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G. P. Fritzke
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STRESS-CORROSION CRACKING OF ION EXCHANGE RESIN TANK AT SLAC

Introduction

To my knowledge, the failure of a 316 stainless steel ion-exchange resin tank is the first documented instance of a stress-corrosion failure at SLAC. The circumstances surrounding this incident and the implications for the future are serious enough to warrant some attention being drawn to the common causes of stress-corrosion failures and their potential at SLAC.

The basic research to determine the causes for stress-corrosion cracking (SCC) failures in the austenitic (300 series) stainless steels has filled volumes, but the true mechanism is elusive and still hypothetical. There is much known, however, about the conditions necessary for SCC to occur. The most important conditions are that a halide (most commonly chlorine, or a chloride, which is more active than the other halides — iodine, fluorine, and bromine) be present and that the part be under some tensile stress. There has been no minimum chloride content established, but oxygen must be present in the solution. Minimum stresses of 1000 psi have caused cracks in test sections. Temperature is also a factor with the incidence of cracking increasing as the temperature rises. Cracks in test specimens have been observed at 40^{o}C. All of these minimum factors have been observed when the other conditions are maximized, however. For instance, the low temperature tests incorporated U-shaped specimens bent through yield and therefore containing both plastic and elastic strains, and the chloride content was very high and test times long. So, for failure to occur at any of these minimum conditions, the other conditions are usually severe and obvious. This last statement is emphasized to minimize the fears that all stainless steel parts will catastrophically fall apart if someone spills a salt shaker in the beam switchyard on a rainy day.

Ion-Exchange Tank Failure

What amounts to an "almost catastrophic" failure did occur to one of two large ion-exchange tanks located in the yard just east of the DAB. This tank was fabricated of 316 stainless steel and had been installed in the latter part of

1965. The tank was charged with about 35 cubic feet of mixed-bed ion-exchange resin containing about sixty percent by volume of anion resin and about forty percent by volume of cation resin. Good low-conductivity (5 micro mho) water had been obtained from this tank until late October, 1970, when the tank was by-passed and removed from the system for cleaning of copper that had built up on resin beads and the inside surface. The copper came from magnet windings and small-instrument cooling lines. The treatment to remove the copper included putting a four percent hydrochloric acid solution in the tank at ambient temperature for about three days. There was no leak evident when the acid was flushed from the tank. About two months later, however, when some new resin was placed back into the tank and the tank was filled with water and pressurized to reach end station system pressure, a leak showed up in a crack near a welded flange in the tank bottom.

This flange had been installed after the tank had been fabricated and was intended to act as a cleanout and inspection hole. The dished bottom of the tank was quite severely distorted in this area by the considerable shrinkage stresses of the heavy weld. The distortion was enough not only to flatten, but also to form a slight reverse curve in the tank bottom in this area.

The cracked section was cut out and metallographically examined for the cause (s) for failure. Although stress-corrosion cracking was suspected at this time, a simple external examination could not distinguish SCC from a fracture due to over-stress. Only a metallographic examination could delineate between the two fracture modes.

Metallography

Microscopically, a ductile, or tearing fracture will be oriented approximately 45° to the surface of a fracture. Brittle fractures, even in such a ductile material as 316 stainless steel, can, if properly restrained, propagate at angles close to 90° to the surface of the material. Such a brittle fracture will have many of the macro-characteristics of a stress-corrosion crack which also will propagate at right angles to the surface. A stress-corrosion crack, however, is further characterized by the many branching cracks that occur with this type of failure and none other.

Figures 1 through 8 illustrate the nature of some of the cracked regions found in this tank. All cracks were closely associated with the base of the inside weld (the area of maximum shrinkage stresses) and the cracks were seen to propagate from the inside (where the chlorine and oxygen solution was) to the outside.

