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FATIGUE DAMAGE INTERACTION BEHAVIOR OF PWA 1480

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The fatigue damage interaction behavior of PWA 1480 single crystal alloy has been experimentally established for the two-level loading case in which a block of low-cycle fatigue loading is followed by high-cycle fatigue loading to failure. A relative life ratio N1/N2 (where N1 and N2 are the low- and high-cycle fatigue baseline lives, respectively) of approximately 0.002 was explored to assess the interaction behavior. The experimental results thus far show evidence of a loading order interaction effect to a similar degree of detriment as has been observed in polycrystalline materials. Current generation single crystal alloys in general, and PWA 1480 in particular, contain pores; indeed, it was observed in all cases that specimen failure initiated from pores connected with or immediately below the surface. Detailed fractographic and metallographic studies are currently being made to assess the nature of the porosity in terms of its effect on fatigue life.

EXPERIMENTAL RESULTS

Specimens of PWA 1480 were fabricated from slab material. The specimen geometry was solid cylindrical, having a 1-inch uniform axis gauge section and threaded ends. The specimens were within 10° of the 001 crystallographic direction.

Low-cycle fatigue tests were conducted in strain control using a specialized electrohydraulic tension-compression testing system (fig. 1, ref. 1). The specimens were tested at room temperature using a computer-generated sinusoidal waveform command of constant frequency (0.2 Hz). Control and data acquisition were performed by computer using a software system described in reference 2. The strain gauge used for strain measurement and feedback had a gauge length of 0.24 inch. High-cycle fatigue tests were conducted with the same equipment, although under load control. The test waveform was sinusoidal; the frequency was 300 Hz.

The results of this baseline fatigue characterization testing are displayed in figures 2 and 3. Failure in all tests is defined as specimen fracture into two halves.

The interaction tests were based on reference low-cycle and high-cycle fatigue life levels of 3000 and 1.5 million cycles-to-failure, yielding a relative life level ratio of approximately 0.002. As the purpose in this program is to identify potentially deleterious life behavior on a cumulative fatigue basis, the tests were conducted so that the low-cycle fatigue loading was applied first, and the remainder of the test was carried out under high-cycle fatigue loading conditions until failure occurred, whereupon the remaining life fraction was measured.

The results of the interaction testing are displayed in figure 4 (where the data are interpreted in terms of a stress-based life criterion) and figure 5 (where the data are interpreted in terms of a total strain-based life criterion). The solid curves in both figures are predictions made using the Damage Curve Approach (ref. 3), where the average of the low-cycle fatigue lives predicted for the applied cycle parameter (stress or total strain) was used for the low-cycle fatigue reference life N_1 and the same procedure was used for obtaining the high-cycle fatigue reference life N_2.

DISCUSSION AND CONCLUSIONS

A large amount of scatter in the baseline fatigue behavior is observed in figure 3, especially in the 10^6 to 10^8 life range. A number of experiments were performed at nominally the same completely reversed stress range; three failures were obtained in the 10^6 range while two "runouts" were observed at the middle 10^7 range. Scatter, although apparently not to the same degree, was observed in the low-cycle fatigue range as well. A preliminary fractographic analysis of the failed specimens revealed cracks initiating at surface or near-surface porosity in all cases. The nature of the porosity varied widely in terms of pore size, geometry, and orientation with respect to the loading (and crystal growth) direction. Preliminary analysis also indicated a change in fracture surface appearance as a function of life: while the failure always initiated at a pore in the case of low-cycle fatigue, the early propagation was on two intersecting crystallographic planes; in the case of high-cycle fatigue the early propagation was on a singularly dominant crystallographic plane. The actual crack propagation phase of failure observed in these experiments is for all practical matters zero in the context of cyclic life. The stress-strain response observed at the onset of failure gave little or no indication of the impending fracture.

The interaction experiments show an interaction effect produced by cumulative loading, although the precise nature of the interaction effect is not well correlated by current cumulative damage rules, such as the Damage Curve Approach. A difficulty in the study of cumulative fatigue damage has been the compounded scatter observed in such studies; that is, if the reference life levels are known to be within a factor of 2, the loading interaction cannot be known to be anything less than a factor of 2. In fact, the factors of 2 compound one another. Preliminary fractographic analyses reveal fracture surfaces which appear quite planar, being perpendicular to the loading axis for applied low-cycle fatigue ratios less than approximately 0.5.

