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FAILURE ANALYSIS OF ROLLER CHAIN DRIVES.(U)
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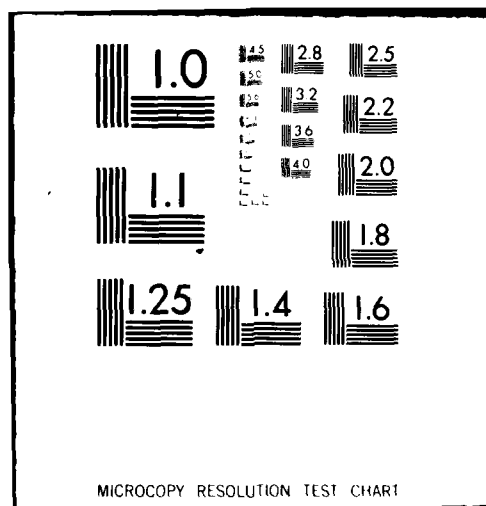
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Results from the NAVSEA sponsored task to analyze failures of a roller-chain drive are reported. Several unexpected failures had occurred after relatively short exposure to sea water. This led to an inspection of the broken parts and fracture surfaces in an effort to determine causes of failure. The static breaking strength and fatigue life of the chain were determined by laboratory tests. Both optical and scanning electron micrographs were used in the analysis. Results show tensile overloading to be the principal cause of failure. However stress corrosion cracking may have reduced the useful life of the case hardened roller-chain pins. Modifications to improve the integrity of the system are recommended.		

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CONTENTS

1. BACKGROUND	1
2. DESCRIPTION OF ROLLER CHAIN DRIVE	1
3. ANALYSIS OF JUNE FAILURE	2
4. ANALYSIS OF JULY FAILURE	3
5. EXAMINATION OF LINKS TESTED BY WESTINGHOUSE	3
6. ROLLER CHAIN TESTS CONDUCTED AT NRL	3
(A) Tensile Test Results	3
(B) Fatigue Test Results	4
(C) Bend Test Results	6
(D) Material Properties	6
7. GENERAL COMMENTS	7
8. CONCLUSIONS	9
9. RECOMMENDATIONS	9
10. REFERENCE	10

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FAILURE ANALYSIS OF ROLLER CHAIN DRIVES

1. BACKGROUND

Unexplained service failures in roller-chain drives used by NAVSEA PMS 395 occurred in June and July, 1979. The chains are standard No. 50 roller type with a double-cotter-type connecting pin link, sometimes referred to as the "master link", used to anchor one end to a solid steel block. Failures occurred in the connecting link. NAVSEA PMS 395-All supplied NRL with broken parts from the June failure for tests and examination. Hardness surveys, chemical analysis, and mechanical tests (simulating both static tensile loading and corrosion fatigue) were used. Both new and used chain links were subjected to laboratory test loadings in an attempt to duplicate the service failures.

A second connecting link assembly, which failed in July, as well as later additional in-service failed parts, were also sent to NRL for analysis. Westinghouse conducted various laboratory tests on chain links and the broken parts from some of those tests were also sent to NRL for further study.

2. DESCRIPTION OF ROLLER CHAIN DRIVE

A roller chain is a series of journal bearings connected together by link plates. Chains are made up from alternate roller and pin links. The common bicycle chain is an example of roller chain. The drive chain passes over two sprocket wheels which impose the working load on the chain rollers. The system is pre-tensioned to avoid slack in the drive chain. During each complete cycle in the drive system, every link in the chain undergoes cyclic loading. In the working strand the preload increases by the amount of the working load while the slack strand experiences a corresponding load decrease. Roller chain manufacturers suggest that endurance is increased if the chain is not allowed to go slack.

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3. ANALYSIS OF JUNE FAILURE

It was reported that this chain had been used in sea water for about one day when it failed; about four days elapsed before the failed parts were recovered. The chain is rated for an ultimate of over 6000 pounds, but the load at failure was thought to have reached a maximum of only 4800 pounds. The broken parts were heavily corroded, thus impeding a thorough study of the fracture surface.

A pin of the connecting link fixing the chain to the support block was broken approximately 0.110" from the link plate near the peened end, Fig. 1. Apparently a crack initiated on the tension side, assuming tensile loading of the chain and the associated bending in the pin. No significant pitting or fretting was evident. The pin was noticeably bent at the fractured end. The fracture surface is shown in Fig. 2 with the origin visible at the top of the figure. The pin is martensite with case hardening to a depth of 20 to 25 mils and a surface hardness of 62 to 63 R_C, Figs. 2 and 3. Although post-fracture corrosion obscured fracture surface details at the origin, the case fracture was predominately transgranular, with some small areas of intergranular failure, Fig. 4. The core fracture was completely transgranular. A longitudinal hairline crack was found in the pin extending in from the surface to the interface between the hardened case and softer core, but it was not near the fracture origin. The probable cause of failure is overloading. There is no indication that the pin was substandard in strength or hardness. Surface hardness of the pin was approximately 60 on the Rockwell C scale.

