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ADVANCED TURBINE ENGINE GAS GENERATOR (ATEGG)

FRACTOGRAPHY OF CAST NICKEL BASE SUPERALLOYS

DAVID F. GRAY

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NOVEMBER 1978

Final Report 1 October 1976 - 30 June 1978

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(U) This technical report has been reviewed and is approved for publication.

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E. C. Simpson
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Fractography	IN-100
Cast Nickel Base Superalloys	Low Cycle Fatigue

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents Teledyne CAE's efforts to correlate the fracture surfaces of cast nickel-base superalloys to known conditions of low cycle fatigue testing (strain range partitioning). Rene' 80 and IN-100 low cycle fatigue test specimens (supplied by NASA-Lewis and TRW materials laboratories) were examined by means of scanning electron microscope (SEM). The fractography obtained with the SEM can be compared to actual engine component failures, and will provide strong indications of the metal temperature, → over

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ABSTRACT (Cont'd.)

creep conditions, strain levels, and cycles imposed, during the events leading to component failure.

FOREWORD

This R&D Materials report is submitted by Teledyne CAE, under contract F33657-76-C-0215. The effort was sponsored by the Air Force Aero Propulsion Laboratory (TBP), Air Force Systems Command, Wright-Patterson AFB, Ohio under Project 681B, Task Area 01, Work Unit 05 with Mr. T. Gingrich as Project Engineer. Mr. Stanley Mathews of Teledyne CAE was technically responsible for the work. The work span covered by this report is 1 October 1975 through 30 June 1978.

This report, Volume IV, combined industry and government version, is the final volume that documents work accomplished directly under the subject contract.

Volume I, Level I Performance, documents that work accomplished under the contract period October 1975 through July 1976. Part I is the government version, Part II is the industry version.

Volume II, Level II Performance, documents that work accomplished under the contract period July 1976 through March 1977. Part I is the government version, whereas Part II is the industry version.

Volume III, Final Technical Report, documents all technical work accomplished and information gained from contract initiation, 1 October 1975, through contract completion, 31 July 1978. As with Volumes I and II, it is published in two parts: Part I, government; Part II, industry.

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FRACTOGRAPHY OF CAST NICKEL BASE SUPERALLOYS

OBJECTIVE

The purpose of this effort was to correlate the fracture surfaces of cast nickel base superalloys to known conditions of low cycle fatigue testing (strain range partitioning) to support Teledyne CAE's 555 gas generator turbine blade materials analysis.

MATERIAL HISTORY

Through the courtesy of personnel at NASA-Lewis and TRW materials laboratories, Rene' 80 and IN-100 low cycle fatigue test specimens were obtained for scanning electron microscope examination. The purpose of the examination was to characterize the features of the fracture surfaces and relate them to the known failure conditions of testing. In turn, the information gained could then be applied to the analysis of failures experienced on service and development engine components.

The Rene' 80 specimens supplied by NASA-Lewis for the Teledyne CAE examination were the individually cast, tubular, hour-glass-shaped specimens with threaded ends as per NASA Drawing CB-300740, shown in Figure 1. The specimens were originally cast as solid bars, machined to the proper configuration, and then given the following heat treatment:

1218°C (2225°F)/2 hours vacuum/argon quench to room temperature

1093°C (2000°F)/4 hours vacuum/argon quench to room temperature

1052°C (1925°F)/4 hours vacuum, furnace cool in vacuum to 649°C (1200°F) within 1 hour, air cool to room temperature

843°C (1550°F)/16 hours vacuum/furnace cool to room temperature

The cast nickel base Rene' 80 specimens examined were vacuum tested at 871°C (1600°F) and 1000°C (1832°F). These specimens had the advantage of clean, oxide-free surfaces. They were taken from a group of specimens that had creep hold times included in that portion of the cycle that was tension, or compression, or both. Some other specimens had no creep hold at all. Tensile and creep-rupture specimens were also examined. Only eight specimens of the Rene' 80 were examined because several of the specimens that represented the failure conditions of interest were not available. These specimens had been used by TRW in their investigations. However, the specimens, with oxide free surfaces, that were examined were very valuable because they provided information at two temperatures and a fair spectrum of failure conditions and characteristics. A full NASA report* (Reference) has been published on this fatigue work.

REFERENCE

Kurtovich, C.S., "Ultrahigh Vacuum, High Temperature, Low Cycle Fatigue of Coated and Uncoated Rene' 80", NAS CR-135003 (TRW-ER-7861), April 1976.

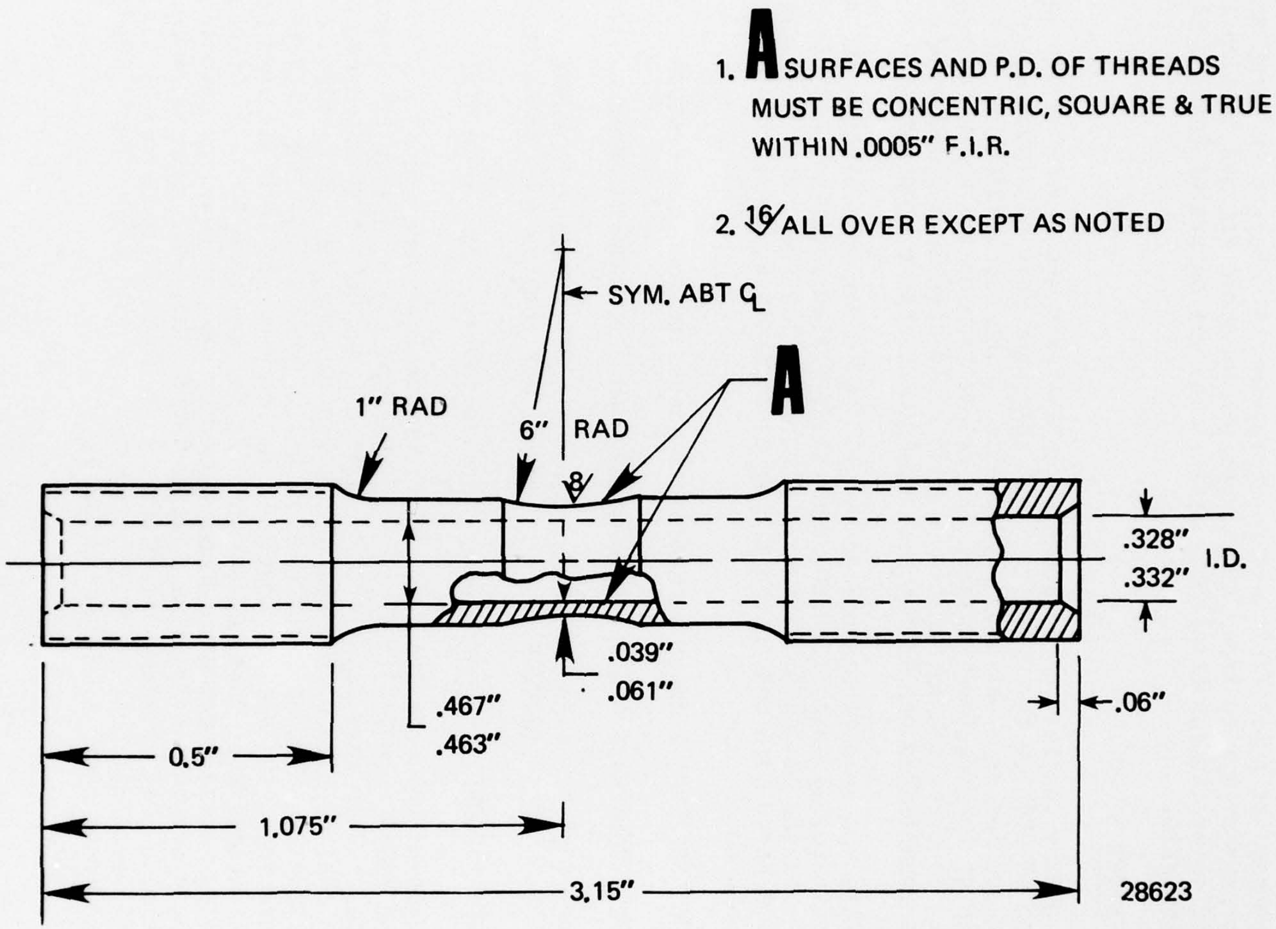

Figure 1. Test Specimen Configuration

Cast nickel base IN-100 specimens (also per Figure 1) were also supplied by NASA-Lewis that had been tested in air at 926°C (1700°F). Some of these low cycle fatigue specimens had been tested with creep hold times in the tension or compression portion of the cycle, or both. Other specimens in this group had no creep hold times at all. No tensile or creep-rupture specimens were available from this group of specimens. The scanning electron microscope examination of these specimens proved to be equally valuable, because they did have oxide on the fracture surfaces, and because they were tested under controlled conditions. These fracture surfaces can be compared to actual engine component failures and provide strong indications of temperature, creep conditions, strain level and cycles to failure.

