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January 25, 1984
ANPP-28697-BSK/TRB

REGION V/SF

U. S. Nuclear Regulatory Commission
Region V
Creekside Oaks Office Park
1450 Maria Lane - Suite 210
Walnut Creek, CA 94596-5368

Attention: Mr. T. W. Bishop, Director
Division of Resident
Reactor Projects and Engineering Programs

Subject: Final Report - DER 82-61
A 50.55(e) Reportable Condition Relating to Reactor Coolant Pump Diffuser Ring Cap Screws May Fail And Damage Pump
File: 84-019-026; D.4.33.2

Reference: A) Telephone Conversation between J. Eckhardt and G. Duckworth on October 21, 1982
B) ANPP-22368, dated November 22, 1982 (Interim Report)
C) ANPP-23026, dated February 16, 1983 (Time Extension)
D) ANPP-23278, dated March 17, 1983 (Time Extension)
E) ANPP-23798, dated May 18, 1983 (Interim Report)
F) ANPP-27395, dated July 25, 1983 (Time Extension)
G) ANPP-28070, dated October 24, 1983 (Time Extension)
H) ANPP-28639, dated January 18, 1984 (Time Extension)

Dear Sir:

Attached is our final written report of the deficiency referenced above, which has been determined to be Not Reportable under the requirements of 10CFR50.55(e).

50-528
529
530

Very truly yours,

E. E. Van Brunt

E. E. Van Brunt, Jr.
APS Vice President, Nuclear
ANPP Project Director

EEVB/TRB:db
Attachment

cc: See Page Two

IE-27

1/1

Mr. T. W. Bishop
DER 82-61
Page Two

cc: Richard DeYoung, Director
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U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

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FINAL REPORT - DER 82-61
DEFICIENCY EVALUATION 50.55(e)
ARIZONA PUBLIC SERVICE COMPANY (APS)
PVNGS UNITS 1, 2, & 3

I. Description of Deficiency

Diffuser retaining cap screws for System 80 Reactor Coolant Pumps supplied by Combustion Engineering (CE) as part of the NSSS failed in the CE-KSB test loop. These cap screws support the diffuser-suction ring assembly of an idle pump. With the pump running, hydraulic forces unload the sixteen cap screws in question. Two cap screws secure each retaining ring segment and locking devices retain the cap screws. The screws failed either under the head, in the shank or at the first thread. CE has determined that the failure was caused by hydrogen induced stress corrosion cracking as a result of the heat treatment condition of the screw material (Type 410 martensitic stainless steel). The hydrogen induced stress corrosion cracking was accelerated by high stress levels caused by positioning the diffuser halves in a non-preferred orientation in the pump casing.

II. Analysis of Safety Implications

CE has reviewed the potential failure mechanisms and their consequences, including a locked roter, degraded pump coast down and core flow blockage and has determined that:

1) During full power operation hydraulic forces alone can maintain the diffuser in place. Only during startup or coast down is there any potential for axial movement of the diffuser. The design is such that the diffuser-suction pipe assembly is captured radially throughout any axial movement. The diffuser cannot rotate because it is restrained by two keys which engage the mating pump casing ledge. With these design features the potential for impeller binding is remote during startup and coast down.

2) The assessment of the effects on the coast down show the RCP maintains sufficient flow to satisfy the criteria of the safety analysis.

3) The potential for core flow blockage has been examined and it has been concluded that the gap between the impeller and the diffuser is small enough to prevent the escape of particles that are large enough to cause local core flow blockage.

Based upon this discussion, the failure of the cap screws has been determined to be not significant and not reportable under the criteria of 10CFR50.55(e). If the deficiency were to have remained uncorrected, it would not have adversely affected the safety of operations of the plant at any time throughout the lifetime of the plant.

III. Corrective Action

1) CE and CE-KSB have completed a metallurgical and design investigation to determine the causes of the failures. Attachment 1 provides a final report summary. Attachment 2 provides a summary of the design investigation and details of the metallurgical investigation.

2) Three modifications have been implemented to correct the diffuser retaining cap screw failures observed as a result of the pump testing at CE-KSB.

a. The cap screw material heat treatment has been changed to a condition so that the material is not susceptible to hydrogen induced stress corrosion cracking.

b. The diffuser assembly is a two piece arrangement to allow ease of installation. One side of the diffuser has six vanes and the other side has five vanes. Test results show that there is a preferred orientation of the six vane half versus the five vane half. The preferred orientation has been implemented.

c. Wedging devices between the two diffuser halves have been added. These devices limit movement of each diffuser half within the pump case.

The adequacy of these modifications have been verified by testing of production pumps at CE-KSB. Design Change Package 1SM-RC-063 and 2CM-RC-063 have been issued to implement CE's corrective action plan for Reactor Coolant Pump diffuser bolt replacement/modification for Units 1 and 2. NCR's NC-939, NC-940, NC-941 and NC-942 have been issued to repair residual damage within the Unit 1 pumps. Corrective action for Unit 3 will be completed by CE prior to shipment to the jobsite.

ATTACHMENTS

1) Reactor Coolant Pump Diffuser Cap Screw Deficiency, Final Report Summary, dated 4/19/83.

2) CE-KSB Report No. 83-0002, Reactor Coolant Pump Diffuser Bolt Failure Summary, dated 4/12/83.

REACTOR COOOLANT PUMP DIFFUSER CAP SCREW DEFICIENCY

FINAL REPORT SUMMARY

Description of Deficiency

When the System 80 Reactor Coolant Pumps (RCP) were disassembled for inspection after the test runs in the CE-KSB test loop, diffuser retaining cap screws were found to have failed. The screws failed either under the head, in the shank or at the first thread. CE has determined that the failure was caused by hydrogen induced stress corrosion cracking as a result of the heat treatment condition of the screw material (Type 410 martensitic stainless steel). The hydrogen induced stress corrosion cracking was accelerated by high stress levels caused by positioning the diffuser halves in a non-preferred orientation in the pump casing.

The cap screws support the diffuser-suction pipe assembly when the pump is idle. With the pump running, hydraulic forces are sufficient to support the diffuser-suction pipe assembly. Two cap screws secured each retaining ring segment and locking devices retained the cap screws.

Evaluation of Safety Implications

The failure of the cap screws has been determined to be not significant and not reportable under the criteria of 10CFR50.55(e). If the deficiency were to have remained uncorrected, it would not have adversely affected the safety of operating the plant at any time throughout the lifetime of the plant.

CE has reviewed the potential failure mechanisms and their consequences, including a locked rotor, degraded pump coast down and core flow blockage and has determined that:

a) During full power operation hydraulic forces alone can maintain the diffuser in place. Only during startup or coast down is there any potential for axial movement of the diffuser. The design is such that the diffuser-suction pipe assembly is captured radially throughout any axial movement. The diffuser can not rotate because it is restrained by two keys which engage the mating pump casing ledge. With these design features the potential for impeller binding is remote during startup and coastdown.

b) The assessment of the effects on the coast down show the RCP maintains sufficient flow to satisfy the criteria of the safety analysis.

c) The potential for core flow blockage has been examined and it has been concluded that the gap between the impeller and the diffuser is small enough to prevent the escape of particles that are large enough to cause local core flow blockage.

Description of Corrective Actions Taken

Three modifications have been implemented to correct the diffuser retaining cap screw failures observed as a result of the pump testing at CE-KSB.

1. The cap screw material heat treatement has been changed to a condition so that the material is not susceptible to hydrogen induced stress corrosion cracking.

2. The diffuser assembly is a two piece arrrangement to allow ease of installation. One side of the diffuser has six vanes and the other side has five vanes. Test results show that there is a preferred orientation of the six vane half versus the five vane half. The preferred oventation has been implemented.

3. Wedging devices between the two diffuser halves have been added. These devices limit movement of each diffuser half within the pump case.

The adequacy of these modifications have been verified by testing of production pumps at CE-KSB.

V-PCE-2615
4/19/83

CE POWER SYSTEMS

CE-KSB Pump Company, Inc.
Post Office Box 1007
Portsmouth, New Hampshire 03801

REPORT NUMBER

83-0002

TITLE: REACTOR COOLANT PUMP DIFFUSER BOLT FAILURE SUMMARY

ISSUE DATE: 4/6/83

PREPARED BY: Frazier P. Colon DATE: 4-12-83

8306010078

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FIGURES

1.0 OBJECTIVE

The objective of this report is to summarize the bolt failure history of the bolted connection between the diffuser and pump casing on three CE-KSB Reactor Coolant Pumps during test at the Newington Test Facility.

This summary report highlights the analytical approach and identifies the conclusions and recommendations resulting from this investigation.

2.0 INTRODUCTION

The post test inspection on three of the twenty Reactor Coolant Pump's performance tested in the CE-KSB Pump Company's Newington, New Hampshire Test Facility indicated that five diffuser-to-casing bolts were damaged or had failed.

The bolt failure in Reactor Coolant Pump #1 was originally identified as failure due to improper mechanical assembly procedures. Engineering felt, at the time, that a spherical washer, necked down bolt, and a higher strength bolting material would result in a more conservative bolted connection. The original diffuser-to-casing bolting connection is shown in Figure 1. The bolts were M20 x 40 made from ASTM A193-47 Grade B6 material. The re-designed bolts (M20 x 65 Unbrako KS-17 material) are also shown in Figure 1.

Fifteen Reactor Coolant Pump's were successfully tested with no evidence of any bolt failures. On Reactor Coolant Pump #17, one broken bolt was found and again on Reactor Coolant Pump #20, two broken bolts were found. A tabulated summary of the diffuser bolt failures is shown in Figure 2.

After the bolt failure in Reactor Coolant Pump #20, a thorough review of all bolt failures in the connection was initiated, and the following facts established:

1. The bolt failures occurred within a sector of 1130 to 0130 to the discharge nozzle center (See Figure 3).

2. The bolt failures occurred with diffusers supplied from two different vendors.

3. Failures occurred with virgin bolts.

4. There were no bolt failures on seventeen out of twenty pumps tested.

5. All bolt fracture surfaces were discolored.

6. Bolt failures reported on Reactor Coolant Pumps #1, #17, and #20 occurred with the six vane diffuser half positioned on the right side of the nozzle centerline (viewed from the top of the pump casing).

7. Metalurgical investigations of the failed bolts indicated that the failure mechanism was characteristic of hydrogen induced stress corrosion cracking. There were no reported indications of fatigue failure from the metallurgical examinations.

The next four Reactor Coolant Pumps (20A, 20B, 20C, and 20D) were performance tested with the specific objective of attempting to make the bolts fail in order to identify the failure mechanism. Reactor Coolant Pumps 20A and 20C were tested with special attention to the mechanical assembly procedure with the six vane diffuser half positioned on the right-hand side of the discharge nozzle centerline. Post-test inspection revealed diffuser bolt damage in both tests.

Reactor Coolant Pump 20B was performance tested with special attention to the mechanical assembly procedure with the six vane diffuser positioned on the left-hand side of the discharge nozzle centerline. Post-test inspection revealed no bolt damage.

The three recommendations described in Section 5 of this Report were incorporated into the performance test of Reactor Coolant Pump 20D. Post-test inspection confirmed that there was no evidence of any bolt failure.

3.0 SUMMARY ANALYSIS, PART I

The first effort expended was to review all of the significant loading conditions expected within the operating lifetime of the pump, including hydraulic loads and thermal expansion effects. The ASME Boiler and Pressure Vessel Code, Section III criteria were used in the design review even though these bolts are not Code parts.

The second effort expended was to review the dynamic loads associated with the heatup/cooldown and starts/stops over the lifetime of the pump. The cummulative damage for the cyclic operation over the 40 year lifetime was below one, which satisfies the requirements of the ASME Boiler and Pressure Vessel Code, Section III.

In summary, the analysis reviewed in Part I confirmed that the diffuser-to-casing bolted joint design was acceptable and no stresses could be identified that would have caused the bolt failures.

The metallurgical examination of the broken bolts indicated that the failures were related to hydrogen induced stress corrosion. However, the location of the reported bolt failures (see Figure 3), did not show the randomness expected if the failure mechanism were initiated by hydrogen induced stress corrosion in combination with the normal loadings reviewed in Part I.

