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Extended Abstract

Effects of High Mean Stress on the High-Cycle Fatigue Behavior of PWA 1480*

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To be submitted for presentation at the Conference on Structural Integrity and Durability of Reusable Space Propulsion Systems, NASA Lewis Research Center, Cleveland, OH, June 4-5, 1985.

*Work supported by the National Aeronautics and Space Administration.

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PWA 1480 is a potential candidate material for use in the high-pressure fuel turbine blade of the Space Shuttle Main Engine. As an engine material it will be subjected to high-cycle fatigue loading superimposed on a high mean stress due to combined centrifugal and thermal loadings. The present paper describes the results obtained in an ongoing program at Argonne National Laboratory, sponsored by NASA Lewis, to determine the effects of a high mean stress on the high-cycle fatigue behavior of this material.

Straight-gauge high-cycle fatigue specimens, 0.2 in. in diameter and with the specimen axis in the [001] direction, were supplied by NASA Lewis. The nominal room temperature yield and ultimate strength of the material were 146 and 154 ksi, respectively. Each specimen was polished with 1-μm diamond paste prior to testing. However, the surface of each specimen contained many pores, some of which were as large as 50 μm. Testing was carried out at room temperature in the laboratory air environment. Future tests will be conducted at an elevated temperature in an inert environment.

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*Work supported by the National Aeronautics and Space Administration.

In the initial tests, specimens were subjected to axial-strain-controlled cycles. However, very little cyclic plasticity was observed. For example, figure 1 shows the hysteresis loop at the tenth cycle for a 0 to 0.8% strain cycling test. The hysteresis loop has almost zero width and very little cyclic mean stress relaxation occurred during the test. Since the majority of the tests were conducted at much lower strain ranges where the hysteresis loops have no measurable width, it was decided to switch to load-controlled testing at a frequency of 20 Hz.

Figure 2 shows a summary of all the tests run to date. Tests with mean stresses of 0, 60, and 120 ksi were carried out. The zero mean stress test data fall on a linear extrapolation of low-cycle fatiguer test data for the same material at 1600°F in a high-pressure hydrogen environment [1]. Although the data are limited, the material seems to exhibit an endurance limit which is weakly dependent on the mean stress. Figure 3, for example, shows a Goodman diagram for a life of 10^6 cycles. It is evident that the high-cycle fatigue strength of the material is quite resistant to mean-stress effects.

Several specimens were analyzed by scanning electron and optical microscopy after fracture. Each specimen contained a large number of micropores (figure 4, top) and crack initiation always occurred from one of these micropores. Figure 5 shows crack initiation from a micropore in a specimen (#15-3) that was cycled at a stress range of 120 ksi with zero mean stress. A similar mode of crack initiation was also observed in a specimen (#112-3) that was cycled at a stress range of 38 ksi with a mean stress of 120 ksi, as shown in figure 6. Crack propagation was crystallographic during most of the life; it apparently occurred along {111}-type planes. In both specimens #112-3 and #15-3, the crack that led to failure was initiated by a crack on a different slip plane (figures 4 and 5). Crack growth also appeared to preferentially follow microporosities (figure 7). (The distinct slip band marks along {111}-type planes in the figure are for a test with a rather large (0.8%) strain range. Such slip bands were not observed in the low-strain-range, high-cycle fatigue test specimens.)

Several slight differences were observed between specimens with zero and high mean stress. The specimen with high mean stress (#112-3) appeared to have cracks initiated at several sites, whereas the zero-mean-stress specimen (#15-3, figure 5) had a single crack origin. The high-mean-stress specimen also had a rougher, more textured fracture surface, which may be indicative of a higher crack propagation rate. It also contained several "steps" on the fracture surface (figure 4, bottom). These steps were probably caused either by the linking of two parallel cracks on the same type of octahedral plane or by the intersection of cracks on non-parallel octahedral planes.

REFERENCES

1. D. P. DeLuca, Final Report on Mechanical Properties of Turbine Alloys in Hydrogen at Elevated Temperatures, prepared for NASA George C. Marshall Flight Center, Alabama 35812, by United Technologies Pratt and Whitney Aircraft, FR 14844, 1981.

