STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
MATERIALS ENGINEERING
AND TESTING SERVICES

Office of Structural Materials
5900 Folsom Boulevard
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Summary of SFOBB East Span Eye Bar Failure Analysis

March 17, 2010

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Office of Structural Materials
Division of Engineering Services
Materials, Engineering and Testing Services

PROJECT INFORMATION

04-0G8404
SFOBB Emergency Eye Bar Repair

INTRODUCTION

This report is a summary of the failure analysis that was performed by Larry McKnight Laboratory Inc. and the results of additional chemical and mechanical testing that was done at the Department's Structural Materials Laboratory in Sacramento. These tests were done to assist in determining the most probable cause of failure of the eye bar from the East Span of the San Francisco Oakland Bay Bridge (SFOBB). This report also includes a summary of the failure analysis of the high strength rod material used for the initial emergency repair.

BACKGROUND

The Department contracted with McKnight Laboratory Inc. to conduct a failure analysis of an eye bar failure on the SFOBB East Span (See Figures 1 and 2 below for location). For the analysis, the failure analyst first visited the bridge site and inspected the cracked eye bar, and then portions of the eye bar and both fracture faces were removed for close up visual evaluation, microstructure analysis, chemical analyses, and mechanical testing. In addition, the fracture face and the paint films on the surface of the eye bar underwent Energy Dispersive X-ray analyses to evaluate possible cause(s) of the crack initiation. The Department's Structural Materials Laboratory also conducted additional mechanical and chemical testing to determine properties of the original eye bar material and the high strength rod material that was used for the initial emergency repair.

McKnight Laboratory evaluated specimens of the failed eye bar and the failed high strength rod from the first emergency repair. The reports for all the testing conducted by McKnight are listed in Appendix E and F.

Figure 1: San Francisco-Oakland Bay Bridge East Span. Circled area is location of failed eye bar.

Figure 2: Eye bar showing failure location

EYE BAR MANUFACTURING PROCEDURE

From analysis of original plans and specifications and a report published at the time the bridge was built (See end of Appendix E1), the Department believes that the eye bar is a single piece of steel. Testing and analysis by McKnight Laboratories and the Department confirmed that there is no forged or welded joint between the eye bar shank and head. The evidence gathered during failure analysis indicates that the eye bar was formed from a single piece of steel, the heads likely formed with a die press procedure. There is no evidence to indicate that the eye was a) forged, b) wrapped and then welded, or c) formed independent of the shank and then welded to the shank.

The chemistry of the eye bar shank is almost the same as the chemistry of the head. From a metallurgical perspective, the slight variations in element analysis are within expected parameters for different locations on a single piece of steel (See Appendix A and B for chemistry test reports). Similarly, etching of the material from both sides of the fracture, did not show indication of any change in grain structure, grain orientation, or color in the material from either side of the failure plane. Microstructure analysis did not reveal any evidence of forging flow lines. While it is possible that tempering may have obliterated grain flow lines, there is no evidence to support this.

Based on the direction of small inclusions in the microstructure of the eye bar material, McKnight Laboratories determined that the grain direction at the failure location is perpendicular to the failure plane. This grain direction is noted to be parallel to the long axis of the eye bar shank. Based on the evidence, it is concluded that this element was produced from a single piece of steel and left in the as-formed condition, with no evidence of surface grinding or blending at any of the edges or interfaces. Additionally, there is no evidence to suggest that any forming flaws or defects are associated with the fracture.

Material testing performed by McKnight Laboratories and the Department's Structural Materials Laboratory indicates that the steel meets or exceeds the mechanical properties originally specified for the eye bars. Material tests included chemical analysis of the steel; tensile testing to determine yield strength (Fy), ultimate (tensile) strength (Fu), and elongation; hardness; and macro- and microstructural- analysis of the material.

EYE BAR FAILURE ANALYSIS

The failure analysis indicates that the fracture initiated at the outer edge of the eye bar, and then propagated inward to the center pin location. See the following three photographs for a close up view of the fracture location.

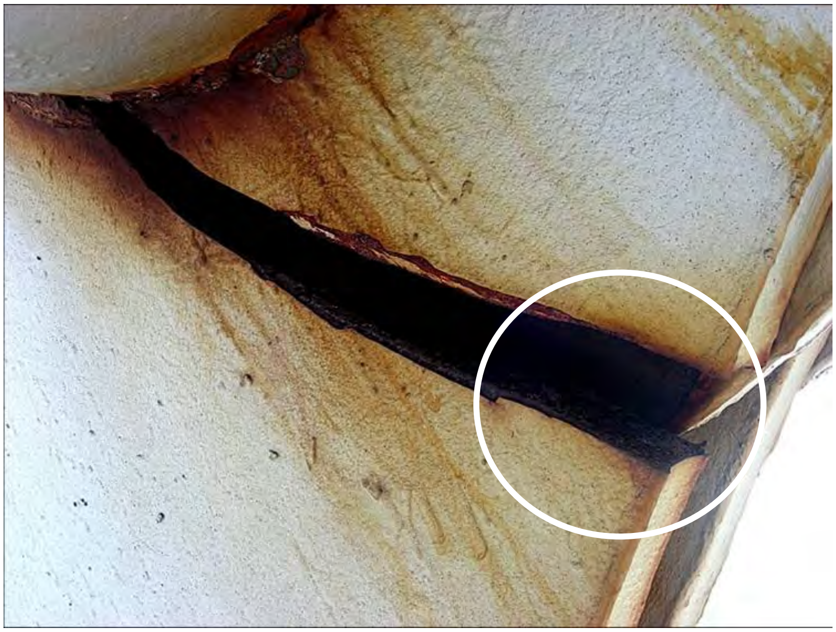


Figure 3: Failure initiation location is circled above and highlighted in following figures.

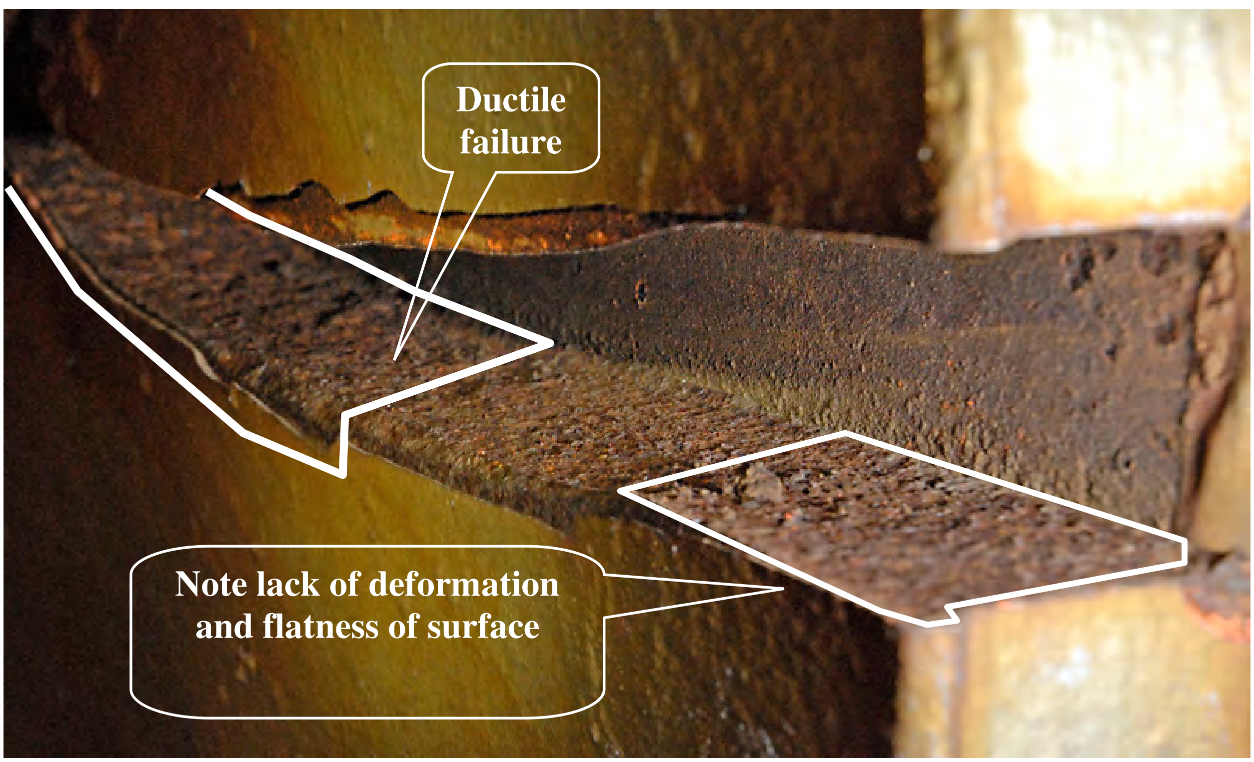


Figure 4: Close-up of the outer edge of the fracture

Figure 5: Close up of fracture showing radial ridges pointing to location of crack initiation

On the edge of the eye bar where the fracture initiated, the manufacturing process left a concave surface configuration that resulted in sharp corners at the top and bottom edge of the eye bar. Figure 6 is a microsection of the edge of the eye bar. Notice the concave surface on the left side of the picture and the arrow pointing to the fracture initiation location. This sharp corner created a point of stress concentration from which the fatigue crack initiated.