These observations led to a further investigation described in Part II where a hypothesis of the bolt failure mechanism is described and the corrective action recommended to eliminate further bolt failures in the diffuser-to-pump casing connection.

4.0 SUMMARY ANALYSIS, PART II

While reviewing the analysis of Part I and in particular the assembly procedure, it was noted on several Reactor Coolant Pumps that the pre- and post-test inspection "as-built" dimensions of the diffuser half and the mating inside diameter of the pump casing showed that the diffuser halves had moved during test. Subsequent calculations did in fact, confirm that this movement was possible.

A more detailed review of the hydraulic loadings on the diffuser halves was undertaken. The conclusion of this review was that it was possible under a certain combination of dynamic loading conditions and "as-built" dimensions combined with the assembly procedure, to cause a significant increase in the diffuser bolt stresses. Calculations verified the evidences noted in the performance tests, that positioning the six vane diffuser half on the right hand side of the pump casing discharge nozzle created higher bolt stresses than with the five vane diffuser on the right hand side.

The resultant moments on the diffuser half tended to pivot the diffuser outermost edges about a keyway in the diffuser. These loading conditions were greatly reduced by physically supporting the two diffuser halves against each other as the resulting moment is directed towards the hydraulic centerline of the diffuser. This physical support was achieved by using two wedges (see Figure 4) positioned in the gap between the two diffuser halves.

5.0 CONCLUSION AND RECOMMENDATIONS

In conclusion, the combination of the hydrogen induced stress corrosion cracking and the movement of the diffuser half causing higher stress levels on certain bolts. reaffirmed the failure locations documented during the post-test inspections.

The recommendations, based on the metallurgical examinations and the analysis of Parts I and II of this report, are:

1. Continue to use Type 410 bolting material with a modified heat treatment procedure.

2. Position the five vane diffuser half on the right hand side of the pump casing to minimize the induced stress levels in the bolts.

3. Install diffuser wedges to limit the movement of each diffuser half.

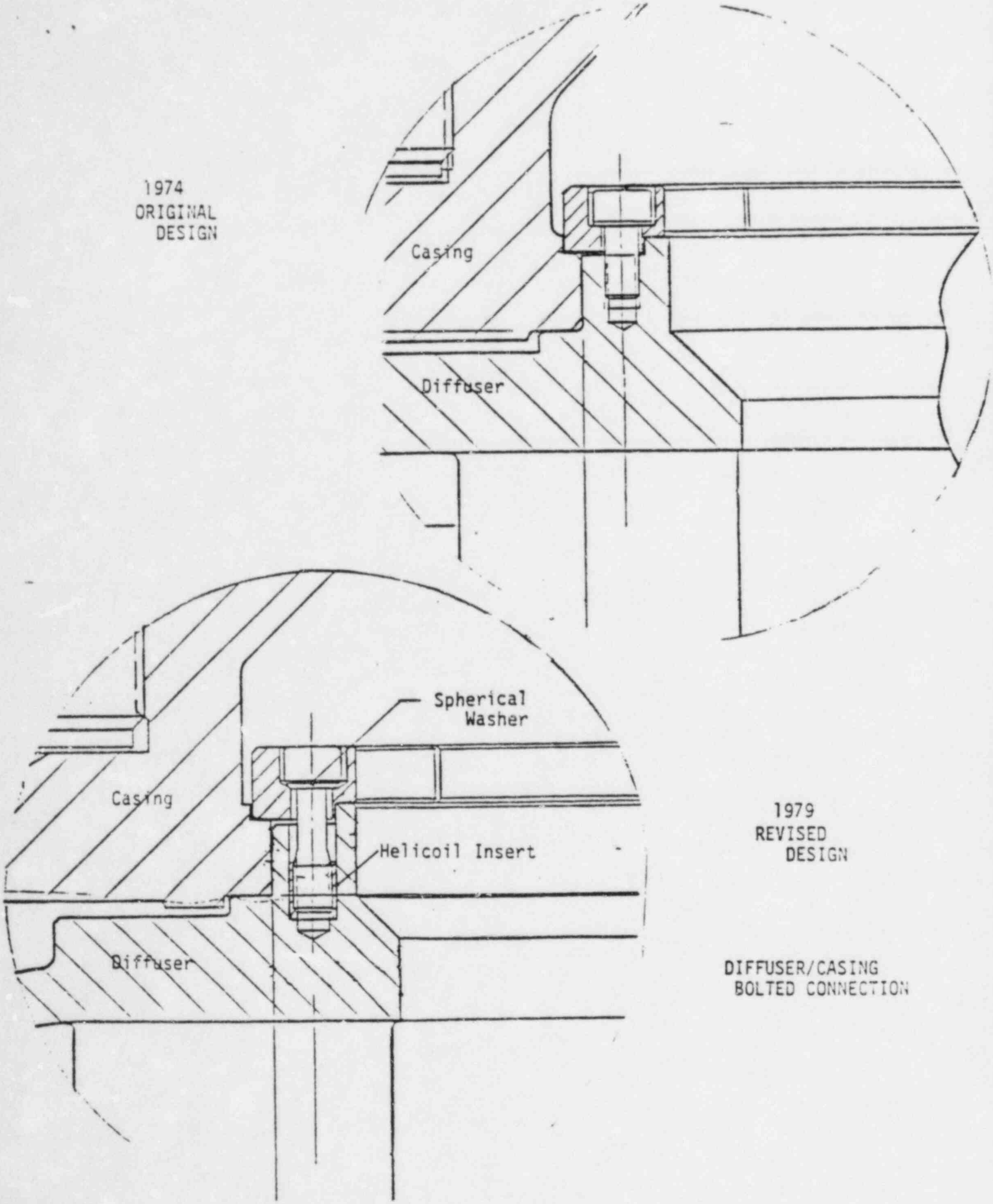

1974
ORIGINAL
DESIGN
Casing
Diffuser
Spherical
Washer
Casing
Helicoil Insert
Diffuser
1979
REVISED
DESIGN
DIFFUSER/CASING
BOLTED CONNECTION

FIGURE 1

FIGURE 2

TABULATED SUMMARY
DIFFUSER BOLT FAILURES
DURING MECHANICAL TESTS AT CE-KSB

	TEST PUMP NUMBER	TEST DURATION HOURS	NUMBER OF STARTS FROM AMBIENT TEMP.	LOCATION OF SIX* VANE DIFFUSER HALF	NO. OF BOLTS BROKEN	COMMENTS
Random Failures	1 (Test 1 - 3)	500+	3	Right	2	(See Note 1)
	17 (Test 2581,2681)	50	2	Right	1	(See Note 2)
	20 (Test 10182,10282	50	2	Right	2	(See Note 3)
Controlled Failures	20A (Test 10582,10682)	30	2	Right	2	(See Note 4)
	20B (Test 10782)	30	1	Left	0	
	20C (Test 10882	30	1	Right	4	(See Note 5)
	20D (Test 10982)	30	1	Left	0	New bolts and Diffuser Wedges.

*Looking down the discharge, as viewed from behind the casing.

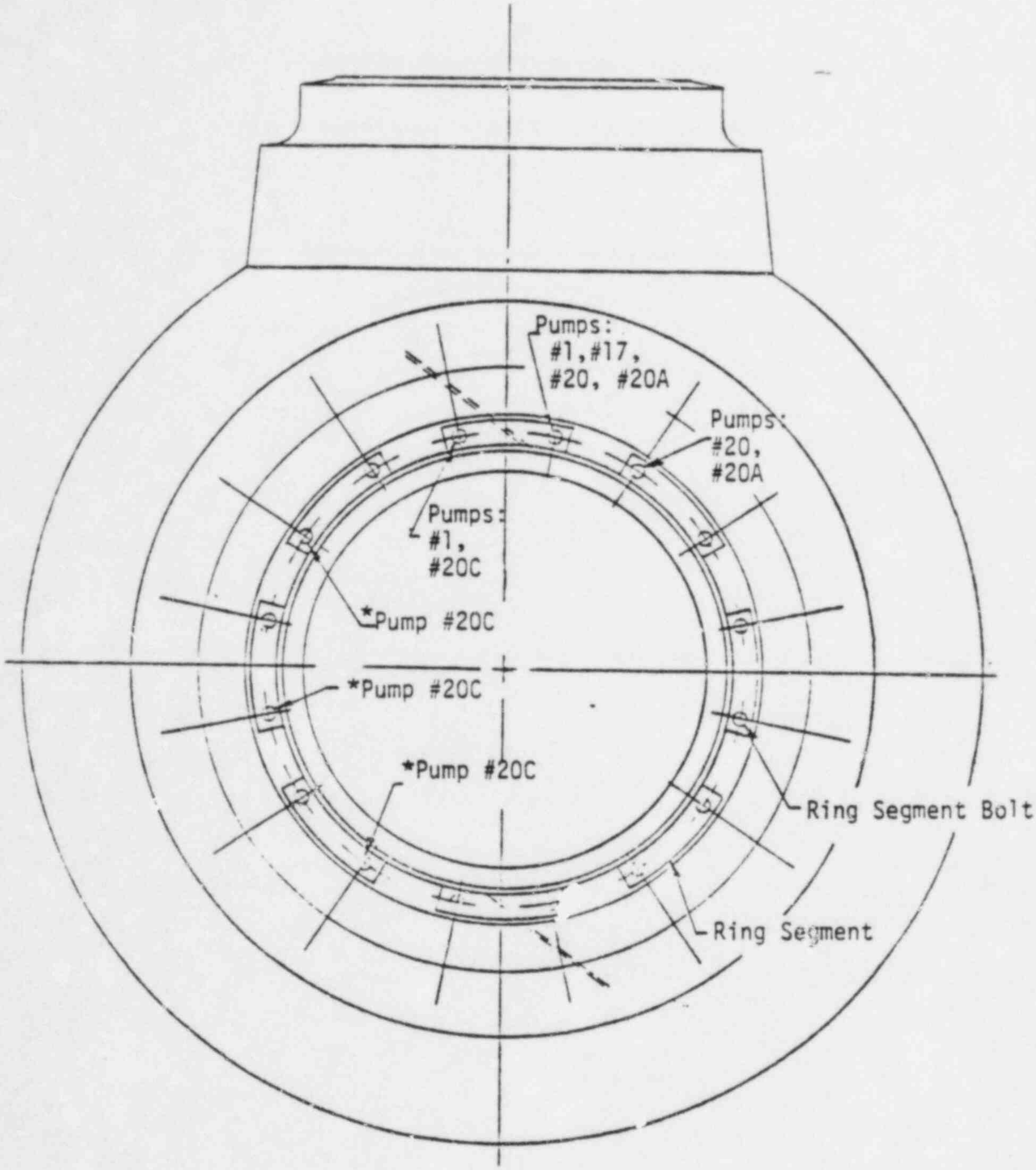
Note 1: Two bolts were found broken and the ring segment was found sitting on the impeller. The exact location of the broken bolts is not certain, but it is thought that they were the "bolts bridging the gap."

Note 2: One ring segment bolt found broken on the ring segment "bridging the gap" on the six vane diffuser half.

Note 3: One bolt was on the ring segment "bridging the gap" on the six vane diffuser half, and the second bolt was the adjacent ring segment on the six vane diffuser half.

