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Descriptors

TARAPUR-1 REACTOR

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VALVES

FRACTURES

STEEL-CR17CU4NI4NB-1

CORROSION FATIGUE

CRACK PROPAGATION

INTERGRANULAR CORROSION

SURFACES

OXIDATION

METALLOGRAPHY

MICROSTRUCTURE

ABSTRACT

Failure analysis was carried out of a failed 17-4 PH stainless steel stem of the valve disc in reactor recirculation system of Unit-1 of Tarapur Atomic Power Station. The examination revealed that the stem failed due to fatigue, accelerated by corrosion. Recommendations have been made to avoid such failures.

FAILURE INVESTIGATION OF STEM OF VALVE DISC IN REACTOR RECIRCULATION SYSTEM OF TAPS UNIT-1

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1. INTRODUCTION

A failed portion of the stem of motor operated valve MOV-1404 was received at Radiometallurgy Division, BARC for failure analysis. This stem, during service, had been operated for moving a valve disc while opening and closing the motor operated recirculation valve MOV-1404 in loop B of TAPS Unit 1. The location of failure is given in fig. 1. The stem was made of SS 17-4 PH in H 1100 condition.

2. BACKGROUND INFORMATION

From the information received from TAPS, it was observed that as per procedure TAPS N-1319-S-440-Annexure-9 for effocient closing of the valve, an over travel of valve disc was necessary. Thus the valve stem movement was about 9 mm more than the acceptable normal position. The valve disc would suffer thermal binding due to constituted problem of over travel and cooling down of valve resulting in binding of valve disc between the body seat openings while trying to withdraw (fig. 2). The valve stem would thus experience compressive stress and torsional stress during closing and tensile stress and torsional stress during opening of the valve.

The chemistry of the water flowing through the valve was exactly that of reactor water and the water temperature was 280°C. The recirculation loop B of the reactor does not have the 6" bypass line across the valve MOV-1404. This bypass line had been cut off and blanked due to leaks on this caused by IGSCC. This modification had been done about 2 years before the failure of the stem of MOV -1404.

The failure of stem of MOV-1404 occured during functional test on the loop . The valve had been closed during the test and while opening the valve , it was observed that the stem had separated from the valve disc. The stem had severed at the root edge to back seat region. The wedge disc was found binding on the valve body between the seats. Inspection of the valve body seating area did not reveal any abnormal scratch marks or damage and seats were seen to be perfectly matching. The disc seemed to have over travelled by about 9 mm, as seen from the markings.

At first the broken piece of the stem from the disc side was received at Radiometallurgy Division, BARC for failure analysis. On request the other broken portion of the stem along with 10 inches long material was also obtained for analysis.

3. FAILURE EXAMINATION

The failed stem was subjected to visual and metallographic examination.

3.1 Visual examination

Since the failed portion (disc side) showed a dose of 6 R/hr on contact visual examination of it was carried out in a hot cell using wall periscope. The fracture surface was sliced off from the piece along with the root and backseat portion (about 1 cm thick) and the piece was examined under a stereomicroscope. Since the piece after slicing had shown a dose of about 2 R/hr, it was further sliced into four quadrants and decontaminated to remove all loose contamination. The particulate contamination was brought down to quite low levels and the dose at 1" distance was around 100 mR/hr in each quadrant piece.

A composite picture of the failure surface (disc side) is given in fig.3, as obtained under a periscope. Visual examination, using a periscope and a stereo microscope, revealed that the failure had taken place in two stages. The peripheral part of the failed surface had the tell tale striation markings of failure due to fatigue with multiple initiation sites at or near the periphery. The final failure had occured at the inner region of the failed surface under tensile/torsional stress. The lip seen at the inner region of the failed surface (fig.3) corresponding to the second stages of failure, indicated that the stem material had limited ductility. There was no necking or dimensional change in any part of the stem and the failure was essentially of brittle nature. At higher magnification under the stereomicroscope, it was observed that there was evidence of signficant corrosion on the failure surface. It was felt that microscopic details on the failure surface had been corroded off. Thus a metallographic examination was essential to get microscopic details of the failure.

3.2 Metallographic Examination

A 2 mm thick piece was sliced off from one of the quadrants (as shown in fig.3) for metallographic examination. The slice was further cut into 3 metallographic specimens, the axial surface of which were examined in polished as well as in etched condition. The metallographic observations supported and confirmed the observations made during visual examination.

