METTEK MATERIALS ENGINEERING TECHNOLOGY LABORATORIES

50-483

FAILURE ANALYSIS OF
CAPSTAN SPRINGS
P/N 1801613-01

METTEK REPORT
NO. PSC130911

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METTEK MATERIALS ENGINEERING TECHNOLOGY LABORATORIES

Pacific Scientific
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September 14, 1983
METTEK Report
No.#PSC130911

Attention: Paul Hadnegy, Quality Control

PROCEDURE

Four capstan springs were submitted for analysis. These exhibited cracks in the radius of some of the tangs. In some cases the tang had broken off completely. These springs were identified as follows:

S/N 21524- 1 tang cracked
1 tang not cracked

This spring was life cycle tested at PSCO in this condition. No laboratory metallurgical testing was conducted.

S/N 21525- 1 tang broken off
1 tang cracked

S/N 21526- No cracks on either tang

S.N 21527- 1 tang cracked
1 tang broken off

The broken tang from S/N 21525 was examined in the SEM. The opposite tang from this spring was cut off and a microsection prepared 90^0 to the crack and in the longitudinal direction.

One tang from S/N 21526 was cut off and a microsection prepared 90^0 to the radius and in the longitudinal direction of the spring wire. This section was examined for microstructure and hardness.

The broken tang from S/N 21527 was examined in the SEM. The opposite tang with the incipient crack at the radius was cut off the spring. The tang was then mechanically broken open to expose the fracture face of the incipient crack. This fracture face was then examined in the SEM.

RESULTS

S/N 21526

Figures 1-8 illustrate the S/N 21526 spring and the burnish marks on the inside face of the tang just above the formed radius. Visual examination under 40X binocular microscope did not reveal any cracks in this spring. The burnish marks are caused by rubbing against the spring enclosure during cycling of the spring. The microsection prepared through one of the two tangs did not reveal any incipient cracks. A hardness survey was conducted on this spring and the results are shown in Table I. This shows that the core hardness was about HRC 43-46 while near the surfce of the formed radius the hardness was HRC 46-50. This converts to an approximated tensile range of 220 to 260ksi. Figure 4 shows the surface of the tang on the back side or unloaded side. No burnish marks are present.

S/N 21525

Figure 5 illustrates the spring and the broken tang. Figure 6 illustrates the fracture face of this broken tang. Examination of the fracture face revealed two distinct zones A and B. In zone A near the formed radius the fracture mode was brittle in appearance while in zone B the fracture mode was dimple rupture. In addidtion the fracture face in zone A was tinted or discolored relative to zone B which was bright and clean. This indicates that zone A was a prior incipient crack. Dot pattern and line scans for Ag were conducted coincident with the edge at zone A. These show slight traces of Ag on the edge of the fracture. A microsection was prepared 90^0 to this fracture. Figure 11 shows the cross section and zone A is indicated. Figure 12 shows a trace of Ag over the edge of the fracture. This is indicative of a crack which formed either prior to or during Ag plating.

A microsection was prepared of the opposite tang which contained a partial crack. This crack is shown in Figures 13-16. The crack is relatively shallow, approximately .0075" deep at this location. The crack depth of zone A on the opposite tang was approximately .010-.020".

A microhardness survey was conducted on this spring. The results are shown in Table II. The hardness of this spring was about the same as for spring S/N 21526 which did not crack. The hardness varied from HRC 45-51 or approximately 220 to 260ksi.

S/N 21527

Figure 16 shows spring S/N 21527. This spring had one broken tang and one cracked tang. Figure 17 shows the broken tang. The burnish wear marks are apparent on the inside face. Figure 18 shows the fracture face and third wear burnish mark adjacent to the fracture (Figure 19). The fracture face is shown in Figures 20 and 21. In zone A the fracture face was tinted or discolored relative to zone B. A scan for Ag was conducted along the edge in zone A. The results are shown in Figures 22-24. There is a trace of Ag smeared over the edge of the fracture. The fracture mode, althrough not pure cleavage or intergranular, appears to be brittle in nature and does show the presence of secondary intergranular cracking. By comparison the fracture mode shown in zone B, Figure 27, is typical dimple rupture.

Figures 28-30 illustrate the opposite cracked tang. The burnish marks are apparent. On this tang there were burnish marks on the back side of the tang (Figure 30). It is believed that these were caused after the tang at the opposite end of the spring failed. Figure 31 shows the profile of the incipient crack at the formed radius is very similar to that found on the broken tang. When this portion of this profile the tang was broken open the fracture face at this crack was exposed. This crack is shown as zone A Figure 32. Zone B represents the portion of the section which was mechanically broken in the lab. Zone A was tinted a yellowish color relative to zone B. A line scan for Ag was conducted in the central area of zone A and the results are shown in Figures 33 and 34. This shows the presence of Ag on the edge of the fracture face. The fracture mode in zone A is illustrated in Figures 35 and 36 while the fracture mode in zone B is shown in Figure 37. The brittle nature in zone A relative to zone B is again apparent. In addition the appearance is similar to the fracture mode found on the broken tang.

CONCLUSIONS

The results indicate that the tangs are fracturing due primarily to the presence of incipient cracks in the formed inside radius of the tangs. The discoloration on the fracture face along the edge of the fracture at this location and the presence of Ag over the edge of the fracture face indicates that these cracks formed prior to or during Ag plating. Magnetic particle inspection performed on similar springs at PSCO before and after Ag plating has shown that the cracks are not present prior to Ag plating but do occur after plating. This indicates that the incipient cracks are forming during Ag plating. Considering these facts-coupled with the brittle nature of the first incipient crack zone it is the writers firm opinion that the cracks are a result of high residual stress in the formed radius of the tang coupled with hydrogen generated during the cleaning and plating operation combining to produce hydrogen induced cracking. This has resulted even though the springs are baked at 375^{0}F for 24hrs. after plating.

It has also been discovered that the springs that crack during plating have all been made by one manufacturer. A second manufacturer who makes the same springs has not experienced the cracking problem although they are plated by the same vendor. It has also been discovered that on the springs in which the tangs crack, the tang was formed after the springs had been aged at 900^0F. In the case of the other spring vendor the tangs are formed prior to age hardening at 900^0F. This indicates that there may be a high inherent residual stress in the radius of the tang on the units where the tang is formed after age hardening.

In addition the springs are stress relieved at 600^0F after being formed. This coupled with the cold work induced during forming may make the spring more susceptible to hydrogen cracking. 17-4 and 17-7 materials when heated in the range of 600-800^0F do tend to show a lower toughness (see attached document in the addendum). The springs, from the second spring vendor, which do not crack, however, also been stress relieved at 600^0F. This suggests to the writer that the forming of the tang after age hardening at 900^0F is the significant cause for the high residual stress which induces hydrogen cracking during Ag plating.

Respectfully submitted,
METTEK Laboratories

L.E. McKnight

L.E. McKnight, P.E.
Consulting Engineer

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TABLE I

MICROHARDNESS MEASUREMENTS

Job No.: PSC 130911 **Date:** September 14, 1983

Load: 500g **Specimen:** 21526 Non-Broken or Cracked

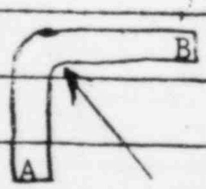
	Position (in)	Position (mm)	Filar Units (μ)	Knoop Microhardness (KHN)	Hardness Converted from KHN
ID			117.2	518.0	48.5C
			117.2	518.0	48.5C
A			116.8	521.6	49C
			122.5	474.2	45.5C
OD			118.4	507.6	48C
Cut End					
ID			118.2	509.3	48C
			118.4	507.6	48C
B			127.5	437.7	43C
			121.8	479.6	46C
OD			121.6	481.2	46C
ID			114.2	545.6	50C
			121.7	480.4	46C
C			122.1	477.3	46C
Radius			120.0	494.1	47C
OD			115.4	534.3	49.5C
					

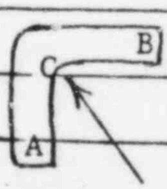
TABLE II

MICROHARDNESS MEASUREMENTS

Job No.: PSC 130911 Date: September 14, 1983

Load: 500g Specimen: 21525

	Position (in)	Position (mm)	Filar Units (μ)	Knoop Microhardness (KHN)	Hardness Converted from KHN
BROKEN TANG		Near End A	118.5	506.7	47.5
		Of Tang	119.9	494.9	47
			122.4	474.9	45.5
		In Spring	123.2	468.8	45
		B Body	118.6	505.8	47.5
			115.2	536.1	49.5
		In Tang	115.1	537.1	49.5
		C Radius	120.0	494.1	47
			116.7	522.4	49
CRACKED TANG			131.1	488.4	ANOMALOUS
		A	119.8	495.8	47
			122.7	474.6	45.5
			120.7	488.4	46.5
			121.2	484.4	46
		B	118.1	510.1	48
			122.7	472.6	45.5
			112.7	560.2	51
			113.9	548.4	50.5
		C	121.9	478.8	46
			120.4	490.8	47
			114.7	540.8	50



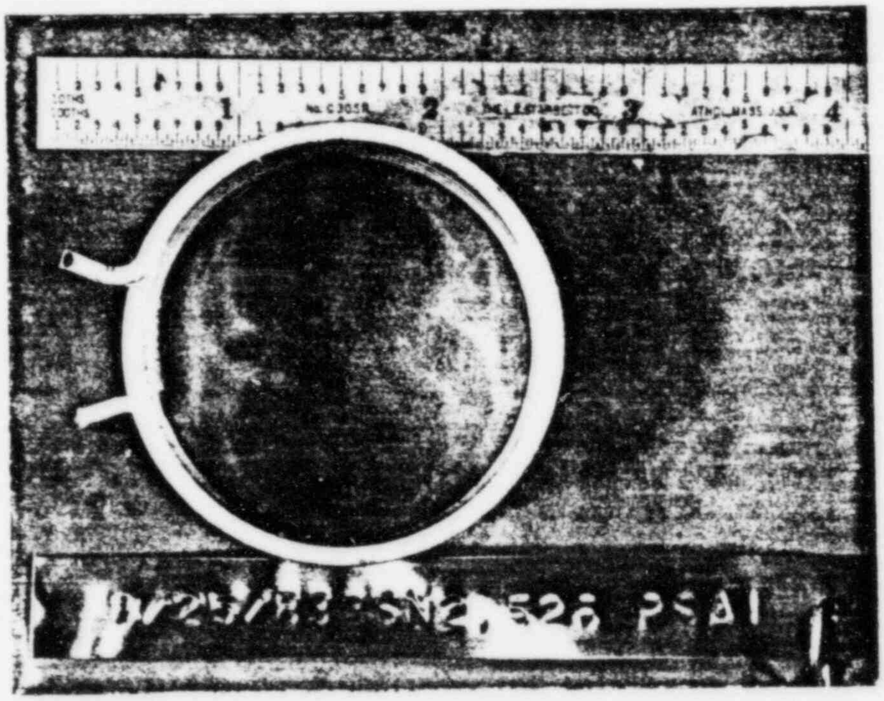


FIGURE 1. Spring S/N 21526.