SUPPLEMENTARY INFORMATION

GRAIN SIZE

The grain size of the specimens examined was estimated to be 0.508 mm (0.020 in.) to 1.0 mm (0.040 in.), based on exterior visual measurements on specimens and estimates from photography included in the reference report.

POROSITY

Extensive shrinkage (microporosity) was seen on the fracture surfaces. This was particularly true of the Rene' 80 specimens.

INITIATION ZONE

Most of the specimens had multiple initiation sites, many of which were associated with microporosity.

TEST METHOD

The test method, except for tensile and creep-rupture, was axial low cycle fatigue. The specimens were 1/2 inch diameter cast hollow tubes. The gage area was hour-glass reduced to a wall thickness of 0.039-0.061 inch.

TEST DATA

The summary data for the specimens examined are given in Table 1. The data presented in the table have been reduced from the actual test data generated to illustrate the type and general magnitude of loading conditions. In this manner, the effect of the loading conditions is thought to be better understood with respect to the fracture surface characteristics. Figure 2 defines the load cycle sequence with respect to creep and specimen notation on the low cycle fatigue specimens.

SUMMARY OF FRACTOGRAPHY

All fracture surfaces were photographed by a scanning electronic microscope (Figure 3) at 400X for direct comparison of surface features with other specimens.

TABLE 1

SUMMARY OF SPECIMEN TEST CONDITIONS

FIGURE NO.	MATERIAL & TESTER CODE	TEST TYPE ***	TEST TEMP (°F)	TOTAL STRAIN RANGE (IN.)	TIME TO FAILURE (HRS.)	CYCLES TO FAILURE	APPROXIMATE TIME IN CREEP (HRS.) TENSION/COMPRESSION
				RENE' 80*			
3	8U-PP-7	PP	1832	.00247	5.0	22115	0/0
2	42U-PP-11	PP	1600	.00296	58.0	217620	0/0
11	26U-PC-8	PC	1832	.00409	19.1	10164	0/19
10	89U-PC-11	PC	1832	.00579	4.9	187	0/5
16	123C-T-3	Tensile	1600				
15	121C-T-1	Tensile	1832				
18	37U-C-7	Creep-Rup.	1600	40 KSI	2.1		
17	25U-C-1	Creep-Rup.	1832	30 KSI	0.7		
				IN-100**			
7	INN 3-PP	PP	1700	.0092	.05	96	0/0
8	INN 17-PP	PP	1700	.0113	.09	160	0/0
6	INN 18-PP	PP	1700	.0064	.17	300	0/0
5	INN 8-PP	PP	1700	.0049	.56	1000	0/0
4	INN 5-PP	PP	1700	.0036	16.3	29400	0/0
14	INN 12-CC	CC	1700	.0121	302.0	17	150/150
12	INN 13-PC	PC	1700	.0058	87.3	139	0/87.3
9	INN 11-CP	CP	1700	.0090	163.9	60	164/0
13	INN 9-CP	CP	1700	.0041	159.3	1100	159/0

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* TRW test specimen code.

** NASA test specimen code.

*** See Figure 2 for description of test loading.

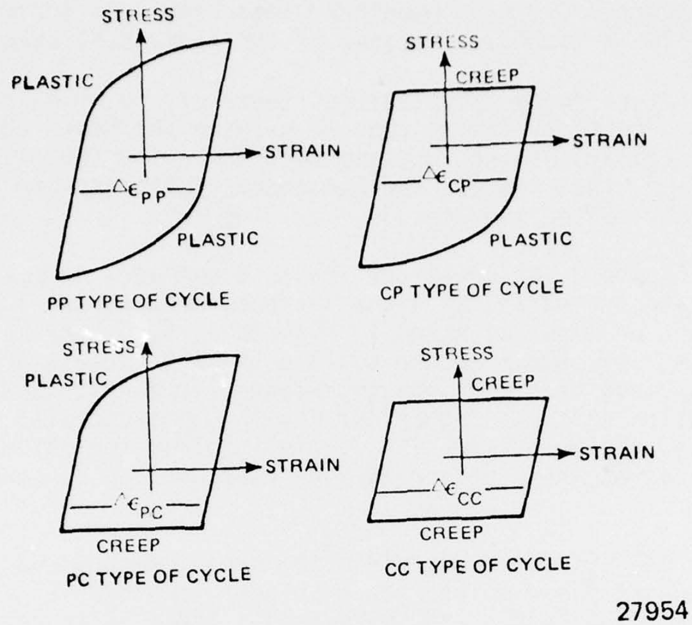


Figure 2. Hysteresis Loops That Define the Fatigue Cycle Types.

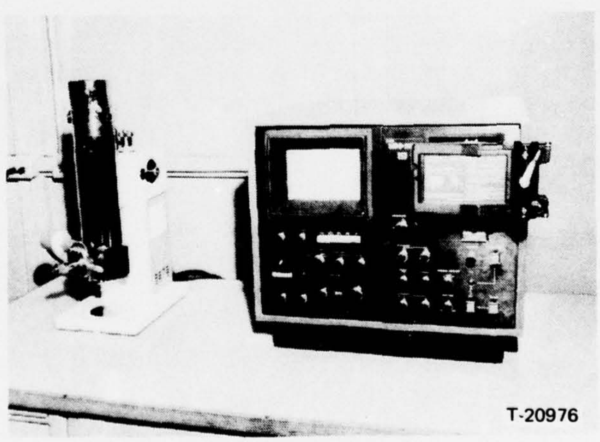


Figure 3. Scanning Electron Microscope - 100 Angstrom Depth of Field Resolution.

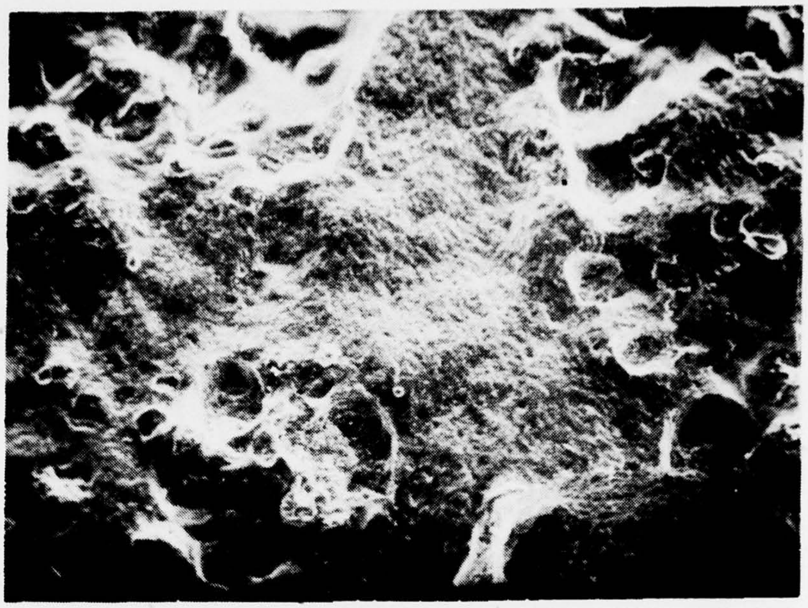
The microscope was an International Scientific instrument having a depth of field resolution of 100 angstroms. Supplementary photographs are included at various magnifications to clarify various features of the individual specimens.

In the temperature range investigated, there was no major indication that the fracture surface characteristics changed between the Rene' 80 or IN-100 material when subjected to similar loading conditions. Except for the presence of oxide on the air tested IN-100, the fracture surface characteristics were also similar on vacuum tested and air tested surfaces.

The pp (see Figure 2 for notation) fracture surfaces were found to have definite striations and transgranular plane surfaces when tested in a total strain range of 0.5 percent or less, as shown in Figures 4, 5, 6, and 7. At greater than 0.5 percent total strain, the fracture surface tends to remain transgranular, but is less planar and seems to prefer the interdendritic zones, as seen in Figures 8, 9, and 10. Initiation at these higher strains may be associated with intergranular specimen surface separation (Figure 10), but slip plane formation is still evident in the interior metal at these higher strain rates, as can be seen in Figures 8 and 9.