Supporting the overload hypothesis, the other pin in the connecting link was found to be bent and cracked in two places at the cotter pin end but did not separate, Figs. 1 and 5. The two cracks correspond to locations just inside and just outside the end of the roller bushing on the tension side of the pin. The cotter pin, which constrains the link plate, had sheared off allowing the plate to move out and impose high bending stresses on the end of the pin.

An attempt to break open the cracks in the pin resulted in fracture 1/8" from the cracks with a fracture surface varying from transgranular at the surface to somewhat intergranular near the center. The end of the pin was corroded, but this did not appear to aid crack initiation. Again, overloading was the probable cause of cracking in this pin.

4. ANALYSIS OF JULY FAILURE

The pin at the support block end of the connecting link broke near its peened end, about 0.130" inside the link plate. Origin is at a corrosion pit, about 0.0016" deep, on the side of the pin subjected to tensile bending stress when the chain is loaded in simple tension, Figs. 6, 7 and 8. In this case, no permanent bend deformation was evident. The case fracture is intergranular to within a few mils of the origin pit where the surface becomes too corroded to determine the cracking mode. The case hardening depth is 0.020" to 0.025". Probable cause of failure is stress corrosion cracking, with some corrosion fatigue.

5. EXAMINATION OF LINKS TESTED BY WESTINGHOUSE

Five Westinghouse connecting-link laboratory test pin-fractures were examined at NRL. Most pins had intergranular (IG) case fractures, Fig. 9. One pin showed transgranular microvoid coalescence (MVC) plus quasi-cleavage with some small IG areas in the case, Fig. 10. The softer core of the pins showed mixed MVC and cleavage with more cleavage where the core grain size was larger. Most of the failed pins exhibited some degree of bend deformation near the fractured end, though less than was found in the June service failure. Two test pins contained secondary cracks; a single crack in one pin, two in the other. All cracks occurred between center and peened end of the connecting link pin, 0.165" to 0.245" inside the link plate.

The pins had been case hardened to a depth of 0.020" to 0.025". Microhardness decreased from 63 R_C near the surface to 45 R_C throughout the core. The microstructure is martensitic throughout the pins; fine grained at the surface and much coarser in the core. One particular pin had coarser core grains, suggesting a higher heat treatment temperature. Apparently the larger grain size caused no problem.

6. ROLLER CHAIN TESTS CONDUCTED AT NRL

(A) Tensile Test Results

Tensile tests at various rates of loading were conducted in air with the double cotter connecting link loaded between a short chain segment and an end block of mild steel. Results from these tests are shown in Table 1.

TABLE 1. TENSILE TESTS OF ROLLER CHAIN LINKS

TYPE OF LINK THAT FAILED	LOADING RATE (LB/SEC)	STATIC BREAKING LOAD (LB)	REMARKS
New Double Cotter Connecting Link	2778	5250	Failure in pin connecting to steel block
New Double Cotter Connecting Link	1351	4990	Failure in pin connecting to steel block
New Double Cotter Connecting Link	284	4840	Failure in pin connecting to steel block
Used Chain Pin Link	278	5420	Failure near center of pin

One connecting link was immersed in salt water under a tensile load of 200 lb for more than 100 hours without failure. The link was then cleaned in acetone and dried 24 hours before being loaded to failure in static tension at 4400 lb. The fracture was intergranular in the pin case with no obvious corrosion pit. The core failed by transgranular fracture. This breaking load, 4400 lb, is well below the working load of the chain drive in service.

Another connecting link was tested with all the clearance slack purposely pushed to one end of the pins. This was thought to create the most severe bending in the pins. The pin in this test failed in the usual manner at 5000 lb while being loaded at 277 lb/sec. This corresponds well with the data in Table 1.

(B) Fatigue Test Results

Several tensile specimens, that is a short section of chain connected to steel blocks, were cyclicly loaded using a sinusoidal load-time profile at 2 Hz between 600 and 2600 lb of applied load. Results from these tests are shown in Table 2. Note that all but one fatigue failure occurred in the link plate.