Metallographic examination of the back seat surface in specimen 1 (fig.3) showed that there was no stellited portion or any such abresion resistant layer on the back seat portion. The back seat surface had an oxide layer almost uniform in thickness . The average thickness of the oxide layer was about 4 microns (fig.4), though at certain regions the thickness was as much as as 20 microns and there were isolated locations having dents at the edge. At two locations on the outer edge of the back seat surface, there were intergranular micro cracks filled with oxide layer (fig.5). The micro cracks penetrated into the material to the extent of 3 to 4 grains of the prior austenite region.

The propogation of the failure at the fractured edge was transgranular and non-branching. The fractured edge showed the presence of a tenacious oxide right from the outer edge near the back seat surface. The thickness of the oxide layer varied considerably from the outer surface towards the axis of the stem. At certain regions it was as thick as 10 microns and up to a distance of 10mm from the outer surface of the stem, this oxide layer had an average thickness of about 3 microns. After a distance of 13.5 mm from the outer edge the oxide layer became non existent(fig.6). The region with no oxide layer on the failed surface extended upto the centre of the stem cross section. Let us designate the region with oxide layer on failure surface as Region A and that without oxide layer as Region 8. Region A accounted for about 30% of the radius in the metallographic specimen examined. Region A did not show any secondary cracking whereas region 8 showed about 4 number of secondary cracks transgranular in appearance and spreading in a direction perpendicular to the main crack propagation (fig.7). The secondary cracks had tenacious oxide filling them.

The microstructure of the material is shown in fig.8. It mainly showed transformed mantensite with prominently seen prior austenite boundaries which had extensive precipitation indicating effects of overaging typical of H 1100 material of 17-4 PH steel. There were ferrite stringers in the material, the size and distribution of which varied from periphery to centre of the stem, which is also typical of 17-4 H steel bars of larger diameters. Microhardness measurements were carried out on the specimens. The hardness was uniform throughout the material of value around 462 VHN. The fracture edge had a brittle appearance.

4. DISCUSSION

17-4 PH steel is a material highly sensitive to heat treatment. Hence, the variation in microstructure with regards to ferrite distribution and precipitation between the peripheral region and centre region of the larger section was seen, as expected. The microstructure observed is typical of H 1100 aged material. Though the material has superior strength properties, it is quite vulnerable to crack propogation once the crack has been initiated. The hardness of the material (462 VHN) is also on the higher side.

The observations made during metallographic examination support and confirm the observations made during visual examination of the failure surface. The region A of the failure surface (fig.6) having tenacious oxide layer is suggestive of the fact that this portion of the failure occured at an early stage in a relatively slow mode. The region B having no adherent oxide layer (fig.6) is indicative of the fact that this portion of failure occured fast after which the stem was not exposed to the in-service oxidising environment for a considerable time which could produce a tenacious oxide layer. The tenacious oxide layer on Region A is almost as thick as that on the outer surface, suggesting that an equilibrium oxide layer had been produced on outer surface as well as on the Region A. The crack propagation in the stem is transgranular and non-branching, which rules out the possibility of the stem failure being due to SCC. The secondary cracking observed in Region B is indicative of fast crack propagation in a brittle material. These evidences all point towards a fatigue failure in the peripheral Region A followed by fast fracture in the inner Region B due to over loading by the high tensile and torsional stresses generated by the driving motor on the stem, as the valve disc lay thermally bound between the body seat openings due to over travel and cooling down of the valve.

The fatigue crack propagation could have been caused by some process of vibration caused in the stem-disc assembly. The reactor water environment caused corrosion of the material of the stem as indicated by the adherent oxide layer. It has been reported that high strength steels like 17-4PH are highly susceptible to corrosion fatigue . The corrosive environment around the stem could have accelerated the fatigue crack propagation in it.

The various factors responsible for initiation of the fatigue cracking are surface and subsurface flaws in the material, asperities or notch effects generated in the material during cycling loading etc.(2) During the present investigation no serious surface flaws were observed in the stem which could be attributed to manufacturing or handling defects. This indicates that the flaws responsible for initiation of stage I of fatigue cracking are likely to have been generated during operation. The significant defects observed on the back seat region of the stem were intergranular micro cracks filled with oxide deposit (fig.5) originating on the outer surface and proceeding inwards. The micro cracks were seen to be extending to about 3 to 4 austenitic grains. Such intergranular microcracks observed on the surface of the stem at the change of section at the root could be responsible for initiation of fatigue failure in the stem.