LIST OF FIGURES

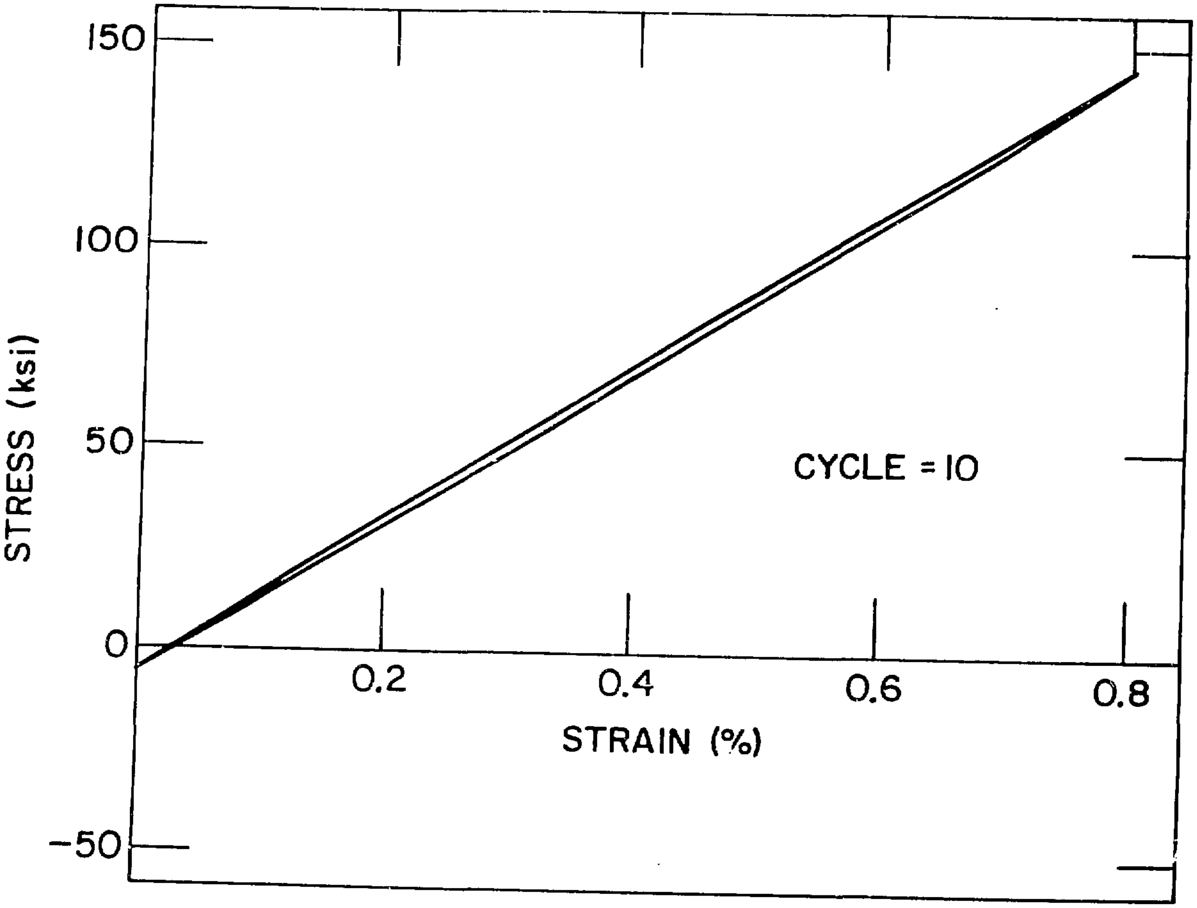