Figure 1 shows the start and Fig. 2 the end of a typical crack. When the crack was examined in the field, the tank shell was bowed out and away from the inside of the tank and Fig. 2 illustrates this fact. The geometry of the fitup is such that the tank head could only move in an outward direction caused by the internal pressure of the LCW system. The region marked "Ductile Region" probably tore as system pressure was being applied. The position of this metallographic specimen is near, but not at the original fracture site. The original site probably has some undercutting by the weld bead which would provide an enhanced stress-concentration factor. Figure 3 is a higher-magnification picture of the ductile-fracture area seen in Fig. 2, and clearly shows the numerous branched cracks typical of stress-corrosion cracking. The specimen, at the microscope, and the original photomicrographs show many thin slip lines that parallel the cracks but these may not reproduce well in this report. Slip lines are seen in stainless steel that has been severely overstressed. These lines appear only in the region of the crack. Many other samples from around the tank section and at some distance from the crack were examined and none contained slip lines.

Figure 4 was obtained next to Fig. 3 and illustrates the branching nature of the crack, as well as numerous slip lines running parallel to the crack.

Figure 5 was obtained in the region where the crack was about to emerge from the weld area seen in Fig. 1. Branching is visible here, too, as it cuts across the two-phased region of "delta ferrite" envelopes surrounding the austenite. This small amount of ferrite, present in all good stainless steel welds, is magnetic and has corrosion resistance equal to the austenite.

Three more photomicrographs, from a different area, further illustrate these characteristics of stress-corrosion cracking. Figure 6 shows the many branches of a crack as it terminates in a weld. Figure 7 again illustrates the slip lines that accompany an overstressed section of stainless steel and Fig. 8 shows some side cracks branching from the main crack. The transgranular aspect of this failure mode is shown plainly in this last photo.

Discussion

The foregoing photomicrographs show conclusive evidence that this failure was by a stress-corrosion cracking mode. Apparently, the high chloride concentration and high stress were sufficient to produce a crack at ambient temperatures and the short time available during the cleaning procedure. (Although the hydrochloric-acid solution was in contact with the stainless steel for about 70 hours, small cracks started by stress-corrosion or crevices in the weld-bead area could store chloride solution, in spite of the many rinses. Therefore, some 60 days (≈1500 hours) may have been the approximate exposure time, instead of only 70 hours.)

Even though branched-cracking is evident, there are only a few branched cracks by comparison with the stress-corrosion cracks cited in the literature. The presence of such a few cracks further bears out the large influence of stress upon the cracking, since failure occurs with a few cracks, and in a shorter time, when the stress level is high.

Installation of a welded flange in such a flexible member as the tank head produced a very highly stressed region. A stress relief anneal could have prevented this failure.

The observations made above are only a few of many that could be made, but enough observations are presented to illustrate the effectiveness of metallography as an investigative tool. Unfortunately, as many people know who have come to me with problems, metallography can be as destructive to a part as it is informative to the requester. For this investigation, metallography was the only unequivocal tool that could determine the cause of failure.

Recommendations

Any source of chloride solutions in stainless steel systems is always a potential source of problems. Initially, chlorides tend to "depassivate" (remove the protective oxide layer that make stainless steels so corrosion resistant) the surface and then provide a constant threat of stress-corrosion cracking where chloride is allowed to reside. Unfortunately, the same crevices that provide the harbor for chlorides many times act as a region of high stress if notch factors are considered. Thus, the vicious circle starts — surface depassivation, stress-corrosion cracking to produce new surface and increased stress, a sharp crack tip, stress concentration, a smaller cross section and on and on until failure finally occurs.

So, a general recommendation for any critical component made of stainless steel is to say away from chloride-bearing salts, solvents, and solutions. Piping systems especially have numerous highly-stressed weld-neck flanges that are welded only from the outside, and thus provide a perfect crevice at the inside surface.

By the way, all common construction materials fail by stress-corrosion cracking. Some of these combinations are:

