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INFORMAL REPORT

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Failure Analysis of a Bolt from "B" Reactor Coolant Pump at the H. B. Robinson Unit 2 Nuclear Power Station

C. Czajkowski

July 1982

CORROSION SCIENCE GROUP

DEPARTMENT OF NUCLEAR ENERGY BROOKHAVEN NATIONAL LABORATORY

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Abstract

A metallographic failure analysis was performed on cracks on the diffuser adapter to casing adapter bolt on the "B", Reactor Coolant Pump from the H. B. Robinson Unit 2 nuclear power plant. The observations included a transgranular cracking failure and pits on the thread area of the bolt. SEM evaluation of the fracture surface disclosed no definitive evidence of fatigue interaction. The report concludes that the bolt failure was due to a stress corrosion cracking (SCC) mechanism caused by high tensile stresses and a probable chloride contamination.

1.0 INTRODUCTION

On April 23, 1982 Carolina Power and Light (CP&L) sent a letter to the United States Nuclear Regulatory Commission (USNRC) Region II (1) informing the Region that 4 of 16 Reactor Coolant Pump (RCP) diffuser adapter to casing adapter bolts had failed at the H. B. Robinson Unit 2 plant. The failures were discovered during disassembly of the RCP pursuant to the utilities 10 year inservice inspection requirements. This information prompted the issuance of Preliminary Notification of Event or Unusual Occurance PNO-II-82-49 (2) from Region II. This notification report outlined the incident and stated that the initial results of the CP&L examinations indicated a stress corrosion mechanism. Subsequent disassembly of a second RCP by the utility disclosed 5 of 16 of the bolts had missing hex heads and that eight other bolts broke during removal (3).

As a result of the original notification by the utility, Region II initiated an independent failure analysis of one of the cracked bolts from the H. B. Robinson Unit 2 Main Reactor Coolant Pump (RCP) "B". The request for the analysis was made to the Franklin Institute which subcontracted the analysis to Brookhaven National Laboratory (BNL) under P.O. #C-67718. This report describes the results of that analysis.

The analysis was to encompass an evaluation of the failure mechanism and a confirmation of the bolting materials chemistry (300 series austenitic stainless steel). The test methods used in this analysis were:

a) Visual/Photography

b) Dye Penetrant Examination

c) Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS)

d) Optical Microscopy/Metallography

2.0 VISUAL/PHOTOGRAPHY/DYE PENETRANT EXAMINATION

The bolt received at BNL was 0.625 inch diameter and 4 inches long (Figure 1), it was non-magnetic and was surveyed by BNL Health Physics to have a 300 mR/hr-γ and a 3R/hr-β count indicating the presence of Co-60 isotope. The bolt had a hex head configuration which had three machined slots used for staking the bolt in place after torquing. Visual examination of the bolt did not reveal any cracks so a dye penetrant examination was performed using Spotcheck Brand (all Formula B) Penetrant Type SKL-HF/SKL-S, Developer Type SKD-NF and Cleaner/Remover Type SKC-NF. Figures 2-5 represent the results of the dye penetrant examination. The pictures were taken approximately 90° apart in relation to the bolt's outside surface. It can be clearly seen on the photographs that the indications encompass approximately three threads and are approximately 1/2 inch from the bolt's end.

3.0 SEM/EDS

The crack was opened for evaluation by cutting a small counter notch in a thread and then by applying a bending moment. The fracture face (Figures 6 and 7) was essentially transgranular with a somewhat stepped appearance. There was no definitive evidence of fatigue striations or river markings.

During the examination of the fracture face various indications of pitting were observed on the machined portion of the threads (Figures 8 and 9). Additionally one pit was noted to be at the root of the notch in the approximate plane of the fracture face (Figure 10). Another area (Figure 11) appeared to be a possible site for pit initiation.

EDS examination of the base metal for constituents was accomplished (Figure 12) and revealed the alloy to be similar to type 304 stainless steel. Additionally, EDS examination of the darker area near the bolt tip displayed a

Molybdenum peak (Figure 13). This scan was repeated at a higher accelerating voltage (Figure 12) and the Molybdenum peak disappeared. This is indicative that the Mo was a surface phenomenon only and was possibly related to the use of a Molybdenum-type lubricant on the bolt's threads.

Due to the decontamination treatments performed on the bolt prior to SEM evaluation, EDS analysis of the fracture surface for contaminants and possible corrosive species was considered fruitless and was omitted from the evaluation. It was felt worthwhile however, to attempt an analytical SEM technique for determining the environment responsible for stress corrosion cracking of austenitic stainless steels (4). This technique produced data on Type 316 stainless steels in both hydroxide and chloride environments. It is based on the observations that in chloride solutions, the corrosion product is chromium rich while in hydroxide solutions the corrosion product is iron rich. The determination of the environment responsible for the cracking is based upon the Cr/Fe ratio as measured by EDS peak heights. The data produced in Reference 4 showed consistently higher Cr/Fe ratios for chloride cracking (0.6-0.9) while lower ratios were evident for hydroxide cracking (0.4-0.6). This technique was performed on the fracture face of the bolt in 5 scans traversing the fracture face and is depicted in Figures 14-18. The ratio values ranged from a low of 0.632 to a high of 0.778. Although not conclusive in nature these results do indicate the possibility of a chloride-type stress corrosion cracking phenomenon.

4.0 OPTICAL MICROSCOPY/METALLOGRAPHY

In order to further categorize the fracture phenomenon, two samples were removed from the bolt for metallographic examination. These samples were made by cutting transversely to the fracture face approximately mid cross section of the bolt in a direction towards the bolt head. As clearly seen in Figure 19 the

cracking is predominantly transgranular with some fern-like branching. The second sample was subjected to the ASTM A-262 Practice A test for detection of sensitization. The microscopic examination of this sample disclosed a severely cold worked structure in the area of the threads (Figure 20). This structure had the acicular characteristics of martensite. Additionally, a small crack was noted, which under higher magnification (Figure 21) appeared to be transgranular in nature and originating at the thread root.

The bolt material showed no evidence of material sensitization as clearly seen in Figure 22.

5.0 DISCUSSION/CONCLUSIONS

It is widely known that both chlorides and hydroxides will cause transgranular cracking in austenitic stainless steels [5-9]. It is only the chloride however which will cause pitting as well as transgranular cracking in an austenitic stainless. This is partly due to the observations [10,11] that the pitting potential and cracking potential for austenitic stainless in chloride solutions are approximately the same value at higher temperatures.

This being the case, the following conclusions can be drawn from the failure analysis observations:

1) The bolt material is an austenitic type stainless steel (probably Type 304).

2) The bolt material is in the non-sentitized condition and has been subjected to considerable cold working.

3) There was no definitive evidence of fatigue observed on the fracture face of the bolt.

4) The transgranularity of the crack, coupled with pitting in the thread area of the bolt and the results of the EDS analyses, provide sufficient indica-

tion that the bolt failure was due to a stress corrosion cracking mechanism caused by high tensile stress in the bolt and probable chloride contamination.