The fractographic appearance is reminiscent of polycrystalline materials failing in high-cycle fatigue. This fracture morphology was never observed in the baseline experiments. For applied low-cycle fatigue life ratios of approximately 0.5 and greater, the fracture takes on a character similar to that observed in the baseline low-cycle fatigue experiments.

Detailed fractographic and metallographic studies are being made on the failed specimens in an effort to explain the influence of pore size, geometry, and orientation on fatigue life, as well as interaction behavior.

REFERENCES

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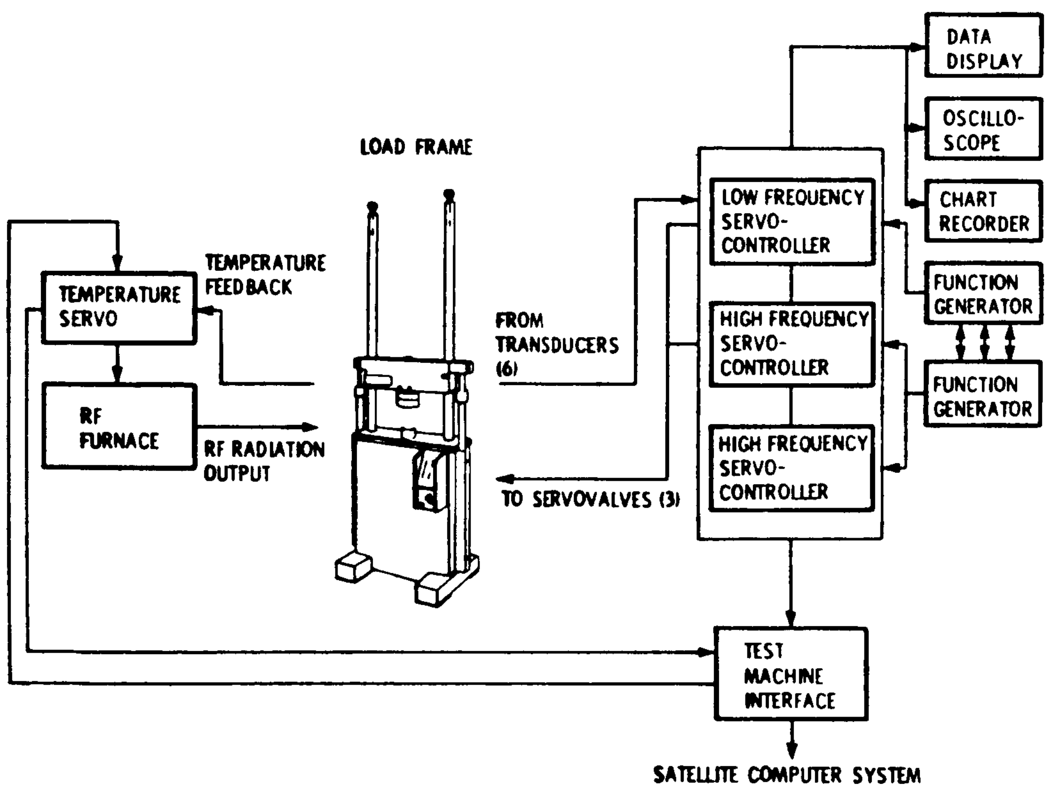

Figure 1. - High-cycle fatigue/low-cycle fatigue materials test system.