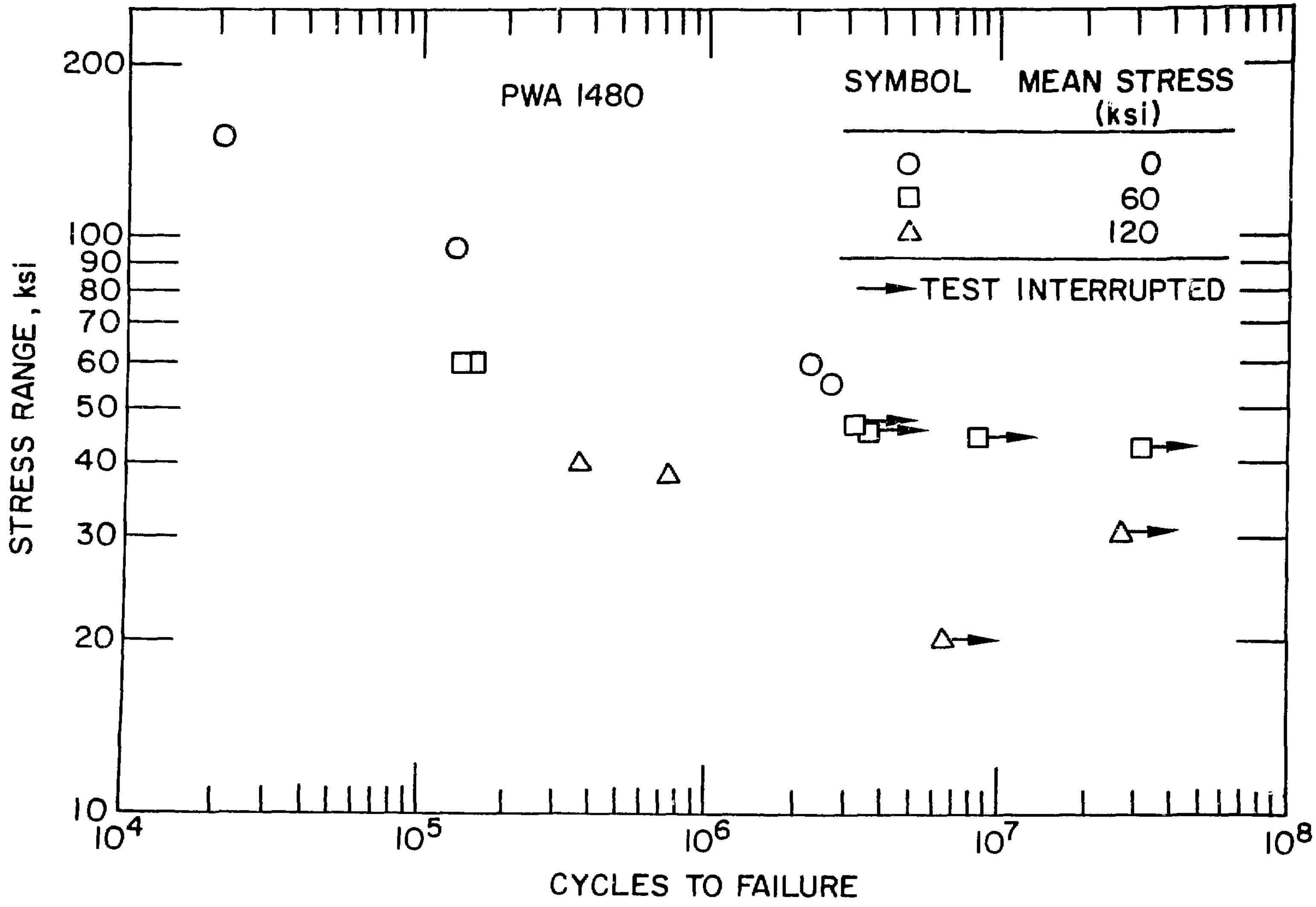