6.0 ACKNOWLEDGEMENTS

The author wished to thank the Franklin Institute for funding the analysis. In addition thanks are due to L. Gerlach, D. Becker, J. Langan, O. Betancourt, and especially Dr. J. R. Weeks for his constant support.

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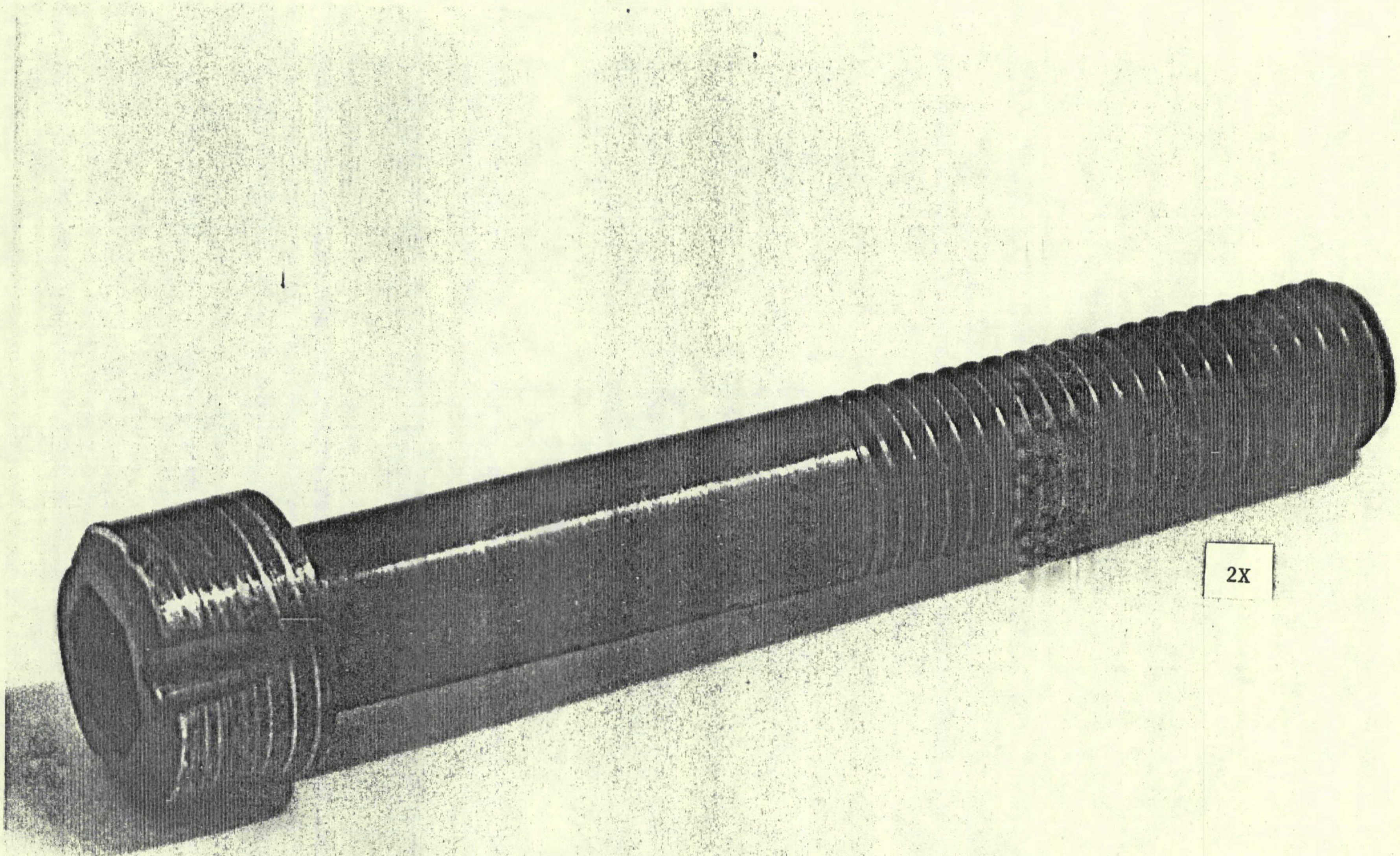


Figure 1. Macrophotograph of "as received" bolt from "B" Reactor Coolant Pump from the H. B. Robinson Unit 2 nuclear power plant.

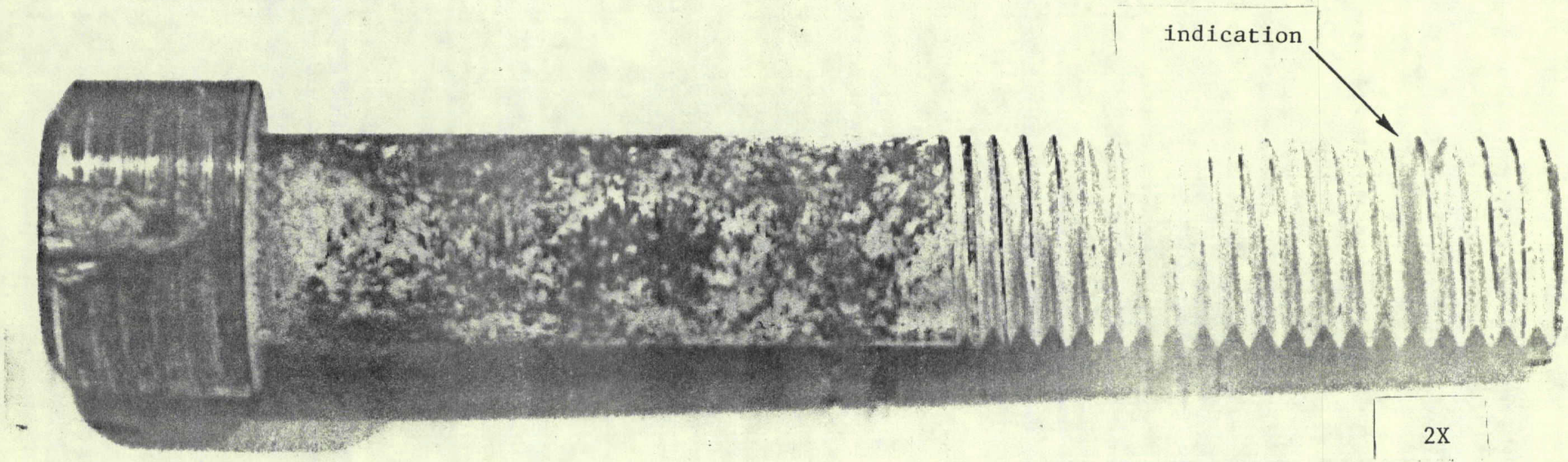


Figure 2. Optical photograph of bolt after dye penetrant examination.