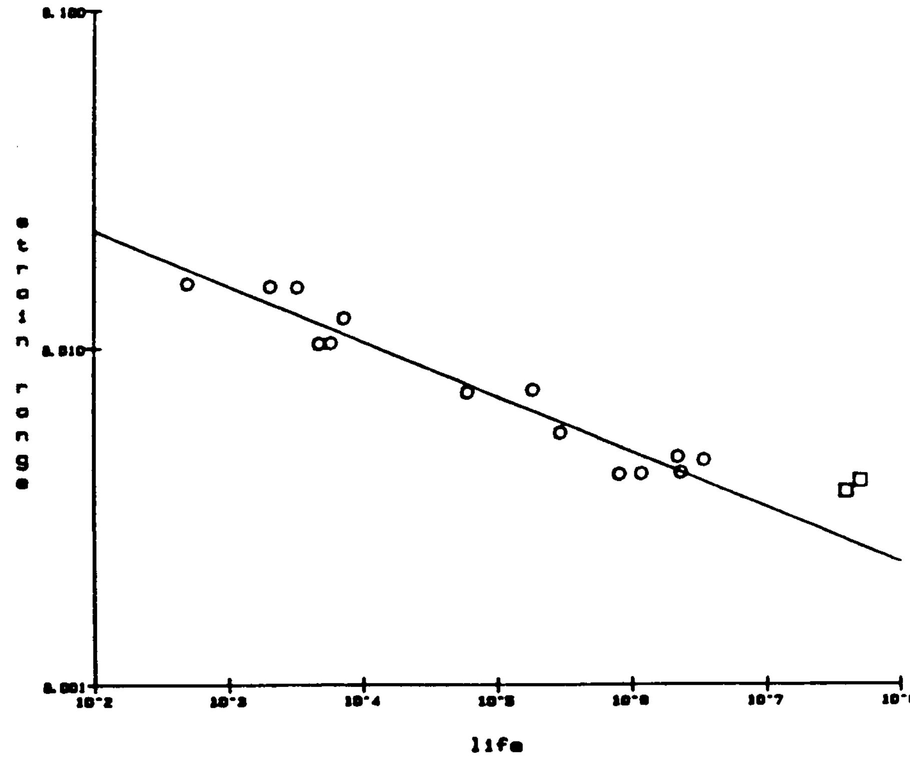

Figure 2. - Fatigue life as function of total strain range.
PWA 1480, SC R.T.

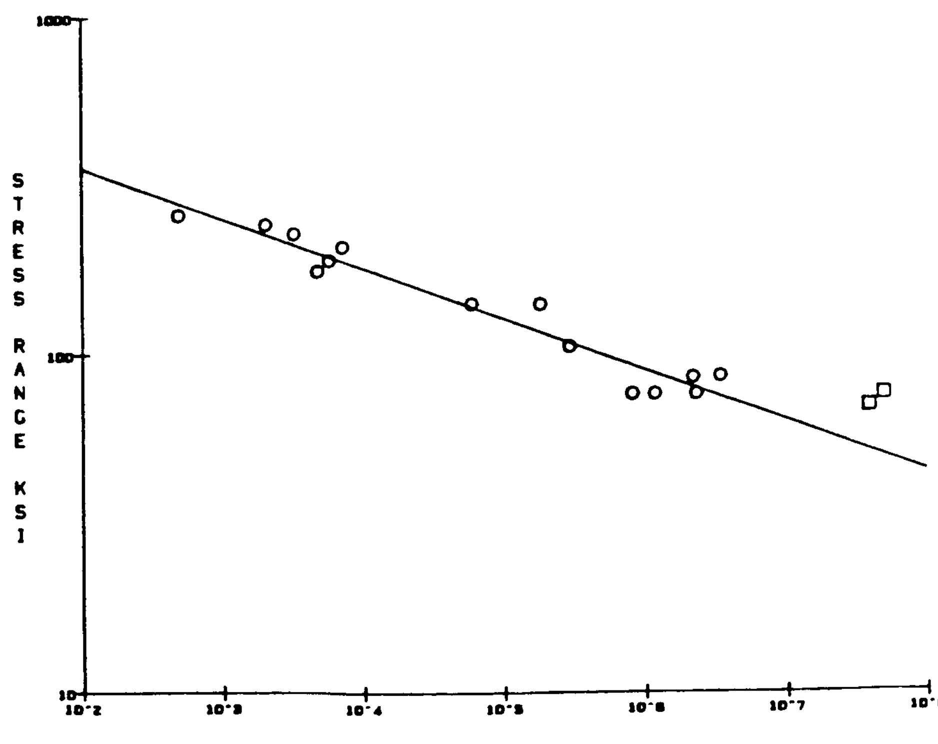

Figure 3. - Fatigue life as function of stress range.
PWA 1480, SC R.T.