Fig. 1



PWA 1480
SYMBOL
MEAN STRESS (ksi)
○ 0
□ 60
△ 120
TEST INTERRUPTED
STRESS RANGE, ksi
200
100
90
80
70
60
50
40
30
20
10
10^4
10^5
10^6
10^7
10^8
CYCLES TO FAILURE

Fig. 2

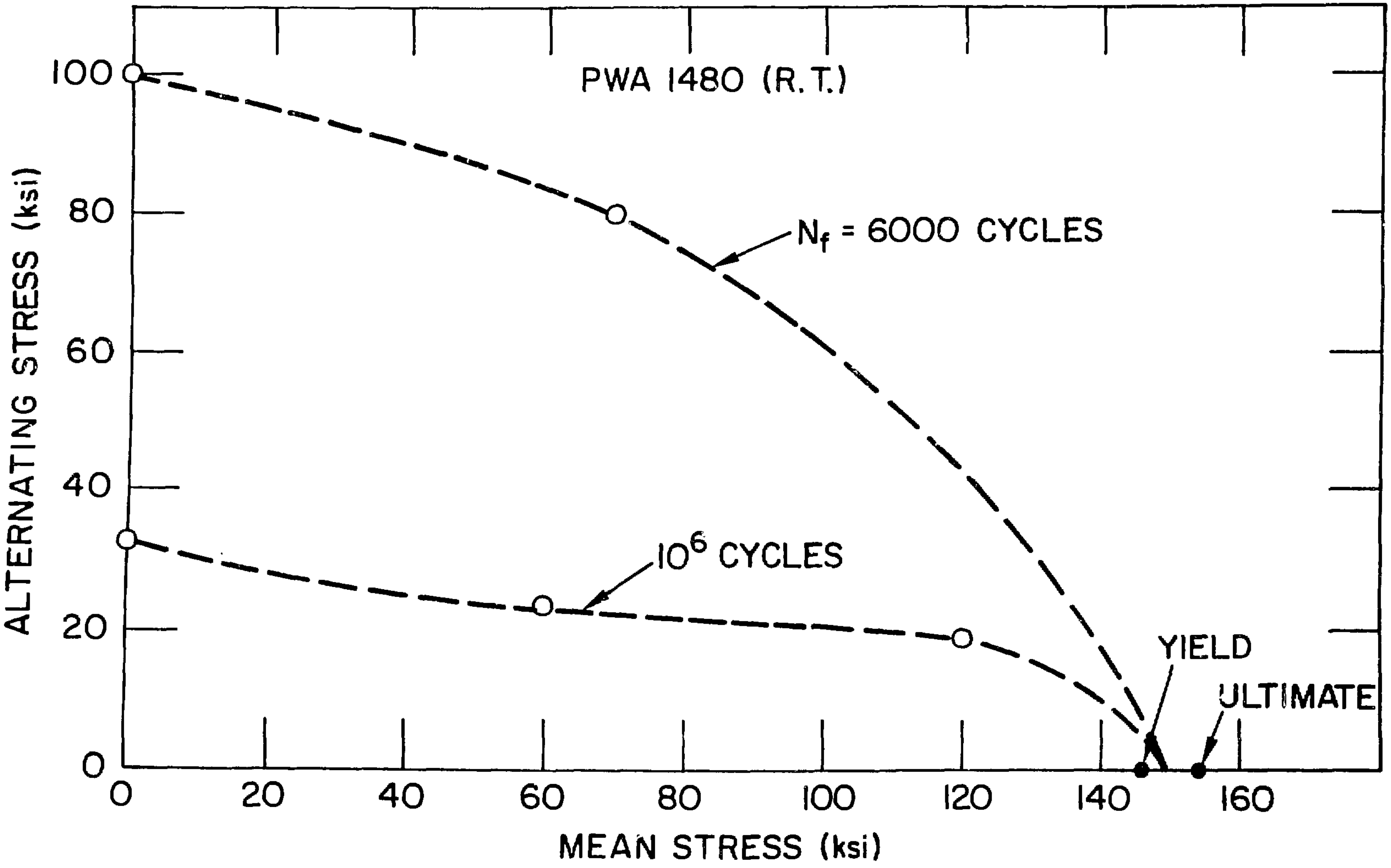

PWA 1480 (R.T.)
N_f = 6000 CYCLES
10^6 CYCLES
YIELD
ULTIMATE
ALTERNATING STRESS (ksi)
MEAN STRESS (ksi)
0
20
40
60
80
100
120
140
160