When a creep hold is introduced into the cycle, such as during cc, pc, and cp loading, the low-profile dimpled, grain boundary rupture is generally more prevalent, as is evident in Figures 11, 12, and 13. These generated grain boundary voids tend to become less uniform in size with lower strains (greater number of cycles of failure), as can be seen by comparing Figures 12 and 13, and are probably the result of void coalescence with time, number of cycles, and grain orientation with respect to the loading direction. The presence of heavy surface oxides and surface contacts during reversed loading tends to obliterate some surface characteristics at times, as may be seen in Figure 14, 15, and 16. However, the general intergranular failure is still evident.

Tensile and short life creep-rupture surfaces are included for the reader to compare fracture surfaces, in Figures 17, 18, 19, and 20. It can be seen that tensile failures at 871°C (1600°F) and 1000°C (1832°F) are both dominated by transgranular rupture and tend to be associated with particulate phases, such as carbide. Short time creep-rupture tends to show evidence of grain boundary influence on the fracture surface, but at 871°C (1600°F) transgranular failure is still present as evidenced by the multiple slip planes in Figure 20.



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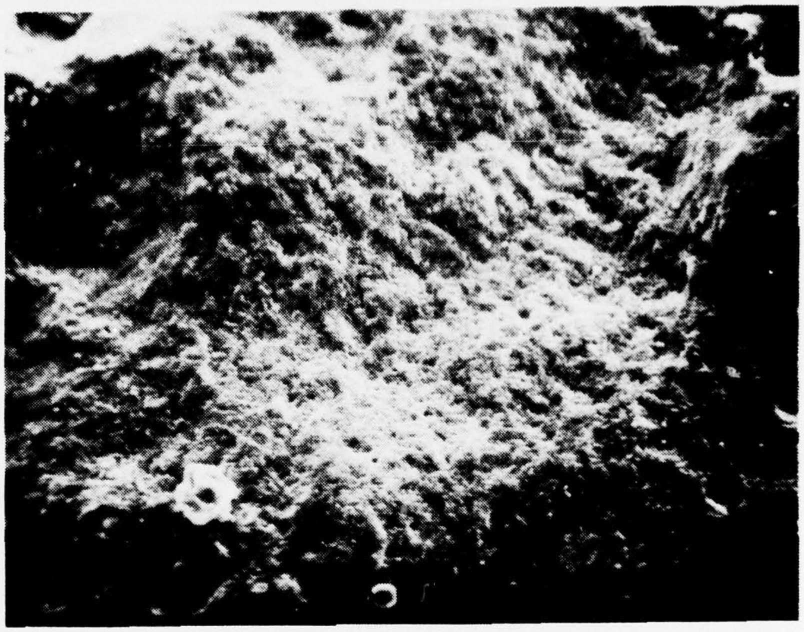

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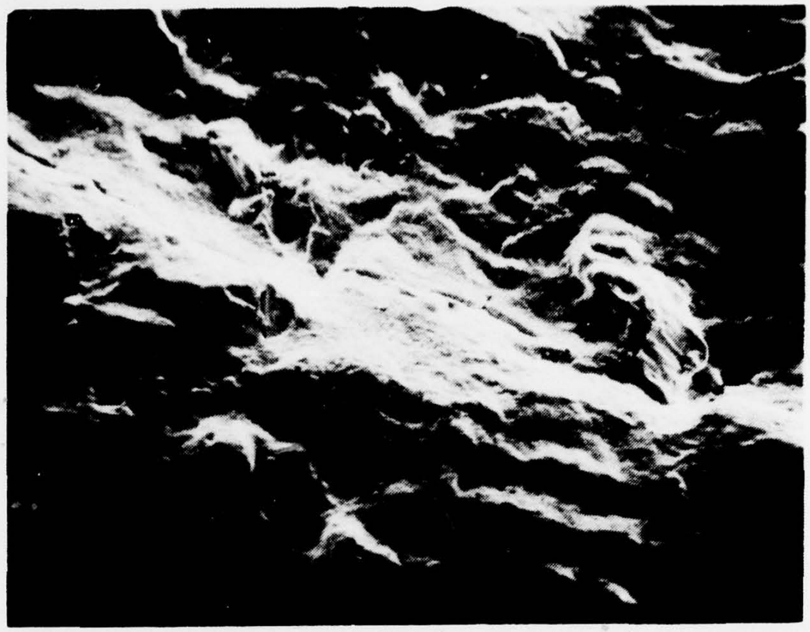
Figure 4. Specimen 42U-PP-11 - Low Cycle Fatigue, PP Loading,
Test Temperature - 1600^{o}F Vacuum
Material - Rene' 80
Total Strain Range - 0.00296, 271,620 Cycles
Top 400X, Bottom 1000X
Transgranular Fatigue Striations



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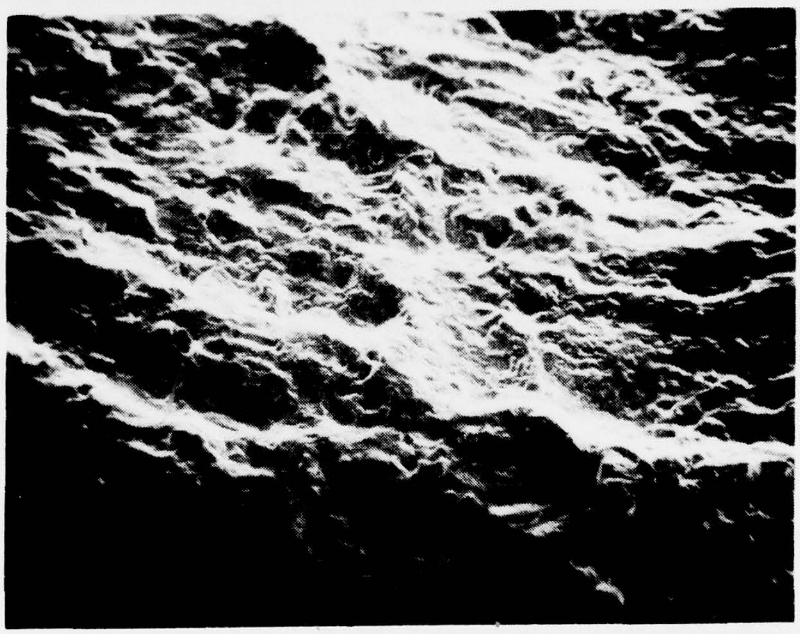

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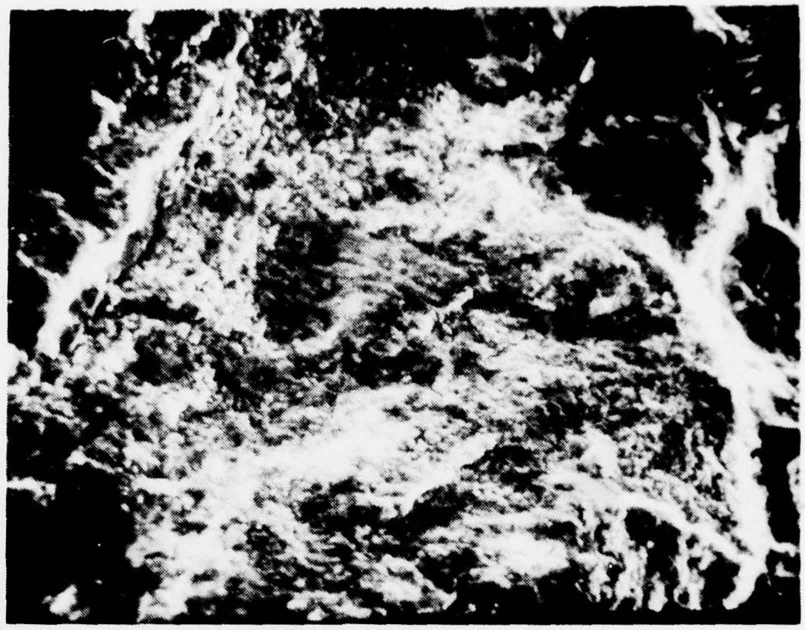
Figure 5. Specimen 8U-PP-7 - Low Cycle Fatigue, PP Loading
Test Temperature - 1832°F Vacuum
Material - Rene' 80
Total Strain Range - 0.00247, 22115 Cycles
Top 400X, Bottom 1000X
Transgranular Fatigue Striations