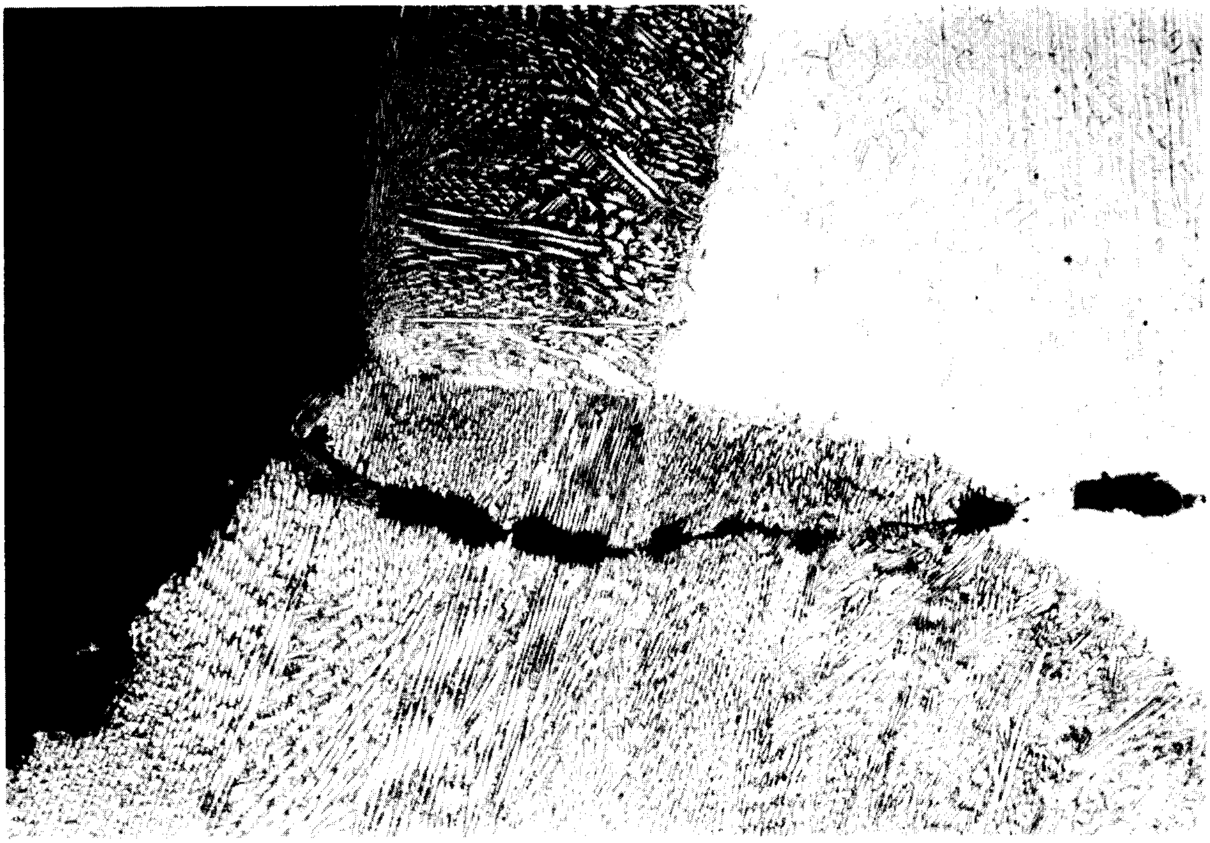
carbon steels	by hydroxides
stainless steels	by chlorides
copper base alloys	by sulfates, chlorides and ammonia
aluminum base alloys	by chlorides

References

1. H. H. Uhlig, Corrosion Handbook (Wiley and Sons, New York, 1948).
2. F. L. LaQue and H. R. Copson, Corrosion Resistance of Metals and Alloys (Reinhold, New York, 1963).
3. L. L. Logan, The Stress-Corrosion of Metals (Wiley, New York, 1966).
4. Proceedings of the Second International Congress on Metallic Corrosion, National Association of Corrosion Engineers, Houston (1966).
5. M. G. Fontana, Corrosion, A Compilation (Hollenback, 1957).
6. U. R. Evans, The Corrosion and Oxidation of Metals (St. Martin's Press, New York, 1968).
7. L. L. Shreir, Corrosion (Wiley and Sons, New York, 1963).
8. N. D. Tomashov, Theory of Corrosion and Protection of Metals (MacMillan, New York, 1966).