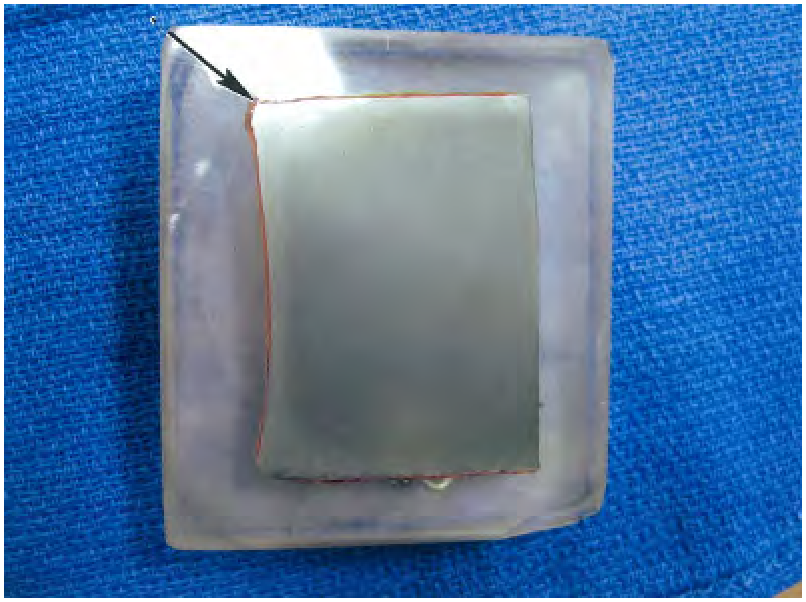


Figure 6: Microsection made below fracture surface. Arrow points to fracture initiation location.

Figure 7 below also shows the layout of the fractured surfaces with the yellow arrow pointing to the outside edge of the eye bar and the fracture initiation location.

Figure 7: Upper and lower portion of fractured eye bar. Fracture origin at arrow location.

Figure 8 below shows the outer edge of the facture face with a white arrow pointing to the fatigue fracture origin. After partial cleaning, there remained a thumbnail area emanating from this corner indicative of fatigue fracture.

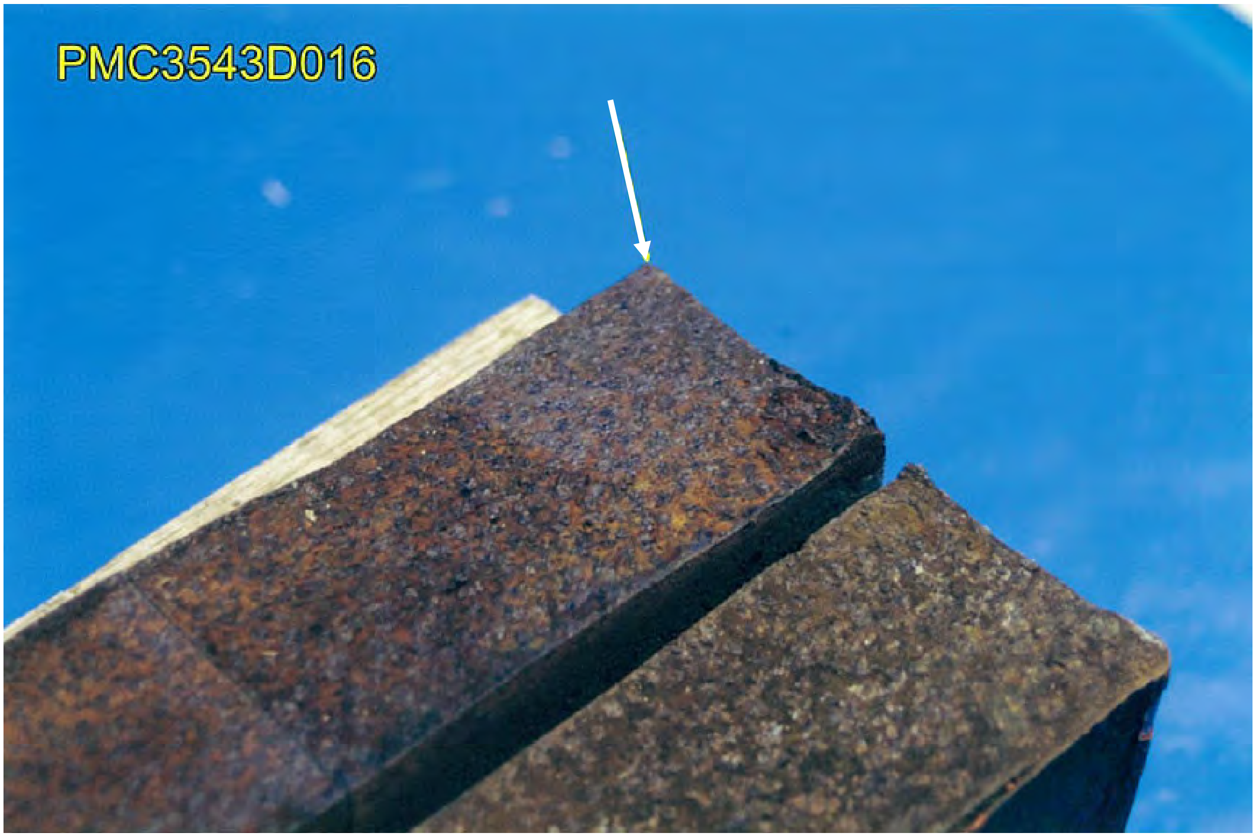


Figure 8: Mating fracture faces at the outer edge of the eye bar. Fracture origin at arrow location.

Other areas of the fracture displayed heavy oxidation and traces of dimple rupture from tensile over load. No evidence of either intragranular fracture or cleavage-type fracture mode appeared at any locations on the fracture plane.

Analysis of the fracture face showed no evidence of paint on the plane of fracture. This indicates that the fracture did not exist at the time the eye bar was originally painted.

Energy Dispersive X-ray analyses of the oxidized plane of fracture revealed primarily iron and oxygen and some chlorine associated with the oxidation process of the fracture face. There was no evidence of foreign material, abnormal inclusions, or defects in the eye bar associated with the plane of fracture. Cross sectional analysis did not discover any material defects, such as stringers, inclusions or laminations.

EYE BAR MICROSTRUCTURAL ANALYSES

The microsections prepared by McKnight Laboratories at the locations shown in Figure 9 as No. 1 to 5, were examined for microstructure and hardness.

Figure 9: Cut locations to remove micros.

The microstructure near the top outer edge of the fracture (corresponding to the arrow location in Figure 6) is shown in the below Figure 10. The microstructure consists of a highly tempered martensitic type structure.

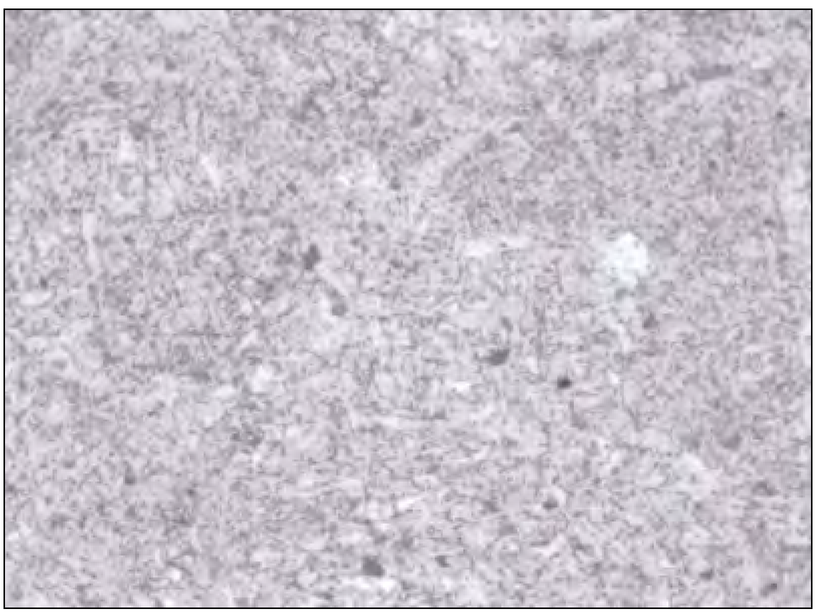


Figure 10: Microstructure near top corner of sample #1 in Figure 6. 500x Etched.