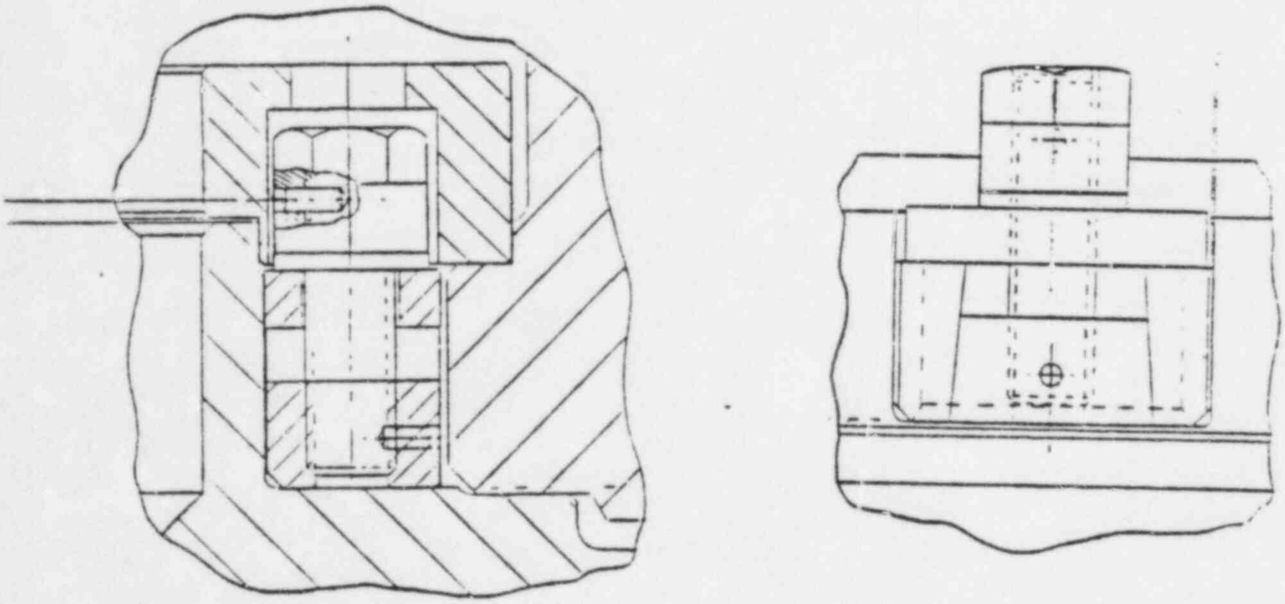
Note 4. One bolt was on the ring segment "bridging the gap" on the six vane diffuser half, and the second bolt was on the adjacent segment on the six vane diffuser half.

Note 5: Four ring segment bolts ultimately found cracked on the five vane diffuser half.



* = Indicated bolt may have been in other hole of the same ring segment.

Report 83-0002 FIGURE 3



DIFFUSER WEDGE ASSEMBLY

6.0 APPENDICES

6.1 Metallurgical Investigation

of

Diffuser/R.C.P. Casing Bolt

Failures

(791350)

by

K. W. Dollansky, P.E.

11-24-82

ABSTRACT

R. C. P. diffuser/casing bolts broke during the test runs at CE-KSB. The bolts were made of Type 410 Martensitic stainless steel, hardened and tempered to a hardness of 40-45 Rc. The type of failure was identified as hydrogen induced stress corrosion cracking. There was no indication of fatigue.

Retempering of existing bolts at higher temperatures to reduce the hardness to <30 Rc did not produce acceptable Charpy impact test results, apparently due to carbide precipitation along the former austenite grain boundaries.

Lowering the hardening temperature from 1750 F to the range of 1650 - 1700 F for Type 410 Martensitic stainless steel bolt material resulted in satisfactory tension and impact values at a hardness of <30 Rc. The improved impact test values are attributed to the presence of some ferrite in the microstructure after heat treatment.

The following heat treatment can be recommended:

Austenitized 1650 - 1700 F - 1 hour - air cooled.
Double Temper 1150 ±25 F - 2 hours - water quenched.

Introduction and Background

CE-KSB requested with Reference (1) an investigation of diffuser/casing bolt failures (SE-8000-163, Rev. 00, 8-31-82) and forwarded to Windsor a total of five broken and/or cracked bolts. The bolts are made according to CE-KSB Dwg. 3-8000-101-2106, Rev. 01 by SPS Technologies in compliance with Type KS 17 of their Unbrako Catalogue.

The material for KS 17 bolts is Type 410 stainless steel hardened and tempered to a tensile strength of 170000 psi minimum. It is understood that the bolts were cold headed and heat treated in a vacuum furnace. The heat treatment consisted of hardening from 1750F/1/2 h in argon and tempering at 600F for two hours, followed by vapor blasting. Tension tests gave 203000 and 207000 psi UTS.

We have received the following failed bolts for examination:

Bolt No. 2: broken in thread, oxidized fracture (see Fig. 1)

Bolt No. 3: broken in fillet shank to head, oxidized fracture (Fig. 1)

Bolt No. 13: broken in stem, oxidized crack, clean fracture (Fig. 2)

Bolt No. 15: broken in stem, two oxidized cracks, clean fracture (Fig. 2)

Bolt No. 11: did not break but cracked through thread (crack oxidized)

All bolts broke or cracked during test runs in the loop (at CE-KSB) in primary coolant at 560F. Bolts No. 2 and 3 broke during a 30 hour test after about 15 hours exposure to the coolant at 560F. Bolts No. 13 and 15 only cracked. These cracks were not noticed and the bolts were supposed to be used again for the following test run. They were retightened and left overnight. The next day the bolt heads were found broken off on the floor of the test area. Subsequent liquid penetrant examination of all bolts revealed the crack in bolt No. 11.

Examination

The bar material for the bolts was supplied by Peter A. Frasse & Co., Inc. and Carpenter Technology Corp. Copies of the material test certificates are attached (Attachments (1) and (2)). We analyzed one of the new, unused bolts sent to C-E Windsor and found the following chemical composition:

C	0.139%	Cr	12.20%
Mn	0.52%	Ni	0.121%
P	0.024%	Cu	0.101%
S	0.008	Mo	0.158%
Si	0.21%		

This analysis is within the limits of ASTM A193, grade B6 (Type 410).

Metallographic examination of the broken and also new bolts revealed the microstructure to be tempered martensite with a grain size of about ASTM No. 7 (Fig. 3, broken bolt No. 13 - microstructure typical for all samples). Normally the former, austensitic grain boundaries should not be visible as clearly after hardening and tempering. This will be discussed later.

The micro hardness was found to be DPH 455-459 (500g load), corresponding to about Rc 46. The macro hardness of new, unused bolts was Rc 41-42.

Tension and Charpy-V impact tests with new, unused bolts (A-bolts) yielded the following room temperature results (see also Table I):

Sample No.	Energy ft-lbs	Lat. Exp. mils	Shear %
1	97	47	70
2	70	26	70

Sample No.	UTS,psi	YS,psi	R of A%	E%
3	195387	146206	67.3	18
4	199727	151262	67.3	18

These values can be expected according to published data, except that the impact values are much higher than one would expect after a temper at only 600F.

The fractured surface of the broken bolts was examined on the scanning electron microscope (SEM). The results were the same for all broken bolts. Bolt No. 13 had the cleanest fracture (free of dirt) with a clear crack (see Fig. 2) and was therefore selected for a more detailed examination.

The crack which initiated the failure of bolt No. 13 (see Fig. 2) is distinguishable at the right hand side of the two SEM photographs in Fig. 4. Fig. 5 shows the same location at higher magnifications. As can be seen the crack is intergranular and follows the former, austensitic grain boundaries visible in the photomicrographs of Fig. 3.

Discussion

In spite of the good mechanical properties listed above the bolts failed. This can be explained if one realizes that the test specimens were removed from the center of the bolts. Cracking, however, started at the bolt surface where residual stresses are at a maximum, especially when machining marks or other sharp corners create locations of stress concentrations.

Such residual stresses are induced, among others, by hardening (cooling stresses and stresses due to volume changes during martensite formation). If low tempering temperatures are used to retain high strength, these stresses may never be removed completely (1). The effect of temperature

and time on stress relief is shown in Fig. 6.51 of (2): for instance, at 600-650F for one hour, 10% of the residual stresses are removed and after 4 hours about 18%: however, at 1150F the stress relief treatment is about 90% effective.

Hardened and tempered martensitic stainless steels can be suseptible to stress-corrosion under certain conditions in environments containing chlorides, hot caustics or nitrates, or hydrogen sulfide (3). If the hardness after heat treatment is low these steels are believed to be immune to stress corrosion cracking. However, heat treated to high hardnesses of >30Rc, they are susceptible. Apparently they fail because of their sensitivity to hydrogen embrittlement (4).

Hydrogen sources are usually steel making, welding and heat treating atmospheres. But hydrogen can also result from corrosion. Therefore, failure in a corrosive medium may be the result of either stress corrosion, hydrogen embrittlement, or both (5). Certain specific combinations of factors, e.g., presence of stresses, notch sensitivity, etc. do produce stress corrosion cracking in 12% Cr steels. The potentially most dangerous medium appears to be that which promotes hydrogen embrittlement (5) (6).

Only tension stresses will produce stress corrosion cracking, especially at the surface which is in contact with the corroding medium. The stresses do not have to be only assembly or operational stresses but can also be residual stresses e.g. from heat treatment. They are most insidious because their magnitude may not be known (5).

Heat Treatment Experiments, Results and Discussion

Based on all this it was decided during the meeting at CE-KSB on 9-30-1982 to retemper existing new bolts (A-bolts) at 1100 or 1150F to produce bolts with a hardness of 30Rc (B-bolts). Retempering within this range was

expected to result in the following approximate properties (according to published data by steel producers):

UTS.ksi	YS.ksi	R of A%	E%	Rc	Charpy V, ft-lbs
125	105	70	22	25	68

The actual test results with B-bolts were as follows (see also Table I):

122 to 132	101 to 112	67 to 70	22 to 25	24 to 28	12 to 20

The tension test results are acceptable, but the impact test results were disappointing, especially with lateral expansion values of only 0 to 5 mils and 0% shear fracture.

The microstructure was similar to that of A-bolts (Fig. 3) but with more clearly defined grain boundaries, possibly due to carbides which precipitated during retempering.

SEM examination of broken impact specimens revealed the fracture to be intergranular, following the former austenitic grain boundaries (Fig. 6, see also Fig. 5A).

Grains or crystals are polyhedral bodies and the surface separating adjacent crystals of different orientations are called grain boundaries as they appear on a polished and etched plane of a micro section. The grain boundaries interrupt the continuity of the lattice planes. They become visible after etching because of the different chemical reactions of the crystal and grain boundary to the etching reagent.

Austenitic grains (and boundaries) exist only in austenitic structure. Type 410 stainless steel is fully austenitic (in equilibrium) only between about 1700F and 2050F. During hardening (continuous cooling) austenite begins to transform to martensite at about 600F within the austensite

grains. This transformation is completed at about 350F. Each plate like volume after transformation is a single crystal of martensite and the former austenitic grain boundaries are no longer visible in the micro structure (unless something was wrong with the steel from the beginning, e.g., segregation of impurities along the grain boundaries).

If the grain boundaries appear again after tempering (see Fig. 3), it can be assumed that particles, most likely carbides, have precipitated during the tempering treatment. This is possible because after hardening the former austenitic grain boundaries are still represented as imperfections in the orientation of the lattice, even though they are invisible. Precipitation of carbides along the former, austenitic grain boundaries can adversely affect properties, e.g., impact resistance, ductility, corrosion, etc.

Based on the above thoughts, it was decided to reheat treat bolts consisting of annealing, hardening (from 1750F), and tempering (at 1150F). Preliminary tests with small pieces showed that the microstructure was free of grain boundaries after annealing and also after hardening. Tempering, however, produced grain boundaries with carbide precipitation. The mechanical test results of reheat treated bolts (C-bolts) were as follows (see also Table I):

At room temperature

UTS,ksi	YS,ksi	R of A%	E%	Rc	Charpy-V, ft-lbs
123-128	107-115	65-67	(*)	23-27	20-46

(*)broke outside gauge length

At 40F

-	-	-	-	-	11-16

Lateral expansion at RT was 3-25 mils, at 40F 1-4 mils; % shear fracture at RT was 0-30%, at 40F 0%.

All reheat treated bolts were liquid penetrant and ultrasonically examined (Attachment (3)) and were found to be without defects. Dimensional checks before and after heat treatment did not reveal any unacceptable dimensional changes.

One of the broken impact specimens was used for metallographic examination. Fig. 7 shows the microstructure consisting of tempered martensite with heavy former austenitic grain boundaries and possibly some ferrite. The DPH hardness was 270-292 (about 27 Rc).