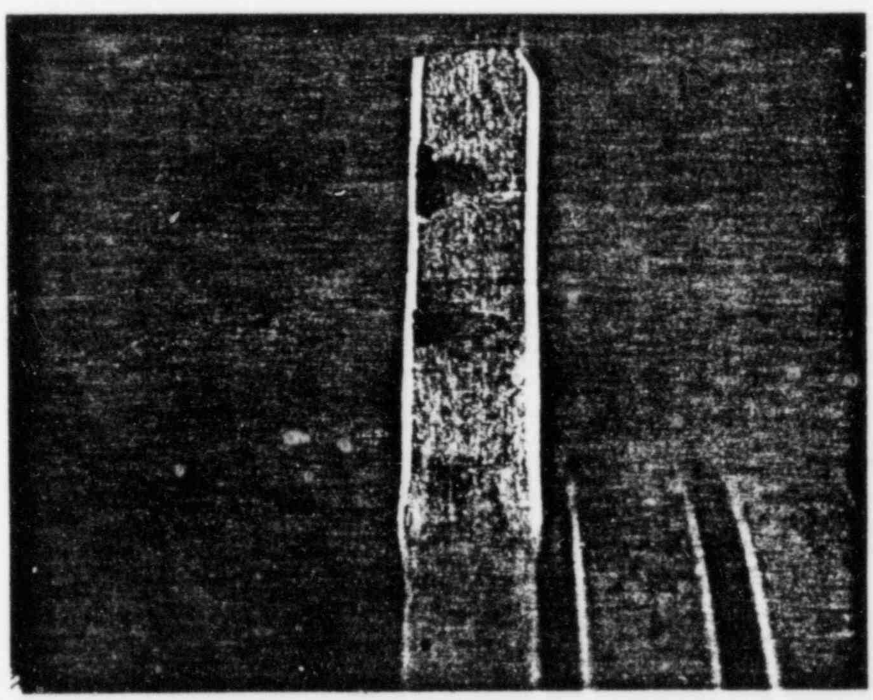


FIGURE 2. Inside face of tang S/N 21526.

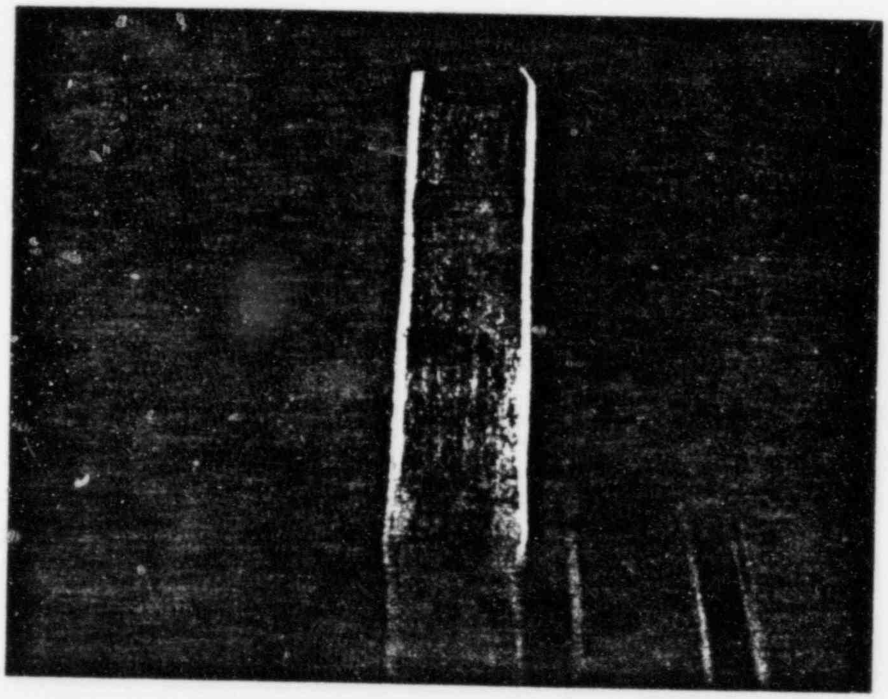


FIGURE 3. Inside face of tang S/N 21526.

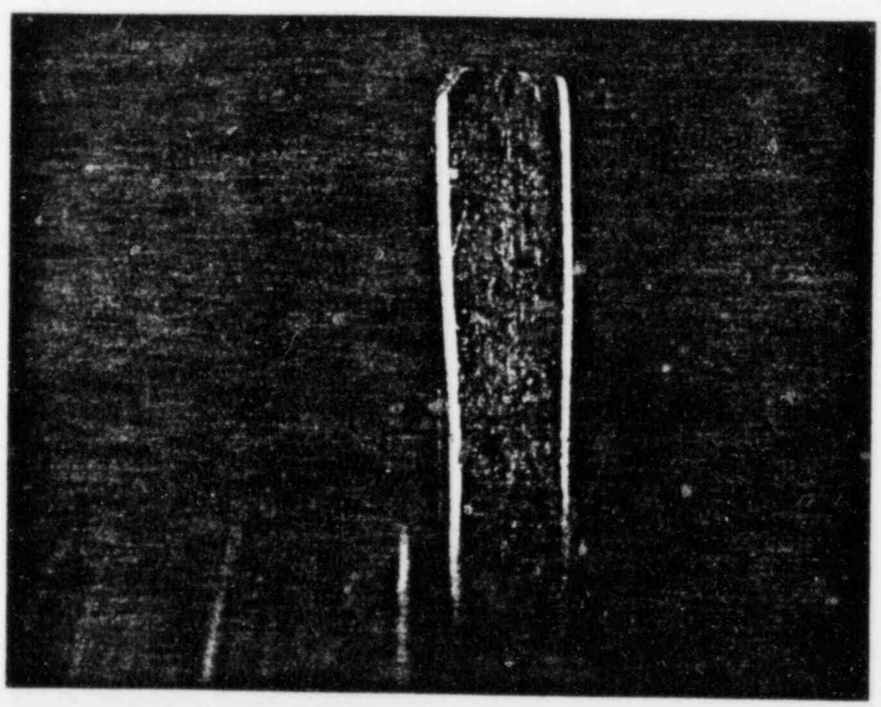


FIGURE 4. Outside face of tang S/N21526.

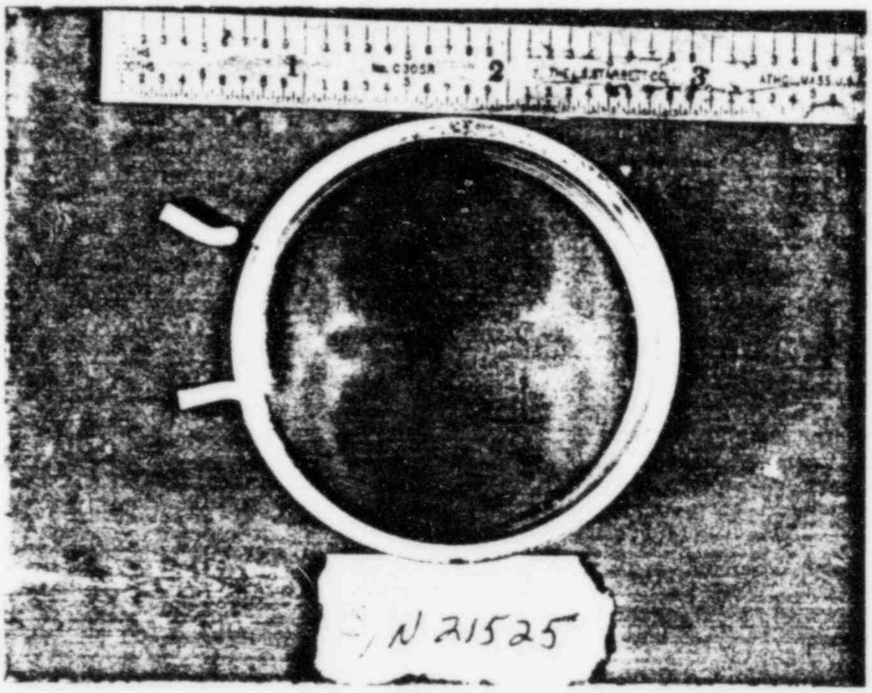


FIGURE 5. Spring as-received S/N21525.

