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NOTCHED FATIGUE OF SINGLE CRYSTAL PWA 1480 AT TURBINE ATTACHMENT TEMPERATURES

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This paper presents results obtained under Option 1 of NASA contract NAS3-23939, "Life Prediction and Constitutive Models for Engine Hot Section Anisotropic Material". The Option 1 portion of this contract is focused on the lower temperature, uncoated and notched features of gas turbine blades. Constitutive and fatigue life prediction models applicable to these regions are being developed. This paper will present fatigue results obtained thus far. The program will continue throughout the current year.

Fatigue tests are being conducted on PWA 1480 single crystal material using smooth strain controlled specimens and three different notched specimens. The smooth fatigue specimens have a circular cross section and a one inch gage length. The notched specimen configurations are shown in Figure 1. The threaded ends of the thick specimen are not shown in Figure 1. The relative orientation of the geometric and crystallographic axes are uniquely defined by a specimen's primary orientation, $\underset{\sim}{P}$, (corresponding to the loading direction and also to the crystal growth direction of the bars from which the specimen is machined) and its secondary orientation, $\underset{\sim}{S}$, (corresponding to the direction normal to the notch). Six different notched specimen orientations will be tested in the program. Thus far, notched fatigue tests have been conducted on three of these orientations: <001> <100>, <001> <210>, and <111> <01$\bar{1}$>.

Isothermal fatigue tests have been conducted at 1200°F, 1400°F and 1600°F. The bulk of the tests have been conducted at 1200°F and are presented here. The strain controlled tests were conducted at 0.4% per second strain rate and the notched tests were cycled at 1.0 cycle per second. Previous tests have shown no material rate dependence at 1200°F. A clear orientation dependence is observed in the smooth strain controlled fatigue results as shown in Figure 3. Figure 4 indicates that much of this apparent orientation dependence is reduced when the life data is plotted versus stress range. The fatigue lives of the thin, mild notched specimens agree fairly well with this smooth data as shown in Figure 5 when elastic stress range is used as a correlating parameter. Finite element analyses were used to calculate notch stresses. The finite element meshes used in the analyses are shown in Figure 1.

In the notched specimens, the locations of maximum principal stress, maximum principal strain and maximum octahedral slip system shear stress do not always coincide.

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Fatigue cracks initiate at micropores at the maximum principal stress location and the crack plane is normal to the principal stress. Final fracture occurs along a <111> crystal plane. Figure 6 shows the initiation site and final crack planes for a thin, mild notched specimen. In this specimen, the maximum principal strain occurs at the minimum cross section while the maximum principal stress is calculated to occur 26 degrees from the minimum section point. In the smooth specimens, cracks initiate at pores near the surface on planes perpendicular to the applied stress.

Even though the data shown in Figure 5 appears to be fairly well correlated, a closer examination shows that some orientation dependence is still manifested. This can be seen clearly in the statistical distribution of the data about the mean trend line as shown in Figure 7; all <111> specimens have lives greater than the mean trend line. This indicates that the fatigue models being developed cannot depend solely upon stress range.

Two of the notched specimens being tested can be considered to be thick in that the ratio of actual thickness to notch radius is greater than or equal to 1.0. Figure 8 shows that these specimens exhibit a somewhat different life trend from the thin specimens. These results indicate that correlating parameters should include the effect of the transverse stress.

When the material is hot isostatically pressed (HIP) to remove casting micropores, a clear improvement in fatigue life is observed as shown in Figure 9. The initiation sites are again at the maximum principal stress location with the crack plane normal to the principal stress.

Fatigue testing will continue to further explore the trends observed thus far. Constitutive and life prediction models are being developed.