Figures 11 and 12 show the type of fracture surface obtained with pins failed through cyclic 3-point bending in the laboratory. These fracture surfaces show the typical fatigue striation markings in the softer core of the pins, but not in the hardened case.

TABLE 2. TENSILE FATIGUE TESTS OF ROLLER CHAIN LINKS

TYPE OF LINK	LOAD HISTORY	REMARKS
Chain Roller Link	A combination of: a) 4550 cycles in air between 600 and 2600 lb at 2Hz b) 4 tensile tests of connecting links to failure c) 17,650 cycles in salt water between 600 and 2600 lb at 2Hz	Failure in link plate
Chain Pin Link	2760 cycles in salt water between 600 and 2600 lb at 2Hz	Failure in pin
Double Cotter Connecting Link	A total of 28,110 cycles between 600 and 2600 lb a) 18,250 cycles in salt water b) 9860 cycles in air	Failure in link plate
Double Cotter Connecting Link	26,390 cycles in air between 600 and 2600 lb at 2Hz - pin in tight-fitting hole	Failure in link plate
Double Cotter Connecting Link	47,070 cycles in air between 600 and 2600 lb at 2Hz - pin in newly drilled oversized hole	Failure in link plate
Double Cotter Connecting Link	46,550 cycles in air between 600 and 2600 lb at 2Hz	Failure in link plate

C. Bend Test Results

The results of a stress corrosion cracking test on a pin from the June failure is shown in Table 3. The 3-point bend test was in a constant displacement machine with the specimen in a covered quiescent 3½% salt solution.

TABLE 3. THREE-POINT BEND TEST ON ROLLER CHAIN PIN

TIME (hr)	LOAD (lb)	MAXIMUM BENDING STRESS (ksi)	REMARKS
0	1000	199	Applied first load
209.2	1200	239	Raised load
209.3	1500	299	Raised load
270.3	1500	298	Gradual load decline
281.1	0	0	Abrupt load drop and fracture after 71.8 hr at 1500 lb load

The fracture surface was intergranular in the hardened case and in the adjacent core where the stress corrosion crack had penetrated, Fig. 13 and 14. No corrosion pit was evident at the origin. General corrosion was obvious from the thick black oxide scale on the pin and a red-orange precipitate in the solution.

Rising load fracture tests in 3-point bending showed one brand of pins to be stronger than another. A faster loading rate produced somewhat higher breaking loads. Generally the fracture strength seemed determined by the properties of the hardened case. A typical load deflection diagram shows a steady rise in the load until the case cracks producing a small drop in load. The load then rises again to a slightly higher peak and drops off as complete failure occurs.

D. Material Properties

Microhardness surveys and metallographic examina-

tions of broken pins indicate normal 1021 steel properties and structure. Such steel has a maximum hardness from water quenching of about 45 R_C. This maximum hardness was obtained in the cores of the pins. The case hardness, 60 R_C to 65 R_C, and hardness gradients were normal for case hardened steel. No metallurgical anomalies were found.

Chips from a chain pin and link plate were sent to a commercial laboratory for chemical analysis. Results which could be obtained from the relatively small amounts of chips are presented below in Table 4.

TABLE 4. CHEMICAL ANALYSES OF LINK PLATE AND CORE OF PIN

ELEMENT	% BY WEIGHT	
	LINK PLATE	CORE OF PIN
Carbon	0.58	(*)
Sulfur	0.024	(*)
Phosphorus	(*)	(*)
Manganese	0.72	0.96
Silicon	0.18	(*)
Chromium	0.06	0.03
Nickel	0.06	0.05
Molybdenum	0.02	0.01
Copper	0.02	0.09
(*) Insufficient sample to perform determination for these elements.		

The analyses indicate that the pins were probably manufactured from a carbon steel, possibly 1021 steel. The chemical analysis of the link plates corresponds to 1060 steel.

7. GENERAL COMMENTS

Figures 1 through 14 show several broken parts and corresponding fracture surfaces. Regarding fracture appearance, the failures initiated at the surface of the hardened case of the various pins. The case hardened region generally exhibited intergranular fracture, with only a few transgranular fracture areas. The core fractures were always transgranular except under SCC conditions, Fig. 13. Stress corrosion failures are usually intergranular in such hard high-carbon material, so transgranular case fractures indicate other than stress corrosion failures. The broken pin from the June failure is severely corroded on the fracture surface so that it is difficult to characterize the separation; however, the overall appearance of the fracture and the degree of

plastic deformation of the broken pin indicates a simple overload fracture. The broken pin of the July failure, however, shows intergranular fracture at an origin in the case associated with a corrosion pit. The pin is not deformed. These facts indicate crack initiation from a stress corrosion crack.