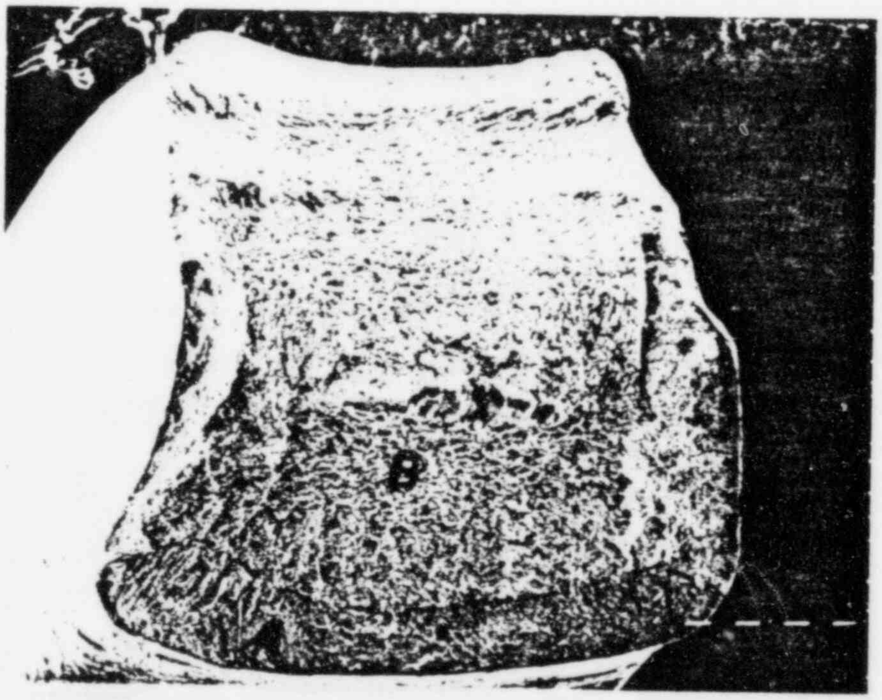


FIGURE 6. Fracture face of tang S/N 21525. 30X

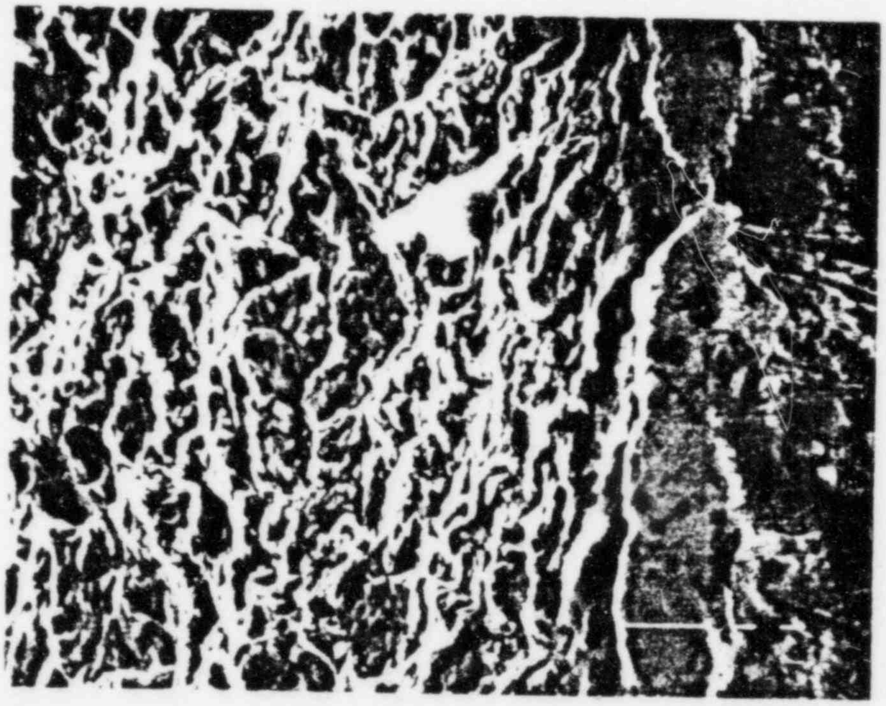


FIGURE 7. Fracture of edge Figure 6. 1000X

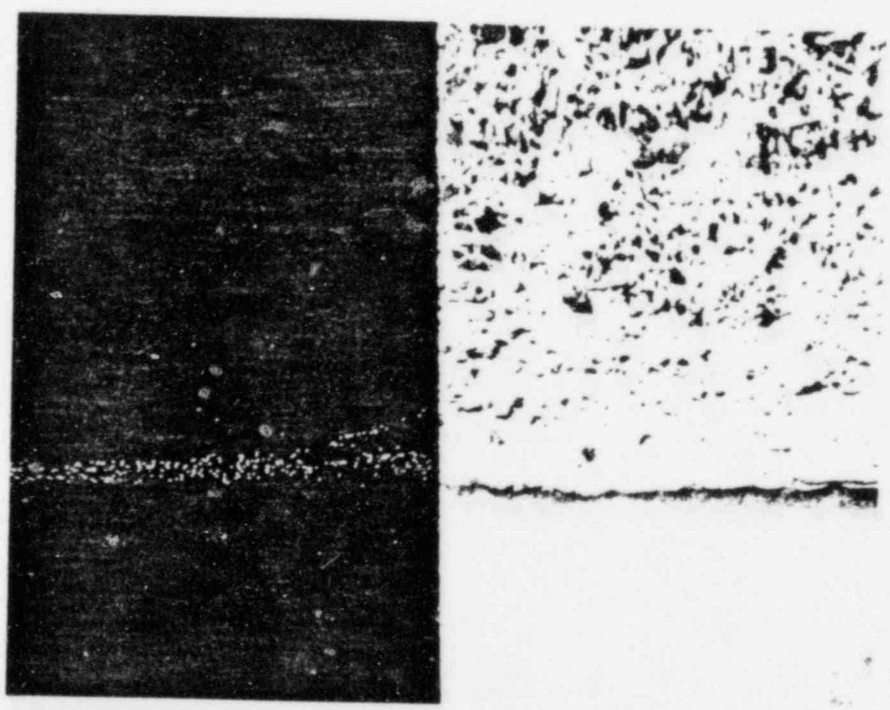


FIGURE 8. Dot pattern scan for Ag at edge. 200X

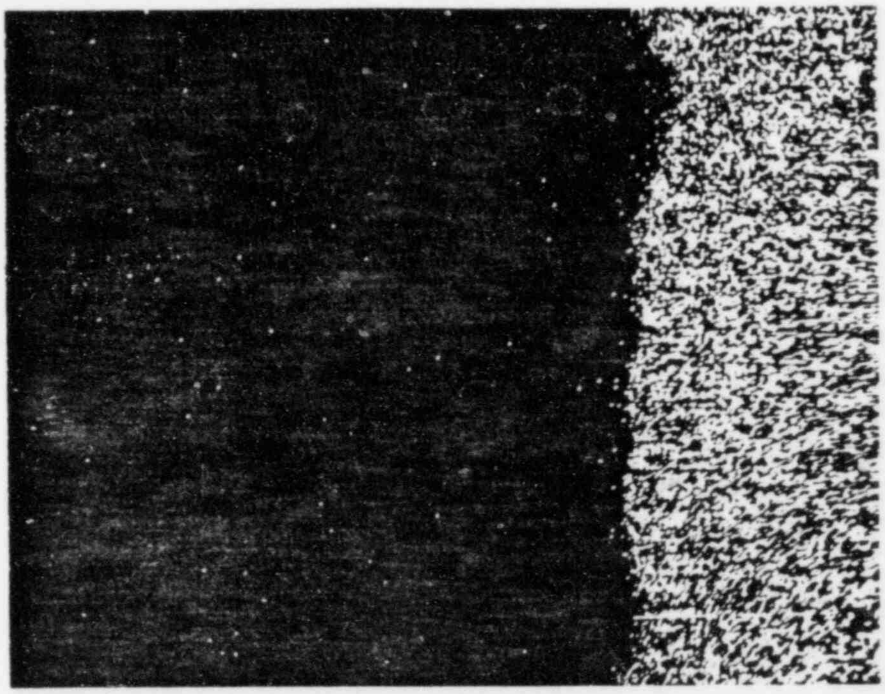


FIGURE 9. Dot pattern scan for Ag at edge. 1000X

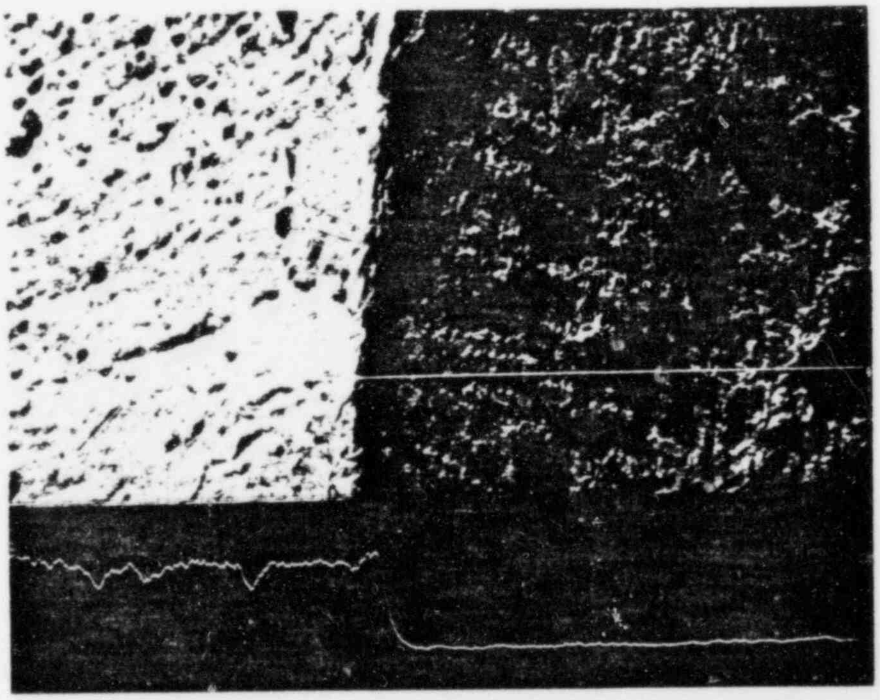


FIGURE 10. Line scan for Ag at edge. 200X

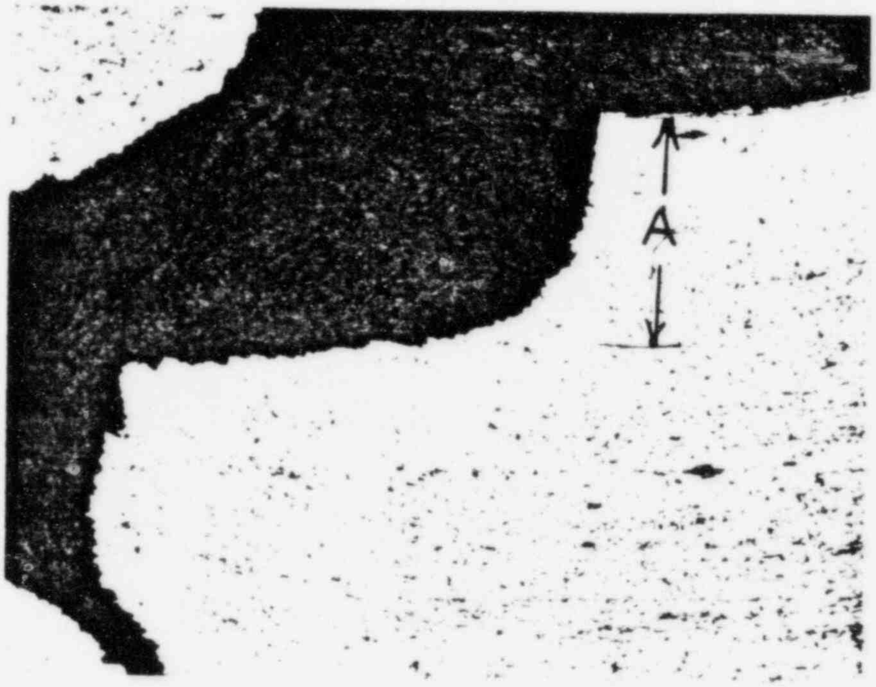


FIGURE 11. Cross section of fracture (Figure 6). 50X