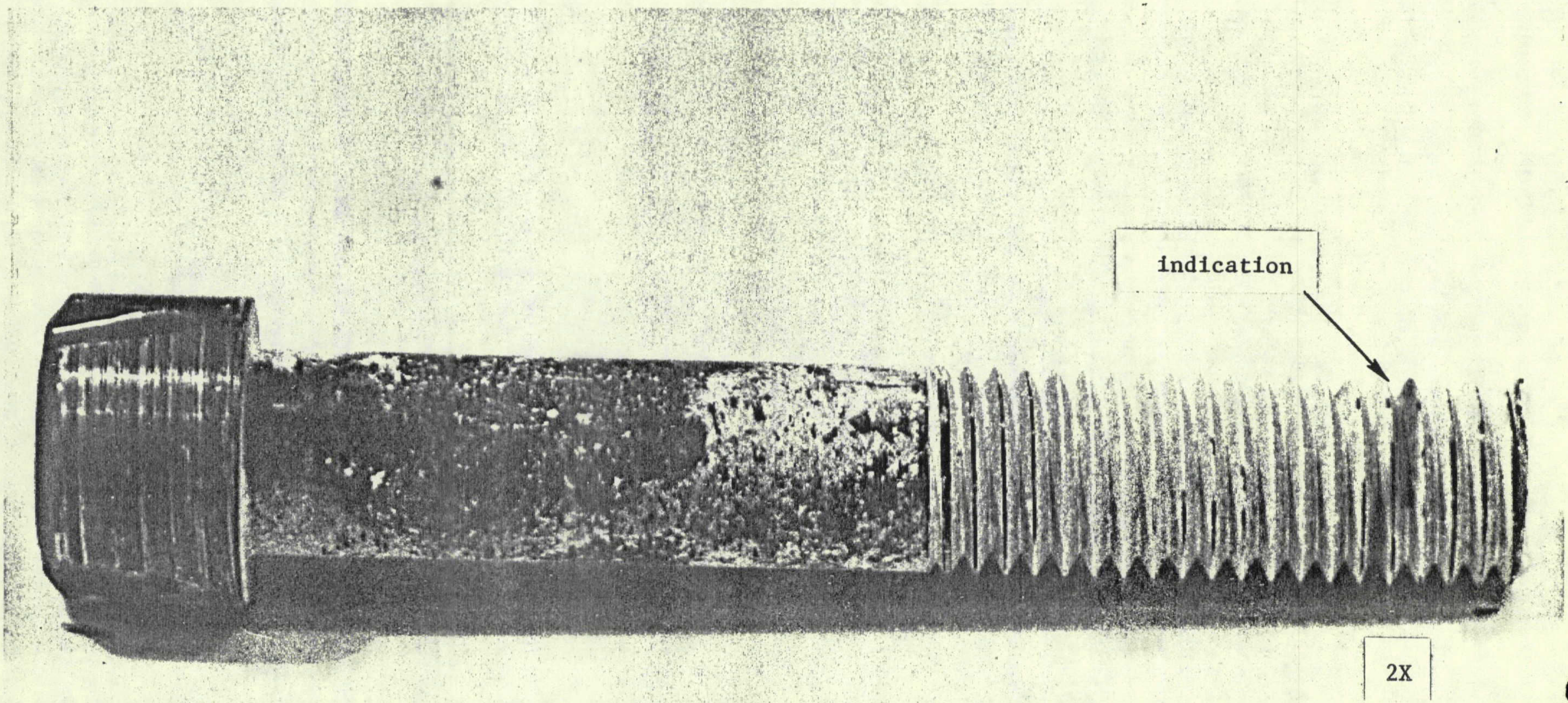


Figure 3. Optical photograph of bolt after dye penetrant examination. (~90° counterclockwise rotation from figure 2.)

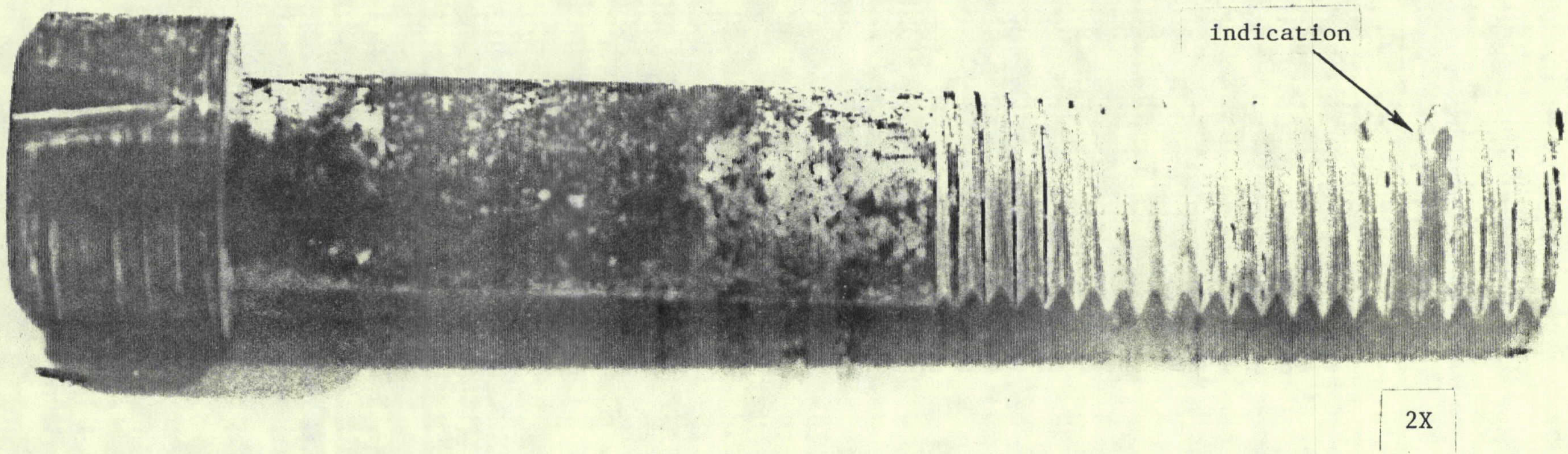


Figure 4. Optical photograph of bolt after dye penetrant examination. (~90° counterclockwise rotation from figure 3.)