Inward toward the center from this area the core microstructure consisted of martensitic grains surrounded by ferrite. This is illustrated in Figure 11 below.

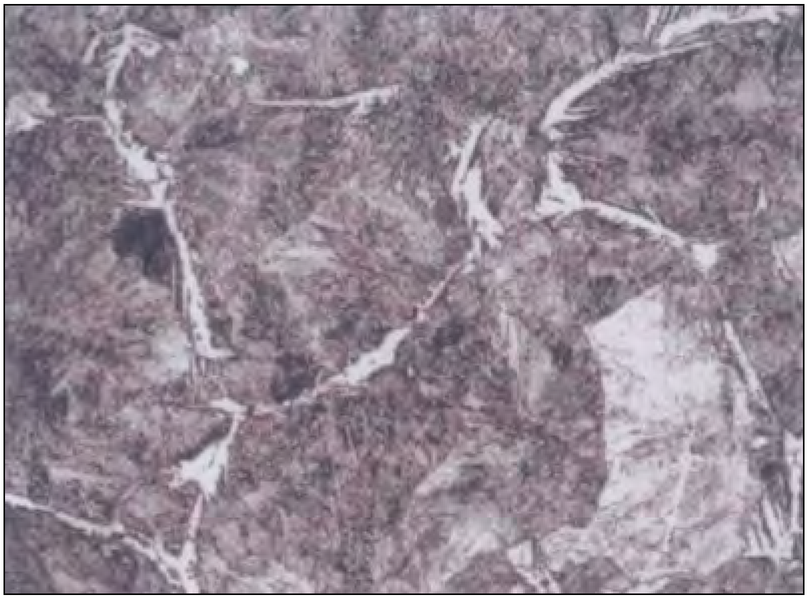


Figure 11: Core microstructure of sample #1 in Figure 10. 500x Etched.

McKnight Laboratories conducted microhardness testing along the top outside edge of the eye bar and from the fracture origin location into the core. The hardness near the outer edges of the eye bar is 20 to 23 on the Rockwell C Hardness Scale (RC), or 97 to 100 on the Rockwell B Hardness Scale (RB); hardness decreases to 94 RB at the core of the eye bar. There were no indications of any hard brittle martensitic zones either at the surface or in the center sections of the cross sections.

In the cross sectional analysis near the fracture, there did not appear to be any material defects, such as stringers, inclusions or laminations.

The chemical analyses of the eye bar are consistent with the medium carbon steel required in the specifications for this bridge. These chemical analyses demonstrated conformance to requirements specified by the manufacturer.

The results of the tensile tests conducted by the Department's Structural Materials Laboratory on the shank material are reported in the addendum and are summarized here and listed in Appendix C:

Test	Fy (ksi)	Fu (ksi)
Longitudinal, Reduced Specimens Average of 2 tests	61.984[1]	95.350
Longitudinal, Full-size Specimens Average of 2 tests	66.630[2]	93.885
Transverse, Reduced Specimens Average of 2 tests	58.137[1]	93.055

[1] 0.2% Offset Method
[2] "Halt of the force" method; no extensometer available for this specimen size
Note: Percent elongation for all the specimens between 20.6% and 26.1%.

These properties meet or exceed the manufacturer's required specifications.

The Department also conducted Charpy V-Notch testing on specimens removed from the shaft section of the eye bar (Appendix C). The average test results are below currently required values for ASTM A 709 Structural Steel Plates for Bridges (15 ft-lb at 40 F). However, these values are typical of materials that were produced at the time the bridge was fabricated. It is notable that Charpy V-Notch testing only became widely used in bridge specifications after the Silver Bridge Failure on Hwy 35 in 1967.

FAILURE ANALYSIS OF FIRST EMERGENCY REPAIR ROD

When the crack in the eye bar was discovered, an emergency repair was put in place using high strength steel rods as part of a saddle apparatus. On October 27, 2009, the repair failed when one of the high strength rods fractured.

The fracture analyses of the failed rod revealed a fatigue thumbnail crack at one location on the perimeter of the cross section of the bar (See figure below). The remaining portion of the cross section of the fracture face showed a complete cleavage type fracture which is indicative of a brittle fracture over-load. The fact that there was one single fatigue thumbnail present on the fracture face indicates that the bar experienced severe unilateral bending stress. This indicates that either the bar was bent during installation or was bearing some place against the blocks or fixture to put this particular bar in bending. As a result of the unilateral bending stress and vibration on the bridge, the combination of these two factors caused the fatigue crack just below the radius of the rib on the bar where it interfaced with the fastener or nut in the assembly.

Figure 12: Fracture surface of failed support rod.

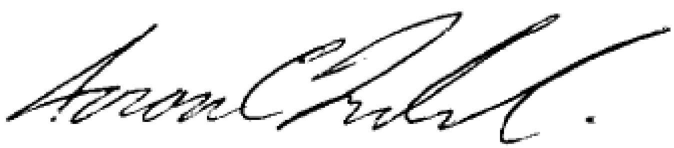
Examination of the microstructure of the rod at the fracture origin revealed no indication of any metallurgical defects associated with the plane of fracture or the fracture origin. Furthermore, mechanical and chemical test of the high strength rod material showed that the material meets all the minimum requirements for ASTM A722, which is the governing specification for the bar. See Appendix F for the McKnight Laboratory reports.

Additional testing on the rod was conducted by the Department to determine how a loss of cross section affected the tensile strength of the high strength rod. For this test two rods were notched to simulate the fatigue crack on the surface of the bar. Then, these two bars and one un-notched bar were pulled to failure in tension (See Appendix D for the test reports). The fracture face from the notched bars and the un-notched bar were placed in a Scanning Electron Microscope (SEM) (See Appendix F2).

CONCLUSIONS

The failure analysis of the eye bar revealed that the rolling and shaping of the bar left a point of stress concentration at the eye bar edge along the interface of the shank to the head. As a result, after 70 years of cyclic live loads, a fatigue crack initiated at this location, leading to a loss of cross section. The loss of cross section exceeded the material's ability to carry the imposed load, leading to full cross sectional failure.

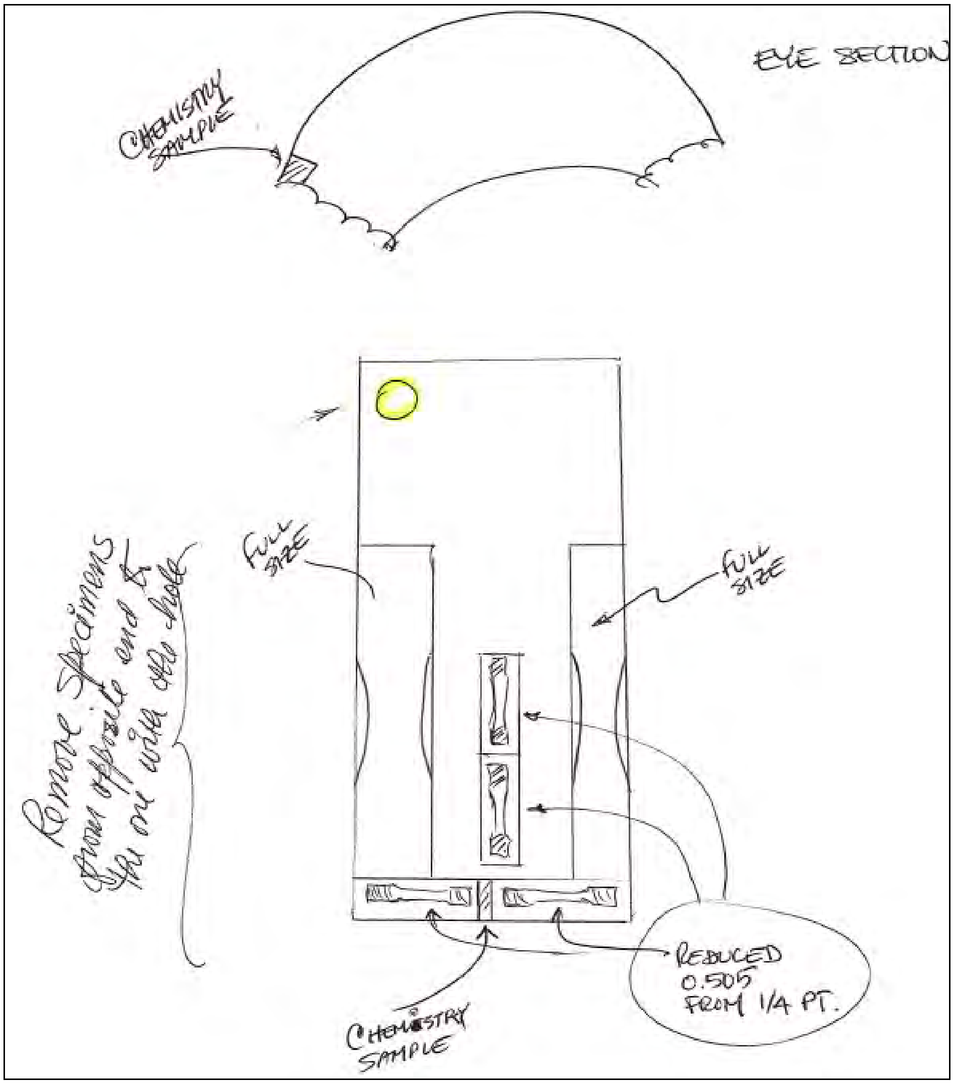
The failure analysis of the high strength bar used on the first emergency repair indicates that the failure was caused by a fatigue crack that resulted from unilateral bending stress and vibration on the bridge.