Fig. 3

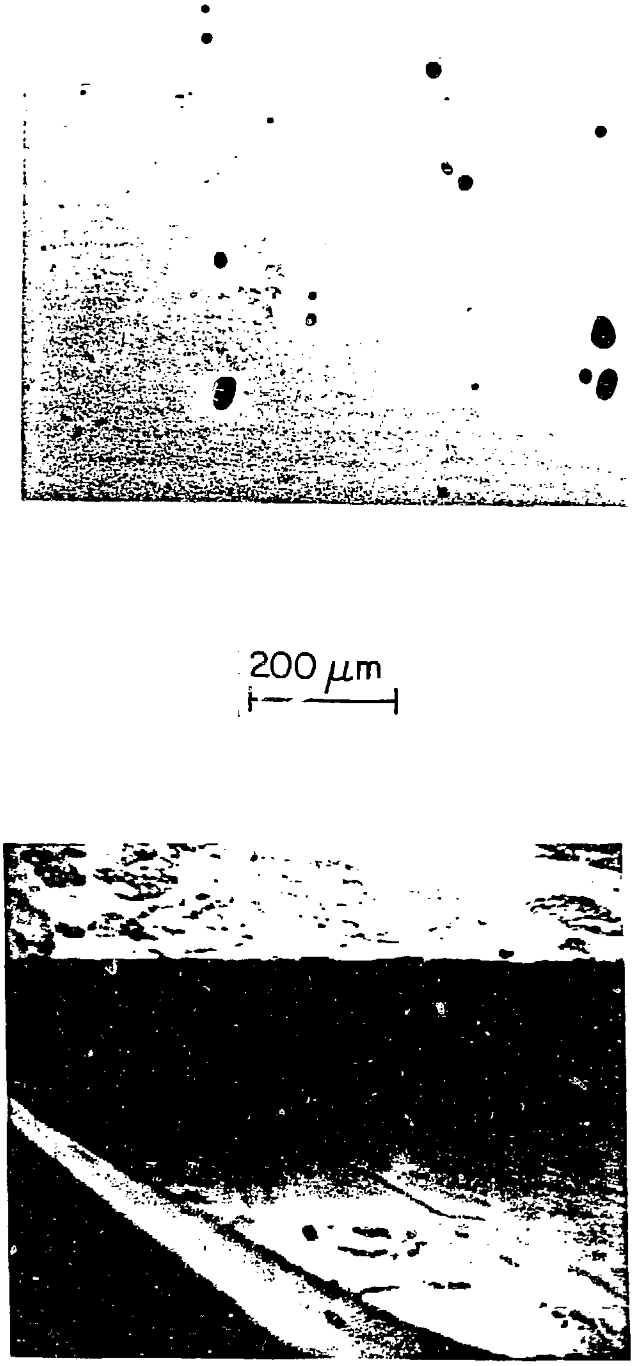


Fig. 4