FIGURE 12. Cross section of fracture (Figure 6). 1000X

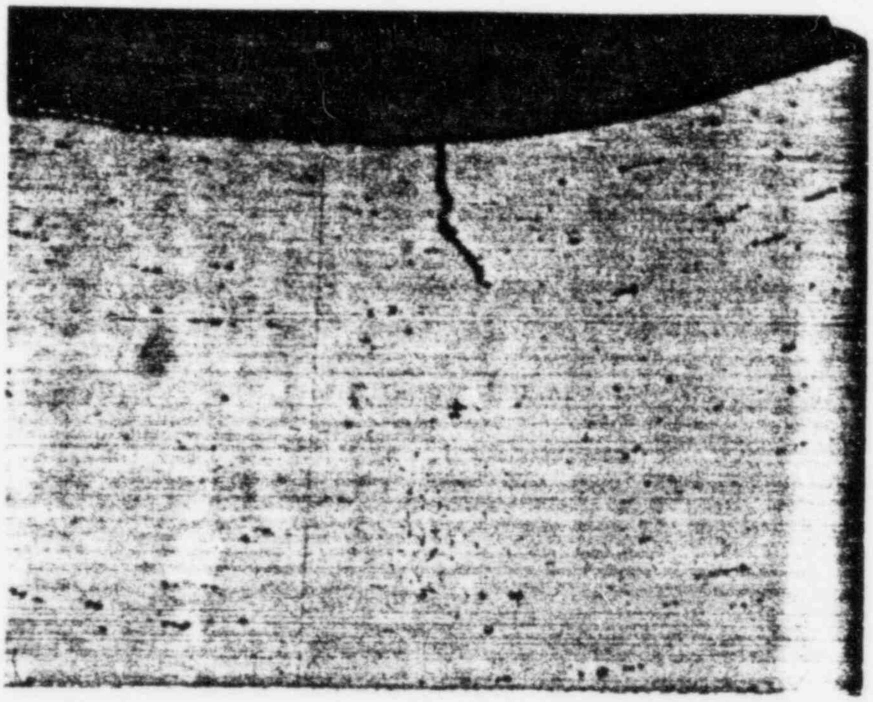


FIGURE 13. Cross section of incipient crack on the opposite tang S/N 21525. 100X

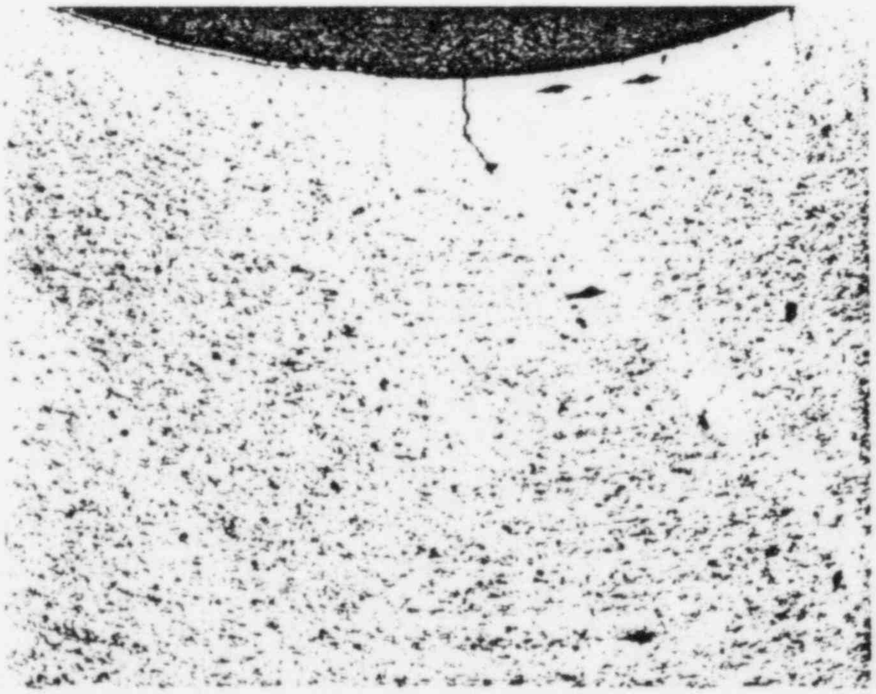


FIGURE 14. Cross section of incipient crack on the opppsite tang S/N 21525. 50X

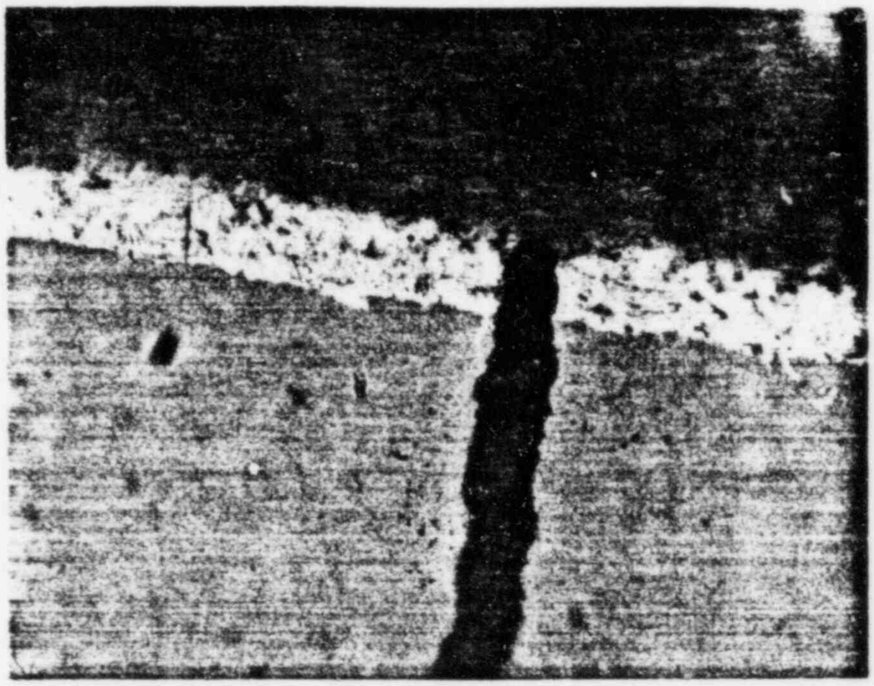


FIGURE 15. Crack shown in Figures 13 and 14. 1000X

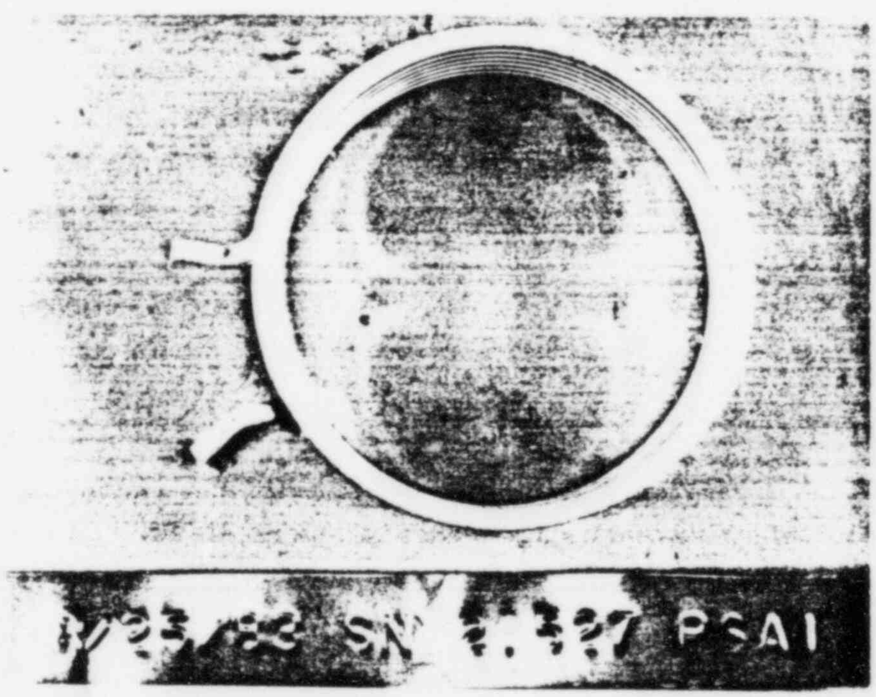


FIGURE 16. Spring S/N 21527 as-received.

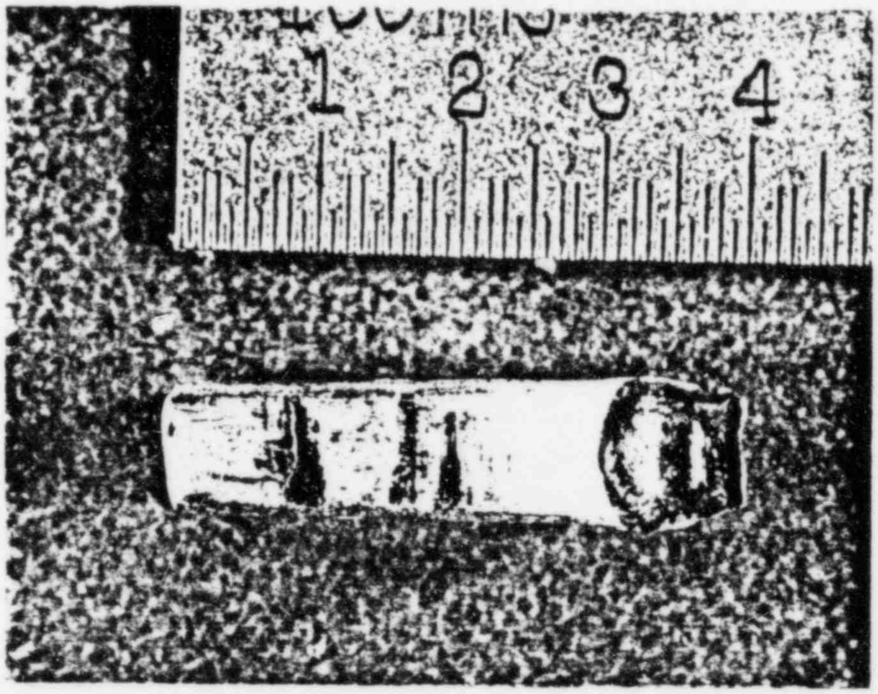


FIGURE 17. Broken tang S/N 21527.