17-4 PH steel is susceptible to hydrogen pick up and intergranular crack formation(3), in case it is adjacent to regions causing corrosion and evolution of hydrogen. Here we have a case of corrosion of the stem material itself, and the hydrogen evolved by corrosion in reactor water could cause intergranular hydrogen pick up causing microcracks at the surface of the stem. Once favourable condition for generating vibrations in the stem had been set up, some of these micro cracks could become the origin of the stage I of fatigue crack propagation. Further propagation could have been facilitated by corrosion fatigue in the reactor water environment. The failure in region A accounts for about 30% of the radius from outer surface. Once such a large area of the stem is affected by failure, the remaining central region of the stem, which would be as low as only 50% of the original sectional area, would become the weak link. The high tensile and torsional stresses set up in the stem of the over travelled and thermally bound valve disc during opening of the valve, would cause the ultimate failure of the stem.

17-4 PH steel in H 1100 condition is expected to have the following mechanical properties:

UTS : 965 MPa (140 KSi)
YS : 795 MPa (115 KSi)
Hardness : (31-38) HRC (310-370 VHN)

The hardness of the stem material examined was found to be 462 VHN, which is much higher than that of the H 1100 material. In fact the equivalent strength of a steel of hardness 462 VHN would be in the higher range of that of 17-4 PH in H 900 condition (UTS: 1310 MPa, Y.S: 1170 MPa). This shows that the original H 1100 material had deteriorated in mechanical properties due to prolonged ageing during long residence time at the reactor water temperature and as such can no more be considered to be in H 1100 condition. This observation indicates that 17-4 PH steel is not suitable for prolonged use at the reactor water temperature (540°F), if the original properties of the stem are to be retained. It is possible that the same phenomenon would occur in other precipitation hardening steels which may restrict their use as stem material for such valves.

5. CONCLUSIONS

The failure of the 17-4 PH SS stem of MOV-1404 occurred by fatigue accelerated by corrosion in the reactor water. The stage I of fatigue failure was most probably initiated at the intergranular cracking at outer surface of the stem caused by pick up of hydrogen released during corrosion of the 17-4 PH material in reactor water environment. The fatigue failure accounted for about 50% of the total sectional area of the item.

The findings suggest that 17-4 PH steel is probably not suitable for use as the stem material for motor operated valves in service in TAPS reactors. The stems of remaining such valves could also fail if the operating conditions of environment and stress are identical to those experienced by MOV-1404. To prevent further failures of such stems, it is advisable to go for a tougher stem material which is compatible with the reactor water environment and at the same time which would restrict fatigue crack growth. Incidentally the spare stem for replacement supplied by the vendors is of SS 316, which is a good material for this purpose. The failed 17-4 PH stem has already been replaced at TAPS by a SS 316 stem which had been supplied as replacement spare by the vendors and was acceptable to the station. This gives us confidence that the SS 316 stem, now in operation for the valve MOV-1404, is adequate as far as its load bearing capacity is concerned.

6. RECOMMENDATIONS

a) As the station has already replaced the failed stem by a SS 316 stem in valve MOV-1404 and accepted the load bearing capacity of SS 316 stem, it is recommended that the stem of the remaining such MO valves be replaced by the available SS 316 spare stems.

b) Factors contributing to excessive vibrations or rattling of the stem disc assembly should be controlled.

c) Effort should be made to prevent over travel and consequent seizure of the valve disc between the body seat openings during cooling down of the valve.