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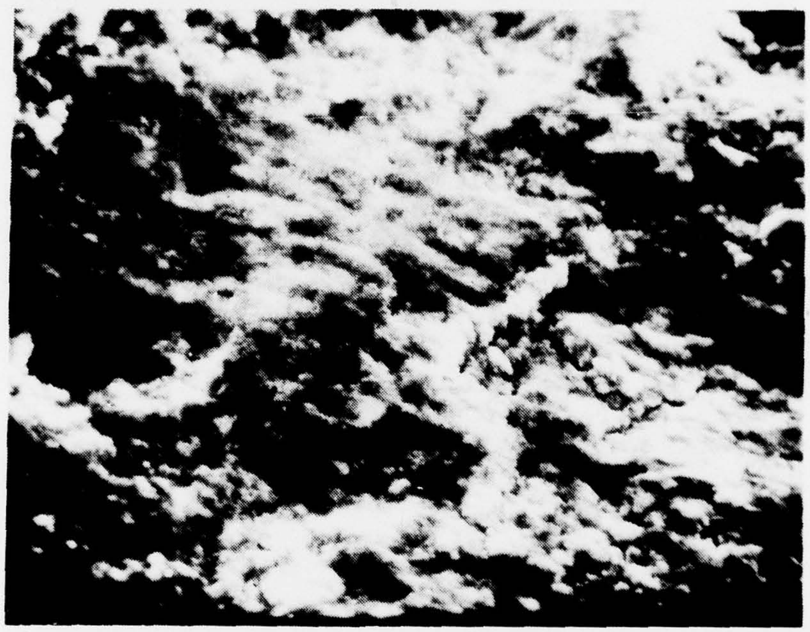

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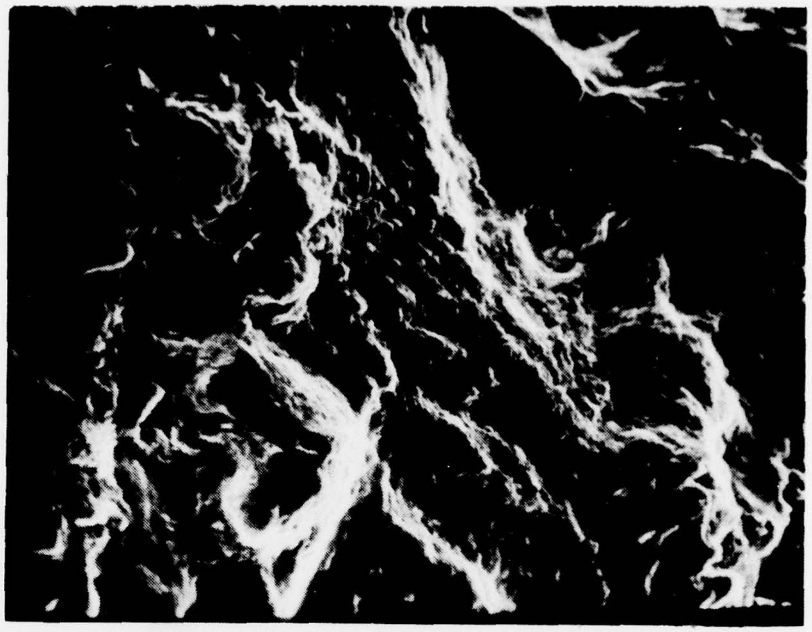
Figure 6. Specimen INN 5-PP - Low Cycle Fatigue, PP Loading
Test Temperature - 1700°F Air
Material - IN-100
Total Strain Range - 0.0036, 29400 Cycles
Top 400X, Bottom 1000X
Transgranular Fatigue



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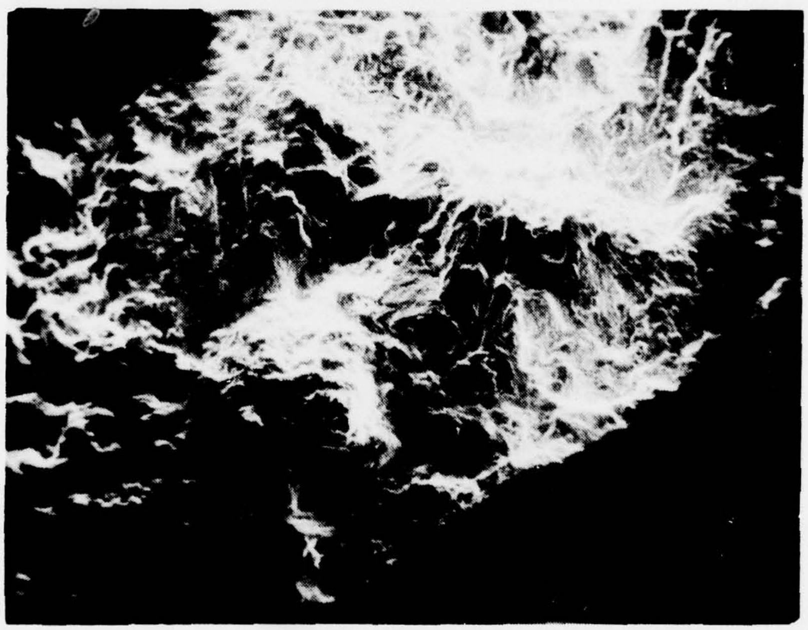

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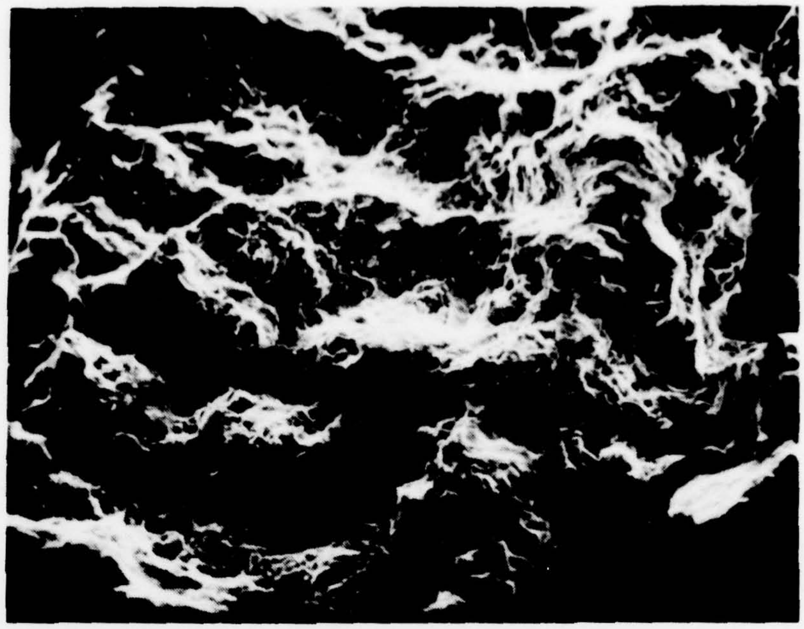
Figure 7. Specimen INN 8-PP - Low Cycle Fatigue, PP Loading
Test Temperature - 1700°F Air
Material - IN-100
Total Strain Range - 0.0049, 1000 Cycles
Top 400X, Bottom 50X
Transgranular Fatigue



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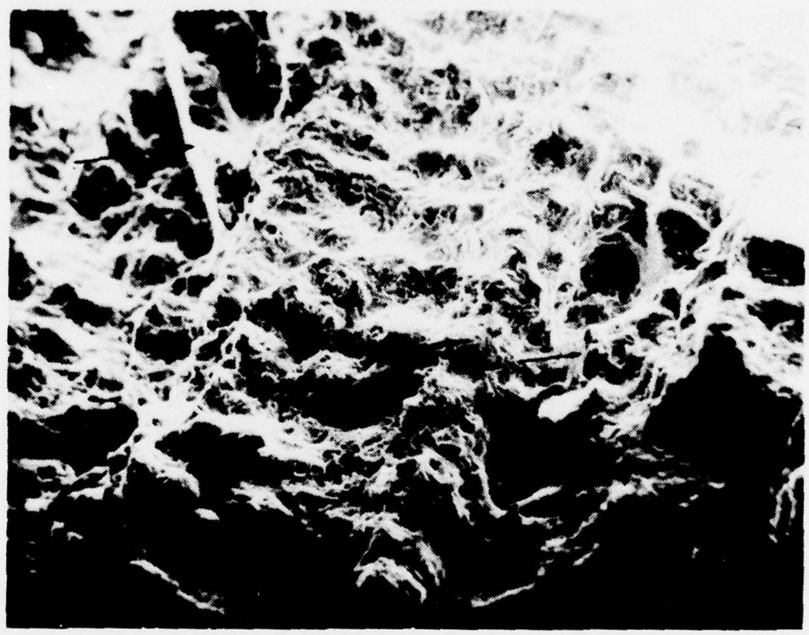