FIGURES

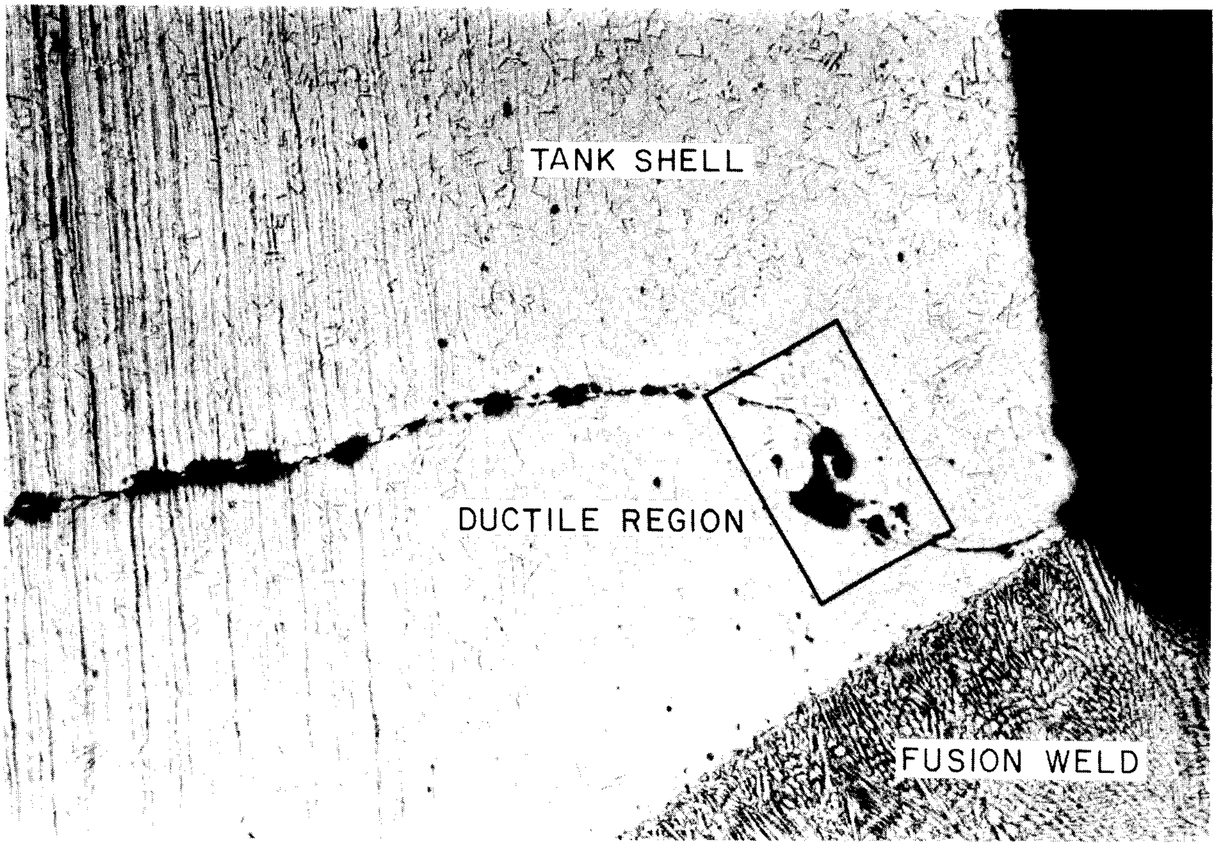
Number	Photo Number	Magnification	
1	HZ-34	85X	Start of stress-corrosion crack at inside surface of tank
2	HZ-36	85X	End of stress-corrosion crack at outside surface of tank
3	HZ-45	680X	Typical branched cracking characteristic of SCC — note slip lines
4	HZ-44	680X	Branched cracking and slip lines
5	HZ-41	340X	Branched cracking in weld area
6	HZ-56	680X	Branched cracking and slip lines near outside surface of tank — Region 2
7	HZ-61	340X	Branched cracking emerging at outside surface of tank — note slip lines
8	HZ-62	680X	Transgranular branch cracks adjacent to main crack