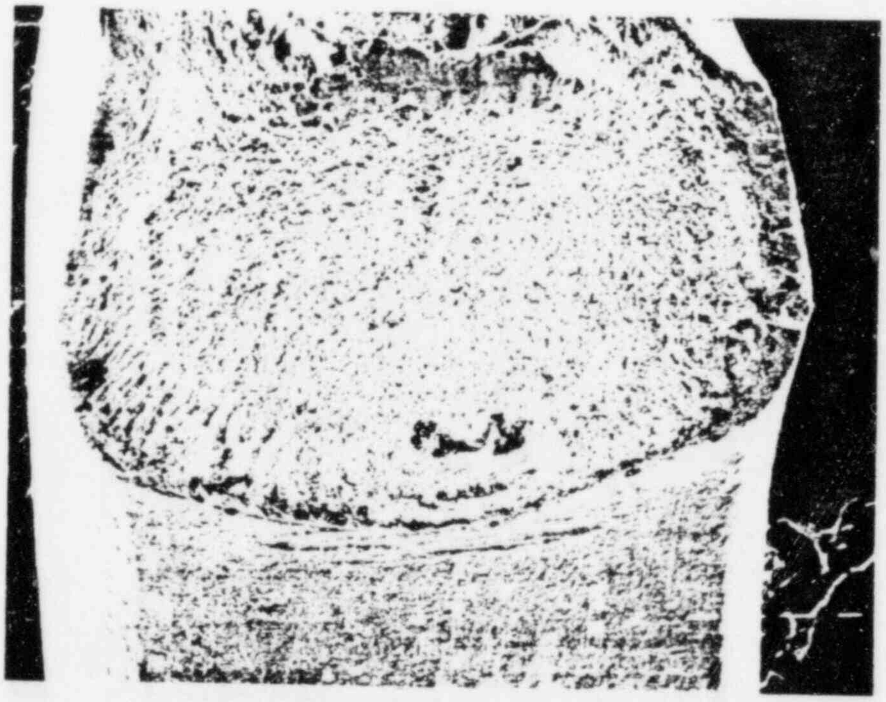


FIGURE 18. Fracture face of tang. 35X

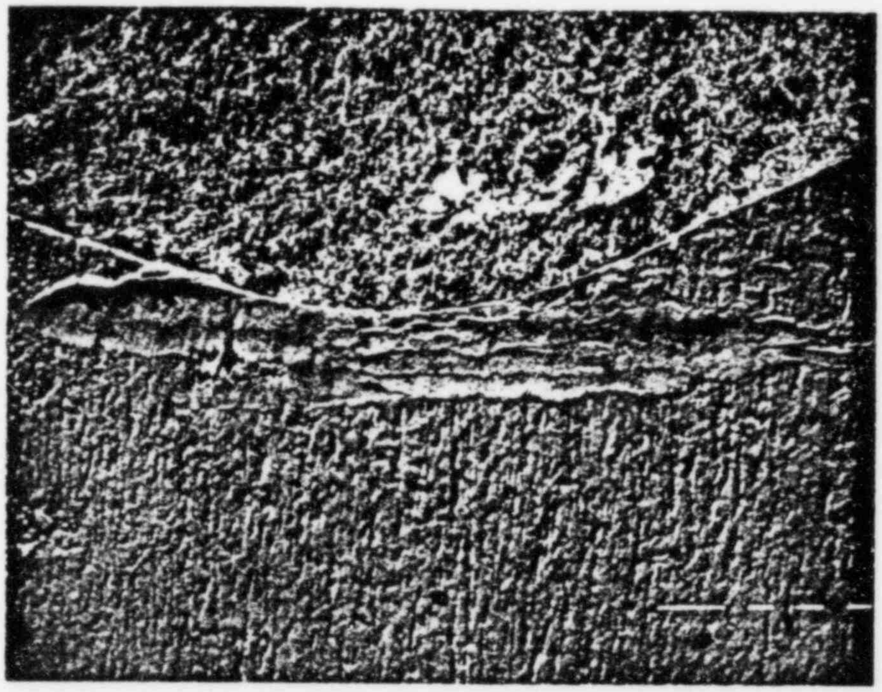


FIGURE 19. Fracture face and edge of tang. 80X

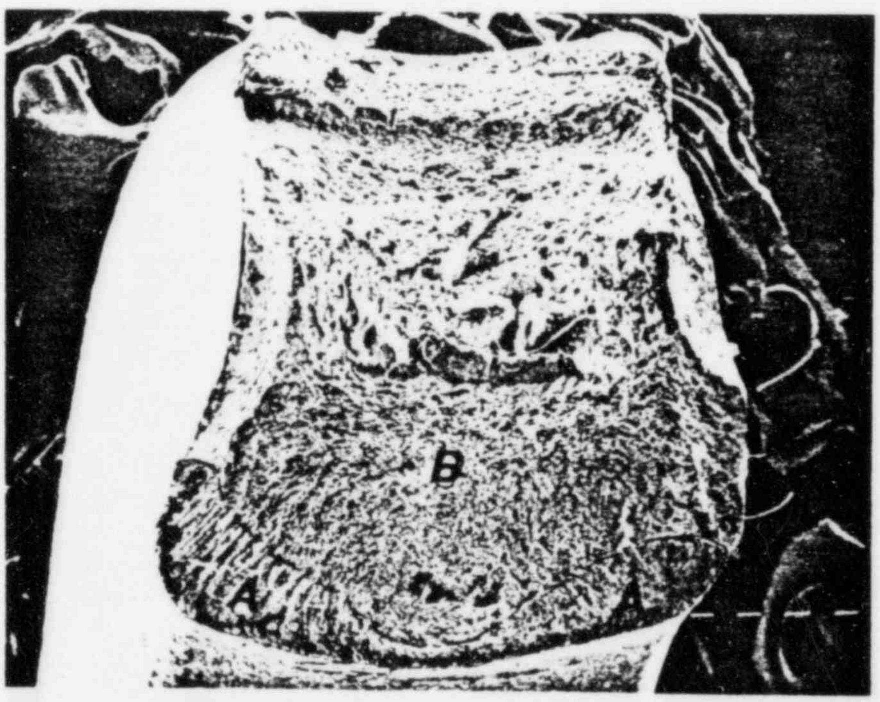


FIGURE 20. Fracture face of tang. 30X

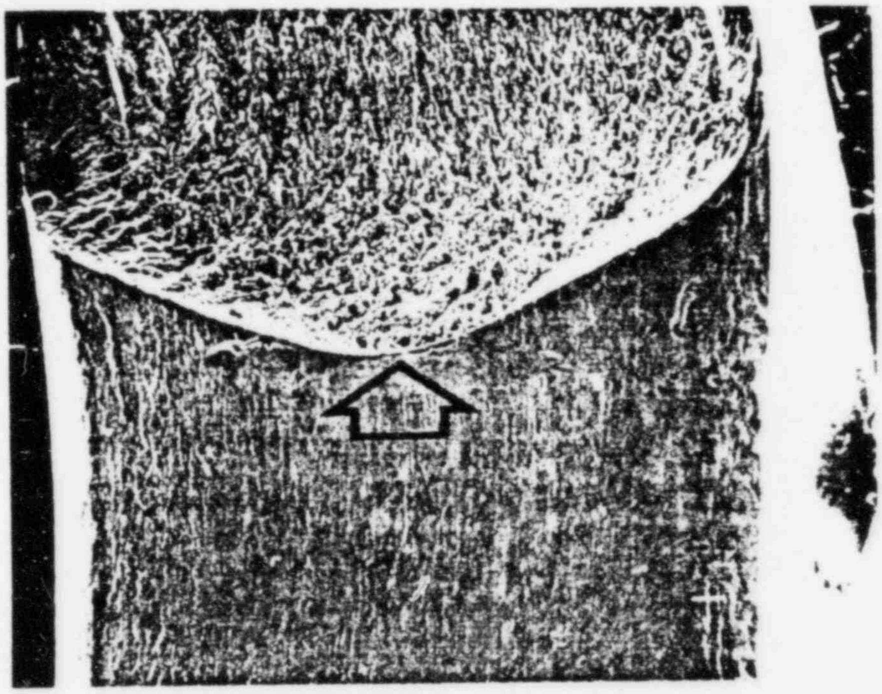


FIGURE 21. Fracture face coincident with radius of tang. 35X

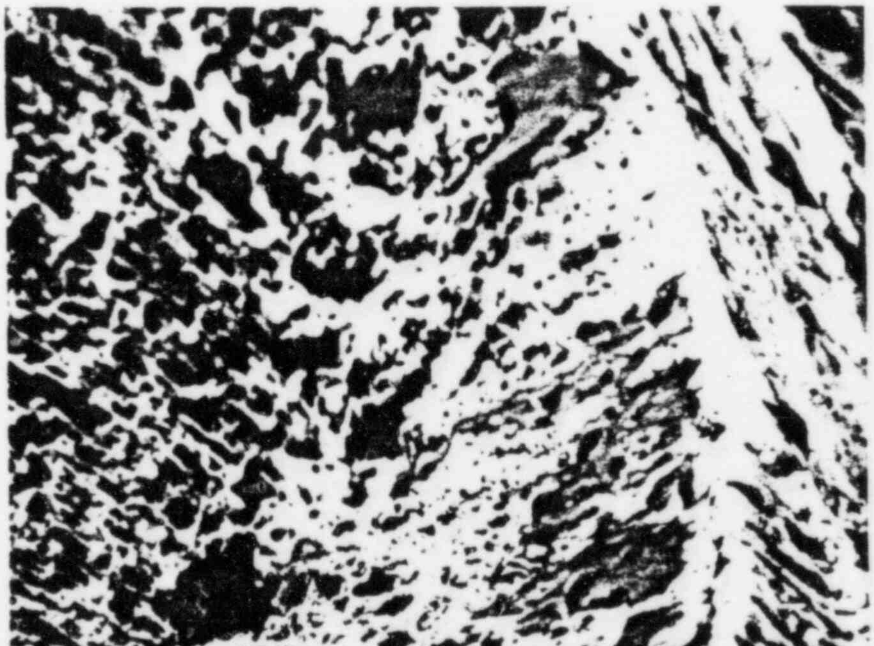


FIGURE 22. Edge of fracture (arrow Figure 21). 350X

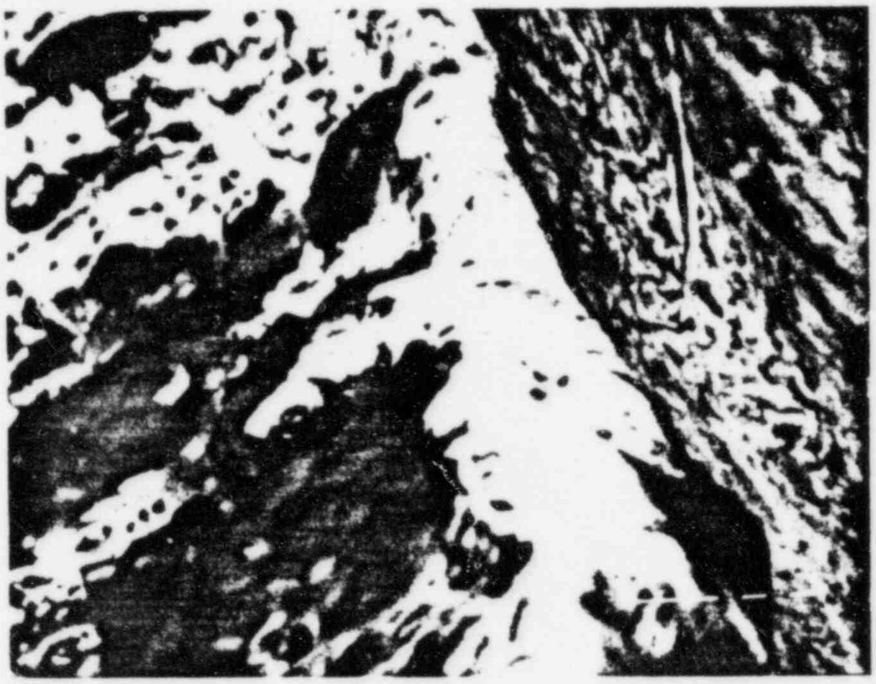


FIGURE 23. Edge of fracture (arrow Figure 21). 1100X

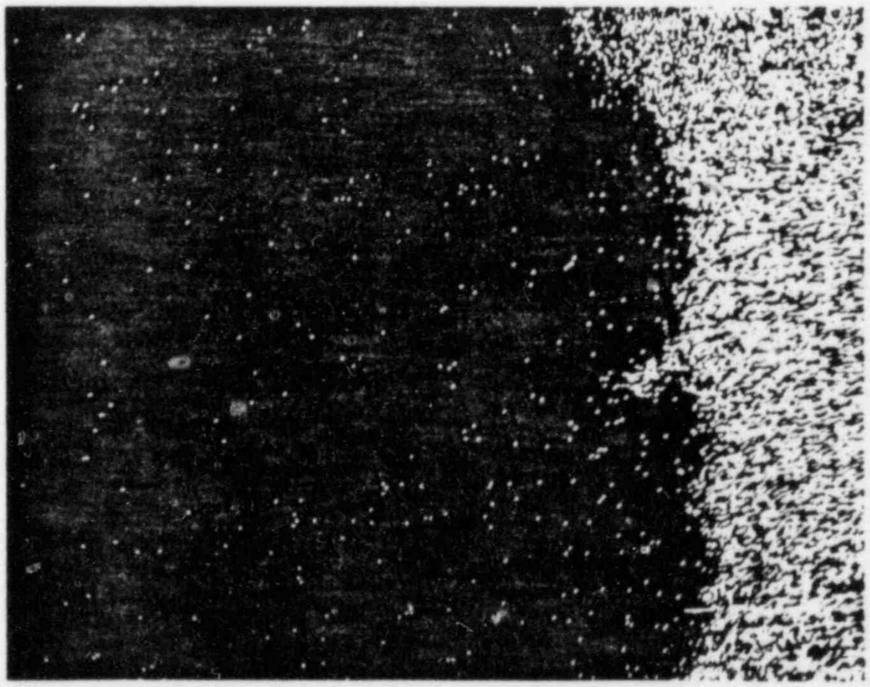