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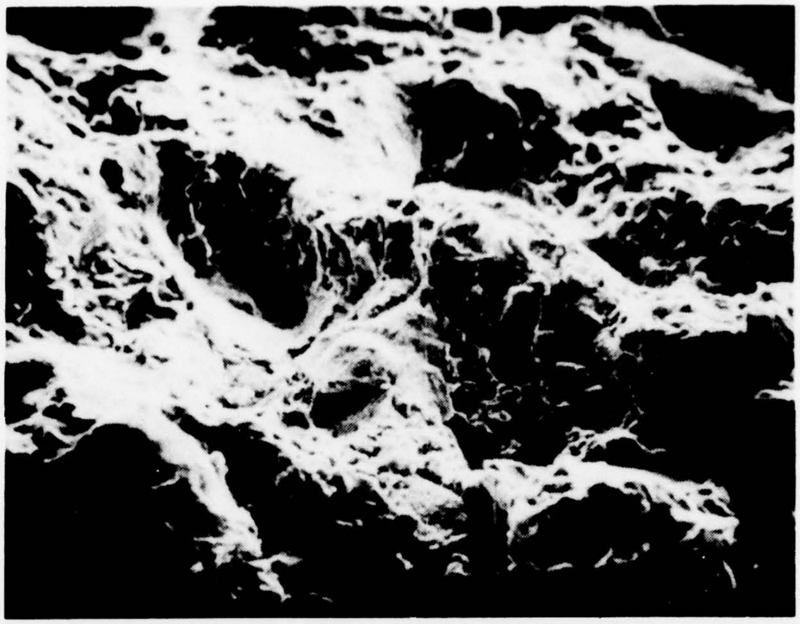
Figure 8. Specimen INN 18-PP - Low Cycle Fatigue, PP Loading
Test Temperature - 1700°F Air
Material - IN-100
Total Strain Range - 0.0064, 300 Cycles
Top 400X, Bottom 200X
Dominant Transgranular (Interdendritic) Fatigue
Note Some Slip Planes (Arrows)



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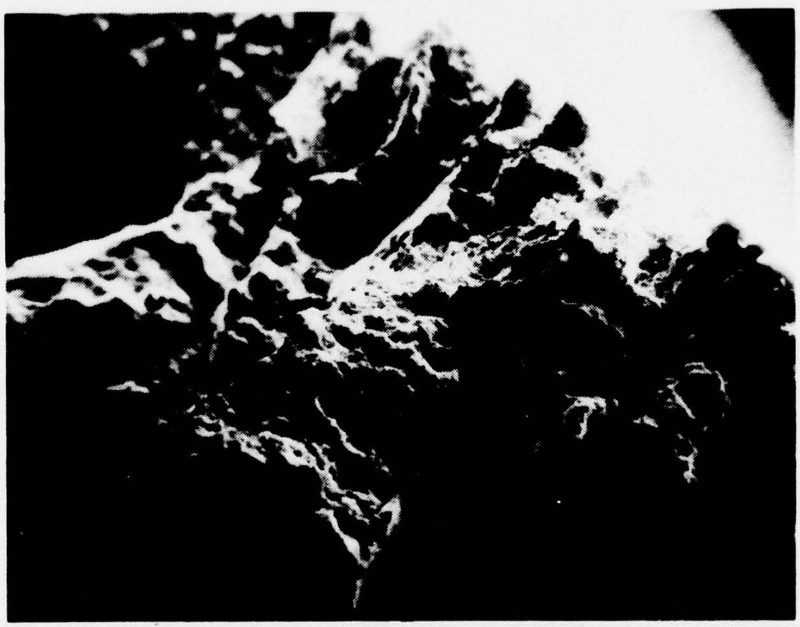

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Figure 9. Specimen INN-3-PP - Low Cycle Fatigue, PP Loading
Test Temperature - 1700° Air
Material - IN-100
Total Strain Range - 0.0092, 96 Cycles
Top 400X, Bottom 50X
Dominant Transgranular (Interdendritic) Fatigue
Note Some Slip Planes (Arrow).

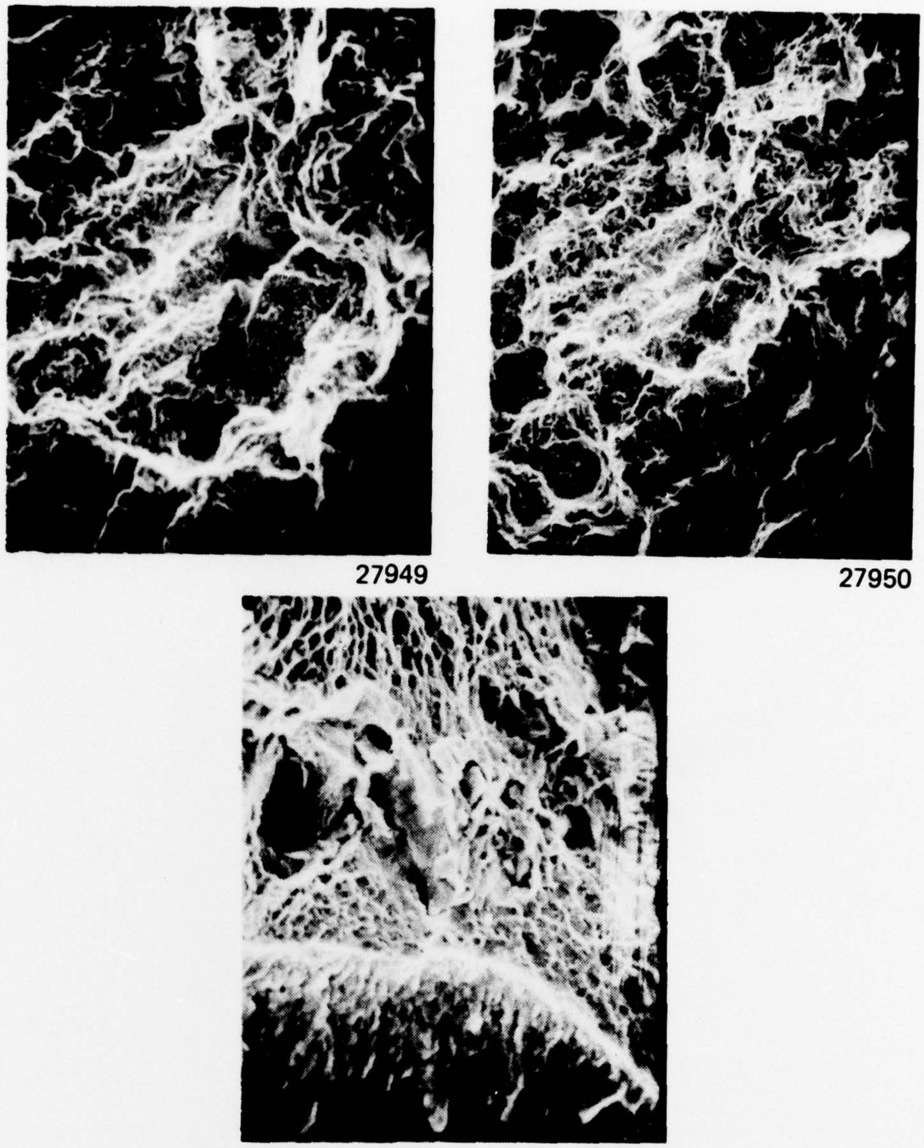

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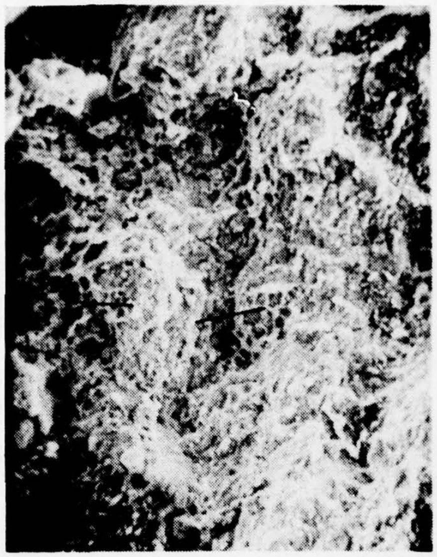
Figure 10. Specimen INN 17-PP - Low Cycle Fatigue, PP Loading
Test Temperature - 1700^{o} Air, Material - IN-100
Total Strain Range - 0.0113, 160 Cycles
Top Left 400X, Top Right 200X, Bottom 1000X
Dominant Transgranular Fatigue
Intergranular Dimpled Ductile Rupture At Specimen Surface Initiation Points (Bottom)