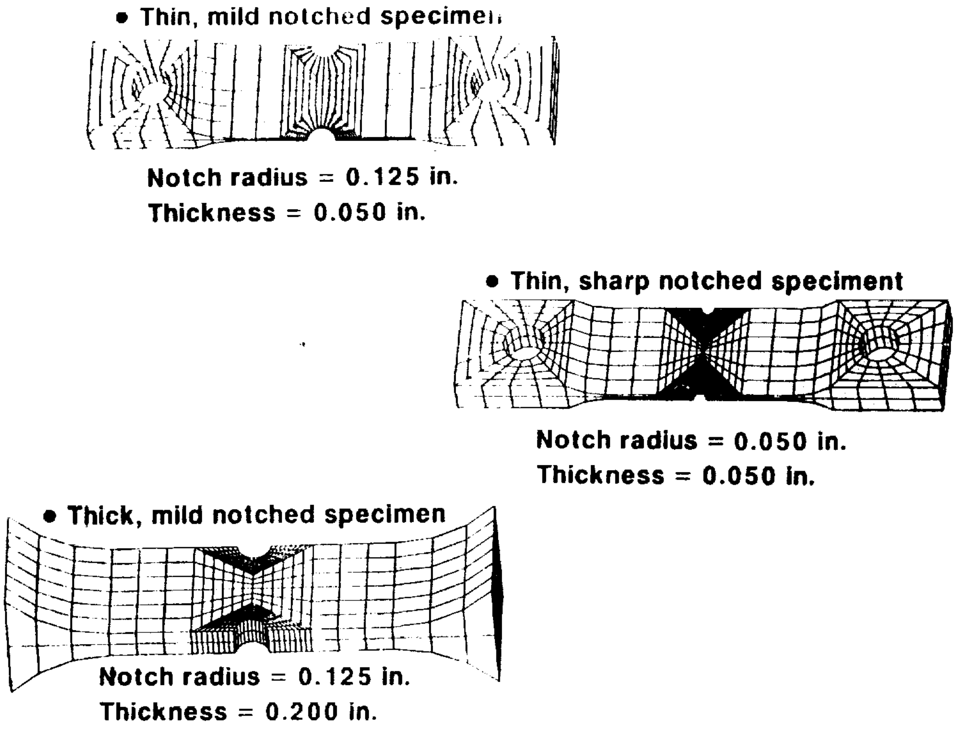


Figure 1. Notched fatigue specimen geometries and finite element meshes used to determine notch stresses.