All heat treatment experiments have resulted so far in good tension and hardness test values but unacceptable impact properties. This can be explained only by the development of precipitates along the former, austenitic grain boundaries during tempering. All experiments consisted basically of hardening from 1750F and tempering at 1150F. This heat treatment is recommended in steel specifications not only domestic but also foreign (e.g., DIN 17 440 "Corrosion Resistant Steels" Grade X7Cr13; JIS G 4303 "Stainless Steel Bars" Grade SVS 51 B). One would be inclined to suspect that the bolts used for the heat treatment experiments were made from a bastard heat. The Test Certificate, Attachment (1), however, does not indicate anything unusual. A sample was sent to MML Chattanooga for investigation.

In the meantime SPS has received more bar material from Carpenter to cover an order issued by CE-KSB (see Attachment (4)). Pieces of this material, 0.8125" diameter, were used for heat treatment experiments and mechanical testing. The heat treatment was again hardening from 1750F followed by tempering for 2 hours at 1150F. Following are the room temperature results ("new" material, see also Table I):

Tests at SPS

UTS.ksi	YS.ksi	R of A%	E%	Rc	Charpy-V, ft-lbs
120.5-122.8	97.7-102.7	65.2-66.6	20.5	23	22-26

Lateral expansion 12-13.5 mils, shear 10%

Tests at C-E Windsor

Charpy-V, ft-lbs	Lat. Exp., mils	%Shear	Rc
26	7	0	24

SPS water quenched one sample after tempering to prevent any possible temper embrittlement. This did not help much:

Charpy-V 30.5 ft-lbs., Lat. Exp. 21.5 mils, Shear 10%

The test results with A, B and C-bolts, and with new material are summarized in Table I.

Because of the poor impact test results, SPS asked Carpenter for assistance. The steel producer recommended oil hardening from 1650-1700F and double tempering at 1150F followed by water quenching. This heat treatment gave good results (see also Table I):

Tests at SPS at room temperature

UTS.ksi	YS.ksi	R of A%	E%	Rc	Charpy-V, ft-lbs
114.5	95.5	69	20	23.5	48-88

Lateral expansion 33-54 mils, shear 40-75%

Tests at C-E Windsor at room temperature

New material

UTS, ksi	YS, ksi	R of A%	E%	Rc	Charpy-V, ft-lbs
115.5	102.5	70.6	20	25	80-93

Lateral expansion 46-56 mils, shear 50-60%

A-bolts annealed + heat treated as above → D-Bolts

125.2	113.1	71.7	20	25	69-129

Lateral expansion 36-71 mils, shear 40-80

SPS also performed Charpy-V tests at 60F and 40F:

Tests (3 specimens) at 60F

Energy, ft-lbs	Lat. Exp., mils	% Shear	Rc
38.5-56	22-39	20-40	24
at 40F			
31-42	21-27.5	20	24

Metallographic examination of one of the broken impact specimens (D-bolt) revealed the microstructure to be tempered martensite without former, austenitic grain boundaries (Fig. 8 top - Vilella's reagent etch, compare with Fig. 7). This micro was also etched electrolytically with alkaline sodium picrate which revealed the presence of about 20% ferrite in the microstructure (Fig. 8 bottom - white particles).

Ferrite particles are present in the microstructure of the sample hardened from 1650-1700F (the actual temperature was 1660-1665F) because a steel with about 12% Cr and low carbon content has its austenite/austenite+ferrite phase boundary within this temperature range. Any ferrite which is present at the austenitizing temperature remains in the structure after hardening and is unwanted because it can reduce tension test properties and hardness. This is obviously the reason why steel producers normally specify a hardening temperature of 1700-1850F.

Oil quenching is recommended when maximum hardness after quenching is needed. In such a case, of course, the hardening temperature should not be below 1700F because ferrite present in the martensitic matrix reduces the final hardness. Therefore, oil quenching is usually recommended in conjunction with a higher hardening temperature of about 1800F. However, oil quenching may be used if desired even if the hardening temperature is 1650-1700F.

A double temper is recommended for steels with retained austenite after hardening (low Mf temperature) to prevent untempered martensite in the microstructure. Since Type 410 has an Mf temperature of about 350F, retained austenite and therefore, untempered martensite is unlikely to occur. However, tempering Type 410 twice will not do any harm and can only improve the properties after heat treatment.

Water quenching from the tempering temperature is usually done to prevent temper embrittlement found in some low and medium alloy steels when cooled slowly through the temperature range of about 1000F to 650F. As shown earlier in this report, water quenching after tempering (by SPS) did only slightly improve the impact properties of a sample hardened from 1750F. As far as our bolts are concerned, water quenching is harmless and can only improve the impact properties after heat treatment.

Conclusions

Summarizing the discussion of the new heat treatment suggested by Carpenter, the much better impact properties obtained with A-bolts and the new material (Attachment (4)) (see Table I) are due basically to the low hardening temperature of 1650-1700F, causing retention of some ferrite in the martensitic microstructure.

A possibly detrimental effect of ferrite on fatigue in a martensitic structure has been known for a long time. Ferrite lowers the fatigue strength of a part if it has been heat treated to a high hardness, for instance, the original A-bolts with a hardness of 40-45 Rc. At lower hardness levels of about 20-26 Rc and in longitudinal direction small amounts of ferrite are harmless.

The presence of ferrite, retained after austenitizing at 1650-1700F and quenching, can be beneficial however, as was demonstrated with the impact tests performed at SPS and C-E Windsor. Islands of ferrite (Fig. 8) in the austenite matrix at hardening temperature dissolve more impurities than the austenite does, thus leaving less impurities which later could segregate along the grain boundaries during tempering. The ferrite particles also increase the area of interphase boundary, and impurities and also carbides spread out over a larger grain boundary area. In other words the grain boundaries are no longer visible in the microstructure (Fig. 8 top). During impact testing the crack does no longer follow the grain boundaries intergranularly but is transgranular giving good impact properties.

In summary one can conclude:

Steel producers recommend a hardening temperature of 1700-1850F for Type 410 stainless steel to be certain that hardness and tension test properties are met, especially when high hardness levels are required.

This heat treatment, however, does not guarantee satisfactory impact properties in every case. This may be acceptable since most steel consumers are interested in hardness and tensile properties and do not even perform impact tests.

If impact testing is a criterion, then the hardening temperature should be lowered to 1650-1700F in most cases (depending on steel making, actual chemical composition, processing, etc.). This heat treatment can produce good impact values together with satisfactory tension test results especially at lower hardness levels. Other properties are not necessarily adversely affected.

Literature

(1) Metals Handbook, 1948 Edition
ASM, 1952,

(2) Welding Handbook, Seventh Edition, Volume 1
AWS, 1976,

(3) Source Book on Stainless Steels
ASM, 1976,

(4) D. J. De Paul: Corrosion and Wear Handbook for Water Cooled Reactors
USAEC, 1957,

(5) J. Z. Briggs and T. D. Parker: The Super 12% Cr Steels
Climax Molybdenum Co., 1965,

(6) E. Houdremont: Handbuch der Sonderstahlkunde,
Springer - Verlag, 1956,

TABLE I

Summary of Mechanical Test Results at Room Temperature*

	TENSION TESTS						CHARPY-V IMPACT TESTS			
Note 1	No. of Tests	UTS Ksi	YS Ksi	R of A %	EL %	Rc	No. of Specimens	Energy ft-lbs	Lat. Exp. mils	Shear %
A-Bolts	2	197.6	150	67.5	18	42	2	83.5	33.5	70
B-Bolts	3	126.2	107.1	68.4	23.3	26.5	6	16.3	2	0
C-Bolts	2	125.5	110.8	66.3	-	25.5	4	28.8	10	8
New Mater.	2	121.7	100.2	65.9	20.5	23.5	3	24.7	10.8	7
Note 2										
New Mater.	4	116.6	100.2	68.2	21.1	23.5	6	79.8	47.8	59
D-Bolts	1	126.2	113.1	71.7	20	25	3	97	53	60
ASTM A193 GR.B6	-	>110	>85	>50	>15	-	-	-	-	-

*These values are the averages for all the specimens discussed in this report.

Note 1:

Heat treatment - A-Bolts 1750F/1/2h/argon+600F/2h/air

- B-Bolts A-Bolts + 1100-1150F/2h/air
- C-Bolts A-Bolts + anneal + 1750F/1h/air+1150F/2h/air
- New Material as received + 1750F/1h/air or argon+1150/f/2h/air

Note 2:

Heat Treatment - New Material 1660F/1h/oil + 2x1150F/2h/water

- D-Bolts A-Bolts + anneal + 1660F/1h/oil+2x1150F/2h/water

57316

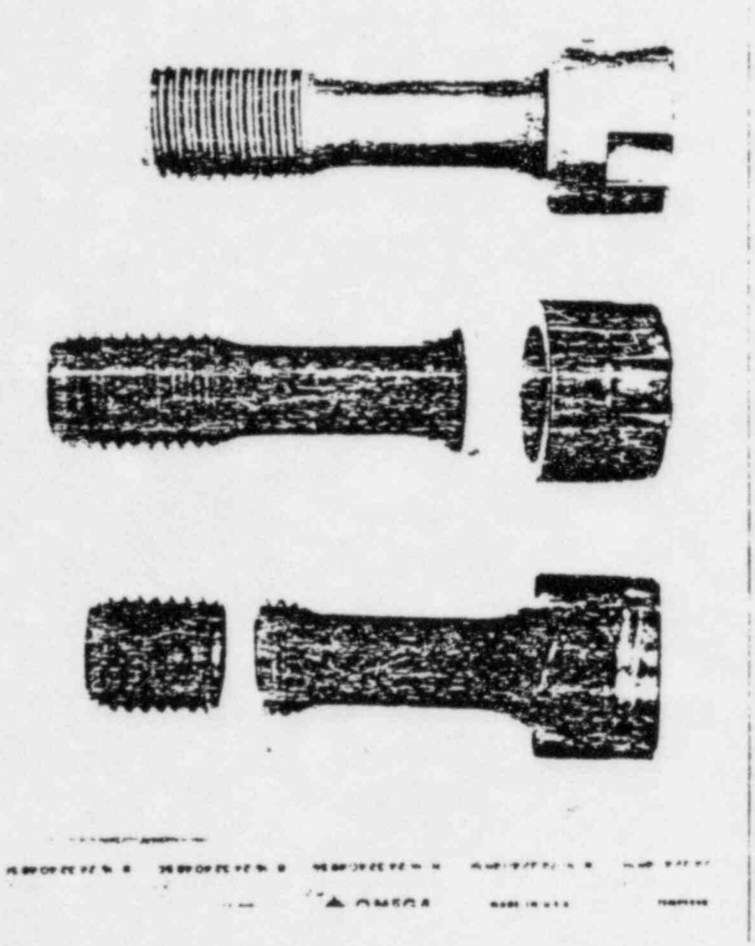
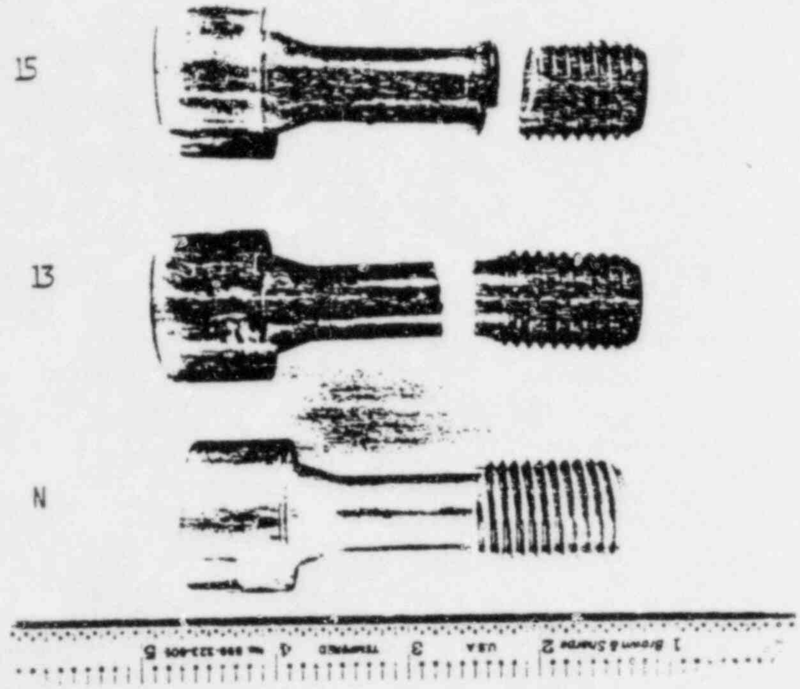