FIGURE 24. Dot pattern scan for Ag Figure 22. 350X

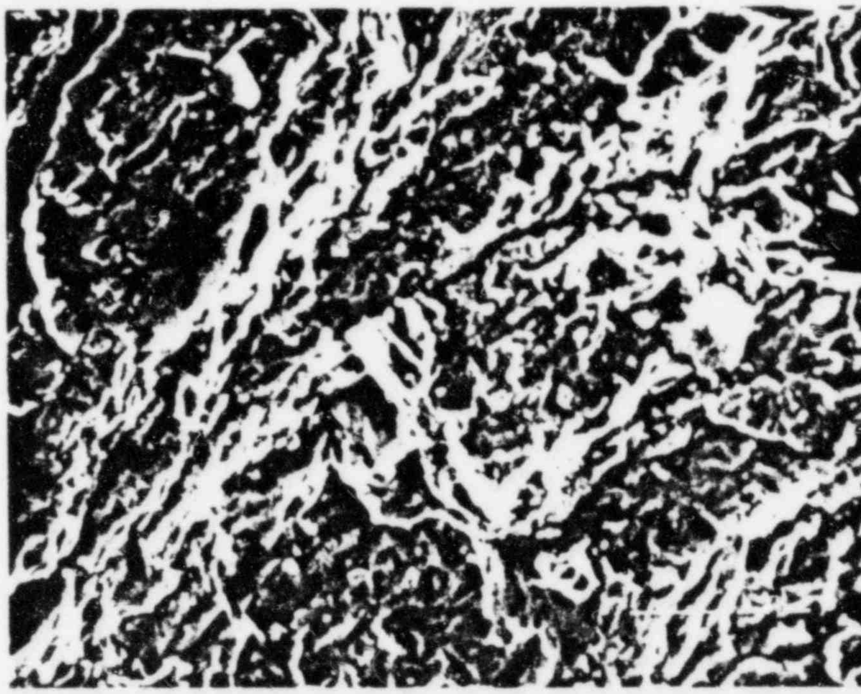


FIGURE 25. Fracture mode zone A Figure 20. 1000X

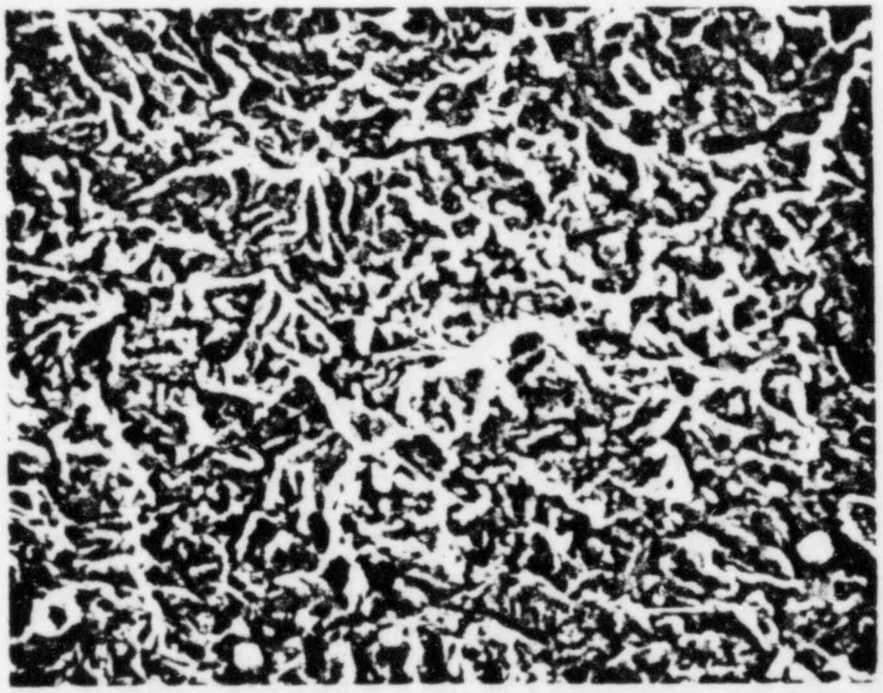


FIGURE 26. Fracture mode zone A, Figure 20. 1000X

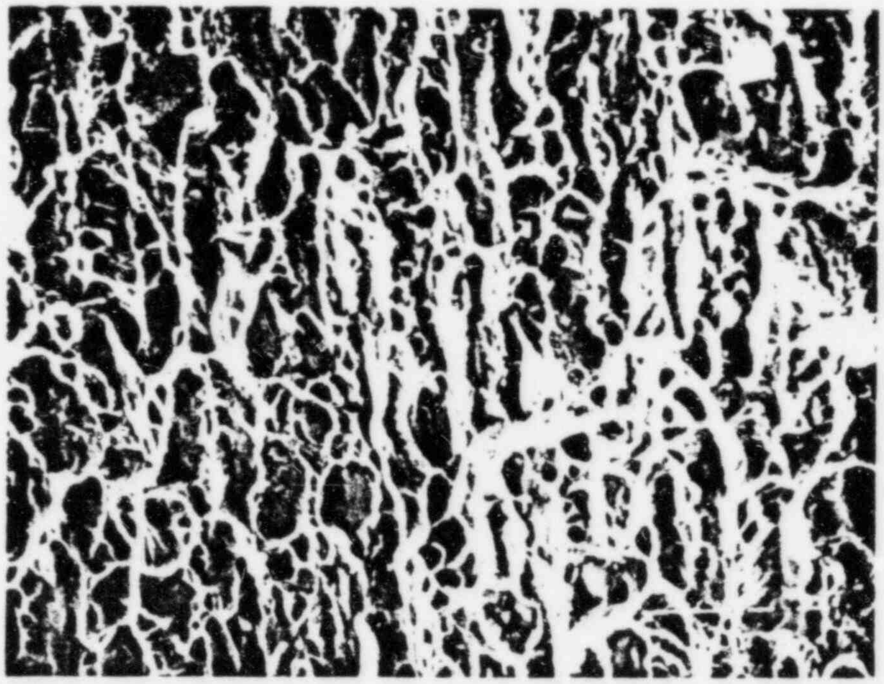


FIGURE 27. Fracture mode zone B, Figure 20. 1000X

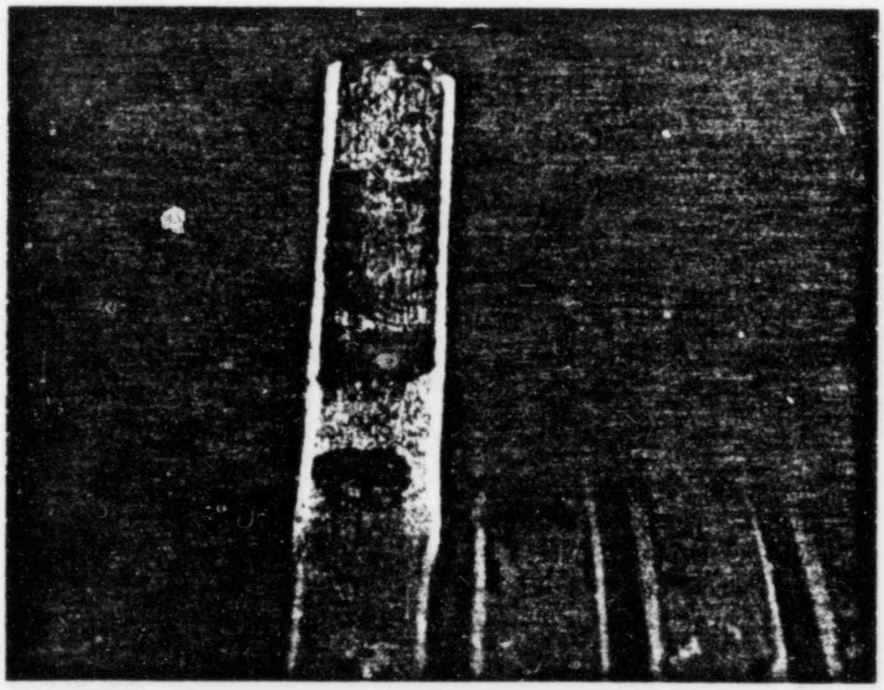


FIGURE 28. Inside face of tang S/N 21527.

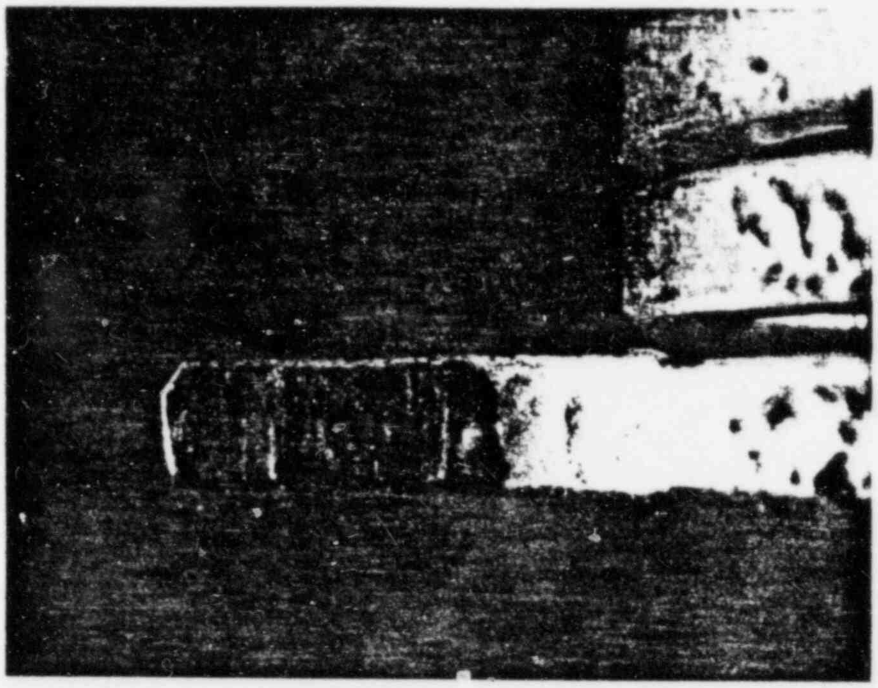


FIGURE 29. Inside face of tang S/N 21527.

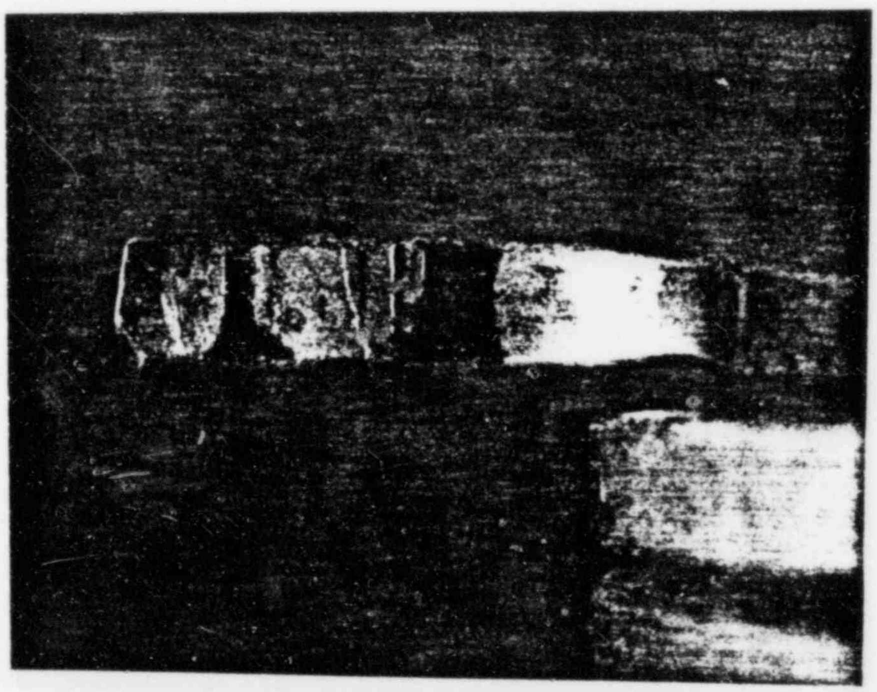


FIGURE 30. Back face of tang shown in Figure 28.