85X

HZ-34
1862A1

Fig. 1



85X

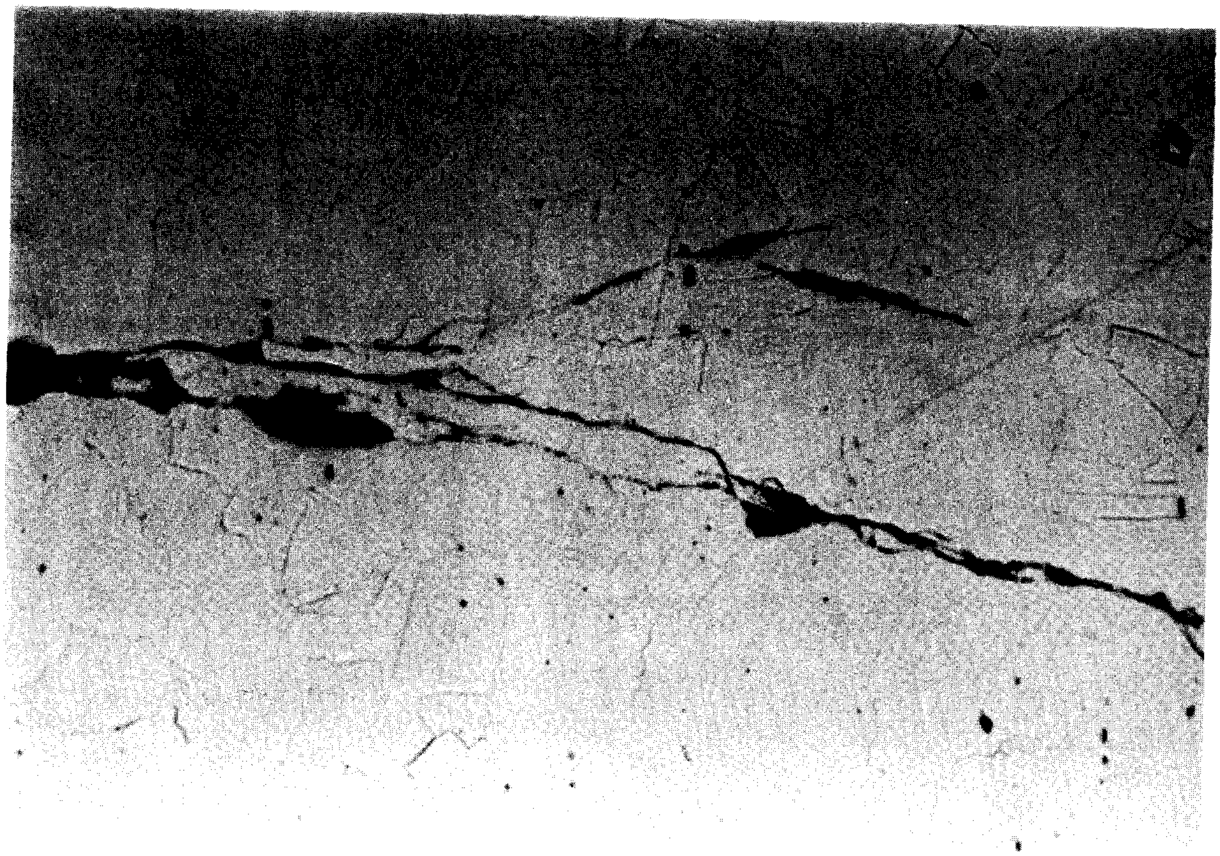
HZ-36
1862A2

Fig. 2

680X

HZ-45