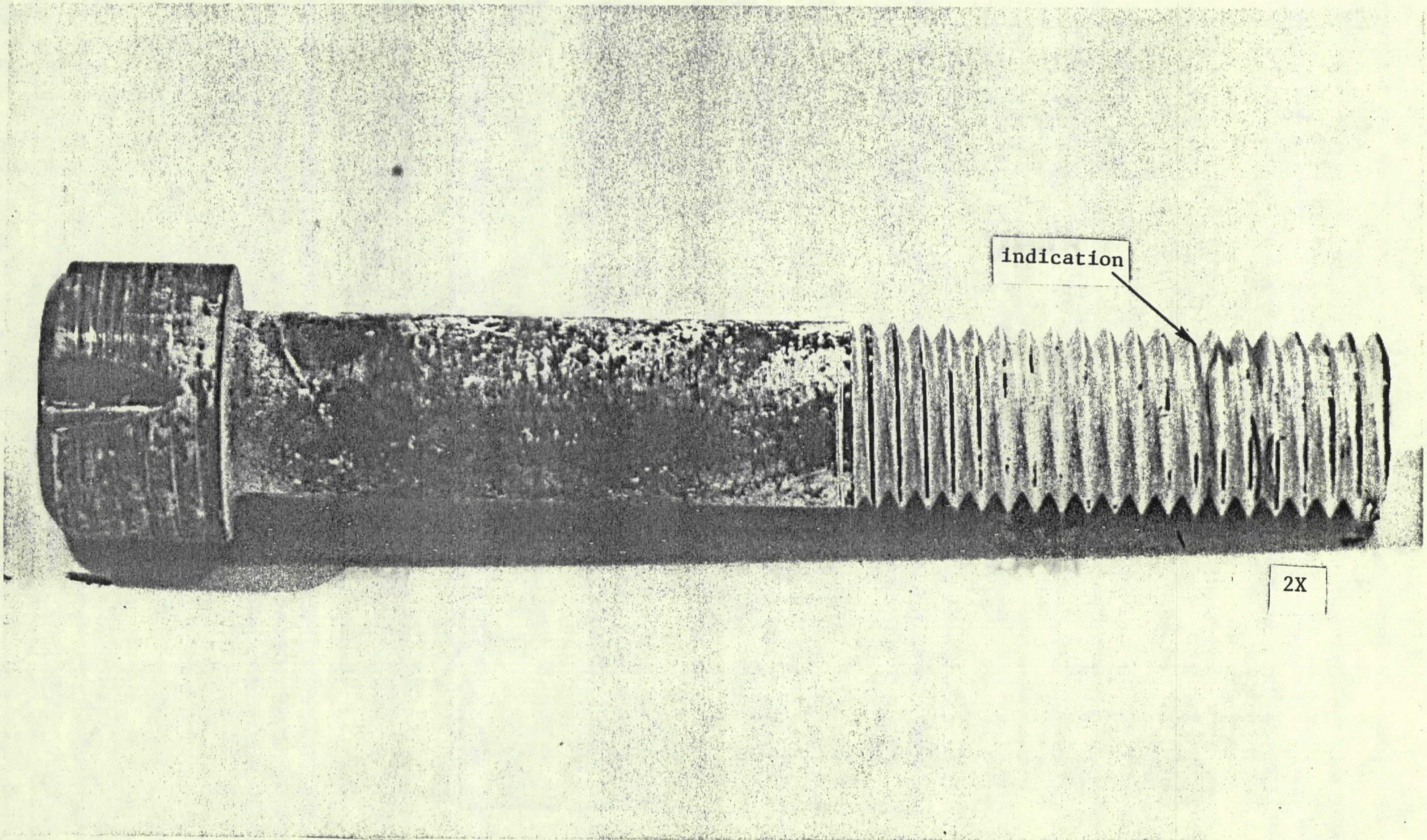


Figure 5. Optical photograph of bolt after dye penetrant examination. (~90° counterclockwise rotation from figure 4.)

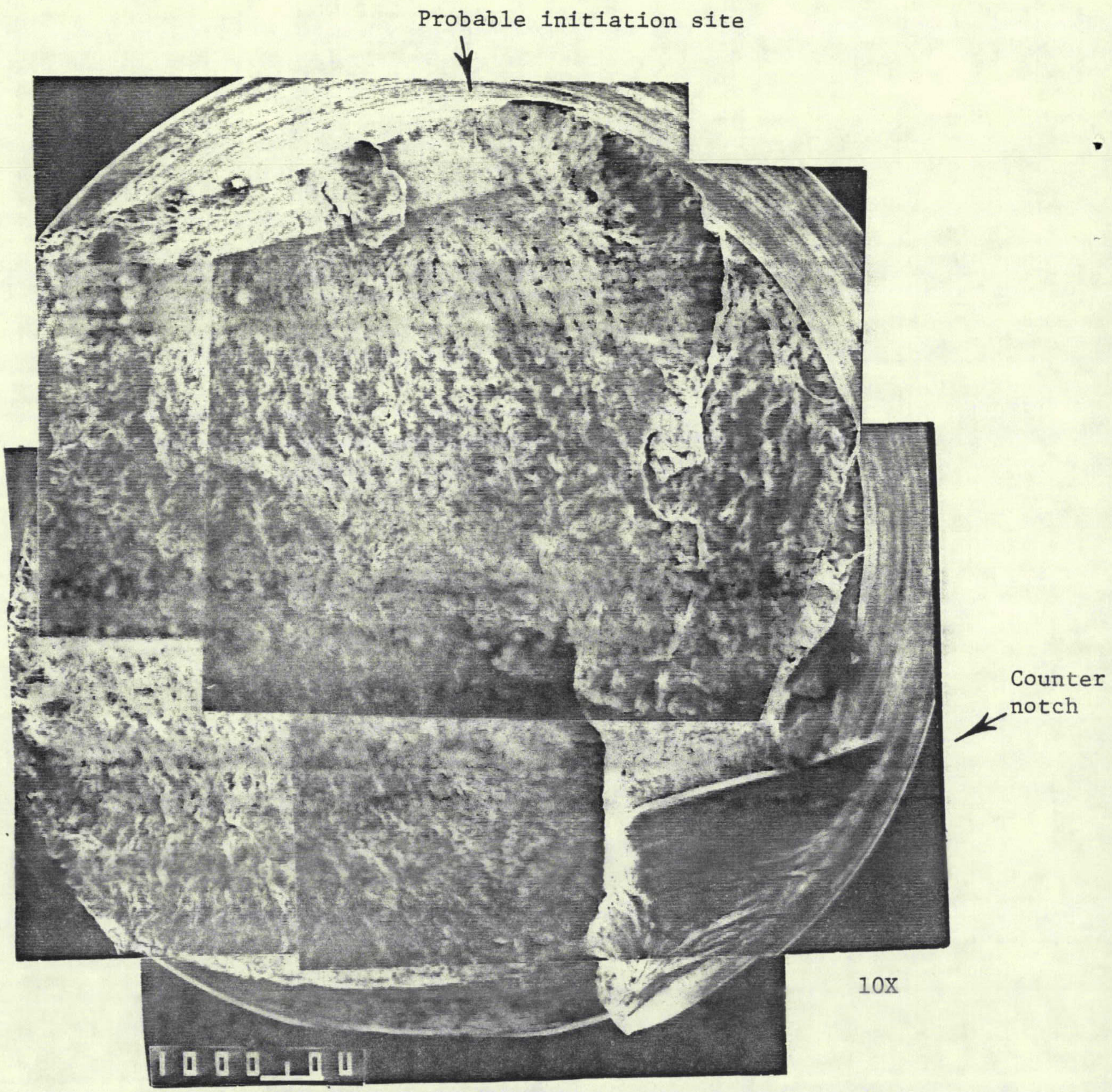


Figure 6. SEM photograph of the fracture surface of the bolt after opening up of the crack