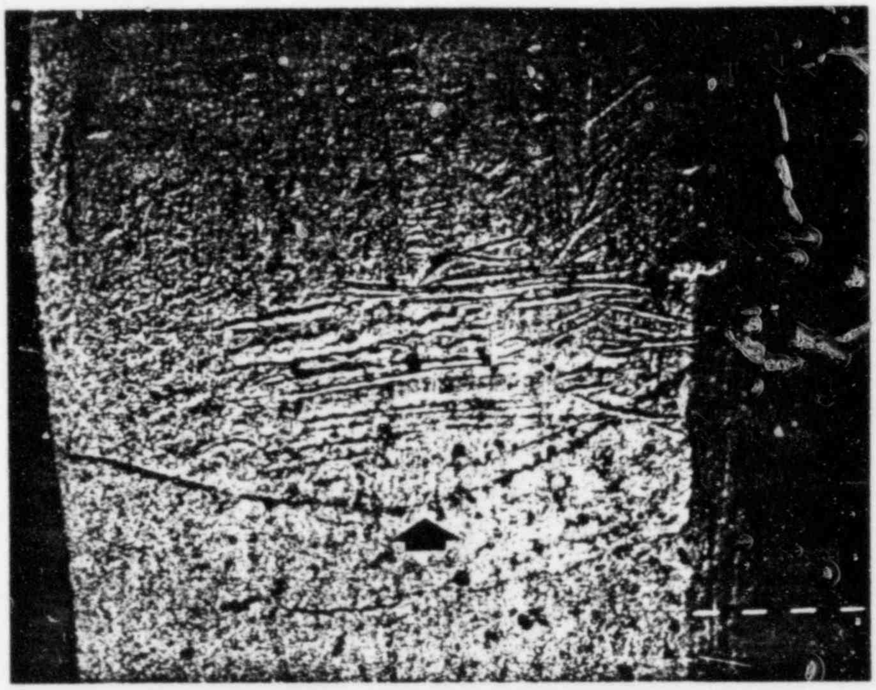


FIGURE 31. Crack at radius of tang. 35X

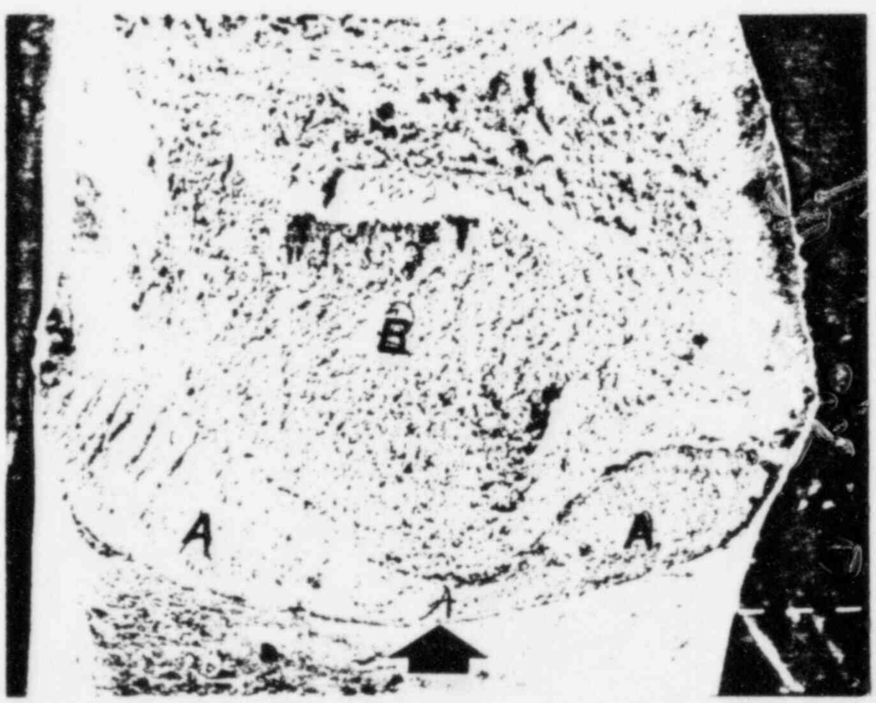


FIGURE 32. Fracture face of crack (Figure 31). 30X

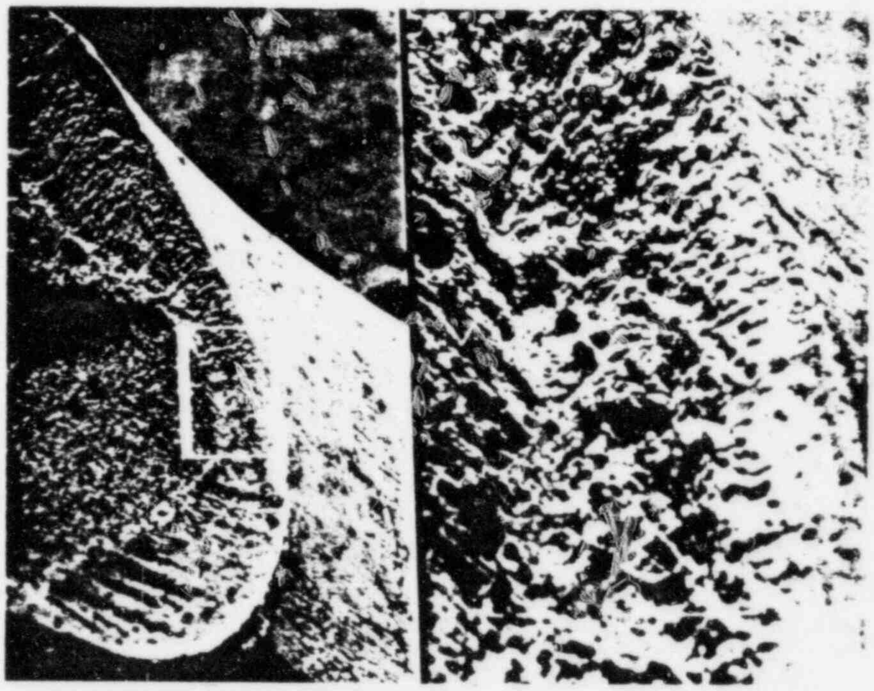


FIGURE 33. Edge of fracture (arrow Figure 32). 40X/200X

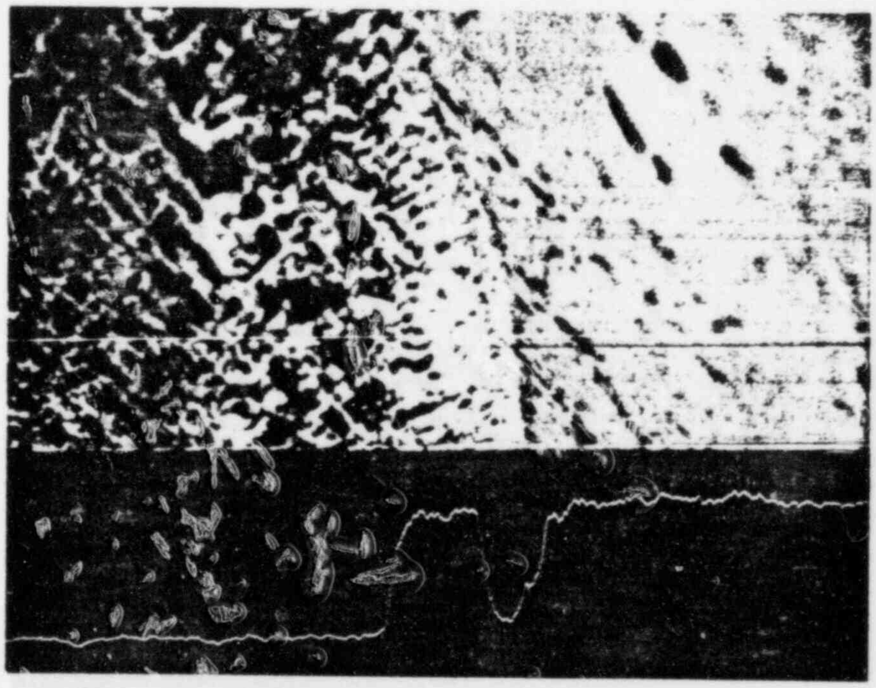


FIGURE 34. Line scan for Ag at edge. 200X

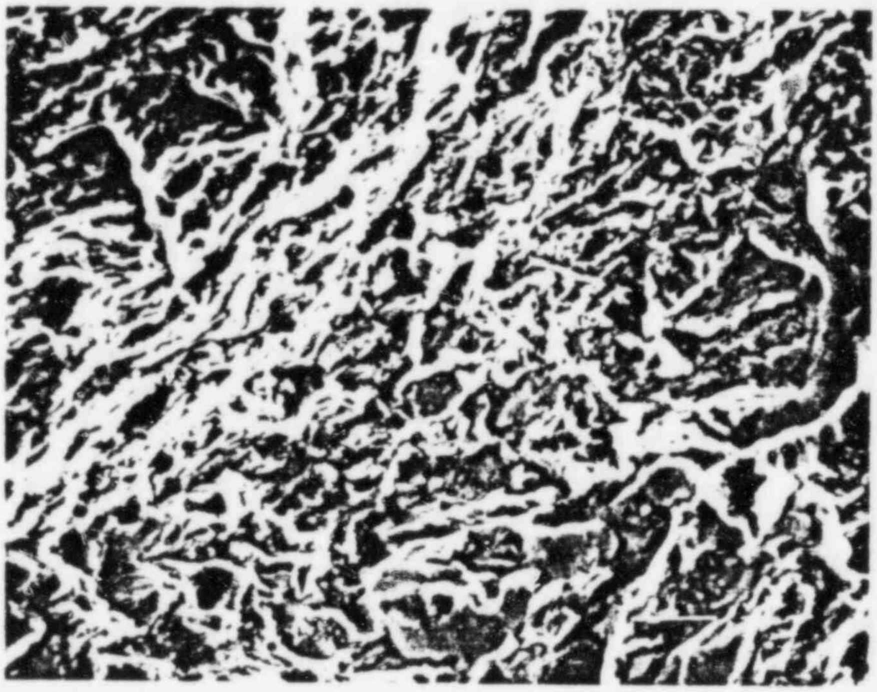


FIGURE 35. Fracture mode zone A, Figure 32. 1000X

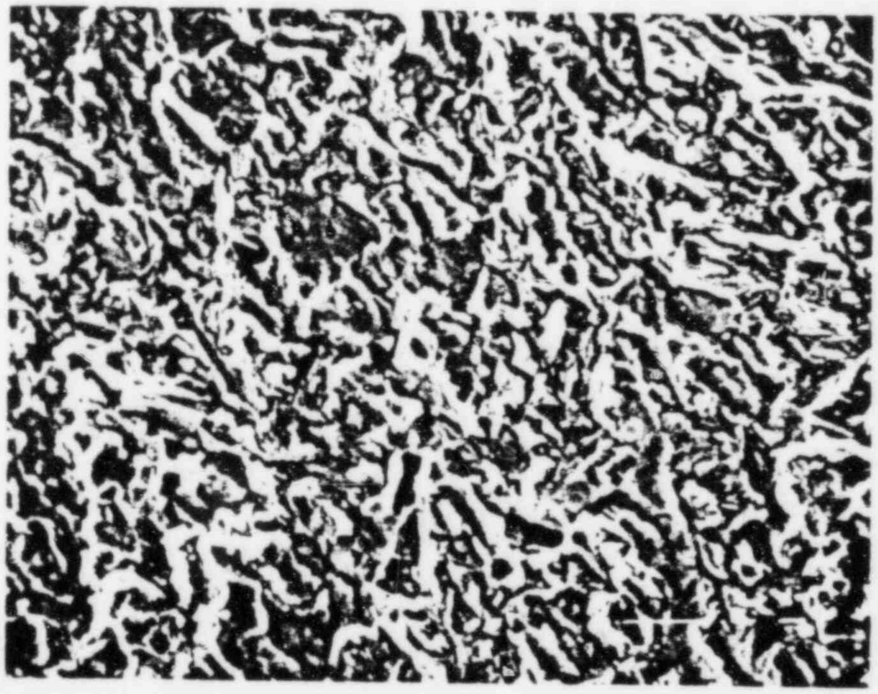


FIGURE 36. Fracture mode zone A, Figure 32. 1000X

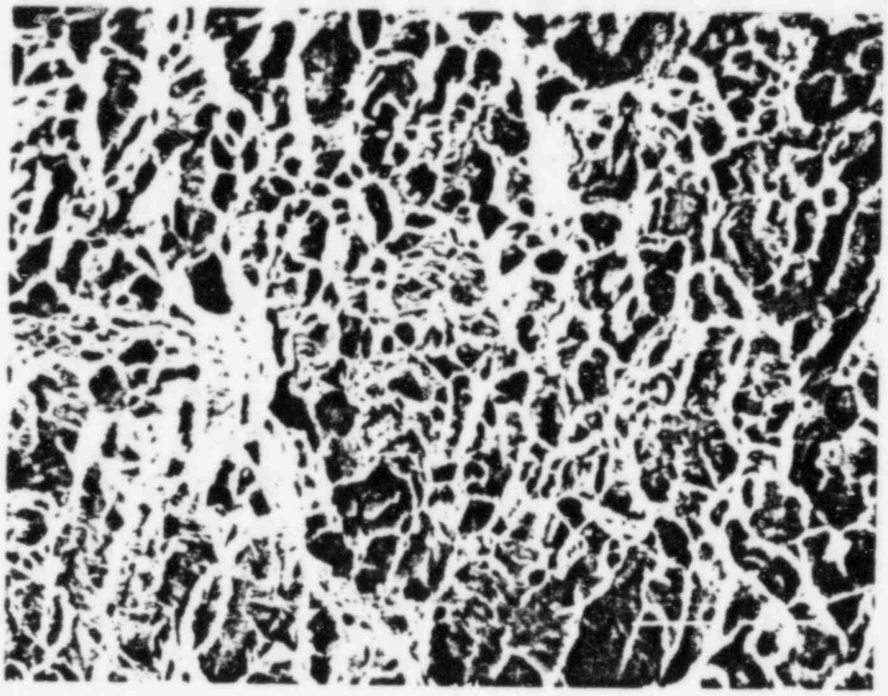
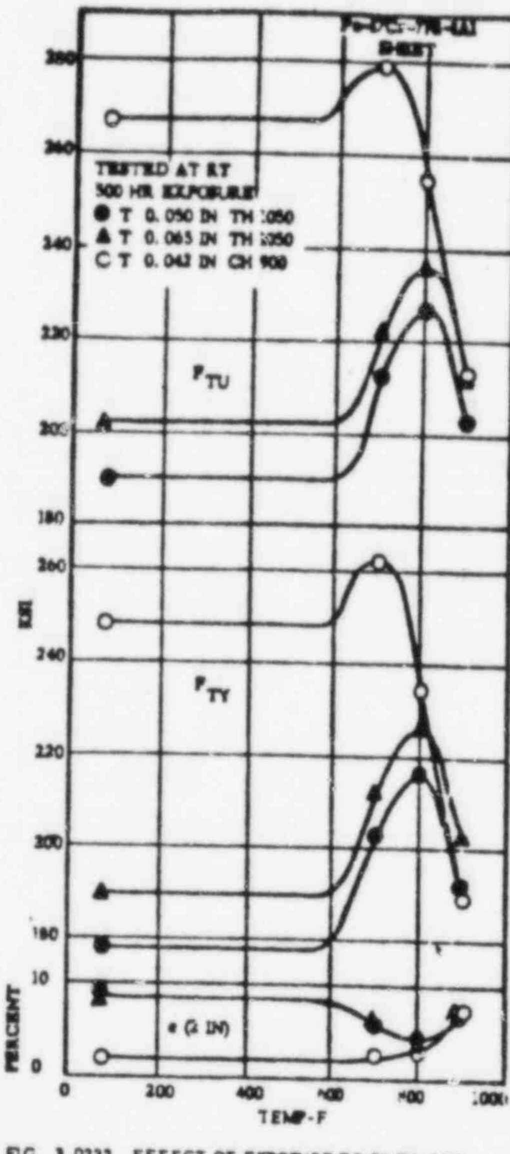


FIGURE 37. Fracture mode zone B, Figure 32. 1000X

APPENDIX

EFFECT OF TEMPERING TEMPERATURE ON TENSILE PROPERTIES OF 17-7 PH STAINLESS STEEL, FROM AEROSPACE STRUCTURAL METALS HANDBOOK, VOL. 1, SYRACUSE UNIVERSITY PRESS, 1965.



	Fe
17	Cr
7	Ni
1	Al

17-7 PH

FIG. 3.0222 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURES ON TENSILE PROPERTIES OF SHEET IN CONDITIONS TH 1050 AND CH 900 (6)

Kin-Tech Division

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1983 SEP 26 PM 1:01

SR 83-01

SHOCK ARRESTOR CAPSTAN SPRING SERVICE REPORT

During testing of Pacific Scientific Company's PSA-1 Shock Arrestors, part number 1801102-05, at Union Electric Callaway Station by Daniel International personnel, 4 of 7 snubbers tested revealed a broken capstan spring tang.

Pacific Scientific Company requested failed springs for independent metallurgical examination. Failed components were returned to Pacific Scientific Company who forwarded broken springs to "Mettek", 1805 E. Carnegie, Santa Ana, CA 92705, (714) 549-1083, for metallurgical and fracture analysis.

One spring exhibiting a visual crack in one tang (removed from snubber S/N 21524 which was returned by Union Electric) was installed by Pacific Scientific Co. into a snubber and subjected to a full load (1500 lbs.) acceleration test. This test was repeated 5 times (10 full load cycles) with no failures. The cracked spring was then subjected to a dynamic load cycling test. This test cycles the snubber at 3 Hertz intervals from 3 to 33 Hertz for 10 seconds at each interval at 100%, 75% and 50% rated loads, a total of 5940 cycles. The cracked spring satisfactorily passed this test.

Springs from the identical lot as those that failed were traced to snubbers located at Kansas Gas & Electric Co. Wolf Creek Station. These were returned to Pacific Scientific for testing and evaluation.

Eleven (11) each 1801102-05 PSA-1 Shock Arrestors returned to Pacific Scientific Co. by Kansas Gas & Electric Co. Wolf Creek Station were visually and functionally tested by Pacific Scientific Co. personnel in the presence of KG&E and Union Electric Co. personnel.

All eleven PSA-1 Shock Arrestors (S/Ns 21511 thru 21521) were disassembled to a level permitting verification that the capstan spring was properly installed and whole. The Shock Arrestors were reassembled and subjected to a successful acceleration test at full rated load (1500 lbs.).

Following successful acceleration test, all eleven Shock Arrestors were disassembled to facilitate visual and non-destructive examination of the capstan springs:

S/N 21511 - No apparent visual defects. Magnetic particle non-destructive examination revealed indications in both spring tangs with one tang exhibiting three separate indications. Indications were suspected to be micro cracks.

1/1 IE-19

SHOCK ARRESTOR CAPSTAN SPRING SERVICE REPORT - (Cont'd.)

S/N 21512 - No apparent visual defects. Magnetic particle examination exhibited an indication of one micro crack on one tang.