ACKNOWLEDGEMENTS

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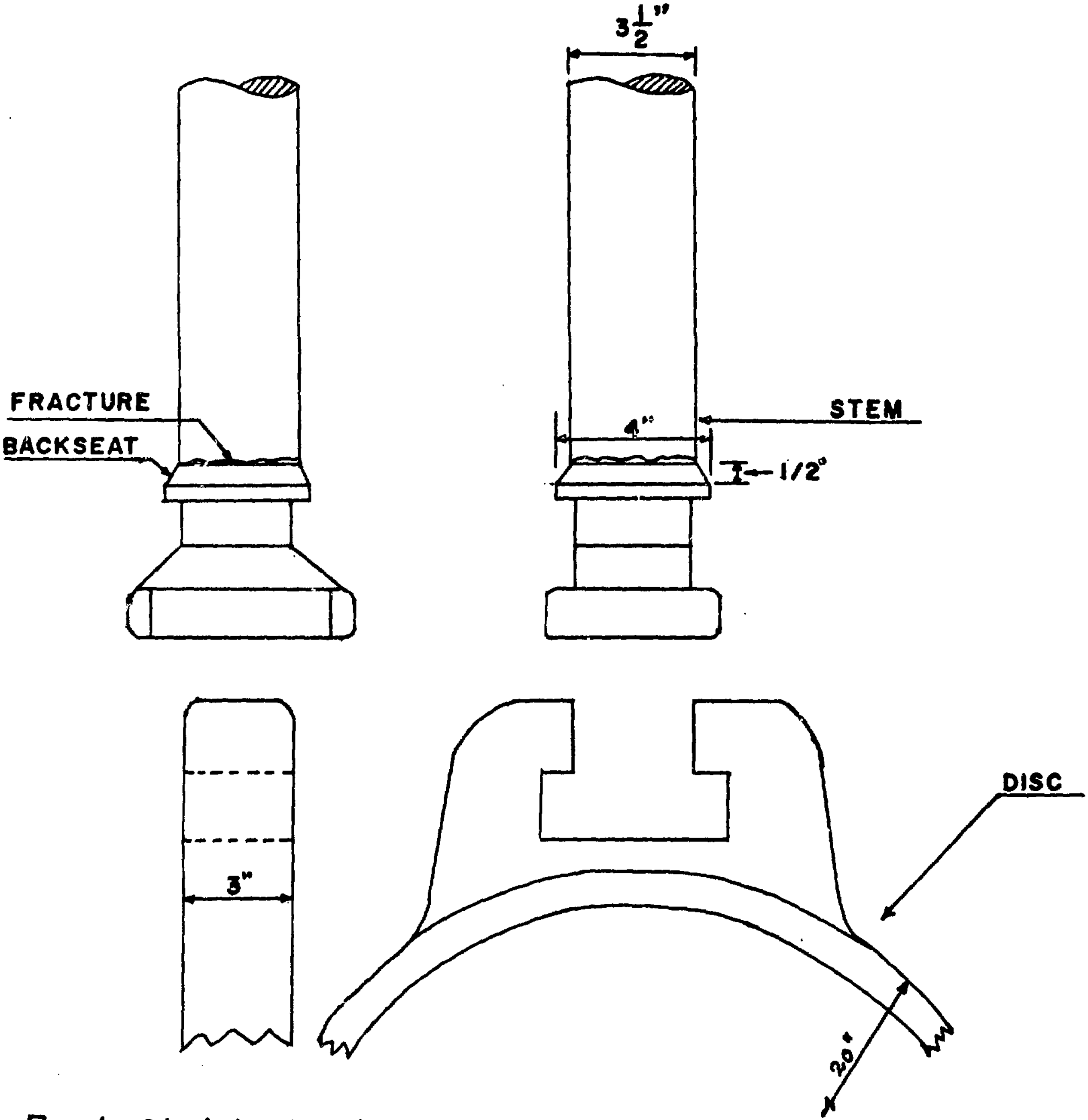