Fig. 1 Broken Bolts No. 2 and 3

57642



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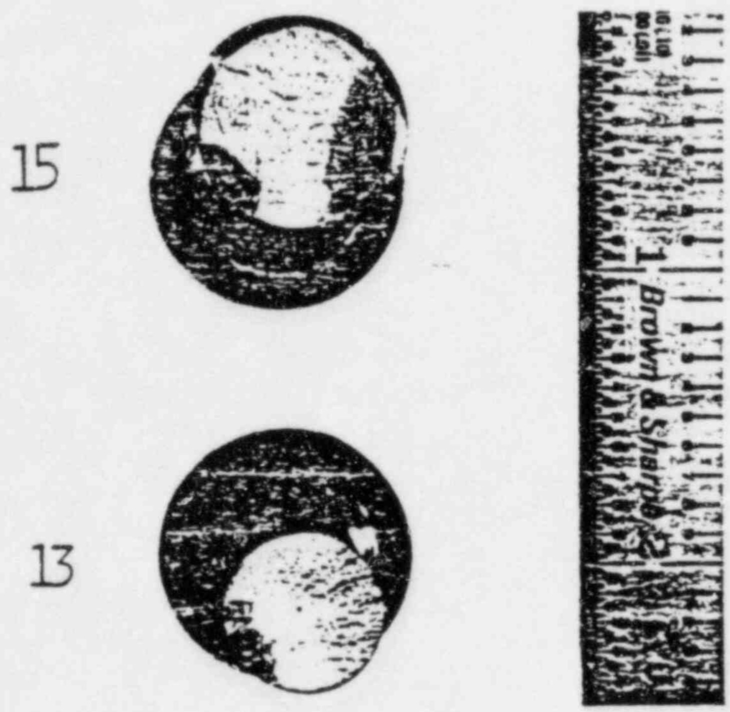
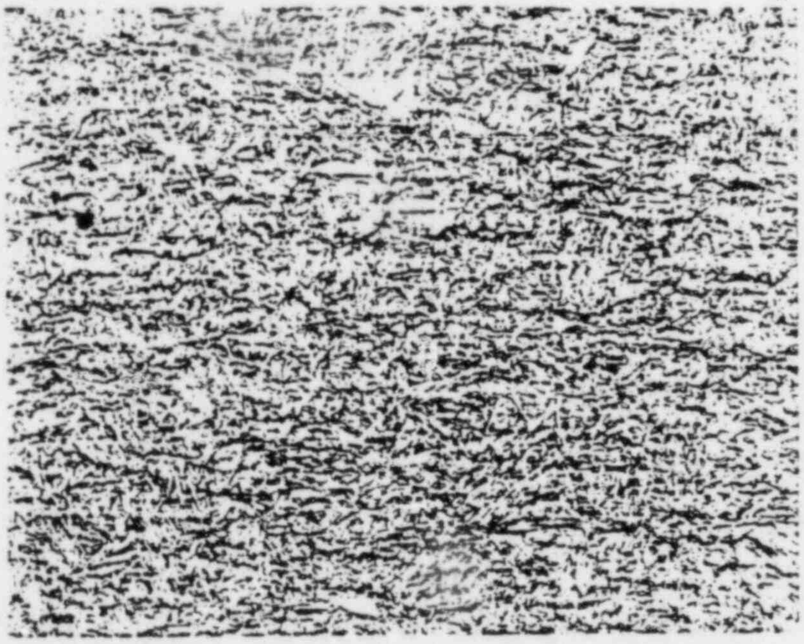


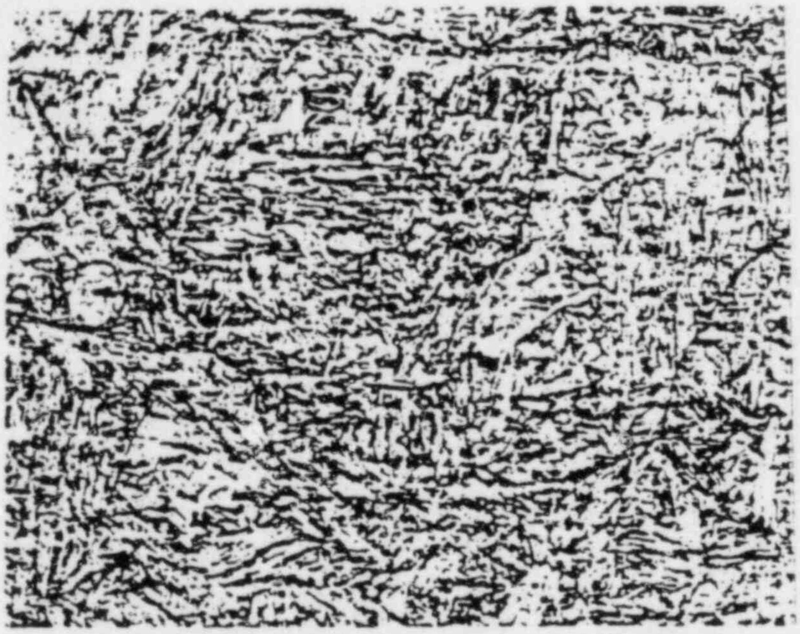
Fig. 2 Broken Bolts No. 13 and 15



57682

500X

Vilella's



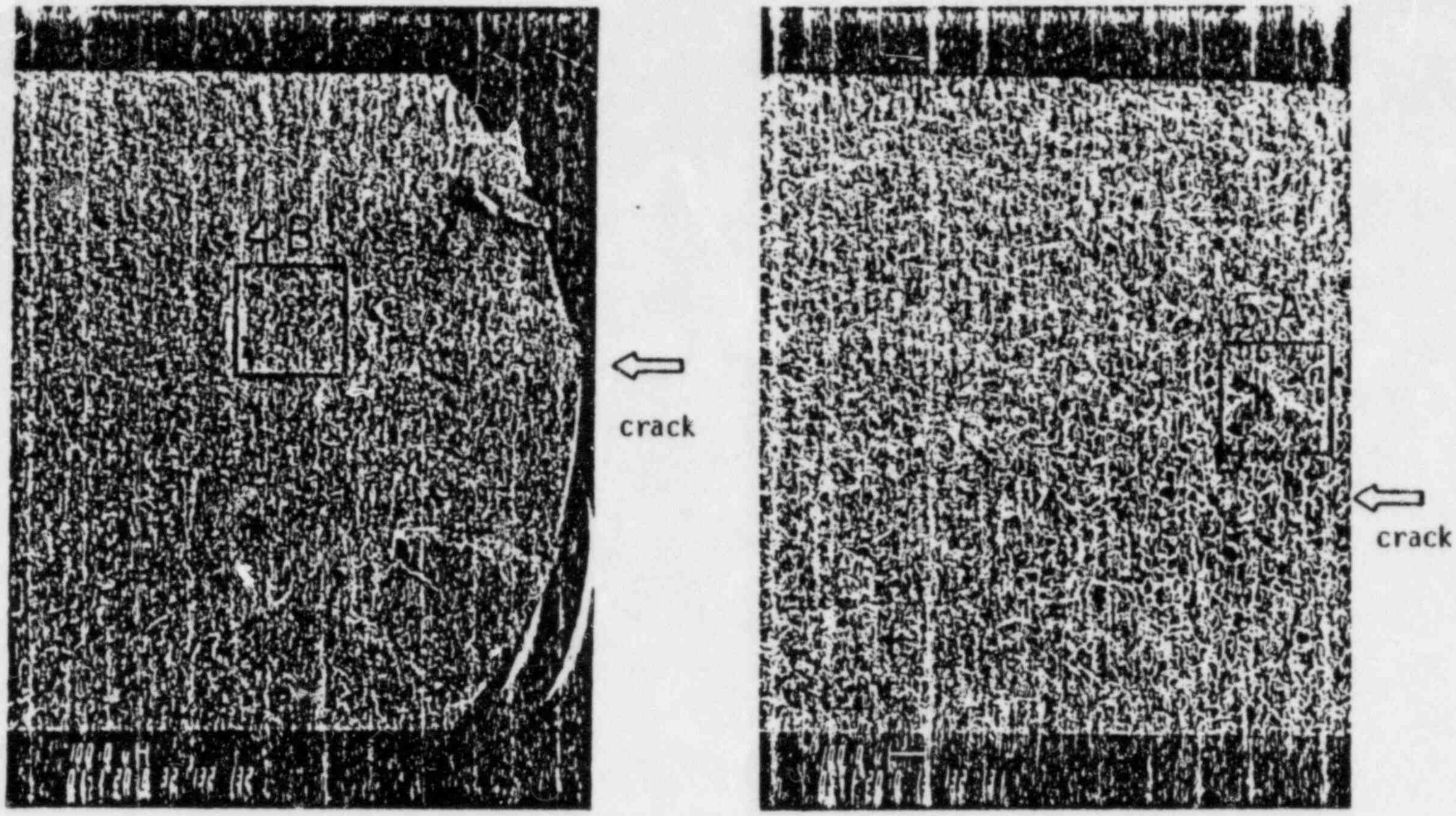
57683

1000X

Vilella's

Fig. 3 Microstructure of Bolt No. 13 (A-Bolt)
Grain Size -ASTM No. 7
DPH Hardness 455-459