Aaron Franklin, P.E.
Structural Materials Representative
Office of Structural Materials

APPENDICES:
A: Structural Materials Laboratory Test Layout –of the Eye Bar Specimens
B: Chemistry Test Reports of the Eye Bar Head and Shank Specimens Shown in Appendix A
C: Mechanical Properties of the Eye Bar's Shank Specimens Shown in Appendix A
D: Mechanical Test Reports on Notched and Un-Notched High Strength Rods used for initial emergency repair
E: McKnight Laboratory Reports on Eye Bar
F: McKnight Laboratory Reports on Failed High Strength Rod from the Emergency Repair

APPENDIX A: Structural Materials Laboratory Test Layout –of the Eye Bar Specimens



APPENDIX B: Chemistry Test Reports of the Eye Bar Head and Shank Specimens Shown in Appendix A.

Subject Caltrans Chemistry Lab notification of sample test results

The STEEL sample described below has received a determination of TESTING COMPLETED.

TL101 No.: C653588
Project No.: 04-0G8404
Manufacturer: FIELD SAMPLE
Batch No.: SM10-0109 'EYE'
External ID No.: SM10-0109
Chemistry Lab Sample No.: C100302

10641 Content, carbon: 0.321 Percent
10641 Content, Si: 0.142 Percent
10641 Content, Mn: 0.63 Percent
10641 Content, P: 0.013 Percent
10641 Content, S: 0.019 Percent
10641 Content, Cr: 0.050 Percent
10641 Content, Mo: 0.0029 Percent
10641 Content, Al: 0.0094 Percent
10641 Content, Co: 0.0088 Percent
10641 Content, Copper: 0.324 Percent
10641 Content, Nb: 0.0025 Percent
10641 Content, Ti: 0.0009 Percent
10641 Content, V: <0.0010 Percent
10641 Content, lead: 0.0062 Percent
10641 Content, Boron: <0.0002 Percent
10641 Content, Fe: 98.3 Percent
10641 Content, Ni: 0.029 Percent

Subject Caltrans Chemistry Lab notification of sample test results

The STEEL sample described below has received a determination of TESTING COMPLETED.

TL101 No.: C653588
Project No.: 04-0G8403
Manufacturer: STRUCTURAL MATERIALS
Batch No.: SM10-0109 'B' SHANK
External ID No.: SM10-0109
Chemistry Lab Sample No.: C100303

10641 Content, carbon: 0.312 Percent
10641 Content, Si: 0.146 Percent
10641 Content, Mn: 0.62 Percent
10641 Content, P: 0.013 Percent
10641 Content, S: 0.021 Percent
10641 Content, Cr: 0.050 Percent
10641 Content, Mo: 0.0029 Percent
10641 Content, Al: 0.011 Percent
10641 Content, Co: 0.0091 Percent
10641 Content, Copper: 0.323 Percent
10641 Content, Nb: 0.0024 Percent
10641 Content, Ti: 0.0010 Percent
10641 Content, V: <0.0010 Percent
10641 Content, lead: 0.0062 Percent
10641 Content, Boron: 0.0004 Percent
10641 Content, Fe: 98.3 Percent
10641 Content, Ni: 0.029 Percent

APPENDIX C: Mechanical Properties of the Eye Bar's Shank Specimens Shown in Appendix A.

1) Tensile specimens.

REDUCED 0.505 SPECIMENS

	Sample	Heat Number	Diameter (in)	Area (in²)	Stress at Offset (psi)	AVG	Tensile Strength (psi)	AVG	Elongation in 4 x d (%)	AVG	Tested By
LONGITUDINAL SPECIMENS	BLB	BL	0.503	0.1987	63175	61948	95960	94350	26.1	25.9	FSaylor
	BLA	BL	0.5	0.1963	60721		94740		25.7		FSaylor
TRANSVERSAL SPECIMENS	TA	BBB-T	0.505	0.2003	59774	58137	94050	93155	22.2	21.4	FSaylor
	TB	BBB-T	0.505	0.2003	56499		92060		20.6		FSaylor

Flat Specimen

LONGITUDINAL FULL SIZE SPECIMENS

Department of Transportation
Structural Materials Testing Laboratory
Flat Specimen
400 KIP

SM Number = 10-0109

Sample	Heat Number	Width (in)	Thickness (in)	Area (in²)	ESTIMATED YIELD (PSI)	Peak Load (lbf)	Peak Stress (psi)	Total Elongation (%)
1		1.813	1.489	2.6996	65666	250032	92618	22.5407
2		1.805	1.4905	2.6904	67594	255997	95152	22.9643

Average Values: Yield = 66630 psi
Tensile = 93885 psi
%El = 22.75

APPENDIX C continued

2) Charpy-V-Notched specimens cut transversal and longitudinal to the eye bar longitudinal axis.

STRUCTURAL MATERIALS TESTING LABORATORY
FORM TM-6 (REV. 11/05)

REPORT OF CHARPY IMPACT TESTS

APPROVED FOR USE BY SMTL QUALITY MANAGER [signature]

Charpy Machine Verification, 0° - 170°		SM No.		Date Received
	Readings	09-0202		3/2/2010
0° Reading		TL-0101 No.		Contract No
Tolerance (170°+/-1°)		C653589		04-0G8403
Material Type:		Temperature Req:	40°F	Lot No.
Bay Bridge eye bar shank		Min. Energy Req:		

SAMPLE	HEAT No.	SPECIMEN ORIENTATION	TEST TEMPERATURE	DEFLECTION ANGLE	ENERGY Ft-lb	AVERAGE Ft-lb	VALUE EXCEEDS THE MACHINE CAPACITY * YES	NO
1		LONG	40°F		5			
2		LONG	"		6			
3		LONG	"		4	4.6		✓
4		LONG	"		4			
5		LONG	"		4			
1		TRANS	40°F		12			
2		TRANS	"		11			
3		TRANS	"		10	11.0		✓
4		TRANS	"		14			
5		TRANS	"		8			

* The value recorded exceeds the machine's testing capacity when the test specimen does not pass between the machine anvils (I.e. stops the pendulum). ASTM E 23

Date Tested
3/8/2010
Lab Technician
Erin

APPENDIX D: Mechanical Test Reports on Notched and Un-Notched High Strength Rods used for initial emergency repair

A722 GR150 Threaded Bar, Nut

Department of Transportation
Structural Materials Testing Laboratory
Rebar Mechanical Couplers

SM Number = 10-0038

Sample	Size	Area (in²)	Peak Stress (psi)	Stress at Offset (psi)	Comments	Tested By
1		2.69	124720	0	A722 Rod (CUT) 1.175	EMccrory
2		2.69	121600	0	A722 Rod (Cut) 1.171	EMccrory
3		2.69	159780	142432	A722 Rod BB	EMccrory

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APPENDIX E: McKnight Laboratory Reports on Eye Bar

1) **Failure Analyses of Eye Bar SFOBB East Span**
2) **Mechanical Testing on Specimens from the Fractured Eye Bar SFOBB East Span**

APPENDIX F: McKnight Laboratory Reports on Failed High Strength Rod from the Emergency Repair

1) **Failure Analyses Saddle Bar for the East Span**

2) **Analysis of Saddle Bar Support East Span Notched and Un-Notched Tensile Tests**

McKnight Laboratory Inc.

FAILURE ANALYSES OF EYE BAR SFOBB EAST SPAN

Report No. MEC091010

Prepared for:

CALTRANS

January 6, 2010

Prepared by:

McKNIGHT LABORATORY, INC.