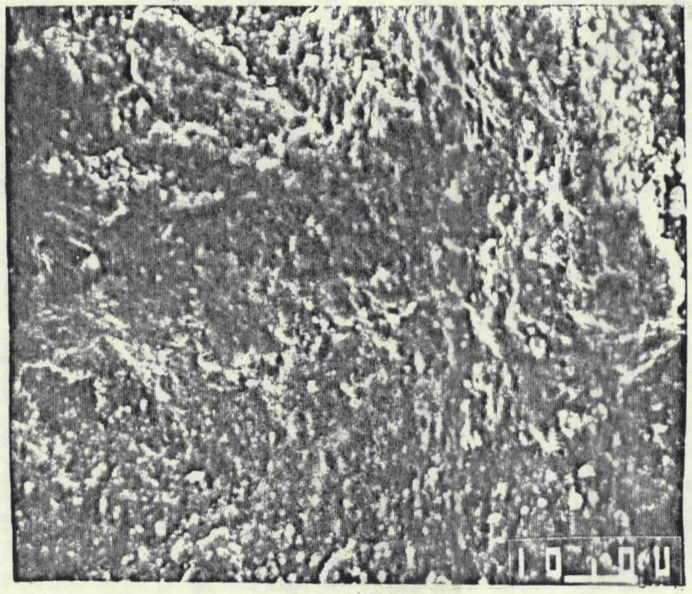


Figure 7. Higher magnification SEM photograph of typical area on specimen's fracture surface

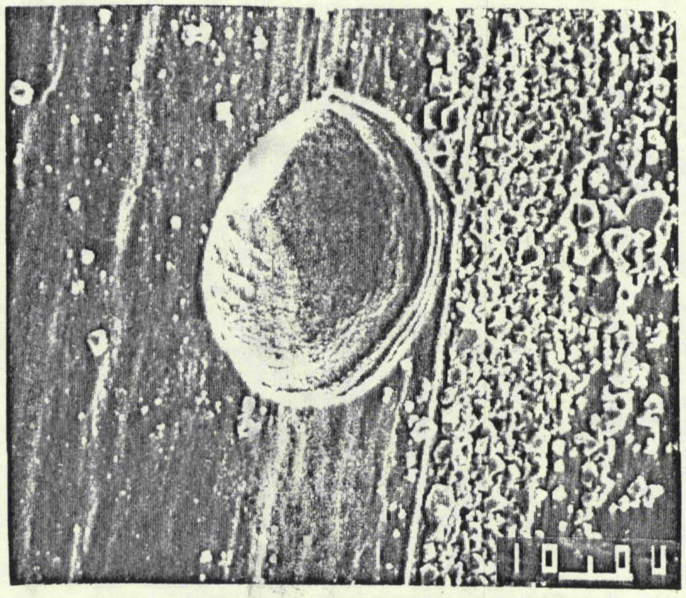


Figure 8. Pit found on machined thread portion of bolt

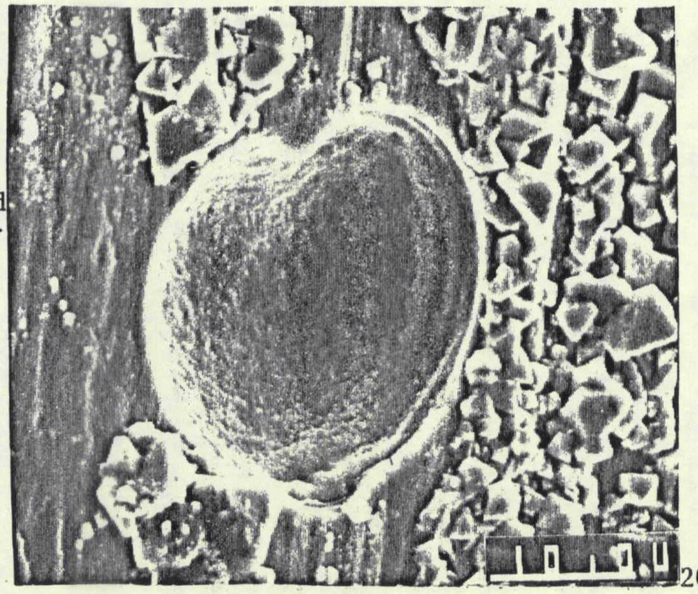


Figure 9. Another pit found on machined portion of bolt

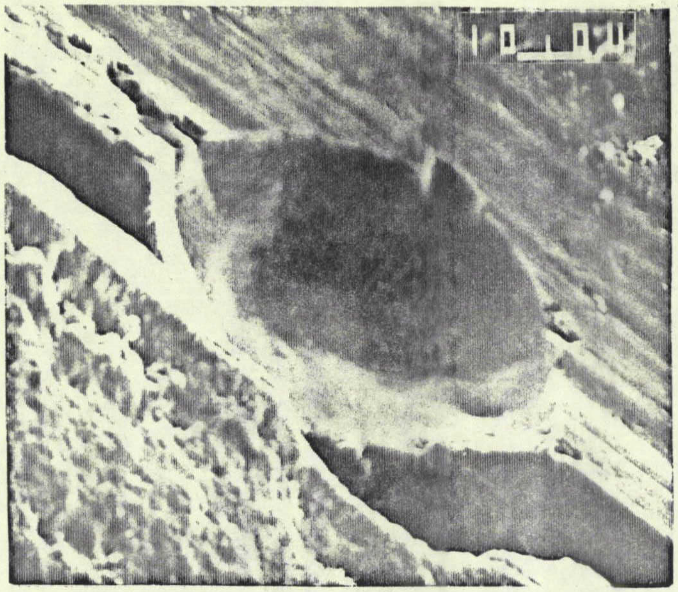


Figure 10. SEM photograph of pit found in the root of the thread adjacent to the fracture surface