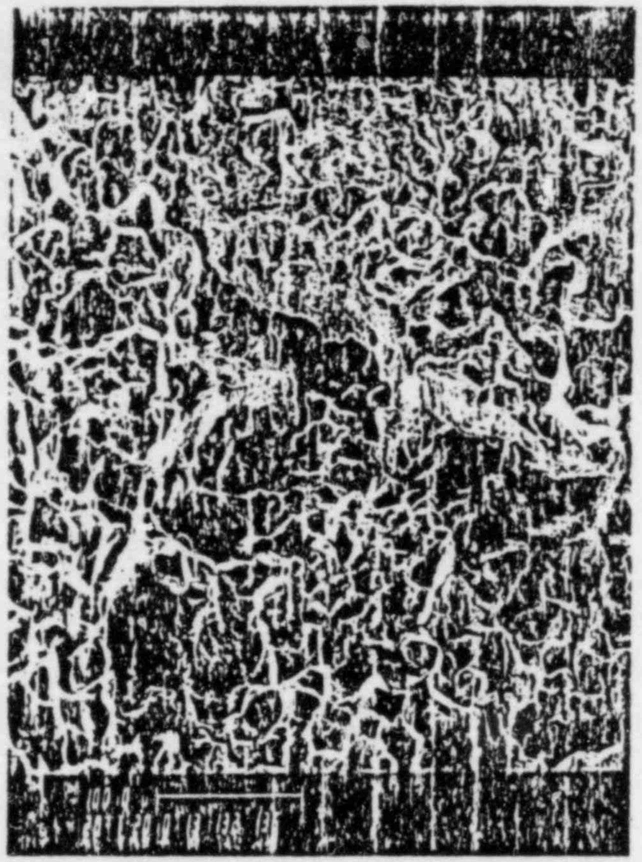
57522 57521



A 10X B 50X

Fig. 4 SEM Photographs of Fracture Surface of Bolt No. 13

57526



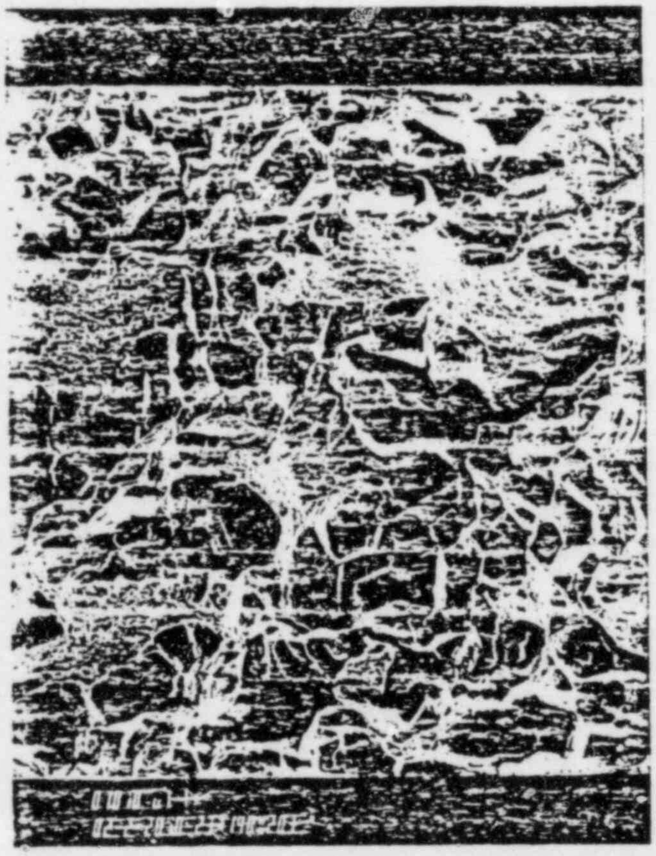
A 200X

57528

B 2000X

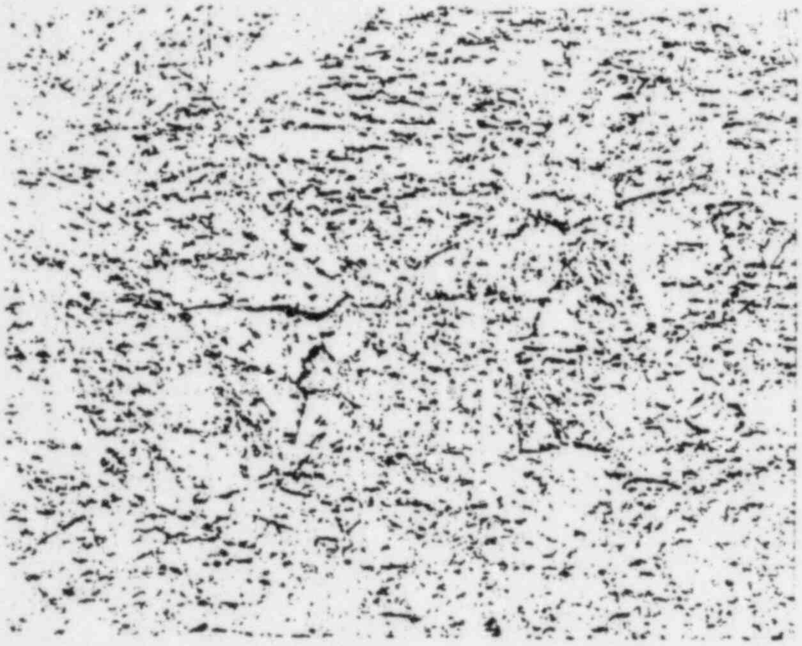
Fig. 5 Same as Fig. 4 but at Higher Magnification, Location of Photographs as Indicated on Fig. 4B

58189



200X

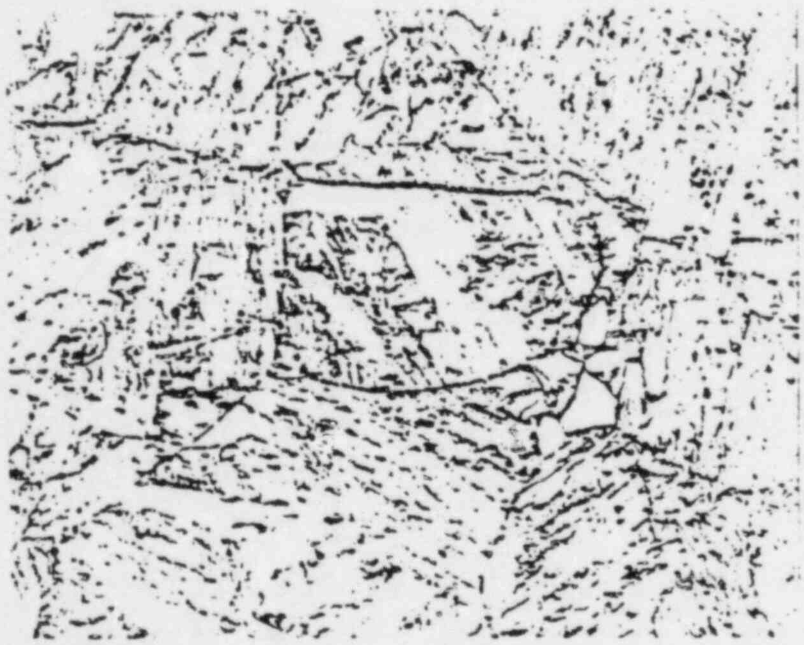
<u>Fig. 6</u> SEM Photograph of Fracture Surface of Broken Impact Specimen from a Retempered A-Bolt (B-Bolt)



58290

500X

Vilella's

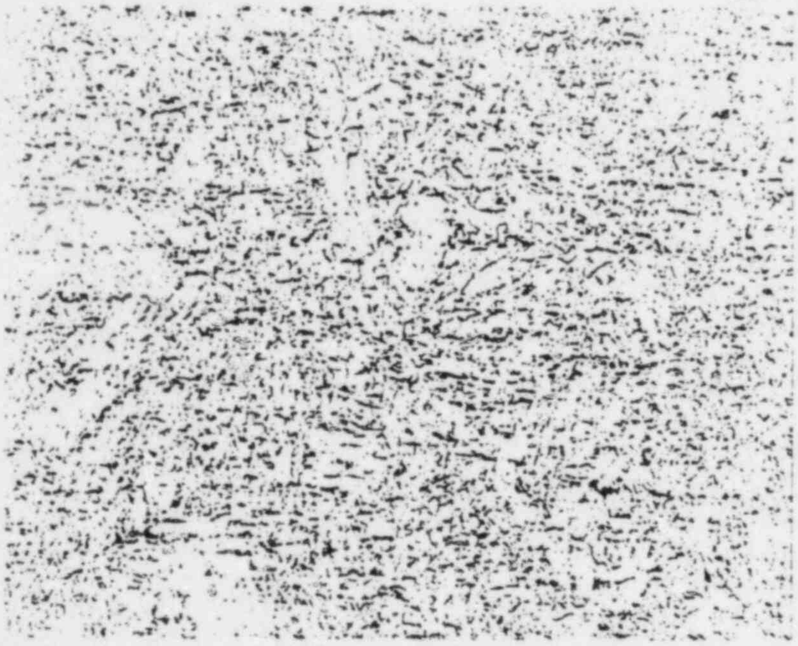


58289

1000X

Vilella's

Fig. 7 Microstructure of a C-Bolt
(completely reheat treated A-Bolt)
DPH Hardness 270-292



58761

500X

Vilella's

58762

500X

Alkaline Sodium Pirate

Fig 8. Microstructure of a D-Bolt
(A-bolt heat treated 1665F/oil+2x1150Fwater)
DPH Hardness 264
Lower Photo: Etched to Reveal Ferrite

CK61L N

NTI-... IKC # C66582

Frasse

ANALYSIS AND TEST CERTIFICATE

SUBJECT TO SELLER'S TERMS OF WARRANTY STATED ON REVERSE SIDE HEREOF

TO

SPS TECHNOLOGIES INC
P O BOX 69 S
JENKINTOWN, PA 19046

YOUR ORDER NO. BLANKET 35001 REL 235789 [illegible]

OUR INVOICE NO. 320313

DISTRICT PHILA

DATE 8-11-80

ATTACHMENT (1)

GRADE	SIZE DESCRIPTION AND SPECIFICATION(S)	QUANTITY (LBS)	HEAT PAINT
410	.8125 ROUND 13/16	260	WHITE

ACC TO AMS-5612B AMS-2303 AMS-5613L ASTM-A-276-77 ~~ASTM-A479-77 ASME-SA-479 QQS-763D~~ EX BHN 169-223 AIM 200-220 COND A DEL CLM (625-02 REV. 3)

CHEMICAL ANALYSIS

HEAT NO.	C	MN	PHOS	SUL	SIL	NI	CR	MO	CU	TI	Pb	CB	[illegible]	AL	[illegible]	[illegible]
95512	.125	.50	.025	.009	.26	.15	11.89	.15	.11			.017		.005	.012	.0[illegible]

MECHANICAL PROPERTIES

● DENOTES LESS THAN

TENSILE STRENGTH LBS. SQ. INCH	YIELD LBS. SQ. INCH	ELONG. % IN 2 IN.	RED. OF AREA %	HARDNESS BRINELL	HARDNESS ROCKWELL		FREQUENCY	SEVERITY	GRAIN SIZE	[illegible]
79,500	40,500	33	78	170						C-44

MECHANICAL CAPABILITIES FOR HEAT TREATED CONDITION ☐ 17-4 PH OR 15 COND ☐ H 900 ☐ H 925 ☐ [illegible]

CAPABLE PROPERTIES — TO AMS-5612B

TENSILE STRENGTH	YIELD	ELONG.	RED. OF AREA							
204,500	163,500	15	62							C-44

JOMINY HARDENABILITY ROCKWELL "C" IN 16THS OF AN INCH

1	2	3	4	5	6	7	8	9	10	12	14	16	20	24	28	32	40

TO THE BEST OF OUR KNOWLEDGE, MATERIAL IS FREE OF MERCURY CONTAMINATION

MATERIAL IS SOLUTION HEAT TREATED FREE FROM CONTINUOUS CARBIDE NETWORK ☐

BEND TEST ______ EMBRITTLEMENT ______ FERRITE ______ MACRO ETCH O.K.

OTHER: MICRO TEST: O.K. METHOD OF DETERMINATION- METHOD # 1 (ETHANT KALLINGS REAGENT) MAGNETIC PARTICLE INSPECTION-F/S-0/0 ANNEALED AT 1500 DEG. F.- SLOW COOLED.

We hereby certify that the above data is a true copy of data ... this product or data resulting from tests performed by ... conventional practices.

Signed Roberta Fauni

6C6220

CARPENTER TECHNOLOGY CORPORATION
P.O. BOX 662 • READING, PA. 19603

CERTIFICATE OF TESTS

DATE 09/24/79

N79-0050
Acc# 053484

SPS TECHNOLOGES
HIGHLAND AVENUE
JENKINTOWN, PA 19046

ATTACHMENT (2)

PHILA

CUSTOMER ORDER NO.	CARP. ORDER NO.	DATE SHIPPED	WEIGHT
33002	RDG6058 L13231		279

PRODUCT DESCRIPTION	SPECIFICATION
STNLS #1 TYPE 410 CG ANNEALED	AMS-5613

SIZE 0.3125 IN. RD

REL #255789-01

HEAT NO. -341465

C	MN	SI	P	S	CR	NI	MO	CU	AL
0.11	0.44	0.35	0.017	0.003	12.40	0.33	0.05	0.06	0.001

SN	N
0.002	0.037

MACRO ETCH TESTED AND APPROVED

HARDNESS AS SHIPPED, BRINELL - 217
HARDENABILITY, ROCKWELL C - 42 - 1750 F AIR TREAT

CMP/IN 4

Report 83-0002

I CERTIFY THIS INFORMATION TO BE TRUE AND CORRECT AS CONTAINED IN THE RECORDS OF CARPENTER TECHNOLOGY CORPORATION

Colette L. Peccia
AUTHORIZED REPRESENTATIVE

NOTE: THE VALUES AND OTHER TECHNICAL DATA SHOWN REPRESENT THE RESULTS OF ANALYSIS AND TESTS MADE ON SAMPLES COLLECTED FROM THE TOTAL LOT. ORIGINAL DATA RECORDS CAN BE TRACED BY REFERENCE TO THE CARP. ORDER NO.