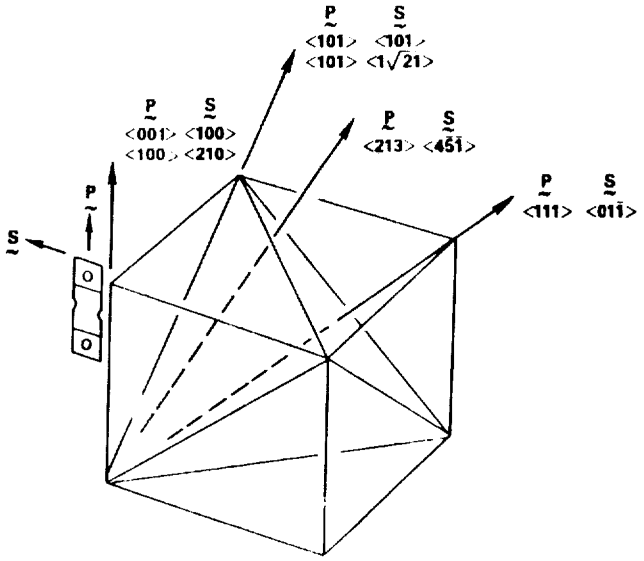
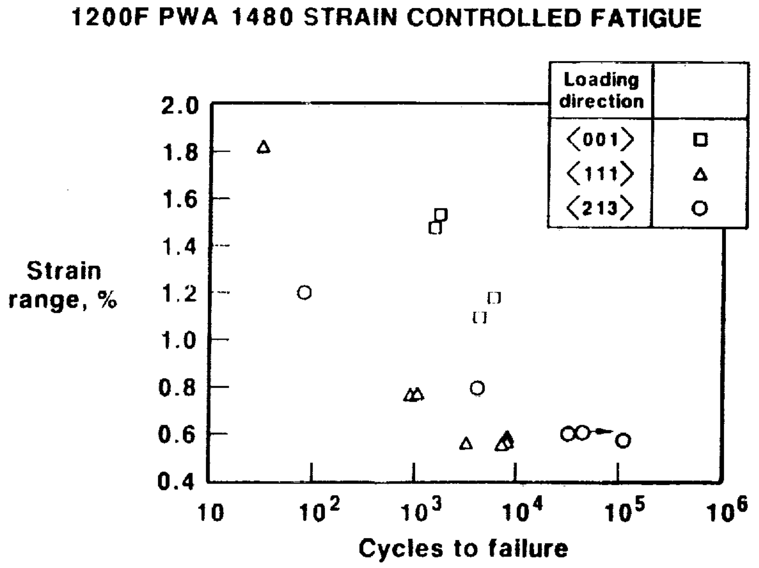
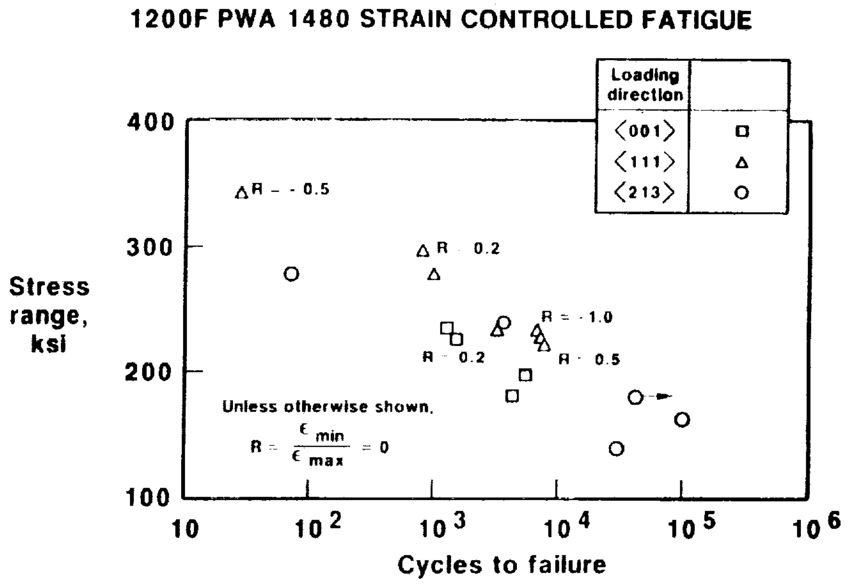


Figure 2. Notched specimen orientations that will be tested.



1200F PWA 1480 STRAIN CONTROLLED FATIGUE

Figure 3. A clear orientation dependence is seen in the smooth strain controlled fatigue lives when plotted versus strain range.



1200F PWA 1480 STRAIN CONTROLLED FATIGUE

Figure 4. Stress range is a better life correlating parameter.

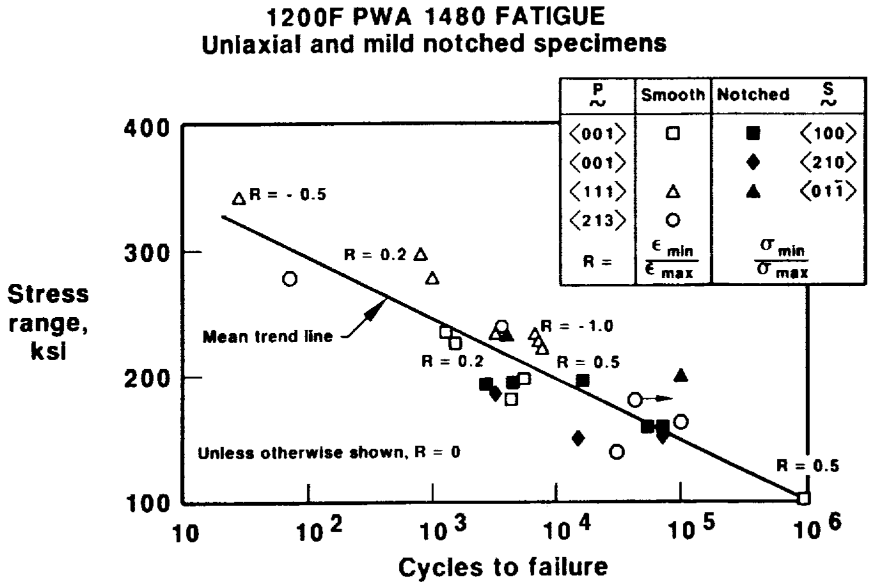


Figure 5. Mild notched and smooth strain controlled lives follow the same trend line.