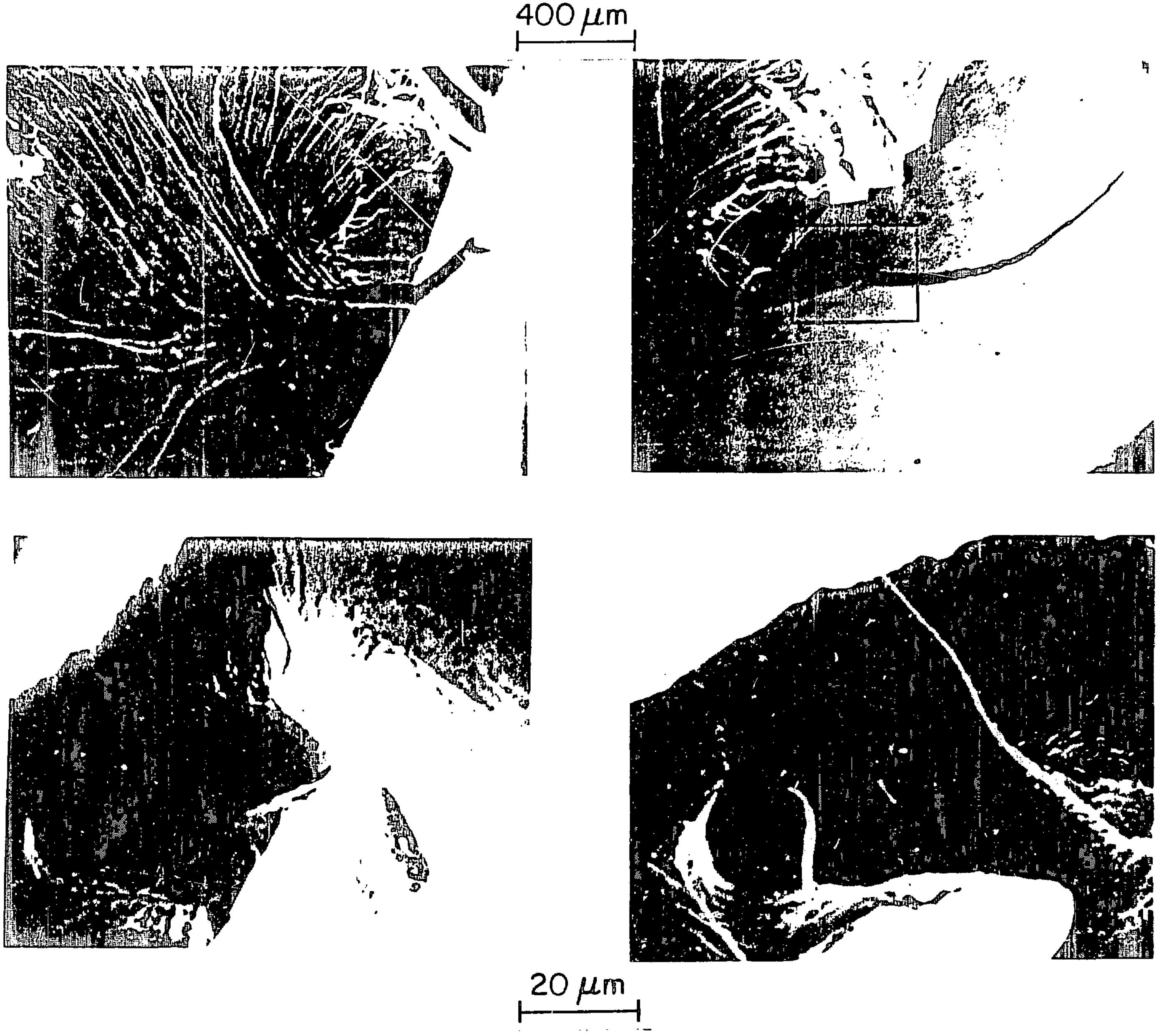


Fig. 5

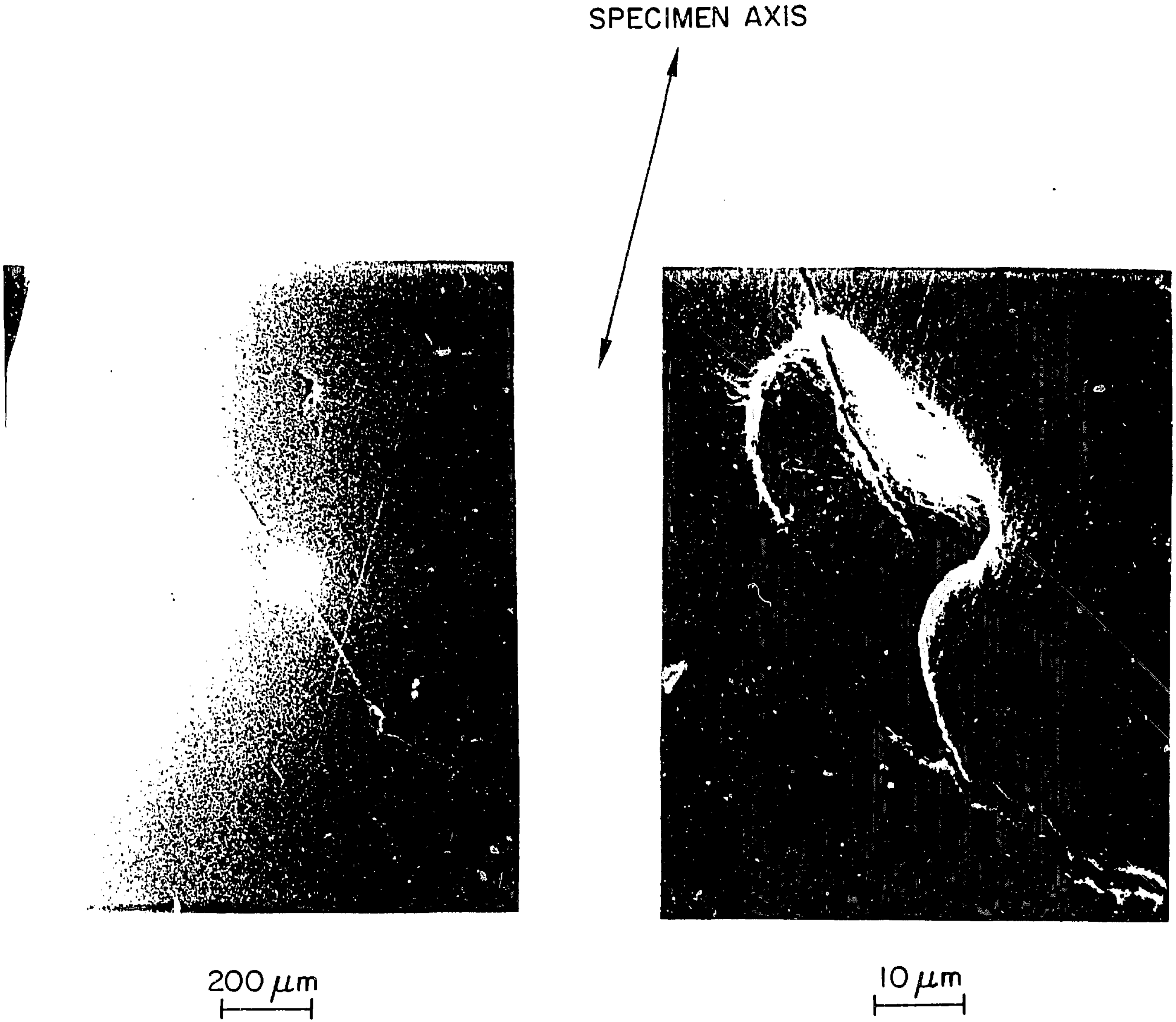