2-138-0

ATTACHMENT (3)

3 SHEETS

INTER OFFICE CORRESPONDENCE

TO K. Grilansky	DEPT.-LOCATION 9454-510
FROM C. Moss	DEPT.-LOCATION 9451-12T2
SUBJECT RCP Capscrews (8) A and B ~~Belt~~	DATE 10/14/82

MESSAGE:

The capscrews received yesterday have been inspected by UT and found to contain <u>NO</u> defects. Attached please find a copy of the test parameters and calibration.

ORIGINATOR DO NOT WRITE BELOW THIS LINE SIGNED Clifford Moss

REPLY:

DEPT LOCATION	SIGNED	DATE / /

SEND WHITE AND PINK COPIES WITH CARBON INTACT- PINK WILL BE RETURNED WITH REPLY

(3)

CE POWER SYSTEMS
COMBUSTION ENGINEERING INC

CALIBRATION DATA SHEET

Plant/Unit: CE
Comp/System: [illegible]
Zone: N/A

Data Sheet No.: [illegible]
Procedure No.: N/A
Rev/Change No.: N/A
Cal. Block No.: [illegible]
Surface (ID/OD): [illegible]
Block/Comp. Temp: 7? °F/ 7? °F

SEARCH UNIT	
Scan Angle: 0°	Mode: LONG
Fixturing (if any):	SEARCH UNIT IN IMMERSION TANK
Style or Type No.:	GAMMA
Size & Shape:	.25" DIA ⌀
Frequency:	10.0 MHZ
Serial No/Brand:	KB AER-TECH K0424
Measured Angle:	N/A
Cable Type & Length:	6' BNC-BNC
Couplant Brand:	TAP WATER
Couplant Batch:	N/A

CALIBRATION	
Axial	X
Circ	N/A

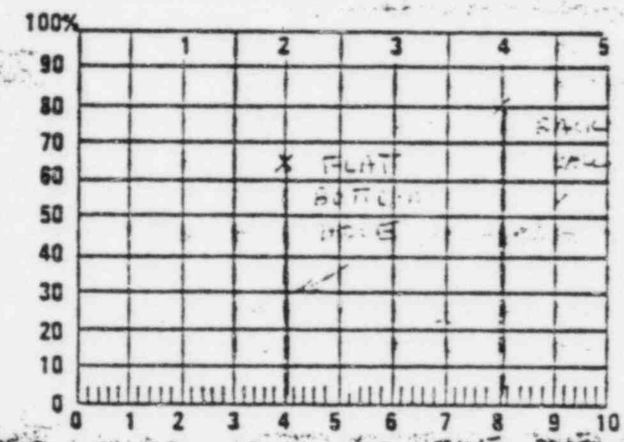
SCAN AREA	
0° WRV	N/A
0° Mat'l	X
⊥ To Weld	N/A
∥ To Weld	N/A

	0° ~~or ⊥ TO WELD~~			∥ TO WELD		
IDENT	SWEEP POS	AMPL %	ATTEN dB	SWEEP POS	AMPL %	ATTEN dB
FBH	4.0	65	72			
B.W.	8.0	80	72			
					N/A	

INSTRUMENT SETTINGS	
Mfg/Model No.:	KBI-USL-38
Serial No.:	# 21130C
Pulse Length/Damping:	N/A / MIN
Mode Select: SFD	Reject: MIN
Freq.: 5.0 M	Rep. Rate: N/A
Filter: N/A	Video: N/A Jack: T
Sweep Length	C: .5" F: 4.50
Sweep Delay	C: N/A F: 6.75
Gain 0° ~~or ⊥~~	C: 40 F: 32
~~Gain ∥~~	~~C:~~ ~~F:~~

Scan Sensitivity: 78dB = FTS.[illegible]

CAL. CHECKS	TIME
Initial Cal.	1200
Intermediate	N/A
Intermediate	N/A
Intermediate	N/A
Final Cal.	1715



Screen Divisions, 10 = .?25 in.

INSTR. LINEARITY CAL.	High	Low		High	Low
1	100	50	5	40	20
2	90	42	6	32	16
3	65	30	7	25	12
4	50	15	8	1?	7

AMPL. CONTROL LINEARITY		
Initial	ΔdB	Result
80	-6	40
80	-12	21
40	+6	77
20	+12	[illegible]

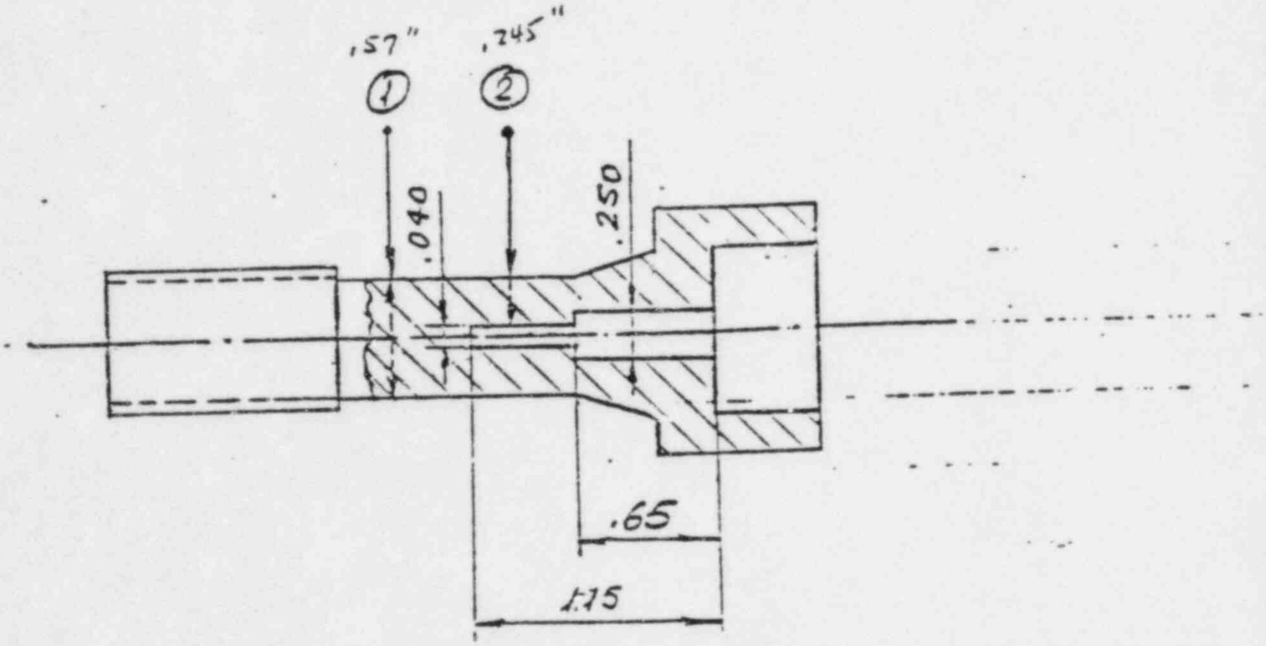
EXAMINATION ~~WELD~~/AREA	Recordable Indications Yes	Recordable Indications No	Scan Limitation Yes	Scan Limitation No	COMMENTS
BOLT # B-7		X			[illegible]
BOLT # A-11		X			[illegible]
BOLT # A-3		X	/		[illegible]
57 FIVE BOLT		X	/		[illegible]
NOT NUMBERED					[illegible]
					[illegible] THE SCREEN WITH
					ACTIVATED TIMED (?) POSITIONS
					[illegible]

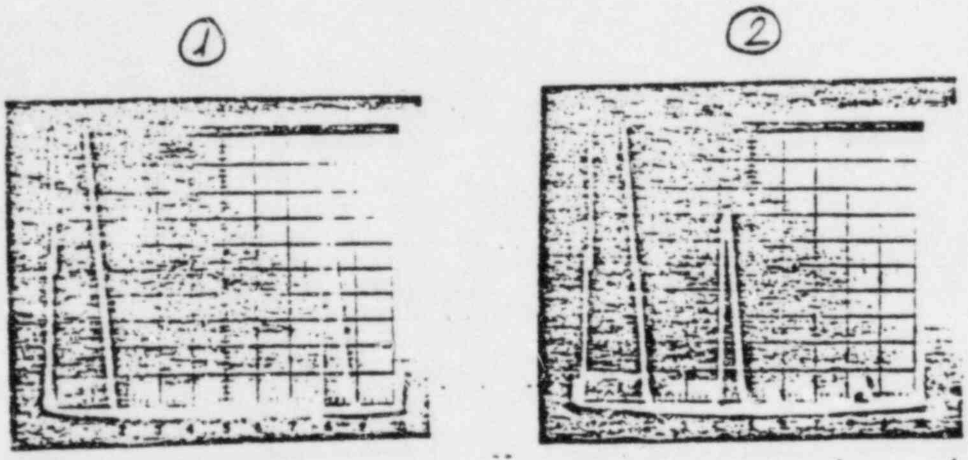
EXAMINERS 1 [signature] Level [illegible] Date [illegible]
2 [illegible] Level ______ Date ______
REVIEWER ______ Level ______ Date ______
AUTHORIZED INSPECTOR ______ Date ______

ADDITIONAL SHEETS? (Check Box)			
Continuation	N/A	Beam Plot	N/A
Supplements	N/A	Other	N/A

Page 1 of [illegible]

Calibration sample of a cap screw.





Back reflection ---- Reflection from the hole

CERTIFICATE OF TESTS
ATTACHMENT (4)

CARPENTER TECHNOLOGY CORPORATION

CARTECH

P.O. BOX 662 • READING, PA. 19603

NOTE:
THE VALUES AND OTHER TECHNICAL DATA SHOWN REPRESENT THE RESULTS OF ANALYSES AND TESTS MADE ON SAMPLES COLLECTED FROM THE TOTAL LOT. ORIGINAL DATA RECORDS CAN BE TRACED BY REFERENCE TO THE CARP. ORDER NO.

DATE OCTOBER 12, 1982

ADDRESS REPLY TO:

HARTFORD WAREHOUSE
POST OFFICE BOX 2419
HARTFORD, CT 06101

S P S TECHNOLOGIES
HIGHLAND AVENUE
JENKINTOWN, PA 19046

GK676B

CUSTOMER ORDER NUMBER	CARPENTER ORDER NUMBER	DATE SHIPPED	WEIGHT
255789-03/95002 10/11/82	HFD-8002 L10348	10/12/82	2129

PRODUCT DESCRIPTION	SPECIFICATION
TYPE 410 CG ANNEALED	AMS 5613 L

SIZE 0.3125 IN. RD

HEAT NO.-854220

C	MN	SI	P	S	CR
0.13	0.45	0.34	0.025	0.001	11.62
NI	**MO**	**CU**	**AL**	**SN**	**N**
0.35	0.04	0.11	0.01	0.006	0.023

DISCS MACROETCHED AND APPROVED

MAX QUENCH HARDNESS, RC - 41 - 1750 F .50 HRS. AIR TREAT

HARDNESS AS SHIPPED, BHN - 197/197

A. W. Sterling

2-70-E

I CERTIFY THIS INFORMATION TO BE TRUE AND CORRECT AS CONTAINED IN THE RECORDS OF CARPENTER TECHNOLOGY CORPORATION
AUTHORIZED REPRESENTATIVE

6.2 Report No. TR-V-MCM-003

6.2

Metallurgical Examination
of
Diffuser/R.C.P. Casing Bolts
Returned from Arizona Unit 2
(791350)

by
K. W. Dollansky, P.E.

1-25 1983

Abstract

Eight broken R.C.P. diffuser/casing bolts were returned from Arizona Unit 2 for examination. One bolt was found to be broken during the de-staking operation. The type of failure was identified as hydrogen induced stress corrosion cracking. The remaining seven were used to pull the diffuser/wedges into position. This operation broke the bolts. All bolts were initially cracked which was attributed to stress corrosion cracking.

All eight bolts originated from the same lot which was examined and discussed in Report TR-MCM-112.