Striations would not be expected in the hardened case under fatigue conditions, but such fatigue markings are observed in the core of pins broken in laboratory fatigue tests. No striations were observed in the core of either of the in-service pin failures.

Test results do not show that the June pin was in any way defective; in fact it is unusually strong. The other pin from that connecting link was also deformed enough to crack the case but not the core. When tested, this pin proved weaker than the new ones, but still not exceptionally brittle since the case fracture is partly transgranular.

Longitudinal cracks were found in the case of many pins but did not seem to contribute substantially to pin failures. Numerous other short, superficial, circumferential gouges appeared on all the pins and were apparently left by machining tools. Since these gouges are oriented in such a manner as to be crack initiators under bending stress, they cannot be viewed as harmless.

Almost all laboratory fatigue failures occurred in the link plates and not in the pins. The service failures examined are all in the pins. This as well as the absence of striation markings in the service failures leads us to believe that fatigue was not a problem in the service application. On the other hand, all tensile overload failures in the laboratory duplicated the pin type failures experienced in service.

The condition of the hole in the block to which the connecting link is attached may be important. After several tests, the hole in the mild steel block became slightly beveled at the block surface. It was felt that this condition caused a reduction in the breaking load. An oversized hole with straight parallel sides did not seem to affect the breaking load. Although not enough carefully controlled data is available to confirm this, it would seem important to keep the hole sides straight and parallel so that the case hardened pins are loaded primarily in shear, with the bending stress kept to a minimum.

8. CONCLUSIONS

The June 1979 failure may have initiated in either pin of the connecting link. There is some question as to whether the severe bending in the one pin could have occurred with the other pin supporting its share of the load. Neither stress corrosion cracking nor fatigue are indicated. Both pins were obviously overloaded.

The July 1979 failure resulted from fracture of the pin in the anchoring block and was probably initiated by stress corrosion cracking.

Increased rate of loading has a small positive effect on breaking load of both chain assemblies and individual pins.

Several chain assemblies failed in laboratory tests at loads near or below the designated working load.

9. RECOMMENDATIONS

Implementation of one or more of the following recommendations should increase the useful service life of the drive chain mechanisms.

- a) Replace the case hardened 1021 pins with pins of greater resistance to stress corrosion cracking, such as MP35N stainless steel.
 - b) Provide better surface finish of the pins to reduce circumferential surface gouges which serve as crack starters.
 - c) Replace the anchoring block when the hole becomes worn. This would minimize bending stresses in the connecting link pin.
 - d) Use a larger, thus stronger, size of chain or adjust system to reduce loading on present chain.
- 3) Use a commercially available stainless steel chain to reduce the corrosion problem. However, the lower rated load for such chain would necessitate an even greater reduction in loading if the present chain size is maintained.

10. REFERENCES

"Failure Analysis of Drive Chain," Letter Report (8430-475:FRS:bjb), addressed to Commander, Naval Sea Systems Command, Attn: PMS 395-All, D. J. Chalupka, dtd 13 September 1979.

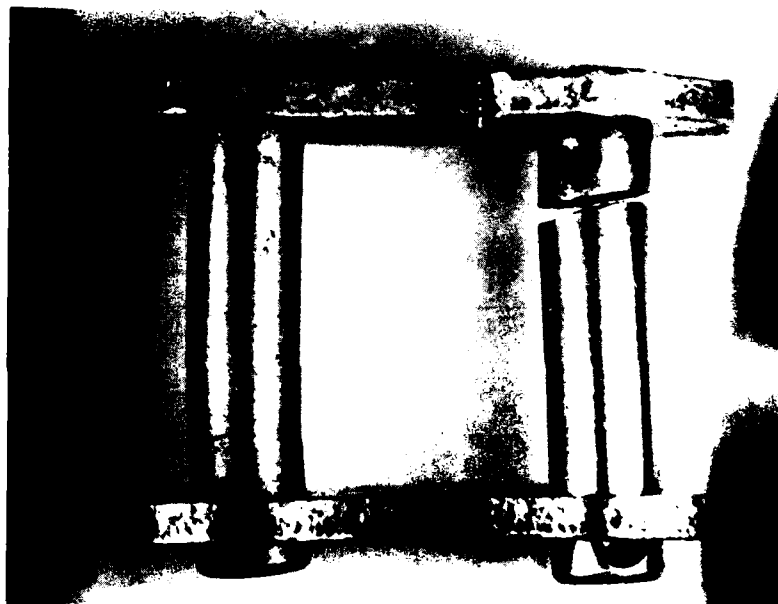


Fig. 1 — The double cotter type connecting pin link which failed in June 1979. Note the bending in the fractured pin. Note the indentation and cracks near the end of the other pin. This was an in-service failure photographed at 3.5X.