Fig: 1. Sketch of stem/disc showing the fracture

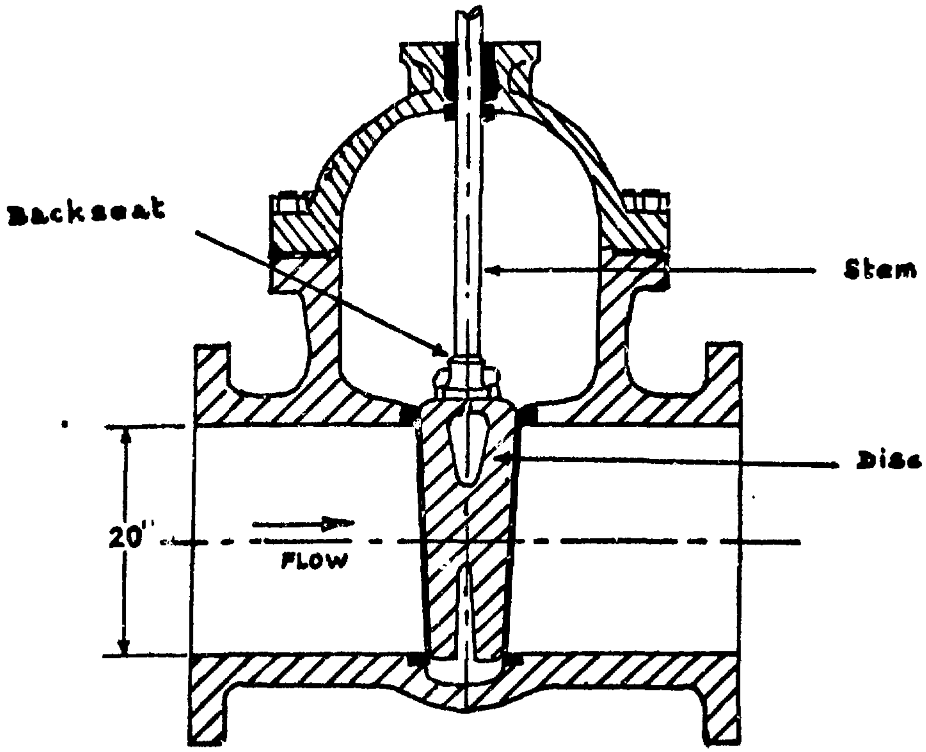


Fig. 2. Valve section with disc in closed position.

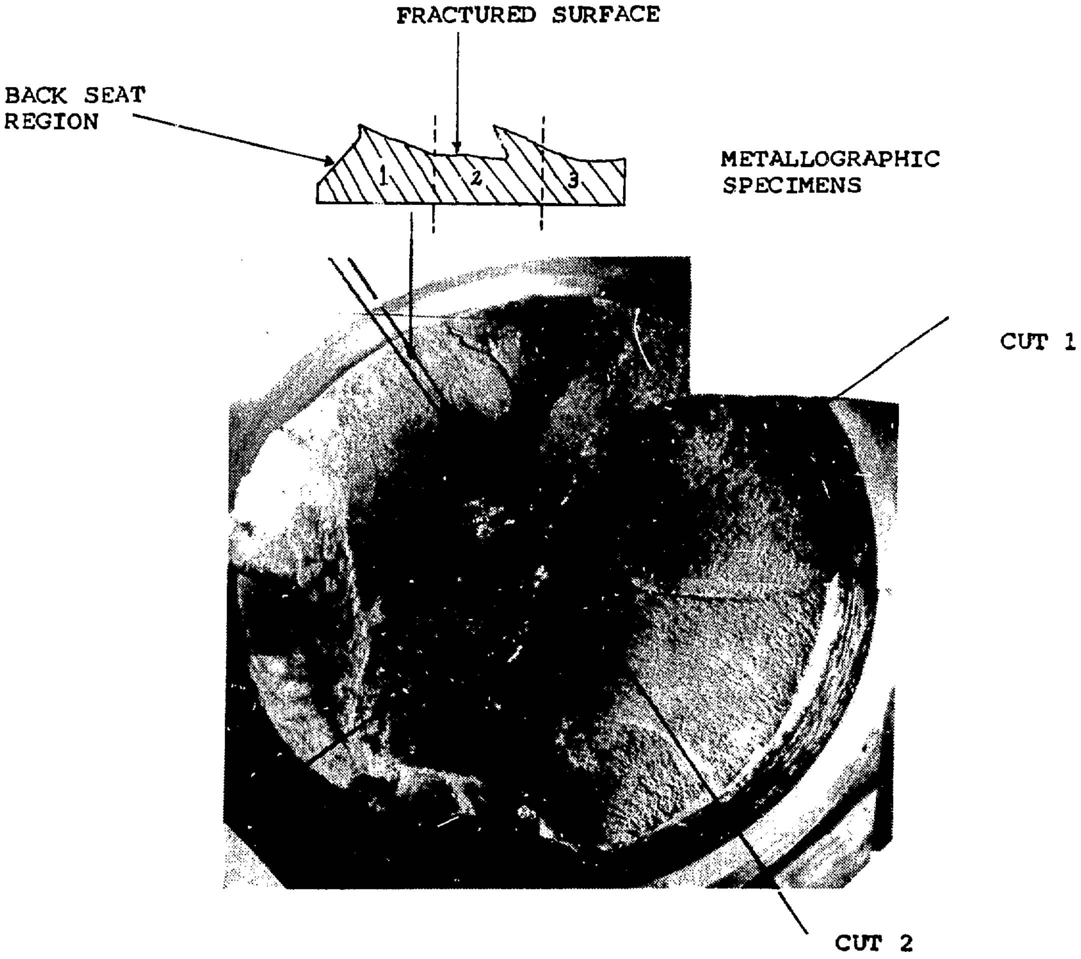


Fig. 3. Periscope Photograph of the Failed Surface.