Larry E. McKnight, P.E.
Principal Consulting Engineer

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ADDENDUM	

PROCEDURE

McKnight Laboratory Inc.

January 6, 2010

CALTRANS
Division of Maintenance
111 Grand Avenue, Room 10-400
Oakland, CA 94623

McKNIGHT LABORATORY, INC.
Report No. MEC091010

SUBJECT: FAILURE ANALYSES OF EYE BAR SFOBB EAST SPAN CALTRANS STATE WIDE DISTRICT

PROCEDURE

On 10/03/09 the writer visited Ken Brown and Rosme Aguilar from the Department of transportation at the bridge site and inspected the location of the cracked eye bar on the bridge. The site inspection was performed on 10/04/09 and photographs were taken of the crack location. Subsequent to the initial visit a portion of the eye bar was cut and one fracture face was submitted for fracture analyses. The part submitted was photographed in the as received condition and than a cut was made below the plane of fracture so that the fracture face could be further examined in the Scanning Electron Microscope. At locations immediately back from the fracture location specimens were cut and removed for microstructure analyses, chemical analyses, and tensile testing.

At a later date in November of 2009, a second section of the eye bar was cut and removed to retrieve the mating fracture face. The mating fracture face was then examined and photographed in the as received condition and matched up with the first section of the fracture that had previously been submitted. Energy Dispersive X-ray analyses were then conducted from the outside edge to the inside edge on the fracture face before any cleaning was attempted. In addition to the fracture face, Energy Dispersive X-ray analyses were also conducted of the paint films on the surface of the eye bar.

Both of the mating fracture faces were severely oxidized and rubbed to the extend that it was impossible to clearly identify the fracture origin and fracture mode. Consequently, it was necessary to attempt to clean the oxide layer off of the plane of fracture so that the fracture mode and origin could be determined. The segments from the fracture face were cleaned repeatedly in a solution of water and a micro 90 solution which is used to remove heavy oxide. Because of the degree of oxidation and corrosion this took repeatedly cycles of ultrasonic and chemical cleaning and scrubbing of the plane of fracture. After removal of much of the oxide layer the fracture face was than re-examined in the Scanning Electron Microscope. Not all of the oxide was removed on the entire fracture face as the rubbing damage and oxidation was so extensive.

After the fracture faces were photographed and analyzed in the Scanning Electron Microscope the micro specimens prepared above the plane of fracture were examined for microstructure and hardness and photographs taken to illustrate the microstructure at different locations. In addition, a sample for chemical analyses was analyzed to determine the chemical composition and three tensile specimens were prepared and tested: One near the top surface, one at the center of the cross section, and one near the bottom surface of the eye bar, and in a direction perpendicular to the plane of fracture. These were tested for tensile strength and compared to the original manufacturer's specification for the eye bar. The copies of the specifications for the eye bar are included on the addendum of this report.

EXECUTIVE SUMMARY CONCLUSIONS

EXECUTIVE SUMMARY CONCLUSIONS

The fracture of the subject eye bar initiated at the outer edge of the eye bar and propagated towards the center pin location. At the outside surface corner edge of the eye bar coincident with the plane of fracture a fatigue fracture initiated and propagated from this location up to the center pin location. The fracture face was extensively oxidized and rubbed on the plane of fracture which made the identification of the fracture mode very difficult due to the heavy oxide layer. In order to determine the fracture mode and fracture origin using the Scanning Electron Microscope (SEM) it was necessary to chemically and ultrasonically clean and remove as much of the oxide layer as possible. The SEM analyses conducted on the plane of fracture confirmed that the fracture mode was fatigue and that the fracture origin was at the top outside corner of the outer edge of the eye bar. On the edge of the eye bar the surface had a concave configuration resulting in sharp corners at the top and bottom edge of the eye bar. This sharp corner observed at the bottom edge created a point of stress concentration from which the fatigue crack initiated.

Other than evidence of fatigue and some dimple rupture from over load failure there was no indication of intergranular corrosion, or cleavage fracture on any portions of fracture plane.

The paint film on the surfaces of the eye bar consisted of a heavily leaded red orange paint on the surface of the steel that was subsequently covered with a gray colored paint which contained a significant amount of aluminum which indicates this was an aluminum filled paint. The analyses of the fracture face did not show any evidence of paint on the plane of fracture which indicates that the fracture did not exist at the time the eye bar was original painted.

Energy Dispersive X-ray analyses of the oxidized plane of fracture revealed primarily iron and oxygen and some chlorine associated with the oxidation process of the fracture face. There was no indication that there was any foreign material or abnormal inclusions or defects in the eye bar associated with the plane of fracture.

The microstructure of the eye bar near the plane of fracture revealed that it was quench and tempered steel consistent with the manufacturing process indicated in the specifications for the eye bar. Near the outer surface the structure was tempered martensite and as one progress to the center of the cross section the microstructure consisted of martensitic grains surrounded by ferrite. Microhardness surveys conducted thru the section of the steel showed that the maximum hardness near the outer surfaces was 20-23RC and near the core or center of the cross section the hardness was RB 84-90. There was no indication of any hard brittle martensite zones at any of the locations thru the cross section of the eye bar. Based on the direction of inclusions in the microstructure the grain direction was identified as being basically perpendicular to the plane of fracture and parallel with the long axes of the eye bar.

The chemical analyses of the eye bar showed that the material was a medium carbon steel with carbon content of approximately .33 and manganese .65. In addition, there was evidence of .30 copper in the composition. The chemistry was compared to the specification for the eye bar and showed that the chemical analyses conformed to the requirements specified by the manufacturer.

The results of the tensile tests conducted on the eye bar and in a direction perpendicular to the plane of fracture revealed that near the surface the ultimate tensile strength was 97.5KSI to 98KSI and the yield strength was 64-64.5KSI. In the center of the cross section the ultimate tensile strength was 85KSI and the yield strength 51KSI. The percent elongation on the tensile specimen near the top and bottom surfaces was 23-26% and at the center of the cross section 29%. The reduction of area near the top surface and bottom surface was 61% and in the center of the cross section the reduction of area was 63%. These tensile properties conformed to the specifications requirement provided by the manufacturer and indicated good ductility.

After this initial analyses was conducted larger portions of the eye bar were submitted to the laboratory for additional mechanical testing. Fig. 106 in the report shows the additional segments that were submitted to the laboratory and illustrate the lay out of additional mechanical tests that are to be conducted. These tests include additional tensile specimens which were identified as T in segments 1 and 2 of the bar and fracture toughness specimens taking in two different directions out of segments 1 and 2. In addition, there are specimens to be removed identified as "G" which are for dynamic modulus testing. These specimens are to be machined into ASTME 1876 specimen configuration. Two additional blocks are to be cut out for possible fatigue testing. These were identified as "F" on the surface of the segments 1 and 2. At this time the fatigue testing coupons will be set aside for possible testing if required. At this point in time no additional testing of the eye bar is being contemplated.

RESULTS

RESULTS

Fig. 1 illustrates the appearance of the San Francisco-Oakland Bay bridge east span with a circled area showing the location of the cracked eye bar. Fig. 2 illustrates the cracked eye bar. Figs. 3 and 4 show additional views of the fracture location which exhibited considerable oxidation and corrosion along the plane of fracture and near the center pin location where the eye bar interfaces with the end of the sleeve. Fig. 5 shows a close up of the heavy oxidation at the end of the sleeve where it interfaces with the eye bar and shows the corrosion attack and staining at this location. Fig. 6 illustrates the width of the eye bar at a location above the fracture location which shows the measurement of approximately 7¼". Fig. 7 illustrates the corner which was determined later to be the fracture origin location at the outside edge of the fracture face. Fig. 8 illustrates the crack opening displacement at the outer edge which was approximately 1½" at the time of the inspection in October 2009. Figs. 9 and 10 show additional views of the heavy corrosion degradation between the end of the sleeve and the end of the fracture of the eye bar. At this location there was very heavy oxide scale on the plane of fracture and a good portion of some of the heavy oxide on the plane of fracture actually chipped and fell out at this location.