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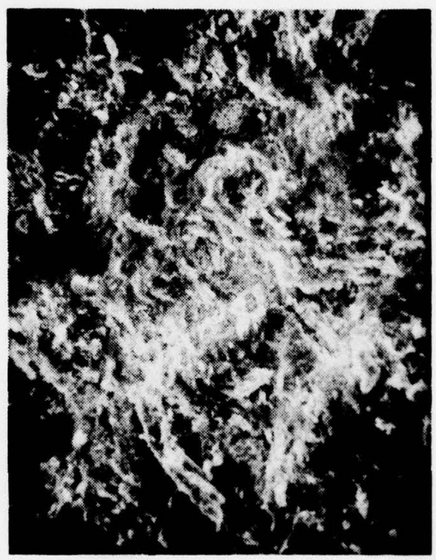

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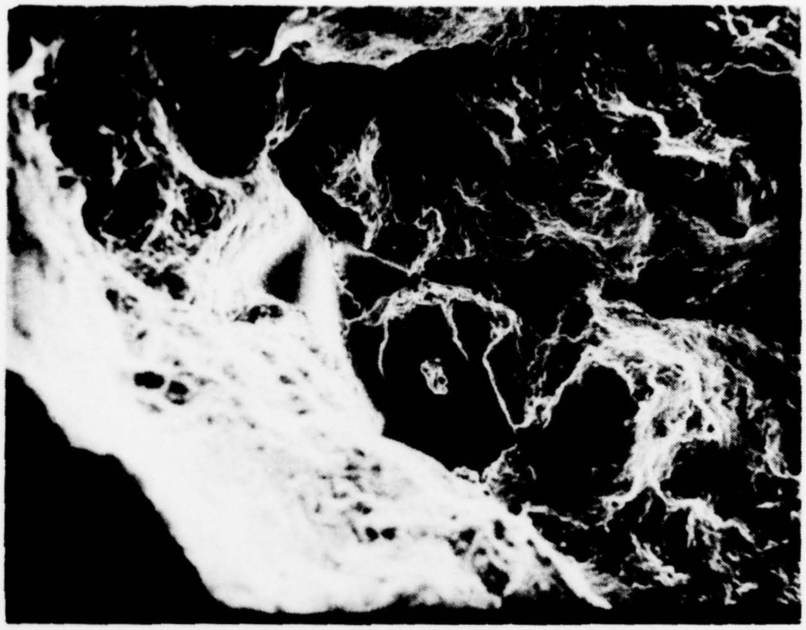
Figure 11. Specimen INN 11-CP Low Cycle Fatigue, CP Loading
Test Temperature - 1700°F Air, Material - IN-100
Total Strain Range - 0.009, 60 Cycles, Test Time 0 163.9 Hrs.
Top Left 400X, Top Right 1000X, Bottom 400X
Dominant Grain Boundary Dimpled Ductile Rupture in Creep Hold Fatigue.



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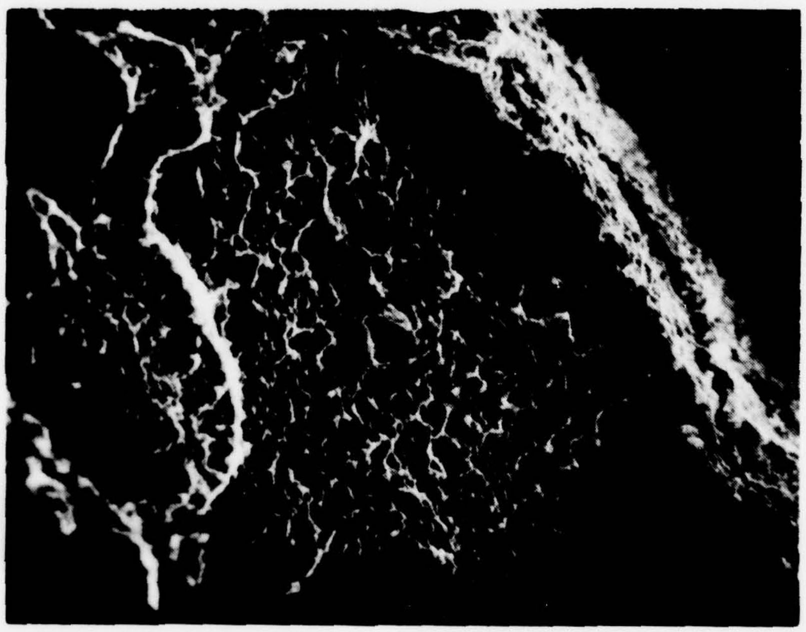

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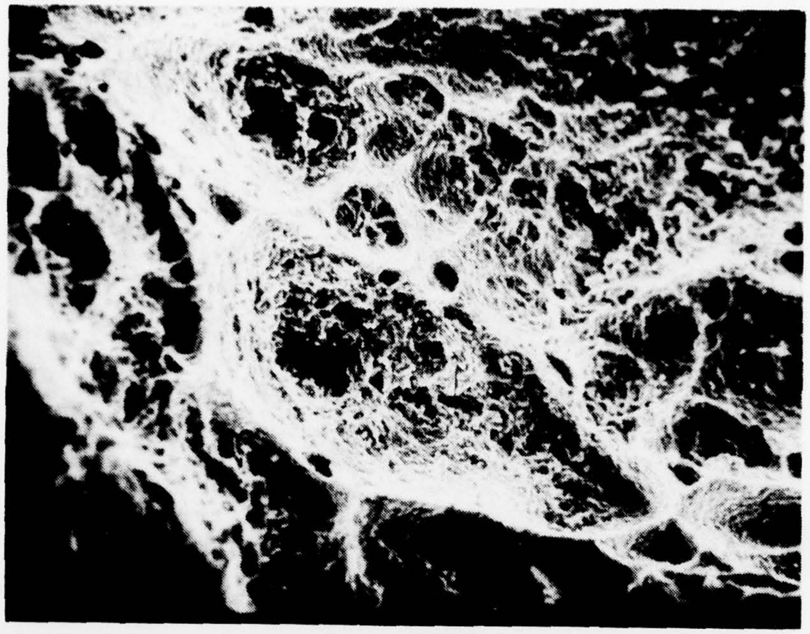
Figure 12. Specimen 89U-PC-8 - Low Cycle Fatigue, PC Loading
Test Temperature - 1832°F Vacuum
Material - Rene' 80
Total Strain Range - .00579, 187 Cycles
Test Time - 4.9 Hrs.
Top 400X, Bottom 1000X
Dominant Grain Boundary Fatigue with Dimpled Ductile Rupture.



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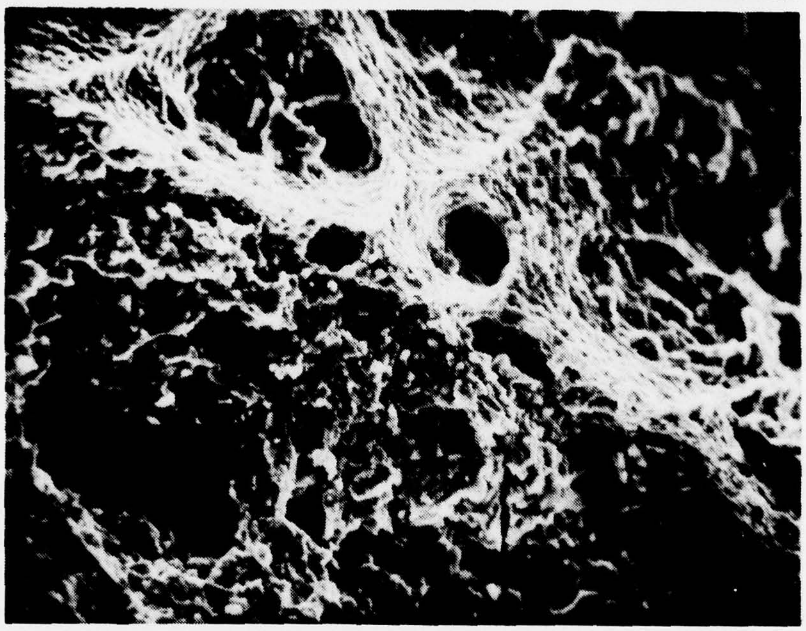

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Figure 13. Specimen 26U-PC-8 - Low Cycle Fatigue, PC Loading
Test Temperature - 1832°F Vacuum, Material - Rene'80
Total Strain Range - 0.00409, 10164 Cycles
Test Time - 19.1 Hrs., Top 400X, Bottom 1000X
Dominant Grain Boundary Fatigue with Dimpled Ductile Rupture. Note Larger Dimple Size with Greater Number of Cycles (See Figure 12).