Fig. 2 — This SEM macrograph of the fracture surface from the June failure shows the fracture origin (see arrow). Depth of the core hardening can be inferred to be 0.020 in. to 0.025 in. from the fracture appearance. (16X).



(a) Fine martensite in hardened area 0.006 in. from the pin surface. Small indent connotes high hardness.



(b) Coarser martensite in core of pin. Larger indent connotes lower hardness.

Fig. 3 — Polished and etched cross-section of the June failed pin shows structure and microhardness indents. (1000X).

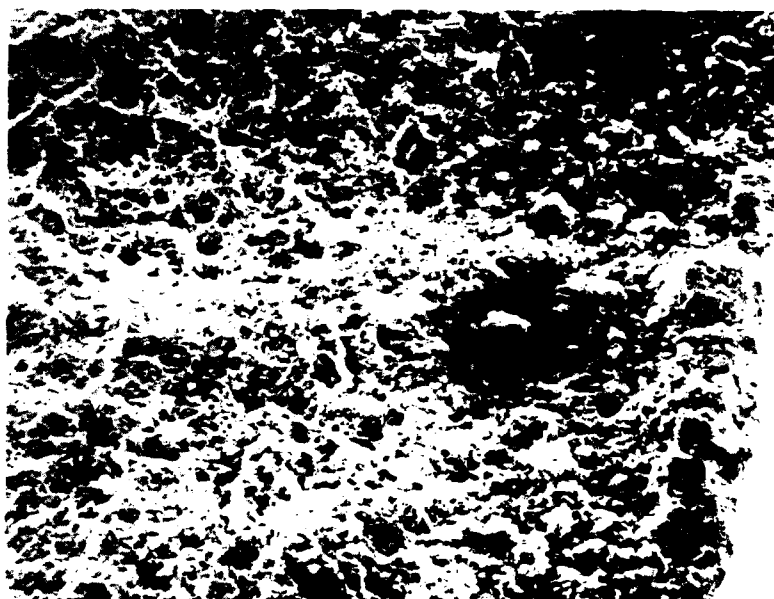


Fig. 4 — SEM micrograph of fracture surface on broken pin from June failure. The overall appearance suggests transgranular fracture, although the post-fracture corrosion and pitting near the origin make this uncertain. (500X).

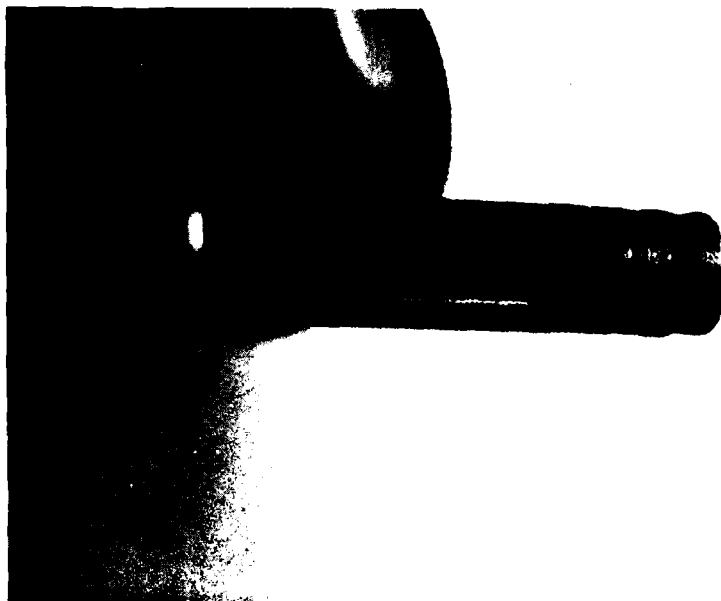


Fig. 5 — The non-fractured, bent and cracked pin from the June failure. Fretting corrosion is evident around the cotter pin and two cracks are visible on the side of the pin subjected to tensile bending stresses. (4X).