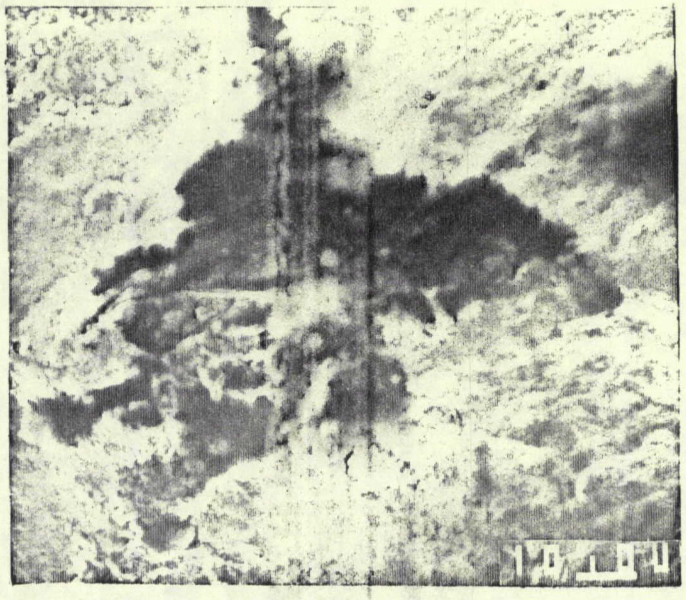


Figure 11. Probable pit initiation site found on machined area of thread

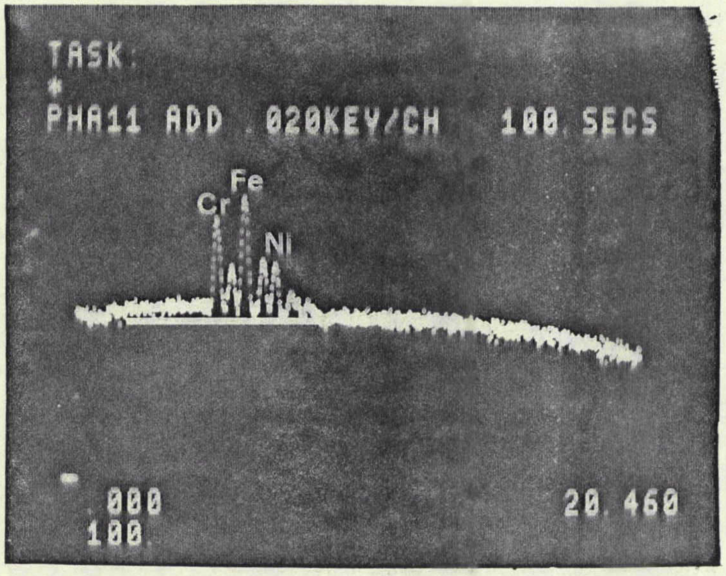


Figure 12. EDS scan of base material for constituents (Cr/Fe .84) (Accelerating Voltage 35 Kv)

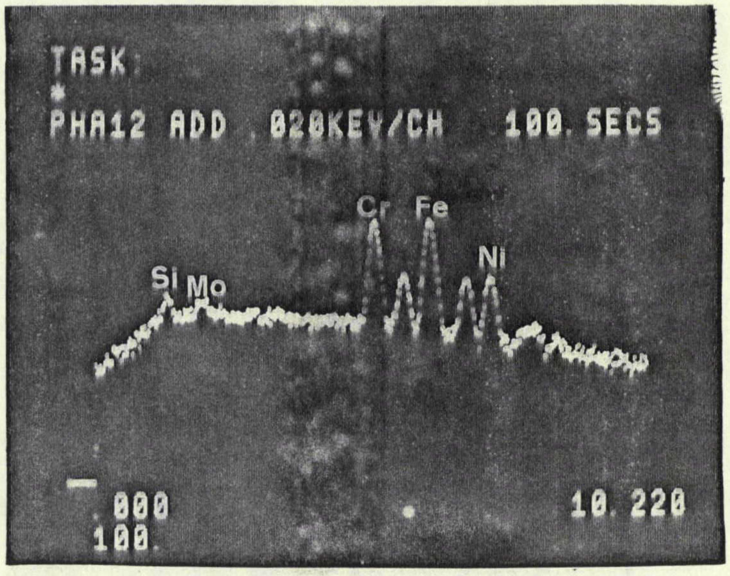


Figure 13. EDS scan of dark area near bolt tip (Accel. Voltage 17 Kv)

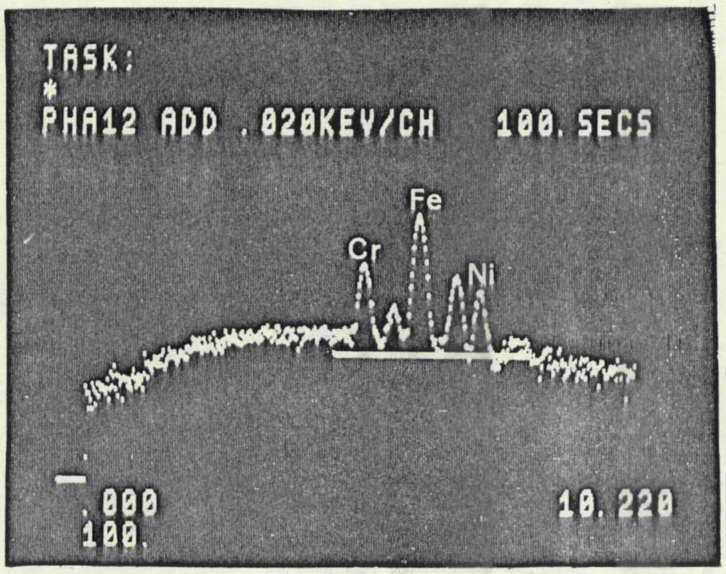


Figure 14. EDS scan of fracture face for Cr/Fe ratio. (Cr/Fe-.632)

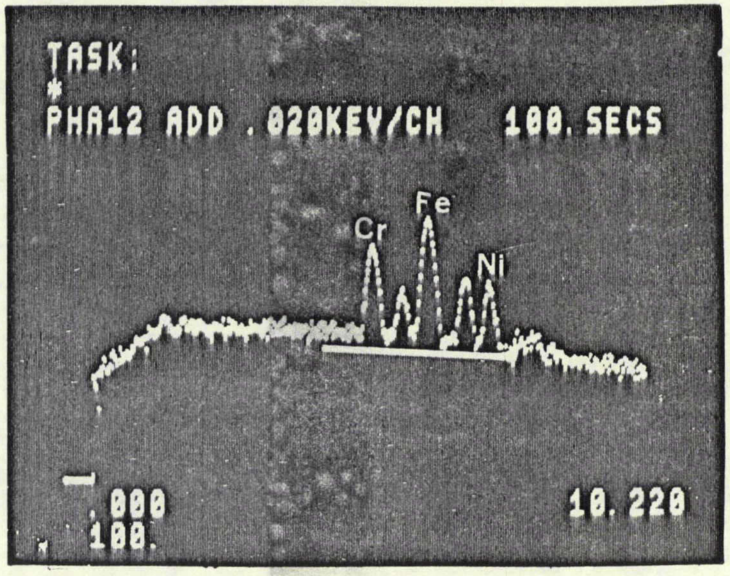


Figure 15. EDS scan of fracture face for Cr/Fe ratio. (Cr/Fe-.778)

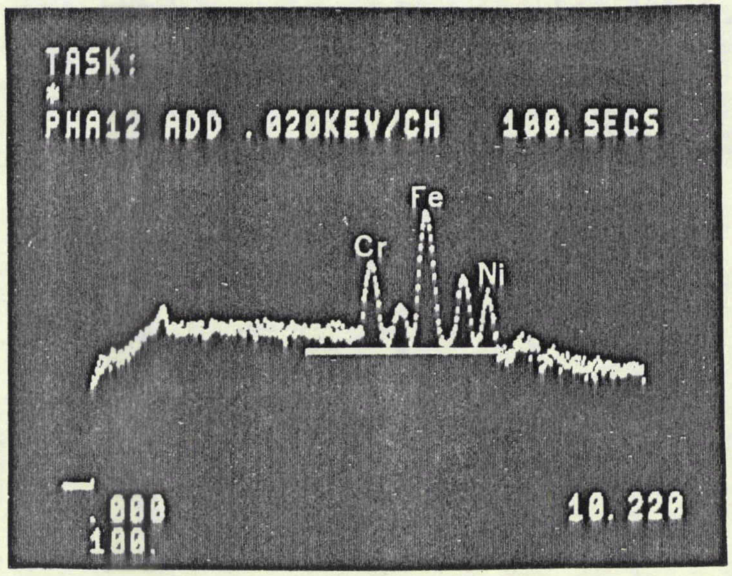


Figure 16. EDS scan of fracture face for Cr/Fe ratio. (Cr/Fe-.667)