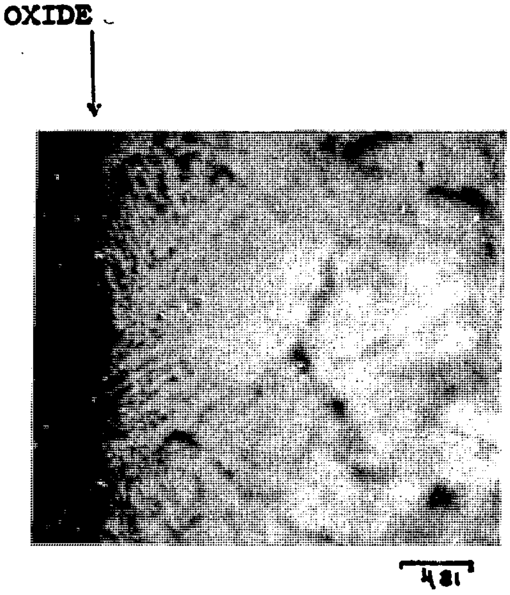


Fig. 4. Tenacious Oxide Layer on the Backseat Surface of the Stem.

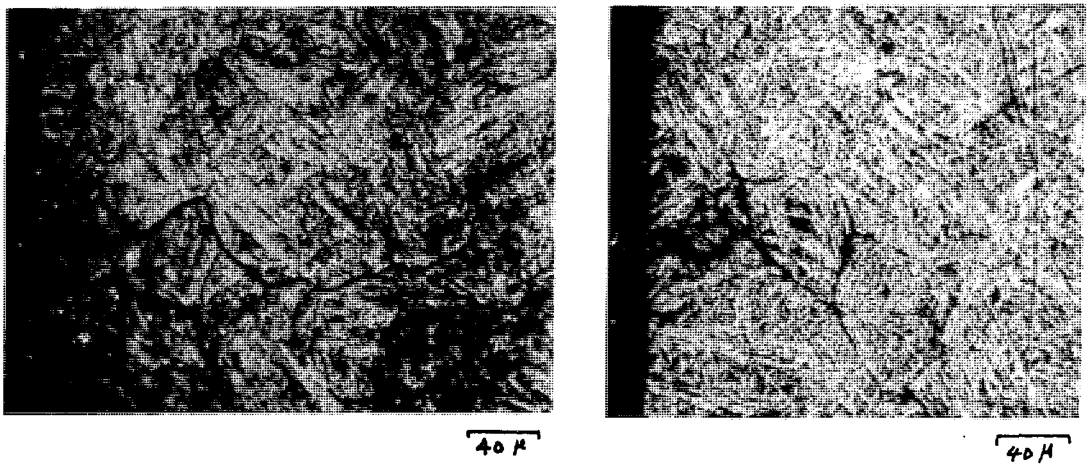
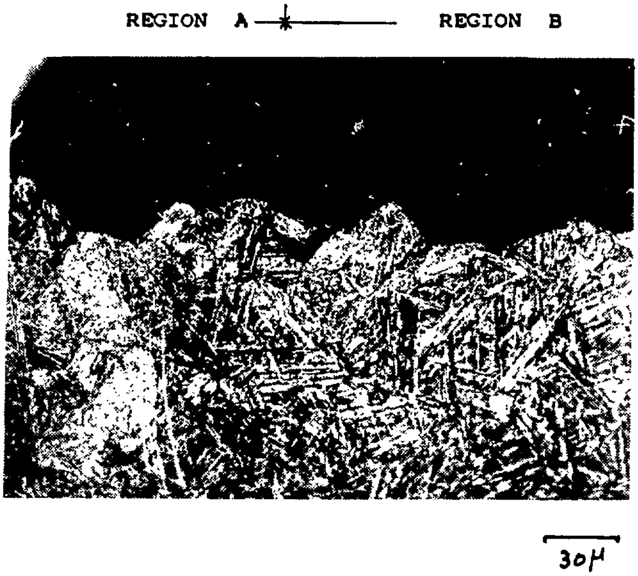
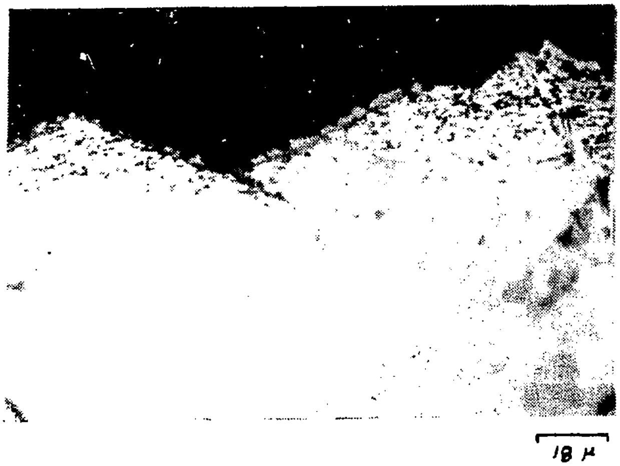