Fig. 6

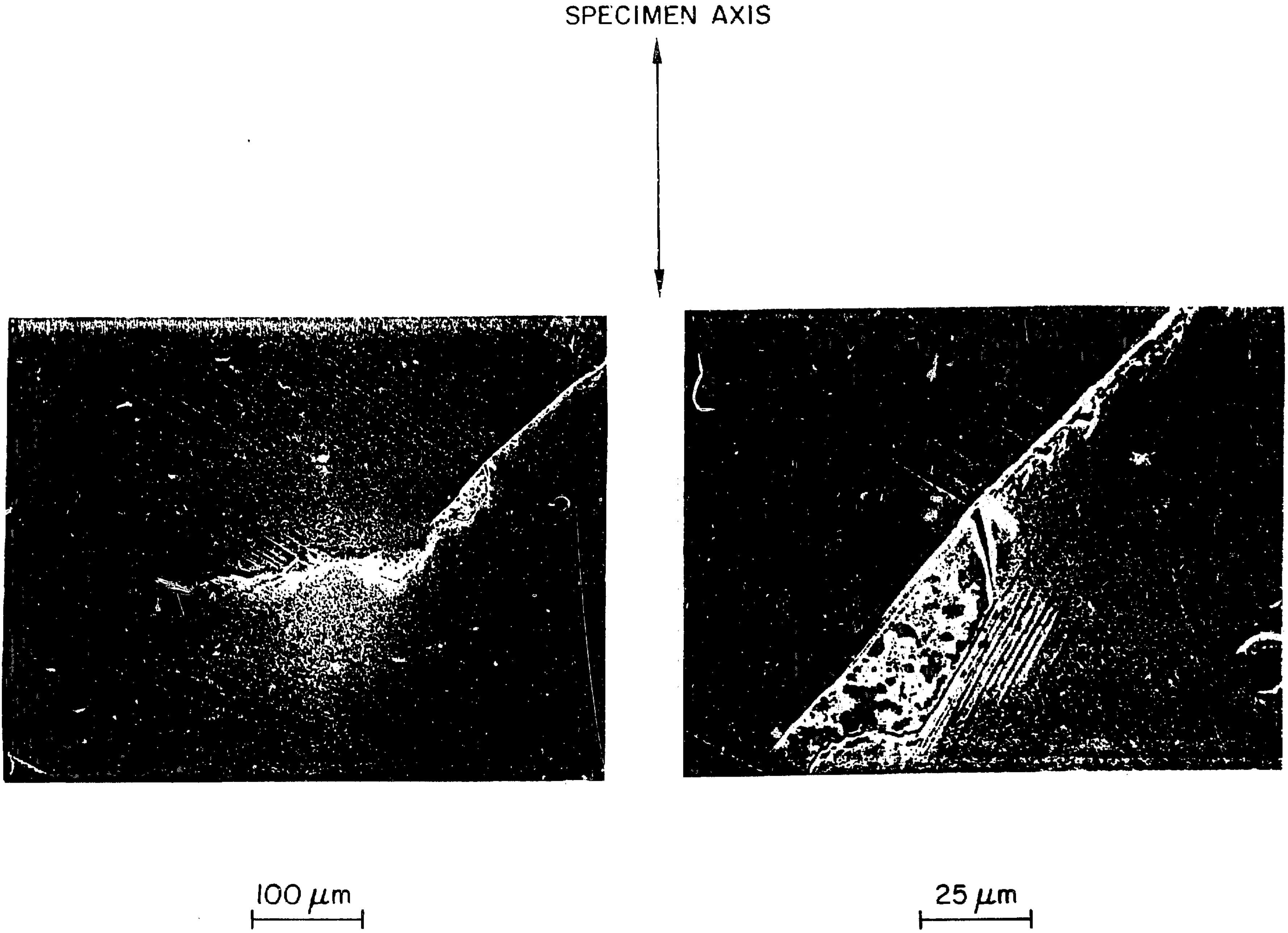


Fig. 7