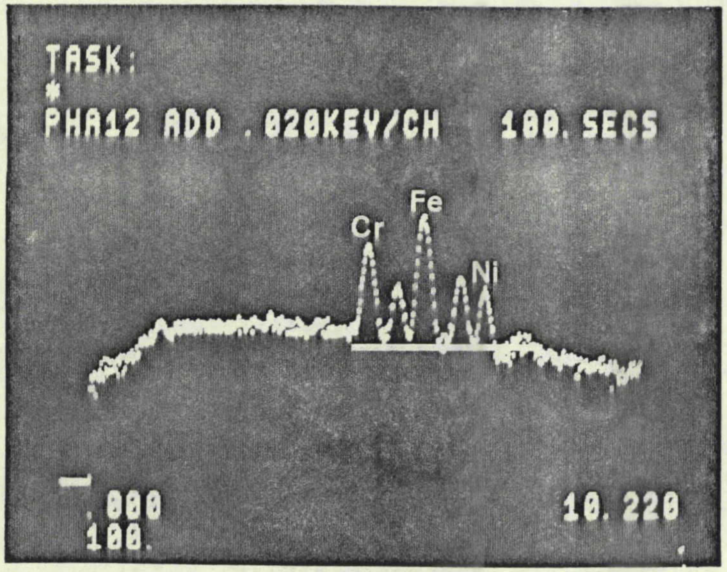


Figure 17. EDS scan of fracture face for Cr/Fe ratio. (Cr/Fe-.765)

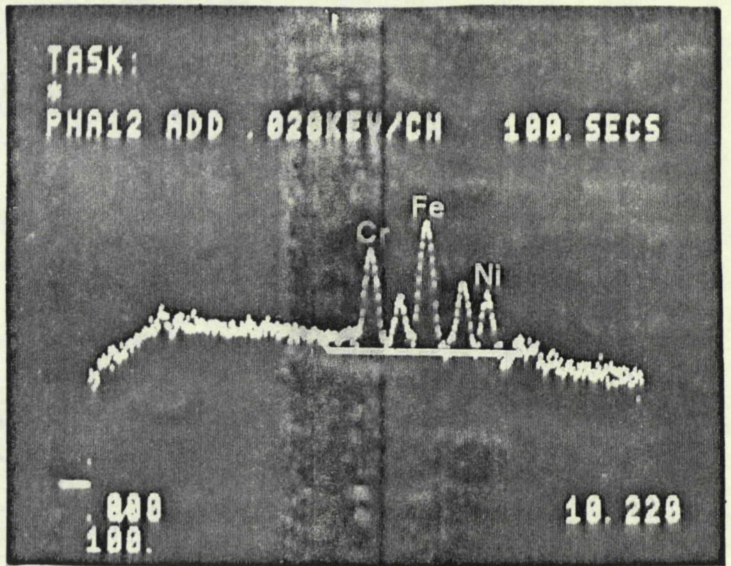


Figure 18. EDS scan of fracture face for Cr/Fe ratio. (Cr/Fe-.765)