Fig. 11 illustrates the first segment of the fractured eye bar that was submitted to the laboratory with the duct tape covering the plane of fracture. Fig. 12 illustrates a close up of the oxidation and preferential wear on the surface of the eye bar where it interfaced with the end of the sleeve. Figs. 13 and 14 illustrate the oxidation and wear on the opposite side of this segment of the eye bar. Fig. 15 illustrates the upper fracture portion of the eye bar and shows the approximate length of the fracture face from the outside edge to the inside edge which measures approximately 14". Fig. 16 illustrates the location of the cut that was made below the plane of fracture to remove the fracture face on this segment of the eye bar. Fig. 17 illustrates the thickness of the eye bar. The nominal thickness of the eye bar was measured and found to be 1.8" and at the extreme inside diameter edge where it mated with the pin the thickness was 1.57" due to preferential wear. Figs. 18, 19 and 20 illustrate the specimens that were cut form the eye bar. Micro sections were prepared at locations 1, 2 and 3 parallel with the plane of fracture and additional microsections were prepared at locations 4 and 5 which were perpendicular to the plane of fracture. In addition, a tensile coupon was removed at the location labeled "Tensile" in Fig. 18 and fig. 20. At this location tensile specimens were prepared near the top surface of the eye bar, at the center of the eye bar, and at the opposite side of the eye bar. These were tested for tensile strength. In addition, a sample was removed for chemical analyses. Fig. 19 illustrates the location of micro specimens 1 and 5. The arrow in this particular photograph points to the corner outside edge where subsequent fracture analyses determined was the fracture origin. Fig. 21 illustrates the appearance of the fracture face before cleaning and Fig. 22 illustrates the appearance of the paint chip samples that were removed from the surface of the eye bar. The fracture face was cut into four different segments along the length shown in Fig. 23, then at locations 1 thru 12 Energy Dispersive X-ray analyses were conducted of the oxidized fracture face. These locations are shown in Figs. 23 thru 27 proceeding from the outer edge towards the inside edge. One can see the extensive amount of oxidation and corrosion attack along the plane of fracture. In this condition it was impossible to determine fracture mode. Fig. 28 illustrates the inside surface area of the eye bar where it interfaced with the pin. EDS analyses were also conducted of the oxide layer at this location. Fig. 29 illustrates the paint chip samples that were removed from the surface. These were labeled as 14, 15 and 16. Fig. 30 illustrates an over all view of the upper portion of the fracture face and the lower portion of the plane of fracture which was submitted on November of 2009. The results of the Energy Dispersive X-ray analyses conducted at locations 1 thru 12 on the oxidized plane of fracture are shown in spectra 1-12, and analyses of the inside diameter surface of the eye bar where it interfaced with the pin is illustrated in Spectrum No. 13. X-ray analyses of the paint chips are illustrated in Spectrums 14, 15 and 16. Results of the X-ray analyses of the oxidized layer show principally iron and oxygen with small trace amounts of other elements such as calcium, chlorine, silicon and in some cases carbon. There is also a small trace of sulfur and a very small trace of lead which is attributed to the paint on the surface of the bar. However, there was no significant presence of lead on the oxidized plane of fracture which indicates that the crack was not present at the time that the lead paint was applied. The principal elements are iron and oxygen. Spectrum No. 14 illustrates the analyses of the red colored portion of the paint chip which was the first layer of paint on the surface of the eye bar. Fig. 15 illustrates the spectrum analyses of the second coat of paint which appears to contain a significant amount of aluminum, oxygen and carbon which is obviously a different composition than the first layer which is principally lead. Spectrum 16 shows the analyses on the surface shown in Fig. 29 which again is principally aluminum, oxygen and carbon. The iron is attributed to the base metal. Based on the overall analyses of the oxide layer there was no indication of any significant deposits such as high silicon oxides or aluminum oxides type of internal inclusions within the base metal. The analyses indicate that the principal elements are oxides of iron which developed in the moist coastal environment on the fracture face.

Fig. 31 illustrates the opposite side of the fracture location of the eye bar on the side opposite shown in Fig. 30. Figs. 32 and 33 illustrate the appearance of the outer edge of the eye bar and Fig. 34 illustrates the outer surface of the eye bar with the arrow pointing to what was subsequently determined to be the fracture origin. Fig. 35 illustrates the appearance of the fracture face. The section shown at the top in Fig. 35 was cut into four segments and these were cleaned and then examined in the Scanning Electron microscope to determine the fracture origin. Fig. 36 illustrates the outer edge with the yellow arrow pointing to the fatigue fracture origin. At the outer edge of the eye bar, even after partial cleaning, there is the appearance of a thumbnail area emanating from this corner which is indicative of fatigue fracture. Figs. 37 and 38 showed additional views of the two sides of the mating fractured face segments that were submitted. Fig. 39 and 40 illustrate the area of the eye bar where it interfaces with the center pin of the assembly. Figs. 41 and 42 illustrate the segment of the fracture at the eye bar interface location after cleaning with the arrows pointing to the location of the plane of fracture coincident with the pin location. Fig. 43 illustrates the mating fracture faces of the eye bar at a location just outboard from the pin location, after cleaning of a portion of the oxide layer. One can see in the pictures shown in Figs. 43 and 44 how the thickness of the eye bar was reduced at the pin location due to extensive preferential wear, abrasion, and corrosion between the sides of the eye bar where it interfaced with the sleeve. On the segment shown in Fig. 44 transverse and longitudinal microsections were prepared thru the heavy oxide chip on the plane of fracture and these examined for microstructure. Results of these analyses are covered in the microsection portion of the report.

Sketch A, illustrates the fracture face profile from the outer edge to the inside diameter edge of the eye bar at the plane of fracture. Based on the SEM analyses the fracture origin was identified at the arrow location illustrated on the sketch and a fatigue crack than progressed from this location towards the inside portion of the eye bar. On one side there was a shear lip area of approximately 6" as illustrated in the sketch and at a different location at the bottom side there was an area of a shear lip approximately 8.5" in length. The worn and oxidized area of the top and bottom edges the eye bar near the pin location are illustrated to the left in the sketch which shows that the nominal thickness of the eye bar was 1. 8" but at the location where the eye bar interfaced with the sleeve the thickness had been reduced due to wear abrasion and oxidation to 1.57".

Fig. 1 San Francisco-Oakland Bay Bridge East Span. Location of cracked eye bar.

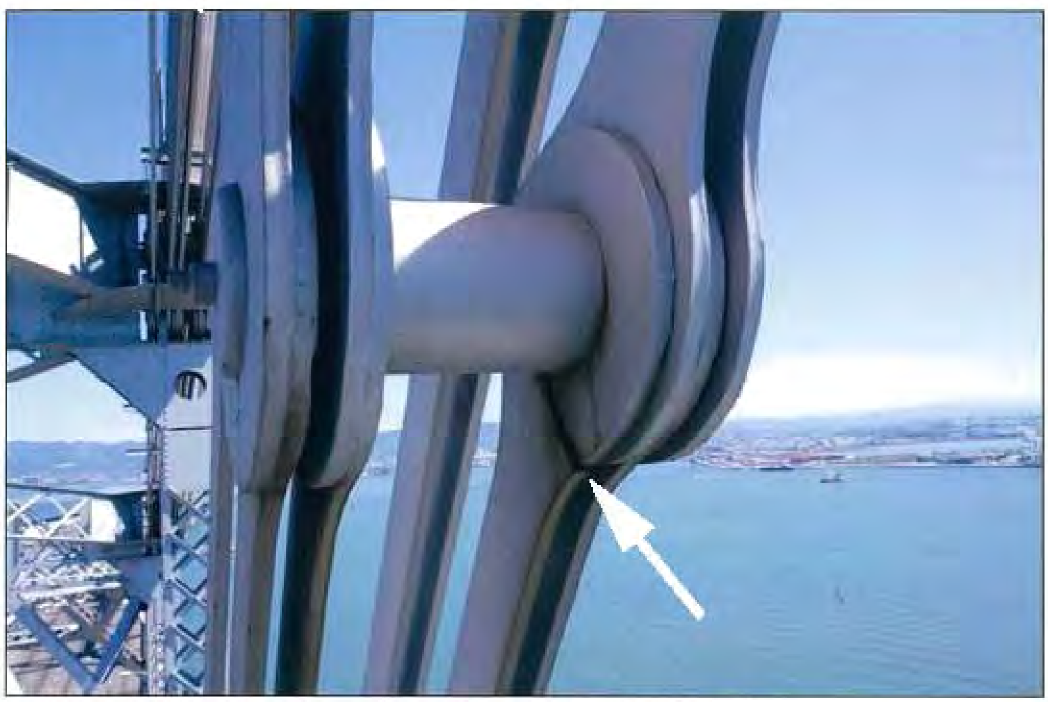

Fig. 2 Location of cracked eye bar. (Looking East)

Fig. 3 Location of cracked eye bar.

Fig. 4 Cracked eye bar.

Fig. 5 Corrosion at sleeve location at end of crack.

Fig. 6 Eye bar above crack location.