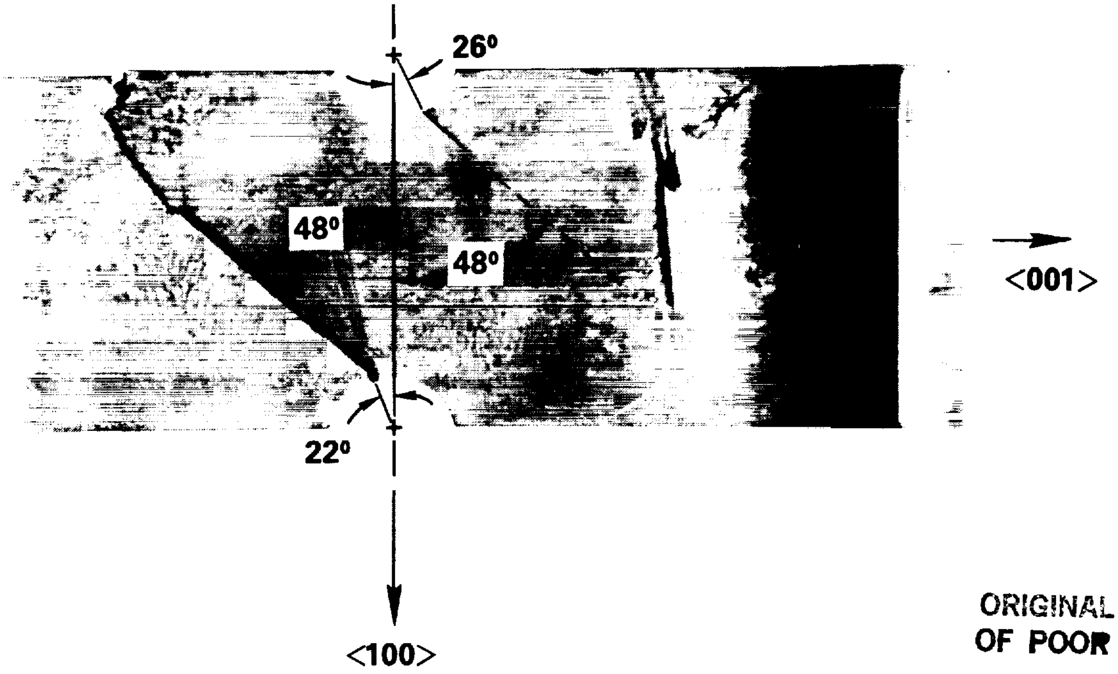


Figure 6. Fatigue cracks initiate at the maximum principal stress location with crack planes perpendicular to the principal stress. Cracks progress along <111> planes in the final stages of crack growth.

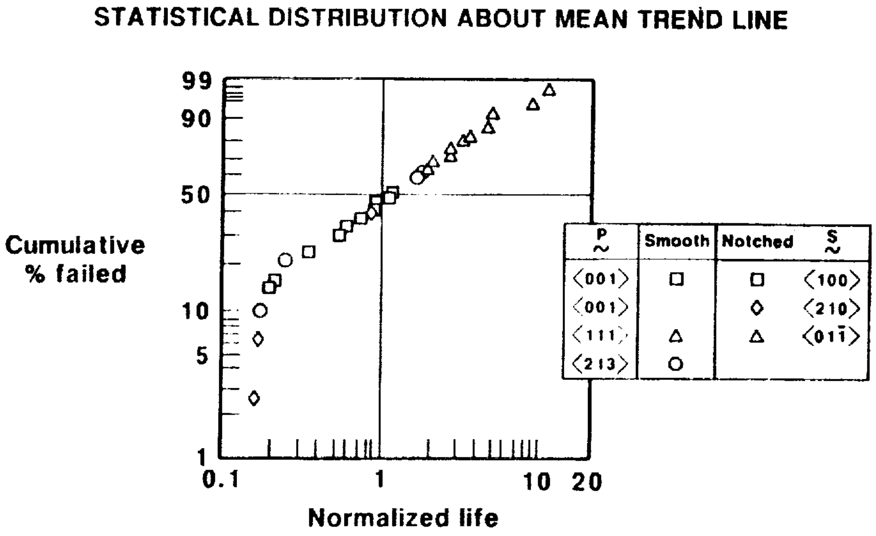


Figure 7. The statistical distribution of failure lives relative to the mean trend line shows that all <111> specimens have lives greater than the mean trend.