27955

Figure 14. Specimen INN-13-PC - Low Cycle Fatigue, PC Loading
Test Temperature - 1700°F Air
Material - IN-100, Total Strain Range - 0.0058, 139 Cycles
Test Time - 87.3 Hrs., 1000X
A Compression Dominated Hold can Damage The Grain Boundary Fatigue Indications, Particularly in an Air Environment.

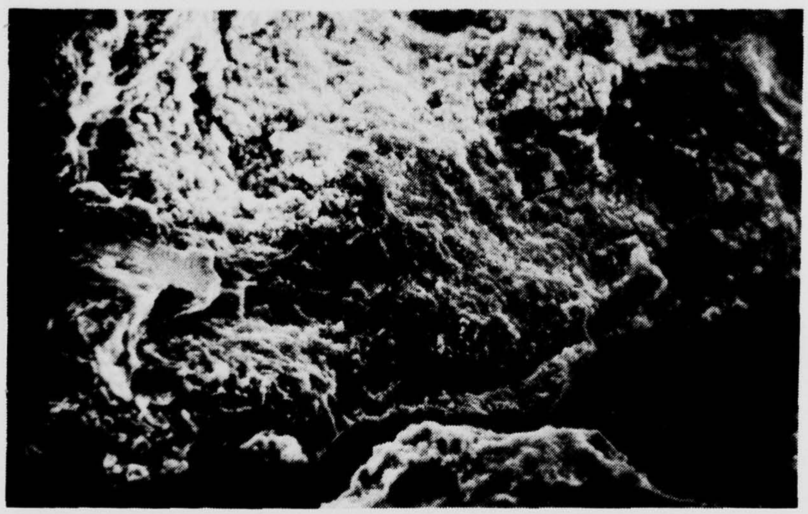

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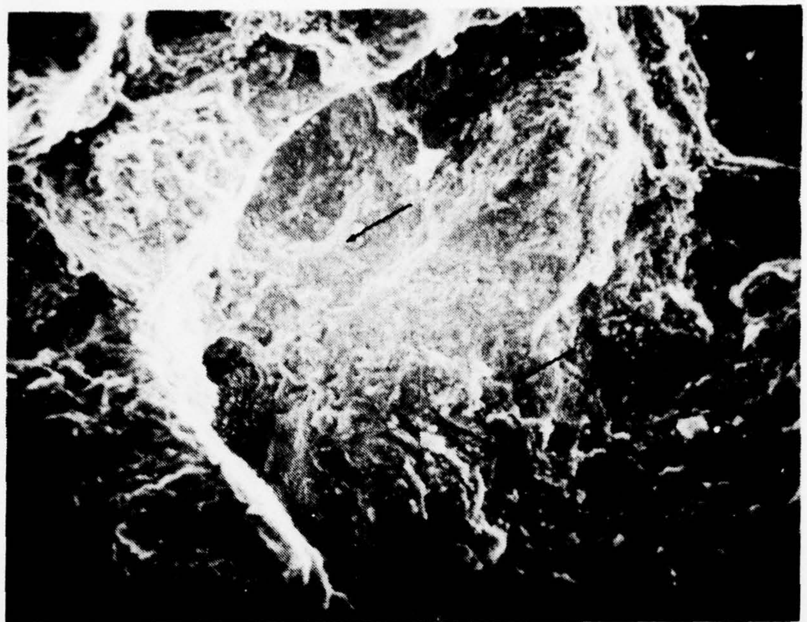
Figure 15. Specimen INN-9-CP - Low Cycle Fatigue, CP Loading
Test Temperature - 1700°F Air
Material - IN-100, Total Strain Range - 0.0041, 1100 Cycles
Test Time - 159.3 Hrs., 400 X
Reverse Loading Can Damage the Dimples Found in Grain Boundary Fatigue, But is Less Damaging in a Tension Hold Dominated Fatigue Load.



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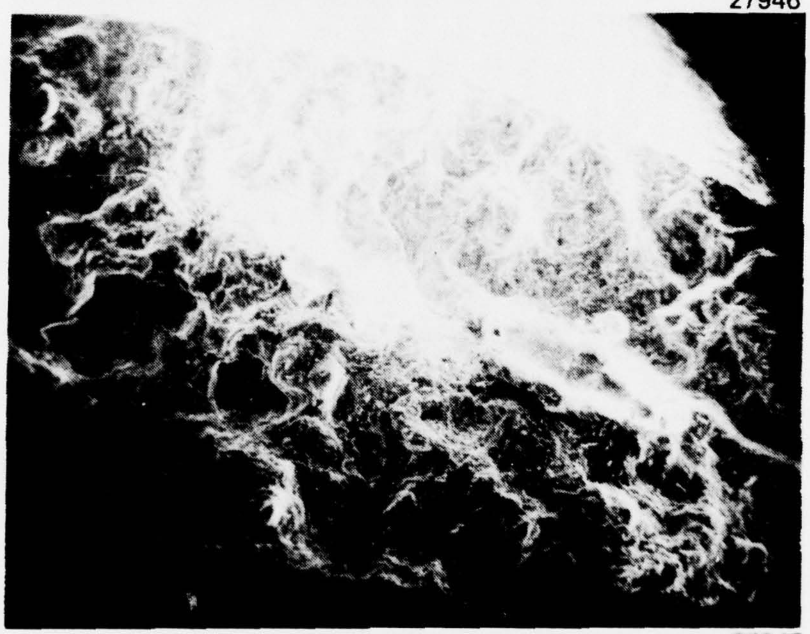

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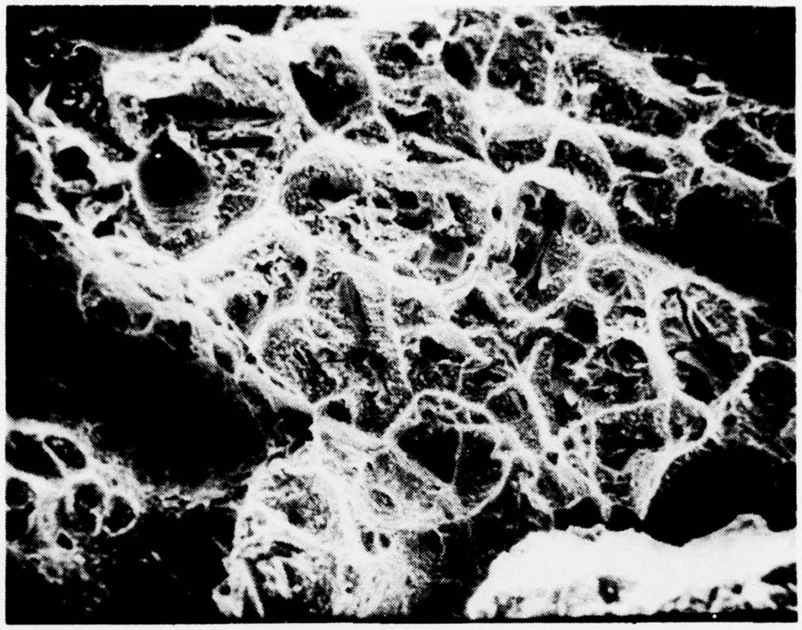
Figure 16. Specimen INN-12-CC - Low Cycle Fatigue, CC Loading
Test Temperature - 1700°F Air
Material - IN-100, Total Strain Range - 0.0121, 17 Cycles
Test Time - 302 Hrs., Top 400X, Bottom 50X
When the Number of Cycles is Low, Grain Boundary Indications (Dimples) are Still Discernible with Creep Hold Times in Both Tension and Compression.