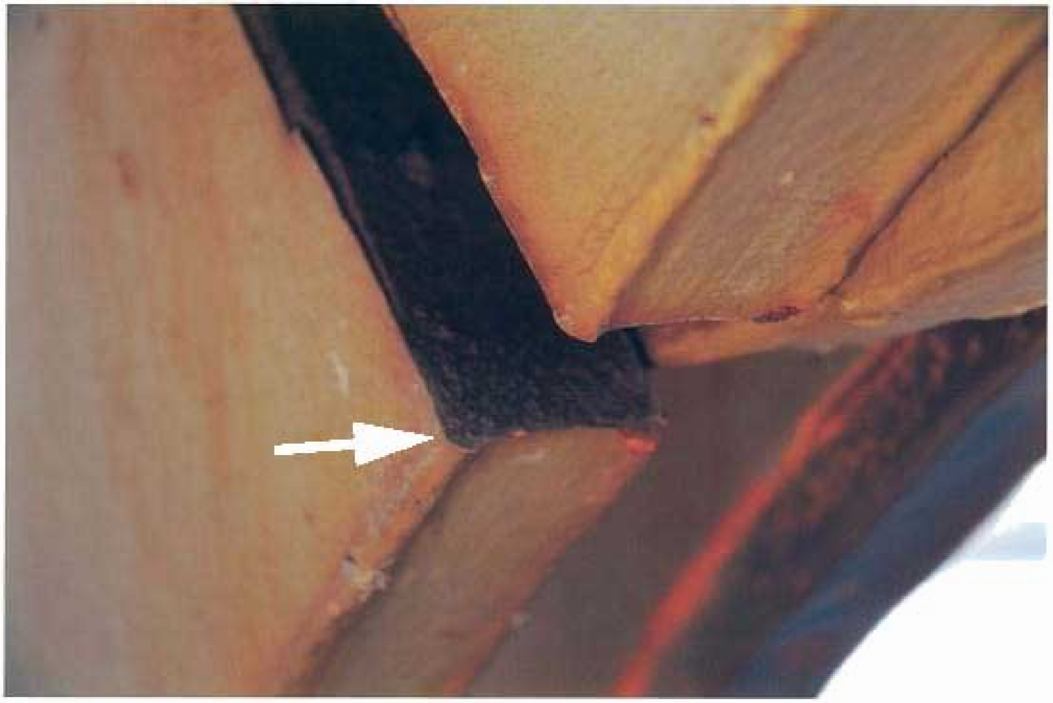

Fig. 7 Fracture face outer edge.

Fig. 8 Crack opening displacement, outer edge.

Fig. 9 Fracture at sleeve location.

Fig. 10 Corrosion at pin location.

Fig. 11 Fracture face segment upper portion.

Fig. 12 Corrosion and wear at sleeve location.

Fig. 13 Fracture face segment upper portion, opposite side.

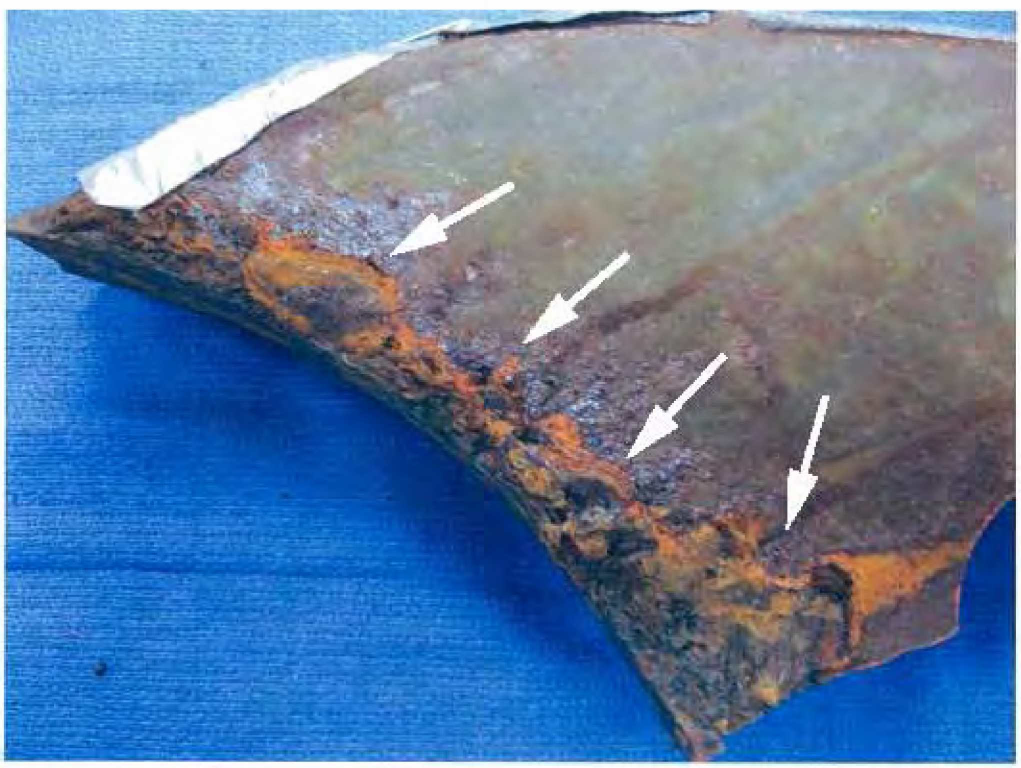

Fig. 14 Corrosion and wear at sleeve location, opposite side.

Fig. 15 Fracture face segment upper portion, opposite side.

Fig. 16 Cut location to remove fracture face.

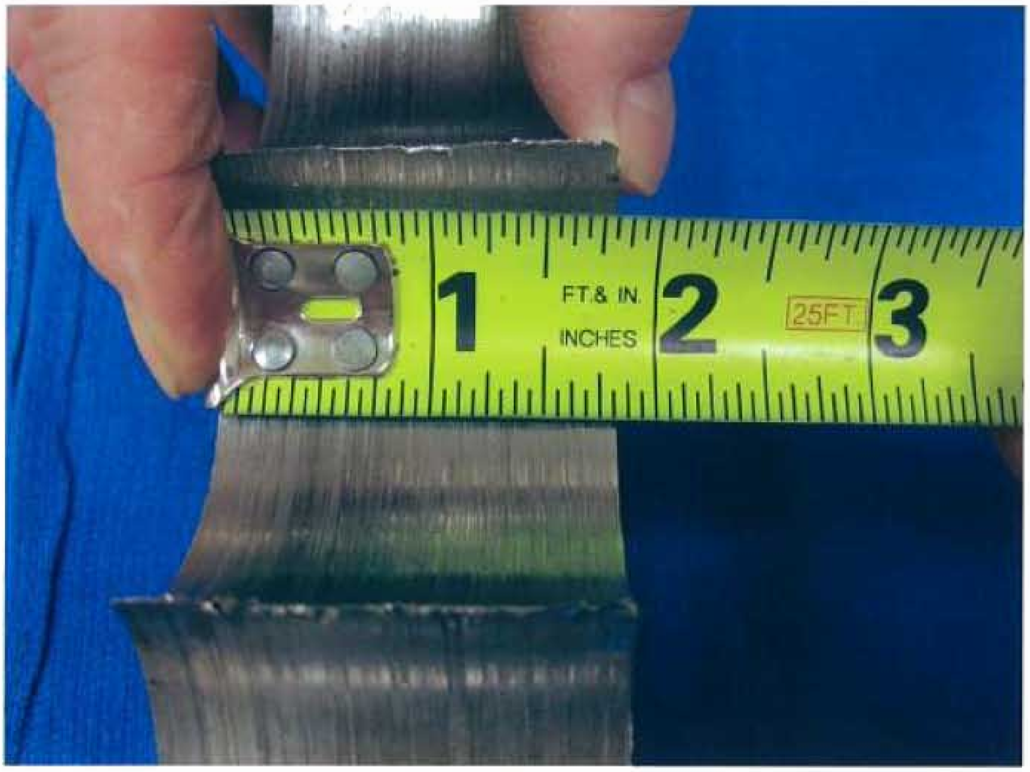

Fig. 17 Thickness of eye bar.

Fig. 18 Cut locations to remove micros, tensile, and chemistry samples.