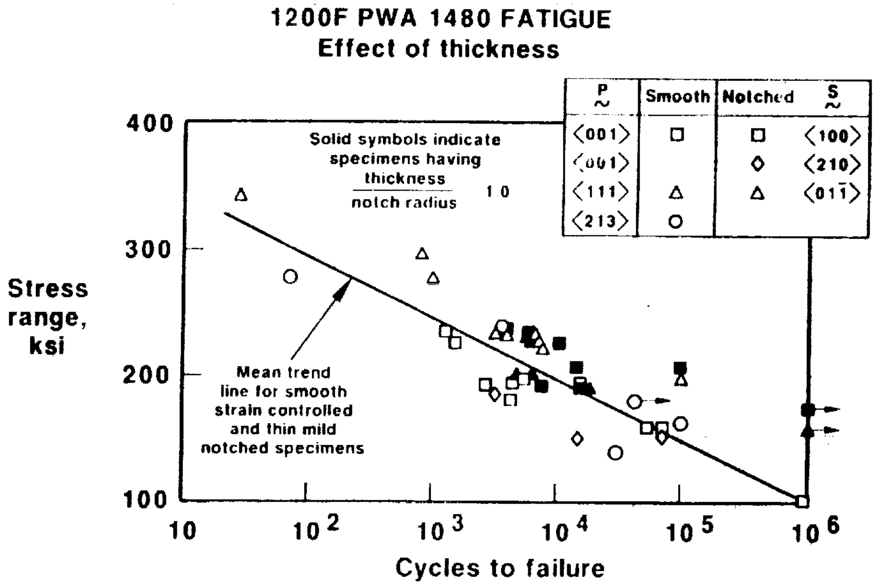


Figure 8. Thin, sharp notched and thick, mild notch specimens display a life trend different than the thin mild notch and smooth specimens.

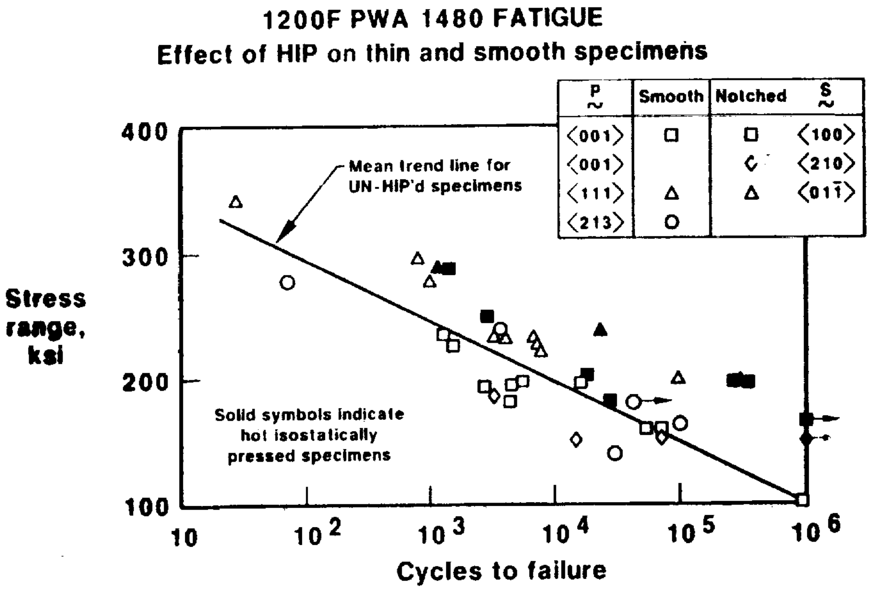


Figure 9. Fatigue life is improved by hot isostatic pressing.