1862A3

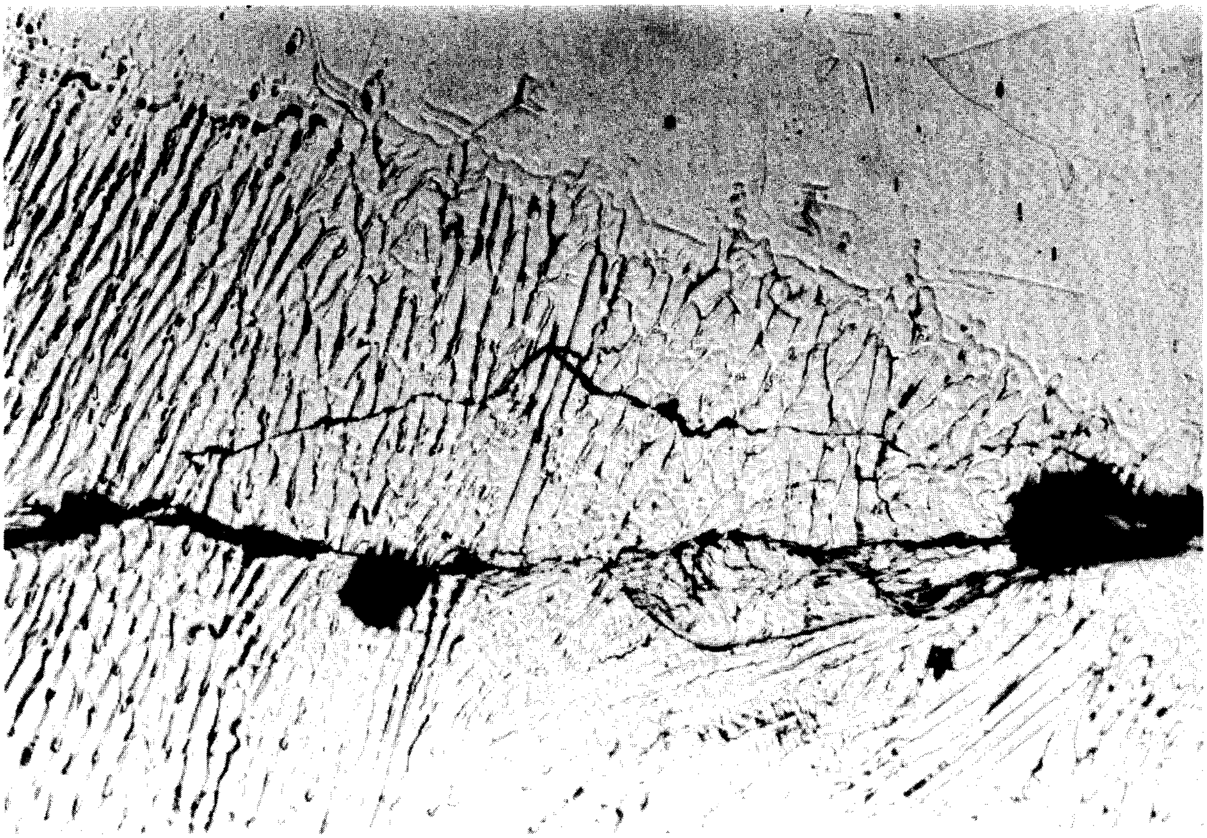
Fig. 3



680X

HZ-44
1862A4

Fig. 4

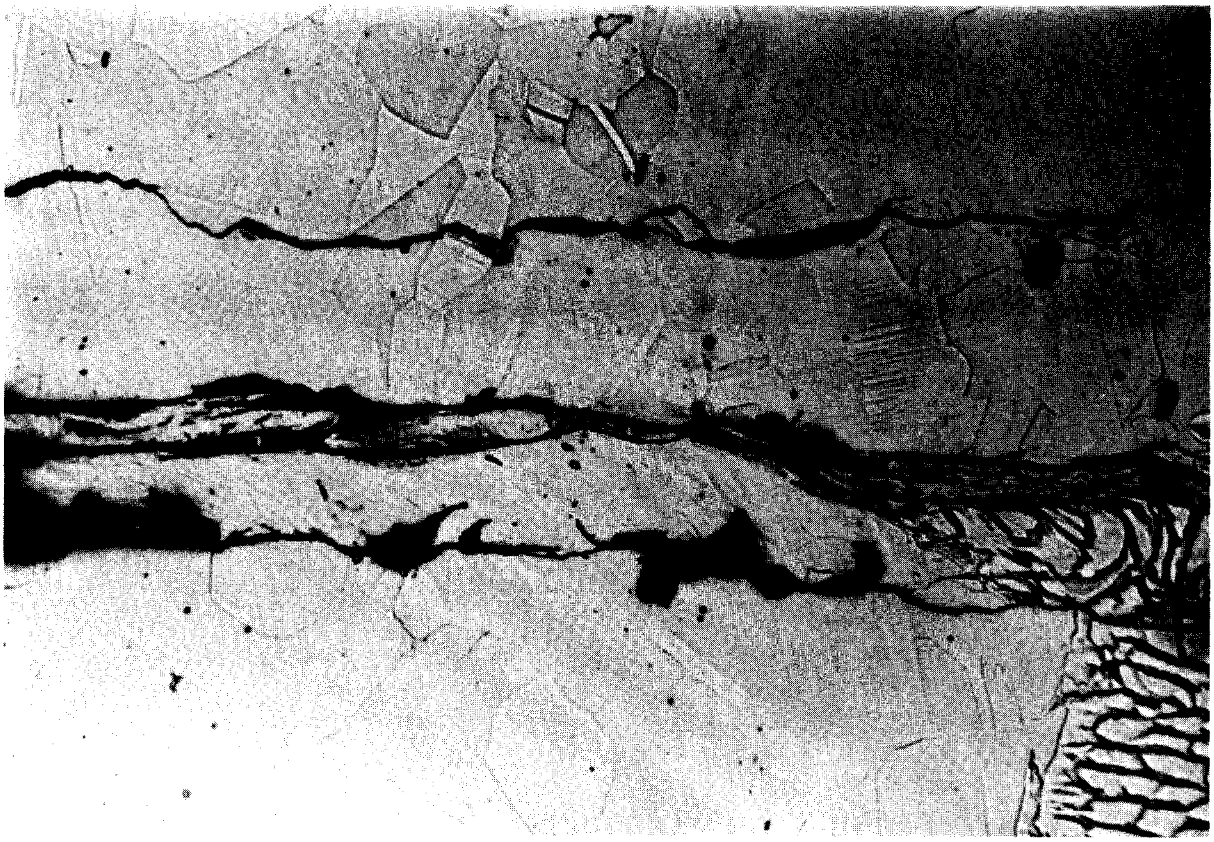