Fig. 5. Intergrannular Micro Cracks with Oxide Deposit in them at Outer Edge of the Back Seat Surface. The micro cracks are wider at the outer surface and extend inwards along austenite grain boundaries.



A. Failure Edge Showing the Boundary of the Region A and Region B.



B. Region A - Details of Oxide Layer on Failed Surface.

Fig. 6. Details of Region A (Oxidised) and Region B (not Oxidised) on the Failed Surface.

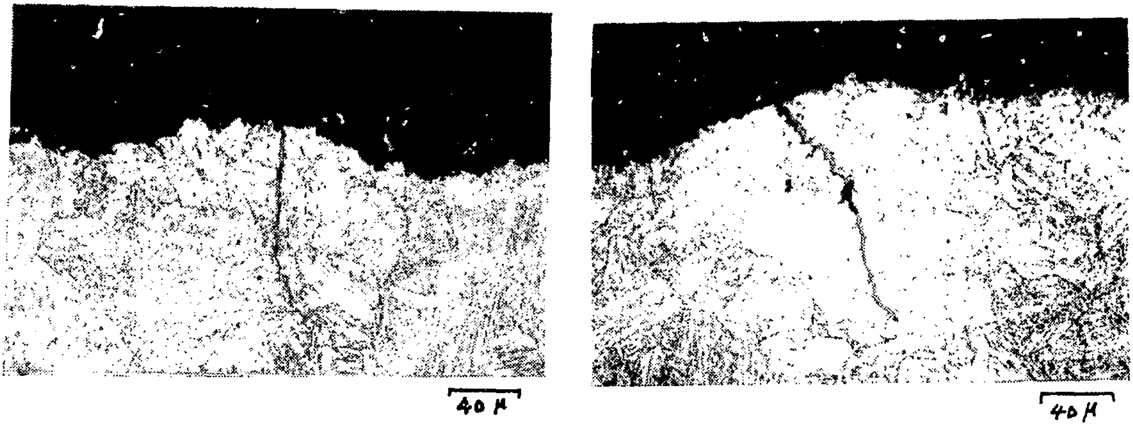


Fig. 7. Secondary Cracking in Region B (not oxidised) of Failure Surface.

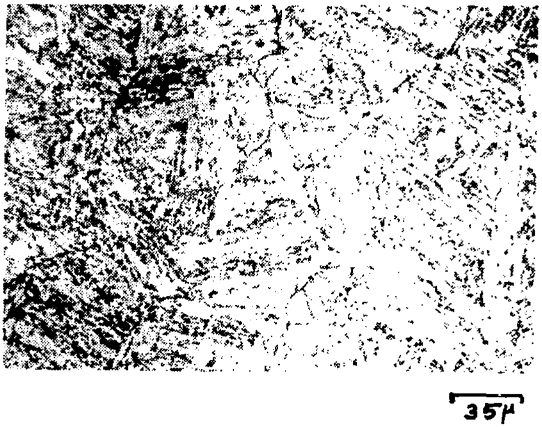


Fig. 8. **General Microstructural of the Stem Material Showing Tempered Martensites and Ferrite.**

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