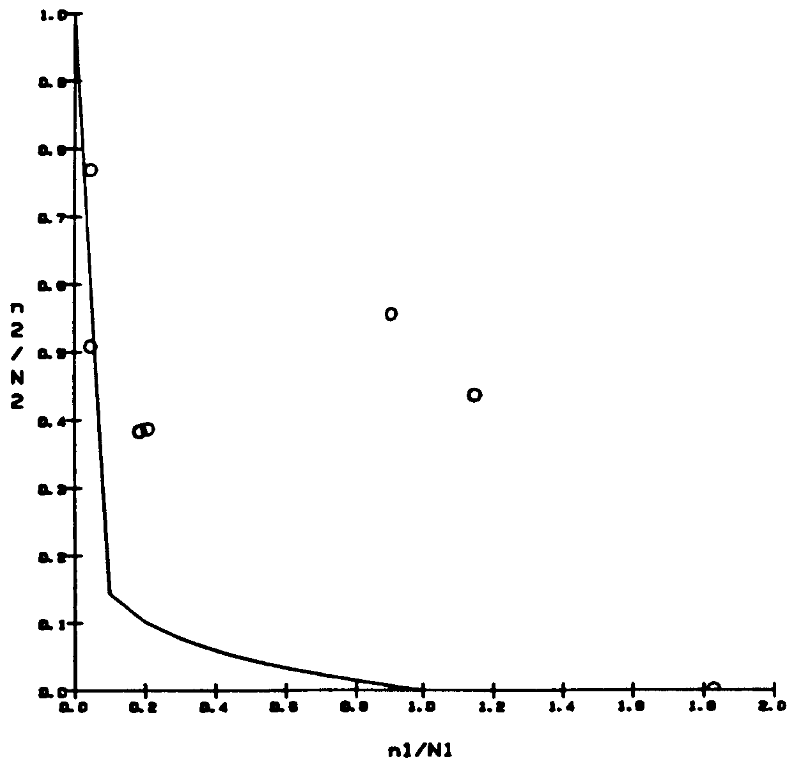

Figure 4. - Results of interaction testing. Data interpreted in terms of stress-based life criterion.

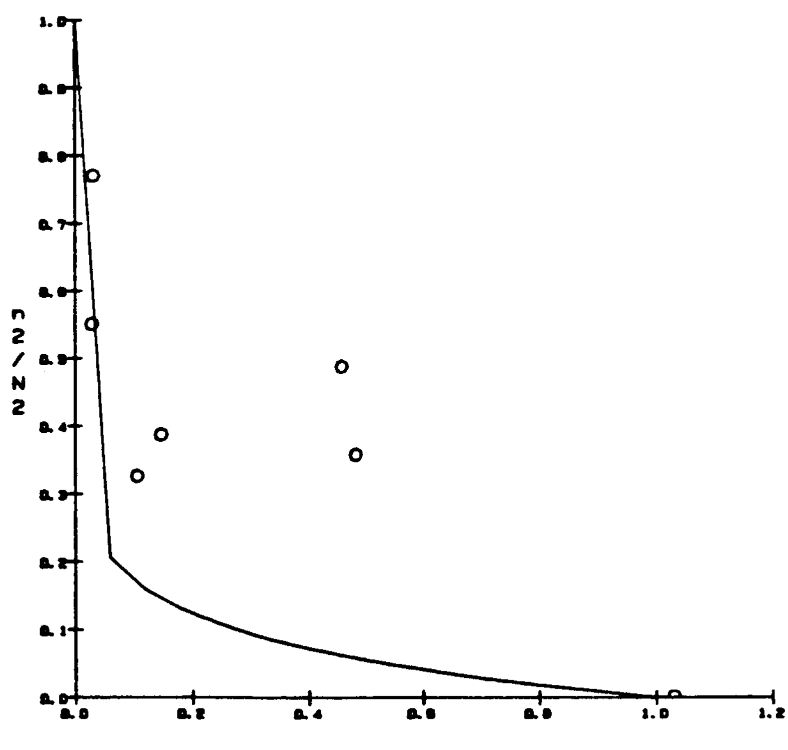

Figure 5. - Results of interaction testing. Data interpreted in terms of total strain-based life criterion.