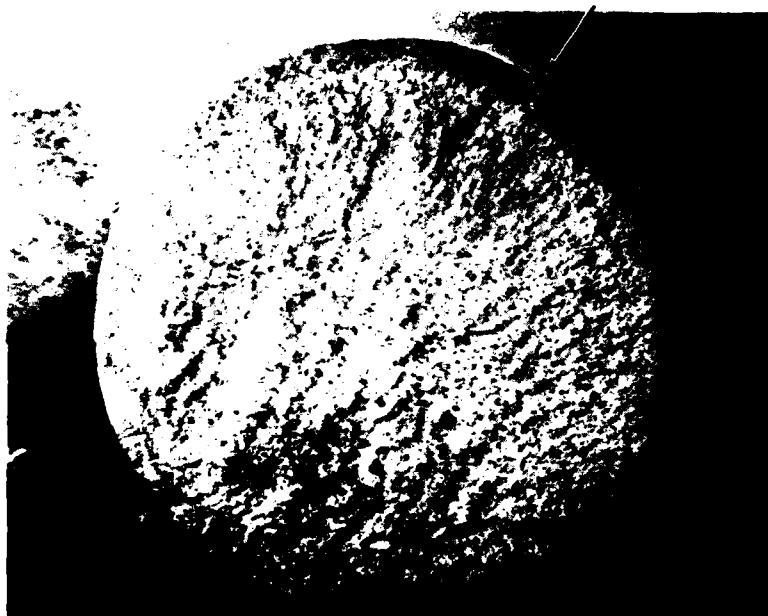


Fig. 6 — Macro photograph of fracture surface of pin from the July failure. The fracture origin is indicated by the arrow and is associated with a pit existing before the crack initiated. (16X).

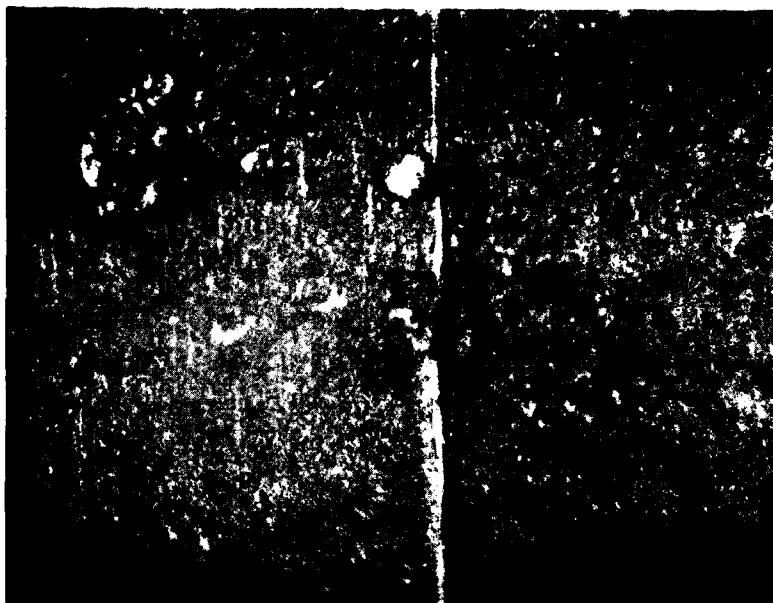


Fig. 7 — Reassembled matching halves of the broken pin from the July failure, showing the corrosion pit on the surface at the fracture origin. This indicates that the pit existed before crack initiation. (60X).

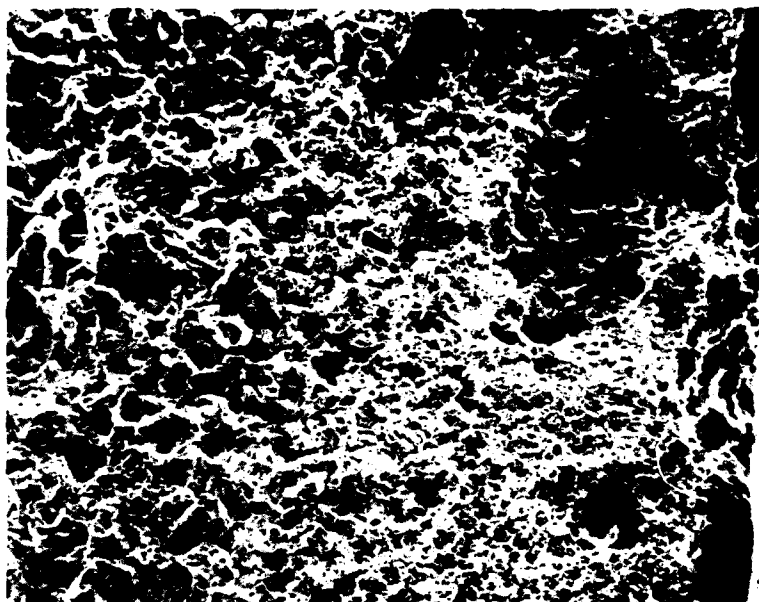


Fig. 8 — SEM micrograph of the fracture origin on the pin from the July failure. Note corrosion pit at surface, corrosion damage on fracture surface near origin, and intergranular fracture in hardened case where not damaged by corrosion. (250X).