Introduction and Background

This report is in continuation of Report TR-MCM-112, dated 11-24/82, submitted to CE-KSB with Memo MCM-82-274 on 11-30-1982.

C-E Windsor received from CE-KSB eight broken socket head cap screws (threaded halves only) for examination. These broken bolts were returned from Arizona Unit 2 following recent rework activities. One of the eight cap screws was found to be broken during the de-staking operation (pump S/N1110-2B, identification "8109-200-016-1 Thread"). The remaining seven were used to pull the diffuser/wedges into position prior to installing the new replacement cap screws, and it was this operation which caused the final breakage of the bolts. It was reported by CE-KSB that these bolts were the original new ones which have never been through operation at either CE-KSB or Arizona Unit 2.

A list of the eight bolts with identifications is shown in Attachment (1).

Examination

All eight bolt samples showed similar fractured surfaces, i.e., an oxidized incipient crack and a clean final fracture (see Fig. 1). Also the surface (shank and thread) of all samples was covered with a dark grey oxide, suggesting that the bolts had been exposed to an oxidizing medium such as, for instance, primary coolant (this would be contrary to information received from CE-KS8; see Introduction of this report).

We selected for the examination bolt sample "8109-200-016-1 Thread" (sample 1) which broke during the de-staking operation, and bolt sample "8109-200-016-3-1 Thread" (sample 3-1) which is representative of all seven bolt samples listed under 2., 3. and 4. in Attachment (1), i.e., rough surface of the final fracture as compared with the fractured surface of sample 1 (Fig. 1)

The bolts came from the same lot discussed in Report TR-MCM-112 and consequently were made from the same grade of steel (Type 410) following the same manufacturing procedure (see Report TR-MCM-112).

Metallographic examination of the samples 1 and 3-1 revealed the microstructure to be tempered martensite with a grain size of about ASTM No. 7 (Fig's 2 and 3) and with clearly distinguishable former, austenitic grain boundaries (see also Fig. 3 in Report TR-MCM-112, the presence of the former, austenitic grain boundary was discussed in this report).

The micro hardness of both samples was found to be DPH 468-470 (500g load), corresponding to about Rc 47.

The fractured surfaces of the two samples were examined on the scanning electron microscope (SEM). The crack which initiated the failure of the two bolts (see Fig. 1) is shown in the left photographs of Fig's 4 and 5. As can be seen the cracks are intergranular and follow the former, austenitic grain boundaries visible in the photomicrographs of Fig's. 2 and 3. The appearance of the crack surface (left, Fig's 4 and 5) is almost identical with that of Fig. 5, Photo A of Report TR-MCM-112, including some secondary cracking between adjacent grains.

The right photographs of Fig's 4 and 5 show the fractured surfaces of the final break of the samples 1 and 3-1, respectively (clean portions of the fractured surface in Fig. 1). The finer appearance of the fracture of sample 1 is believed to be due to the fact that this bolt broke by delayed hydrogen cracking whereas bolt 3-1 broke by overstressing when used to pull the diffuser/wedges into position.

Conclusions

The initial cracking of all eight bolts occurred by hydrogen induced stress corrosion cracking as discussed in detail in Report TR-MCM-112. Bolt 8109-200-016-3-1 broke finally by delayed hydrogen cracking just as the bolts No. 13 and 15 examined and discussed in Report TR-MCM-112. The remaining seven bolts broke,after initial stress corrosion cracking, when they were used to pull the diffuser/wedges into position. It is believed that they also would have failed sooner or later by delayed hydrogen cracking.

ATTACHMENT (1)

Chronology of Arizona Unit 2
RCP Diffuser Ring Segment Bolting

Socket Head Cap Screws, P/N 8109-200-016 were received from the Arizona Unit 2 Site on January 14, 1983. A total of eight (8) broken cap screws were returned from two different pumps - S/N 1110-2A and 1110-2B.

Four major categories have been established as follows:

1. One socket head cap screw was found broken upon de-staking of the locking sleeves from 1110-2B.

   Labeled as: 8109-200-016-1 Head; 8109-200-016-1 Thread.

   The remaining seven socket head cap screws can be separated into three groups according to the location of the fracture.

2. Three socket head cap screws failed at the head/taper/shank transition.

   Labeled as: 8109-200-016-2-1 Head; 8109-200-016-2-1 Thread.
   8109-200-016-2-2 Head; 8109-200-016-2-2 Thread.
   8109-200-016-2-3 Head; 8109-200-016-2-3 Thread.

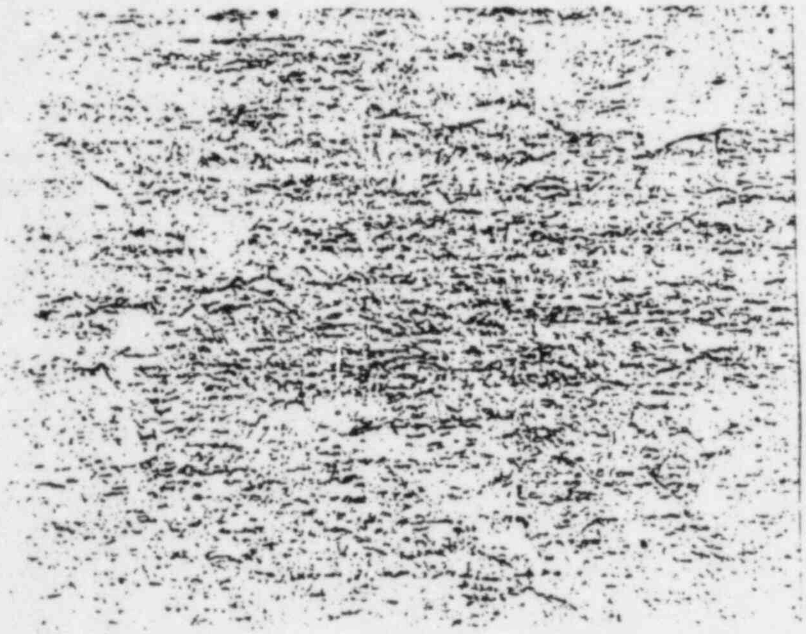
3. Two socket head cap screws that failed approximately one inch from the head bearing surface.

   Labeled as: 8109-200-016-3-1 Head; 8109-200-016-3-1 Thread.
   8109-200-016-3-2 Head; 8109-200-016-3-2 Thread.

4. Two socket head cap screws failed approximately 1-1/8 inch to 1-1/4 inch from head bearing surface.

   Labeled as: 8109-200-016-4-1 Head; 8109-200-016-4-1 Thread.
   8109-200-016-4-2 Head; 8109-200-016-4-2 Thread.

59752



500X

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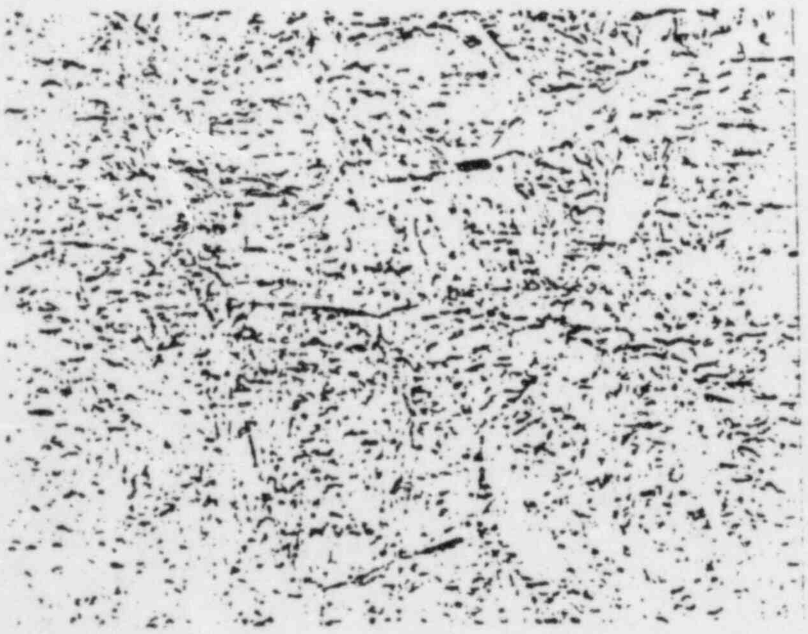

1000X

Vilella"s

Fig. 2 Microstructure of Bolt Sample 1

59754

500X

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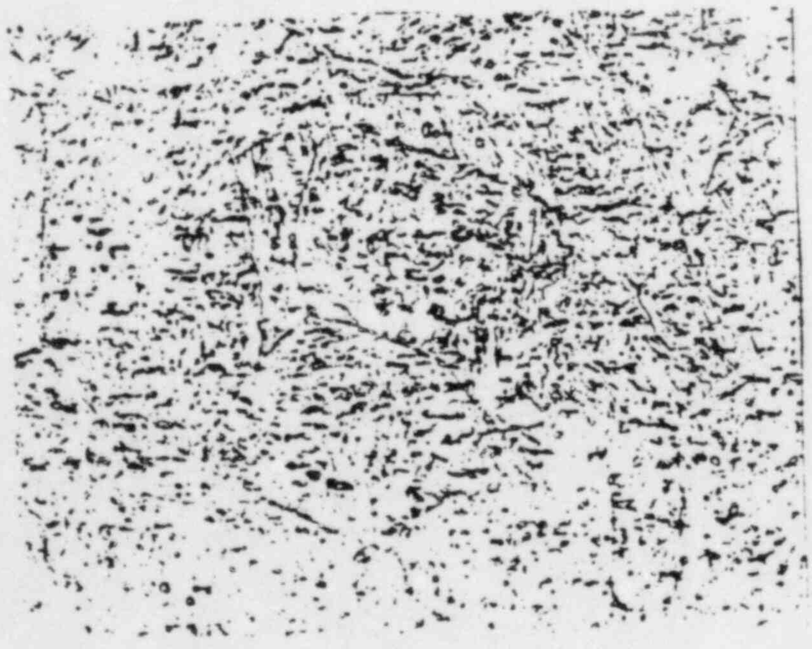

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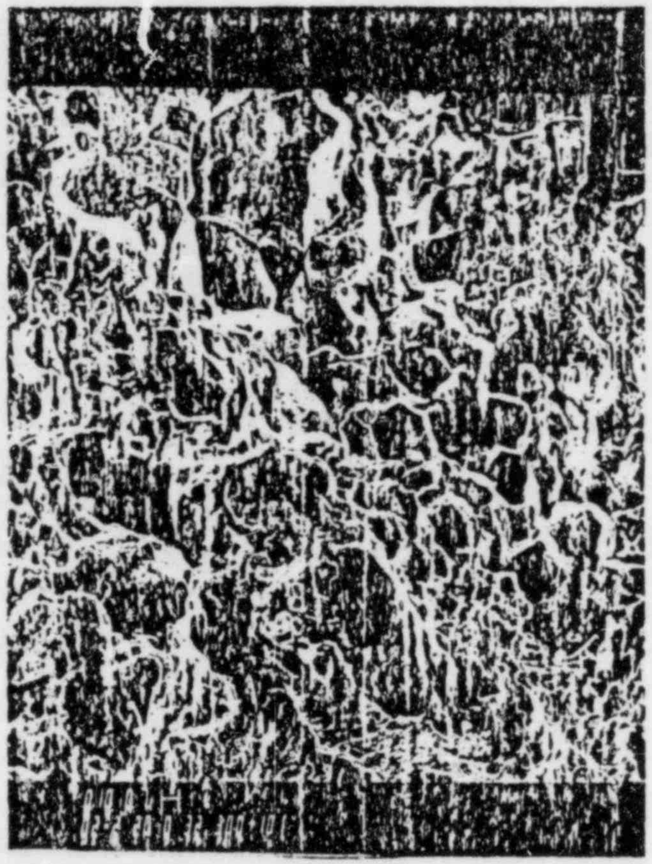
Vilella's

Fig. 3 Microstructure of Bolt Sample 3-1

59695



Crack 250X

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Final Fracture 230X

Fig. 4 SEM Photographs of Fracture Surface of Bolt Sample 1