340X

HZ-41

1862A5

Fig. 5

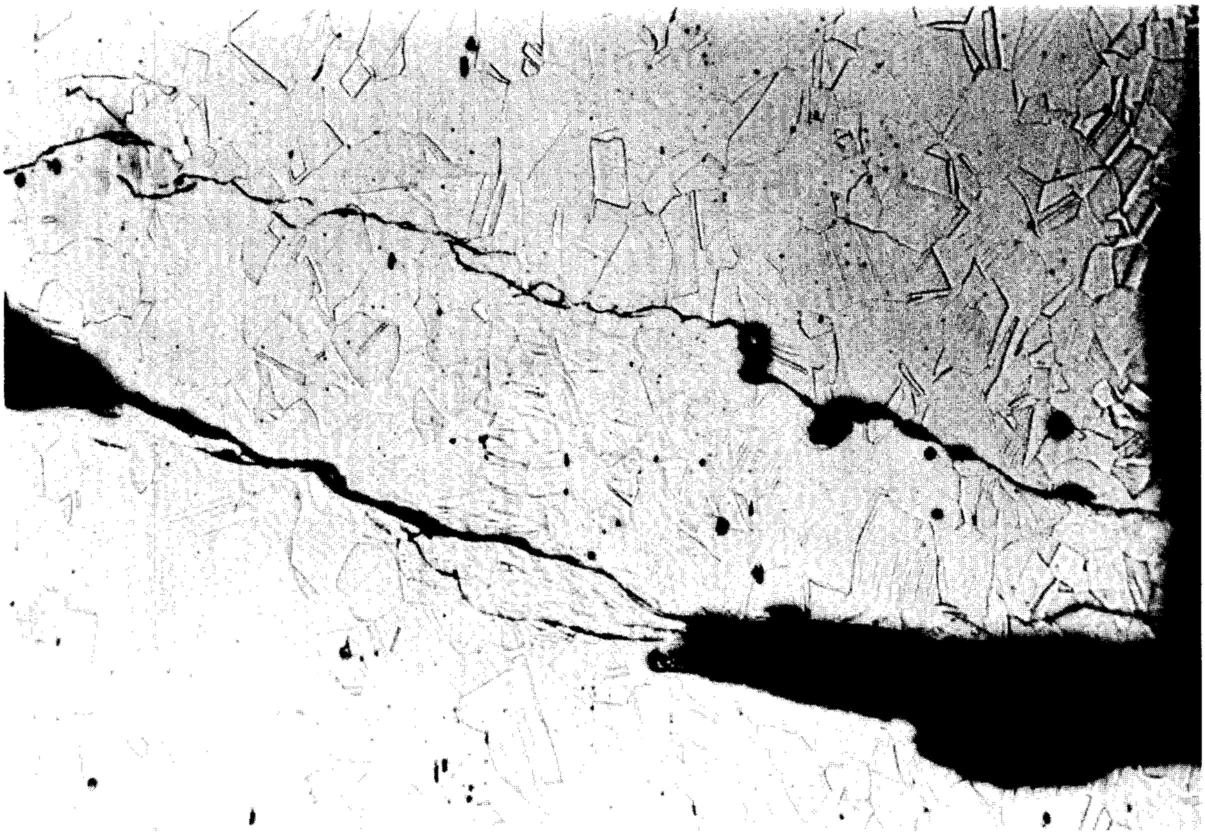


680X

HZ-56

1862A6