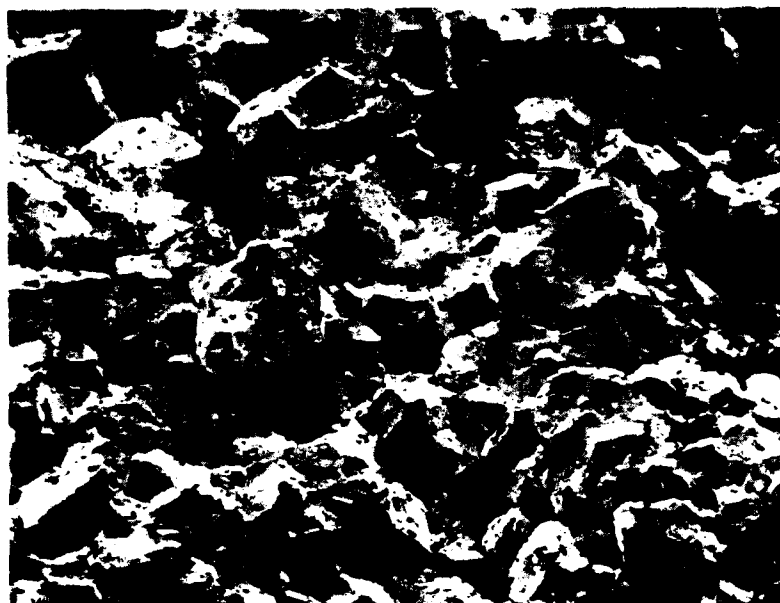


Fig. 9 — SEM fractograph of a pin broken in test by Westinghouse, showing the typical intergranular fracture in the hardened case area. (500X).

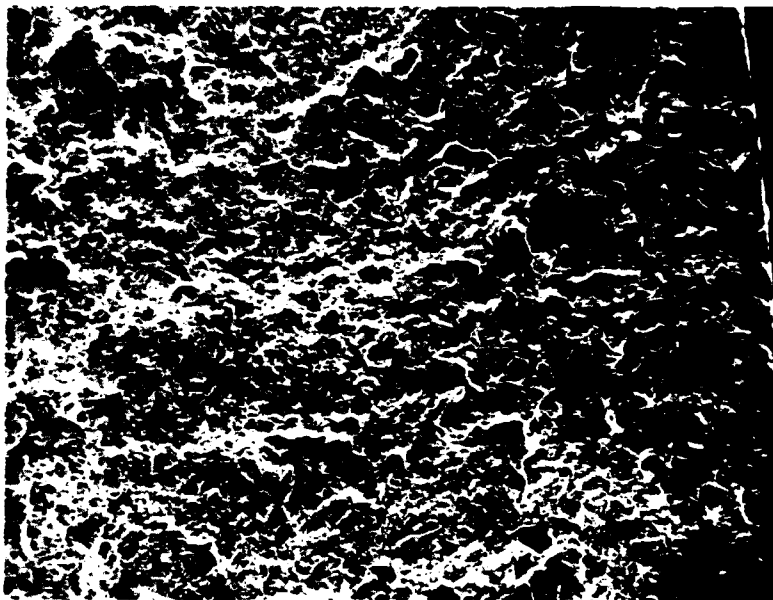


Fig. 10 — SEM fractograph of a pin broken in test by Westinghouse, showing the less common transgranular fracture near the hardened surface. (250X)