S/N 21513 - No apparent visual defects. No magnetic particle examination indications.

S/N 21514 - No apparent visual defects. No magnetic particle examination indications.

S/N 21515 - No apparent visual defects. Both tangs exhibited a magnetic particle micro crack indication.

S/N 21516 - No apparent visual defects. No magnetic particle examination indications.

S/N 21517 - No apparent visual defects. No magnetic particle examination indications.

S/N 21518 - No apparent visual defects. Both tangs exhibited a magnetic particle micro crack indication.

S/N 21519 - No apparent visual defects. Both tangs exhibited a magnetic particle micro crack indication.

S/N 21520 - No apparent visual defects. One tang exhibited a magnetic particle micro crack indication.

S/N 21521 - No apparent visual defects. One tang exhibited a magnetic particle micro crack indication.

Five (5) capstan springs exhibiting non-destructive magnetic particle examination indications were assembled into a test snubber and subjected to a dynamic load of 1500 lbs. at frequencies of 3 to 33 Hertz intervals for 10 seconds each at 100%, 75% and 50% of rated load.

The springs tested represented the "worst case" as determined by the non-destructive magnetic particle inspection. They were S/Ns 21511, 21515, 21518, 21519 and 21520.

Springs, S/Ns 21515 and 21518, survived the entire test (5940 cycles). Spring, S/N 21511, survived 533 full load cycles before both tangs failed. S/N 21518 survived 1800 full load cycles before one tang failed, and S/N 21520 survived 1850 full load cycles before one tang failed.

Metallurgical report by Mettek Material Engineering Technology Laboratories indicates spring cracking occurred because of stresses induced during spring forming which caused hydrogen cracking during subsequent silver plating.

SHOCK ARRESTOR CAPSTAN SPRING SERVICE REPORT - (Cont'd.)

Metallurgical report also explains that, although the spring fracture face exhibited brittleness at the crack onset, the core of the spring was ductile and spring fracture was simple dimple (ductile) rupture. This accounts for the ability of the springs to withstand the full load functional and dynamic load testing conducted and suggests that the useful life of springs which contain cracks remains to be substantial.

The capstan springs are manufactured for Pacific Scientific Co. by a spring manufacturer. These springs are supplied formed, stress relieved and 100% magnetic particle inspected to Pacific Scientific Co., who then subcontracts the springs for silver plating. Pacific Scientific Co. part numbers for the capstan springs are as follows:

PSA-1 (1801613)

PSA-3 (1801614)

Pacific Scientific is effecting corrective action with the spring manufacturer, the nature of which is not yet fully established.

Recommendations

At your earliest convenience, return the affected snubbers to Pacific Scientific for inspection.

Inspection will include removal of spring to facilitate examination for tang cracks by use of magnetic particle or liquid penetrant non-destructive examination.

Urgency of inspection is to be assessed by individual owners based on snubber system application and analysis of results of tests conducted on failed snubbers and reported herein.

Affected Serial Numbers

PSA-1 Pacific Scientific Part No. 1801102-05

S/Ns 15672 thru 16921
18211 thru 21160
21411 thru 22060
22311 thru 22710

PSA-3 Pacific Scientific Part No. 1801106-05

S/Ns 21311 thru 21610
24311 thru 25310
25361 thru 25960
27194 thru 28543