Fig. 6

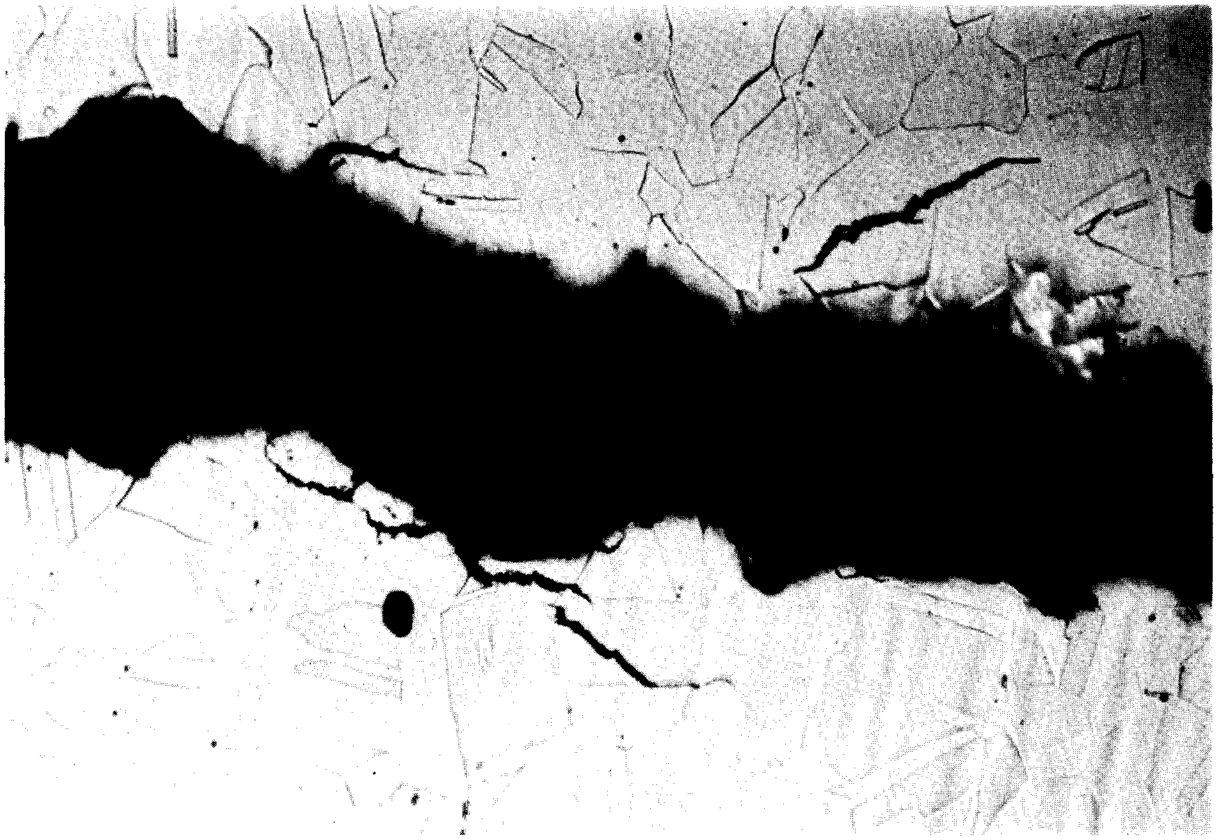


340X

HZ-61

1862A7

Fig. 7



680X

HZ-62

1862A8

Fig 8