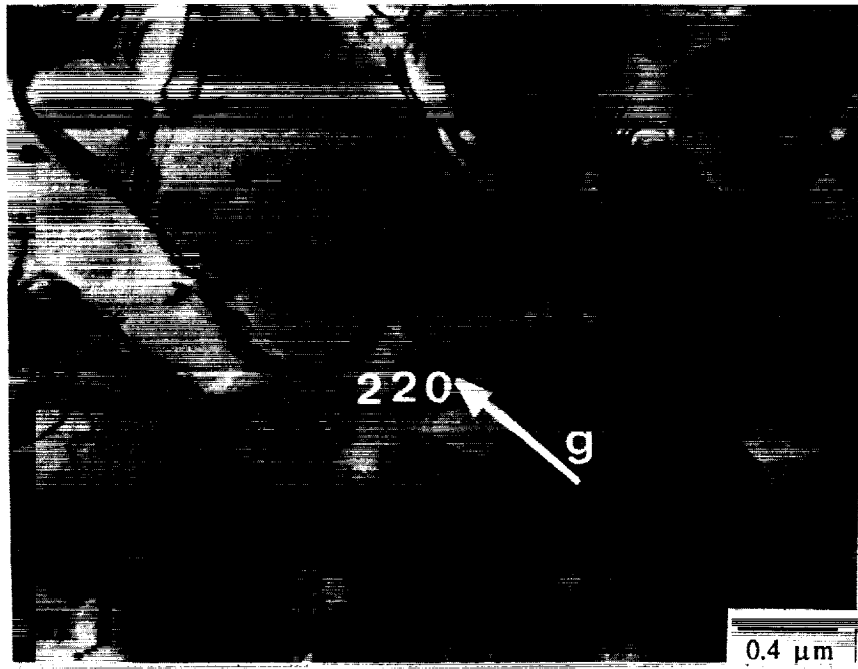


Figure 7. [111] micrograph showing superdislocations bowing around  $\gamma'$  precipitates.

ORIGINAL PAGE  
BLACK AND WHITE PHOTOGRAPH