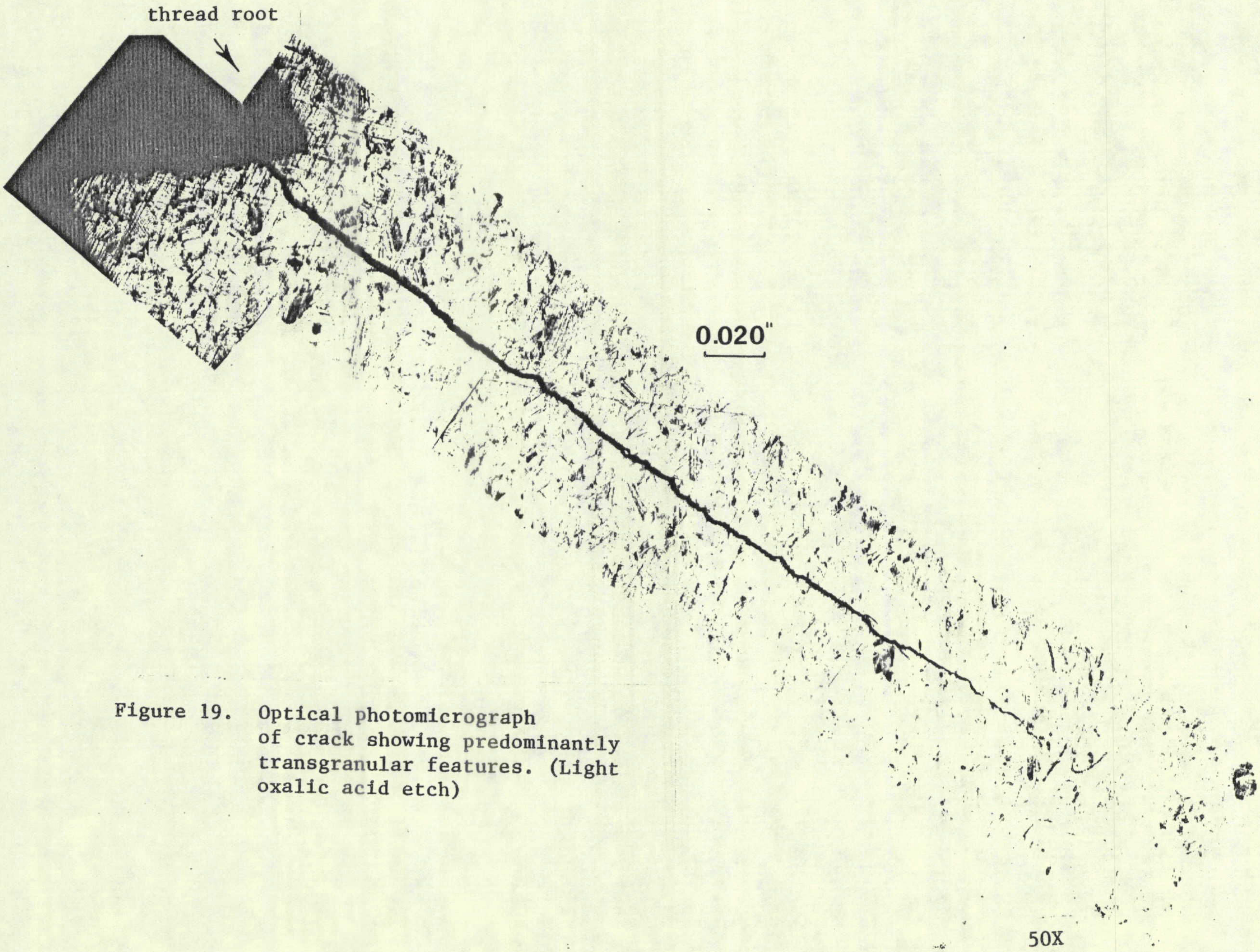
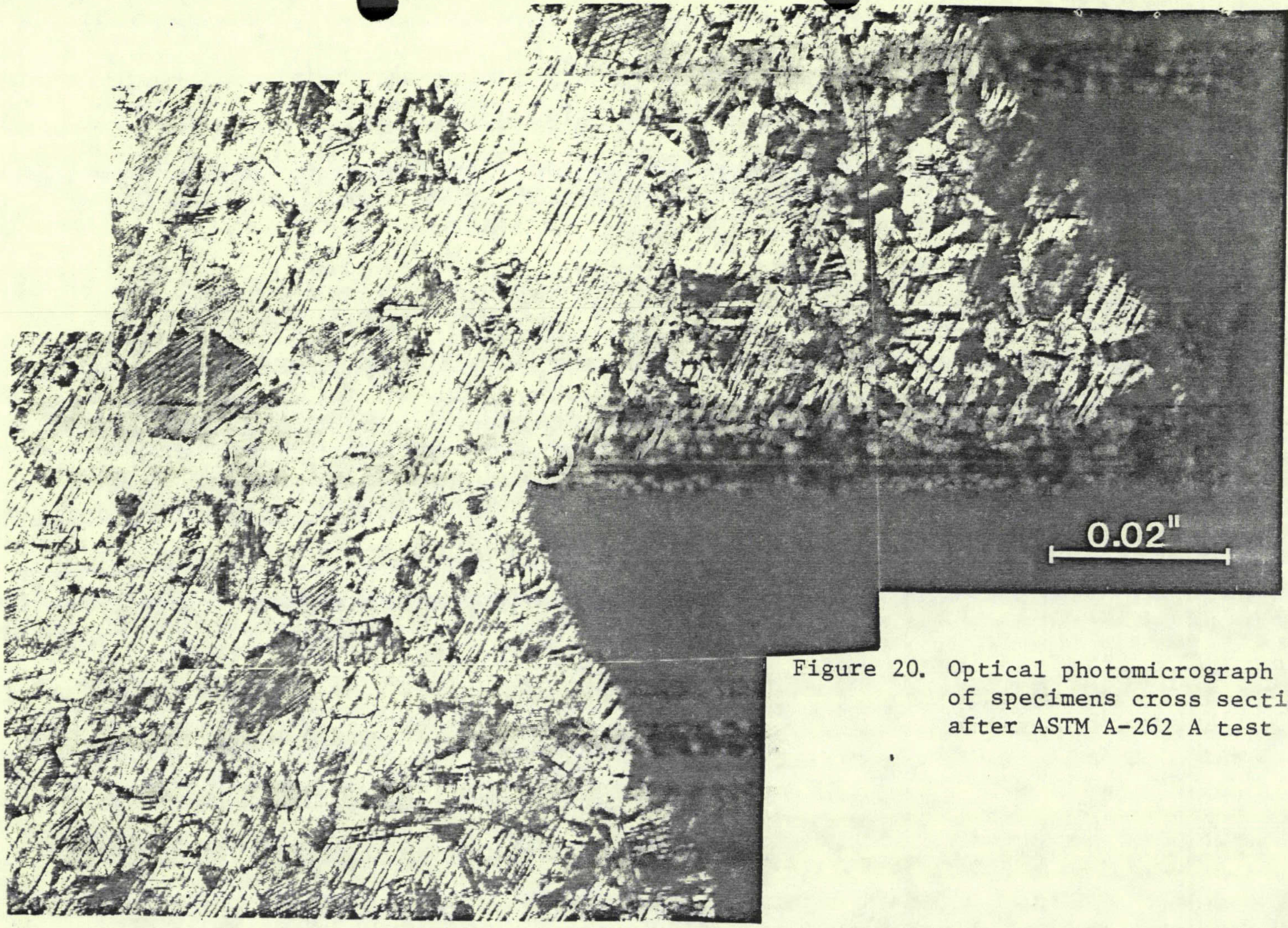


Figure 19. Optical photomicrograph of crack showing predominantly transgranular features. (Light oxalic acid etch)



50X

Figure 20. Optical photomicrograph of specimens cross section after ASTM A-262 A test

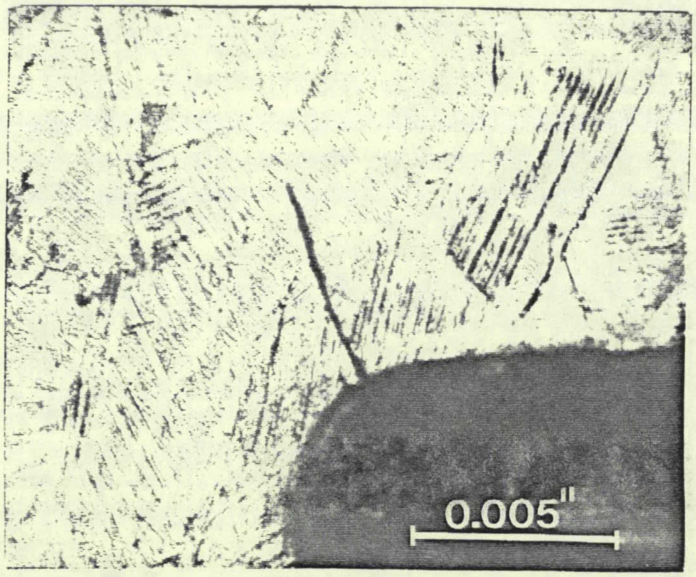
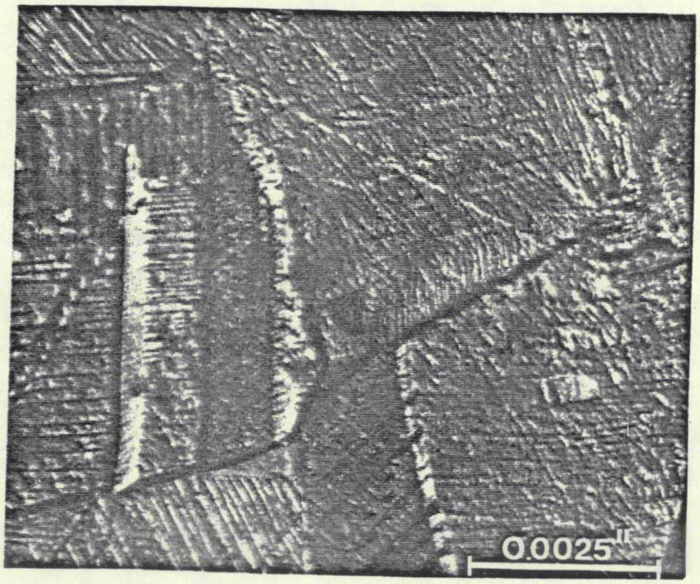


Figure 21. Higher magnification photo of circled area (above)

Thread root

200 X



400X

Figure 22. Optical photomicrograph of bolt base material after ASTM A262 - Practice A showing no evidence of material sensitization