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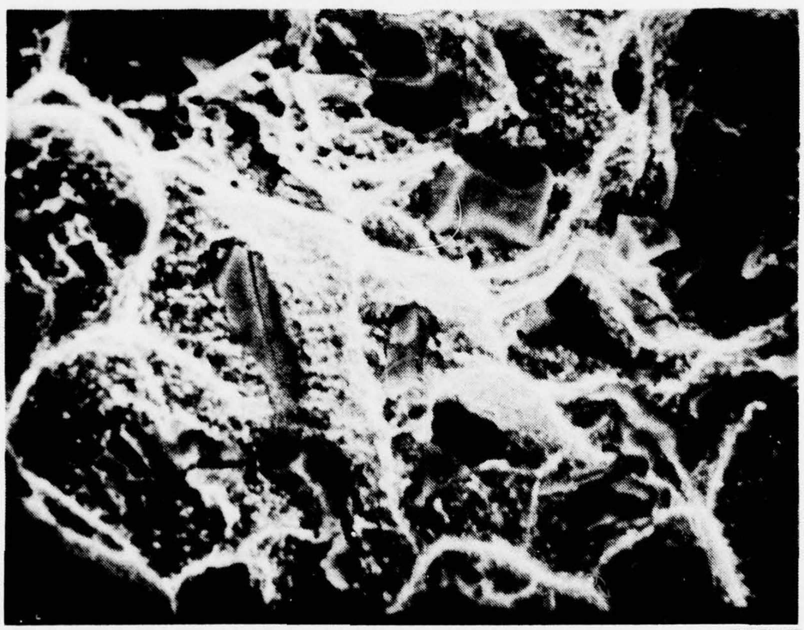

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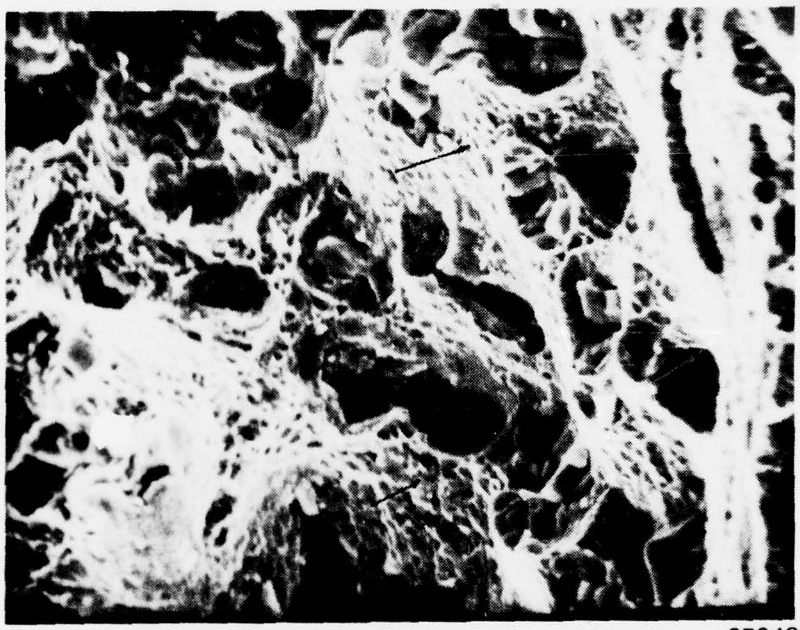
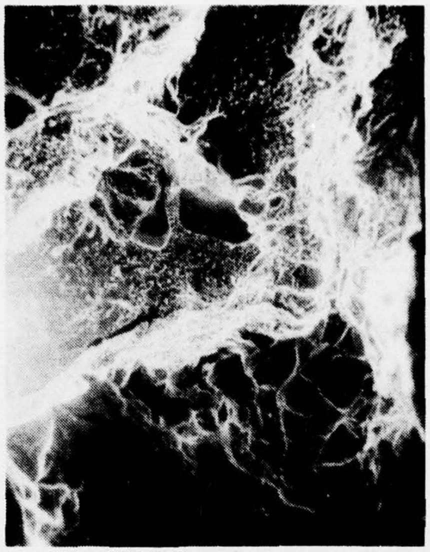
Figure 17. Specimen 121C-T-1 - Tensile, Test Temperature - 1832^{o}F Vacuum
Material - Rene' 80. Top 400X, Bottom 1000X
Short Time Tensile Fracture Surfaces are Transgranular Ductile Rupture Even at High Temperature. Note that Tensile Fracture is Associated with Carbide Phases in the Matrix.

27942

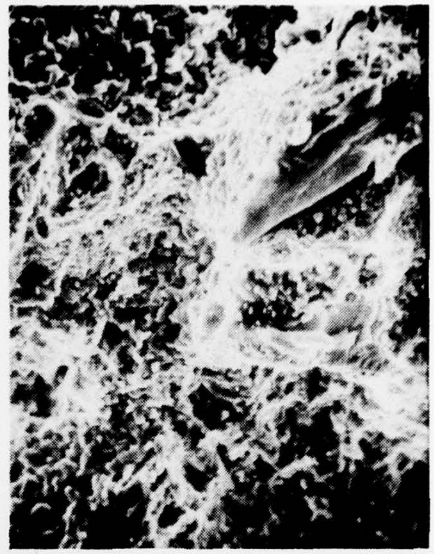


27943

Figure 18. Specimen 123C-T-3 - Tensile, Test Temperature - 1600°F Vacuum
Material - Rene' 80, Top 400X, Bottom 1000X
Short Time Tensile Fracture Surfaces are Transgranular at 1600°F, and Also Associated with Carbide Phases. However, Notice that the Matrix Also Has Multiple Small Dimples (Arrow Typical). Compare with Figure 17.



27939



27940

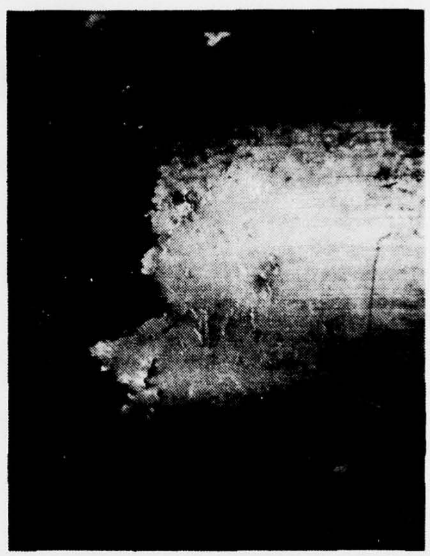


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Figure 19. Specimen 25-C-1 - Creep-Rupture at 1832°F Vacuum
Material - Rene' 80, Top Left 400X, Top Right 1000X, Bottom 6X.
Short Time Creep-Rupture (0.7 Hrs., This Specimen) Shows Some Evidence of Transgranular Influence (See Slip in 6X Photo), but Creep is Evident at Grain Boundaries. It is Interesting to Compare the 1000X Surface Texture to the LCF Specimen of Figure 13.

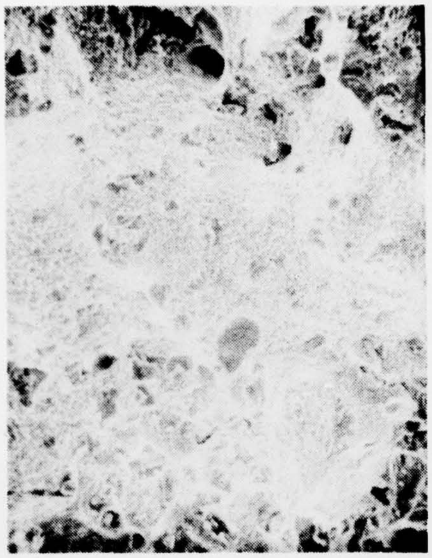

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Figure 20. Specimen 37U-C-7 - Creep Rupture at 1600°F Vacuum
Material - Rene' 80. Top Left 400X, Top Right 1000X, Bottom 6X.
Short Time Creep Rupture (2.1 Hrs. This Specimen) Shows Heavy Influence of Transgranular (Slip Planes at Arrow in 1000X Photo and 6X Photo) Fracture, But Creep Effects are Very Apparent With Grain Boundary Dimpled Structure (Arrow) in 1000X Photo.