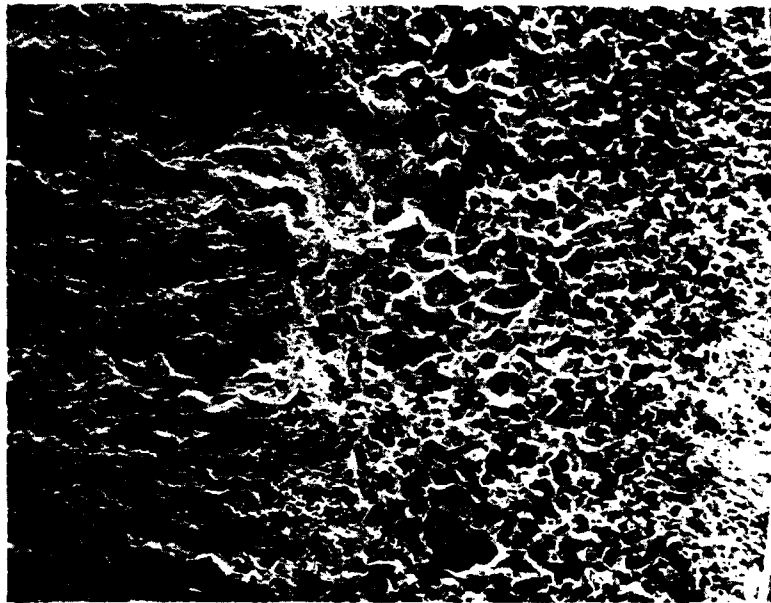


Fig. 11 — SEM fractograph of pin failed by fatigue in air, showing mixed intergranular and transgranular cracking in the case with typical “fatigue markings” in the core. (150X).

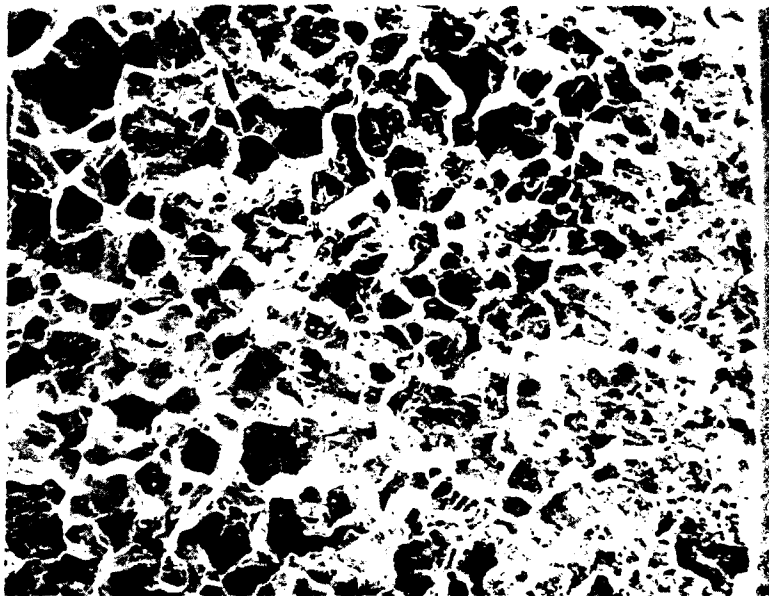


Fig. 12 — A higher magnification of the case area from Fig. 11, showing a mixture of intergranular and transgranular fracture. Transgranular fracture is more prominent near the pin surface. This is similar to what one would expect with corrosion fatigue. (500X).



Fig. 13 — Macrograph of stress corrosion cracked pin tested in 3 point bending. The fracture origin area is near the top of the figure. Intergranular cracking goes well into the core in some spots. (12X).

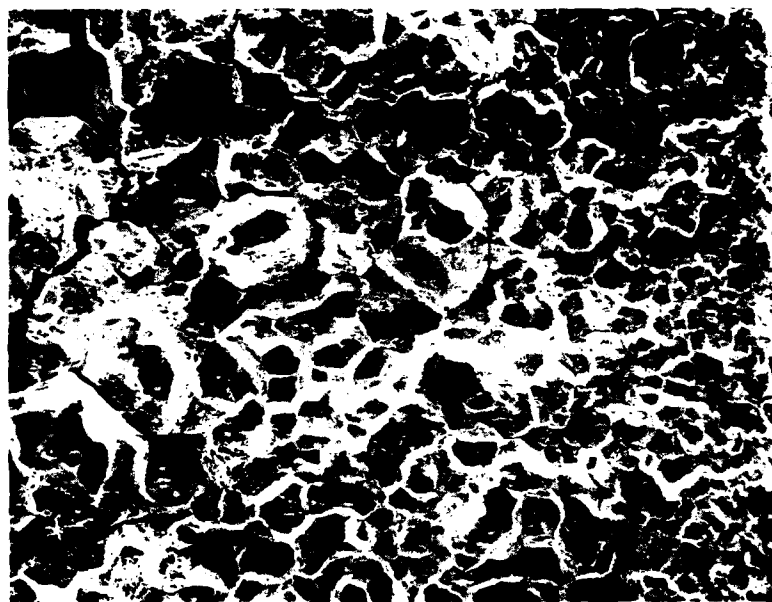


Fig. 14 — A higher magnification fractograph of origin area shown in Fig. 13, showing mixed mode fracture in the smaller grains near the surface and intergranular fracture in the larger grains further into the case. The secondary cracks resulted from acid cleaning of fracture surface. (250X).