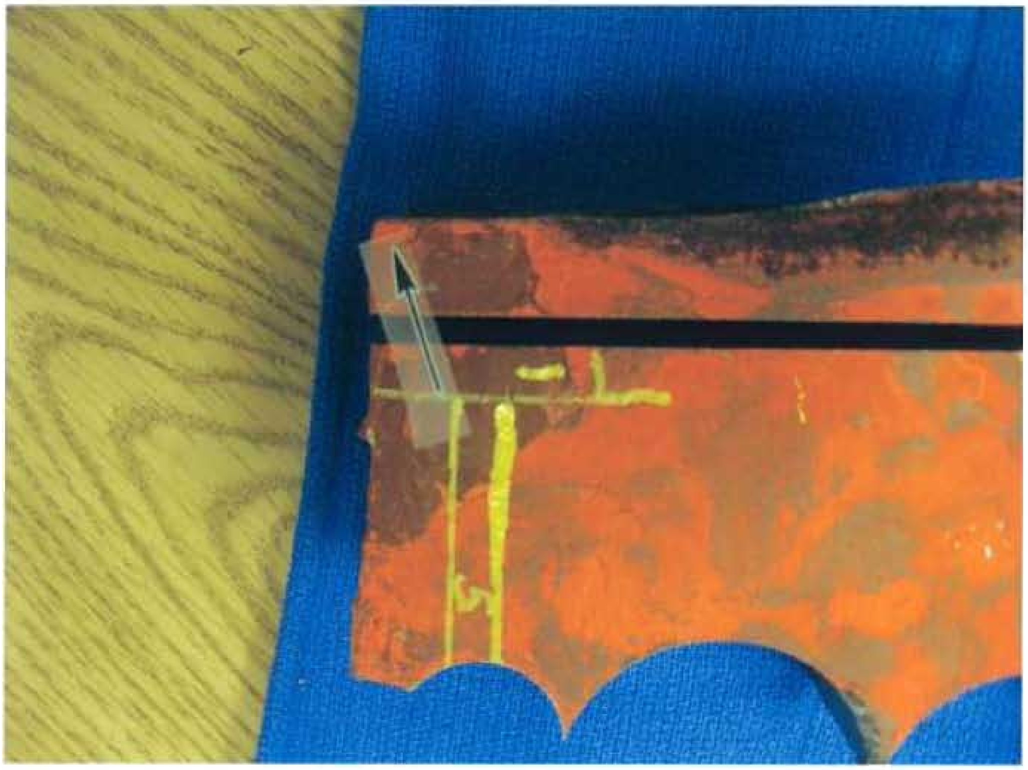

Fig. 19 Location showing micro specimens 1 and 5.

Fig. 20 Cut locations to remove micros, tensile, and chemistry samples.

Fig. 21 Fracture face of eye bar, upper portion.

Fig. 22 Paint chip samples from eye bar.

Fig. 23 Fracture face of eye bar, upper portion. Arrows indicate E.D.S analyses locations.

Fig. 24 E.D.S analyses locations.

Fig. 25 E.D.S analyses locations.

Fig. 26 E.D.S analyses locations.

Fig. 27 E.D.S analyses locations.

Fig. 28 E.D.S analyses locations.

Fig. 29 E.D.S analyses locations.

Fig. 30 Overall photo of upper portion of fracture and lower portion of fracture.

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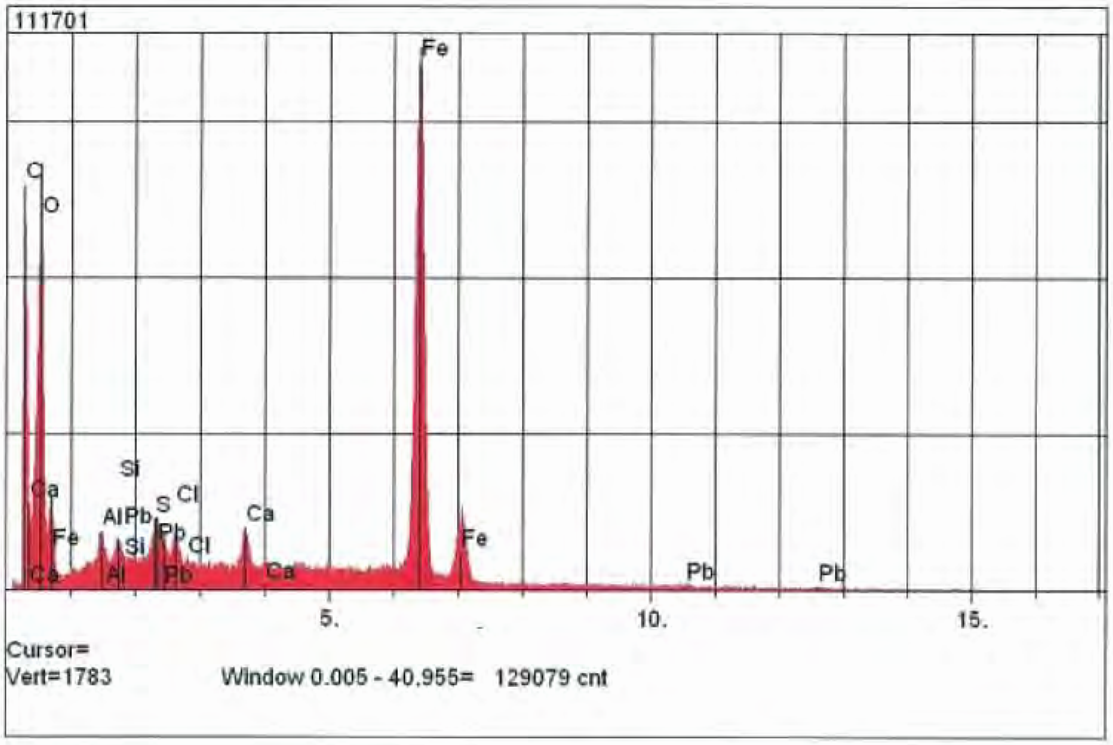
Sample I.D: Location 1



Thursday, December 31, 2009; 12:55:57 AM

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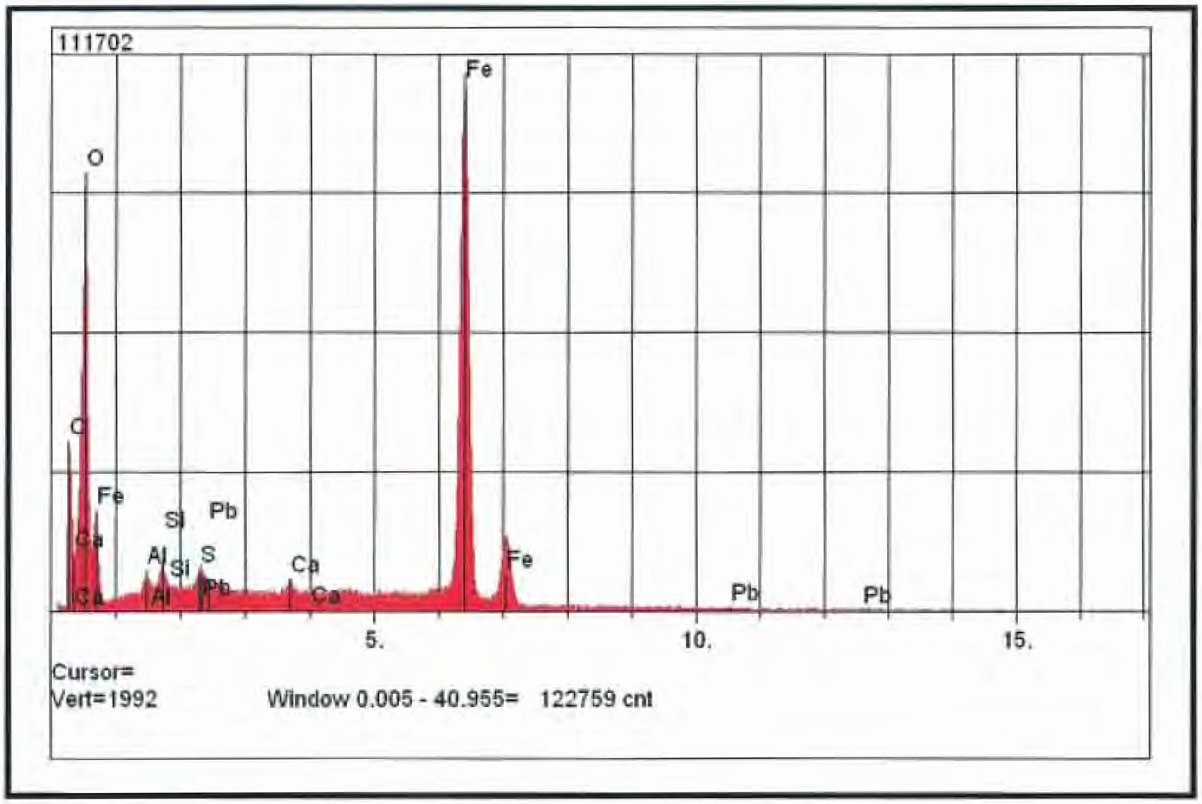
Sample I.D: Location 2



Thursday, December 31, 2009; 12:56:33 AM

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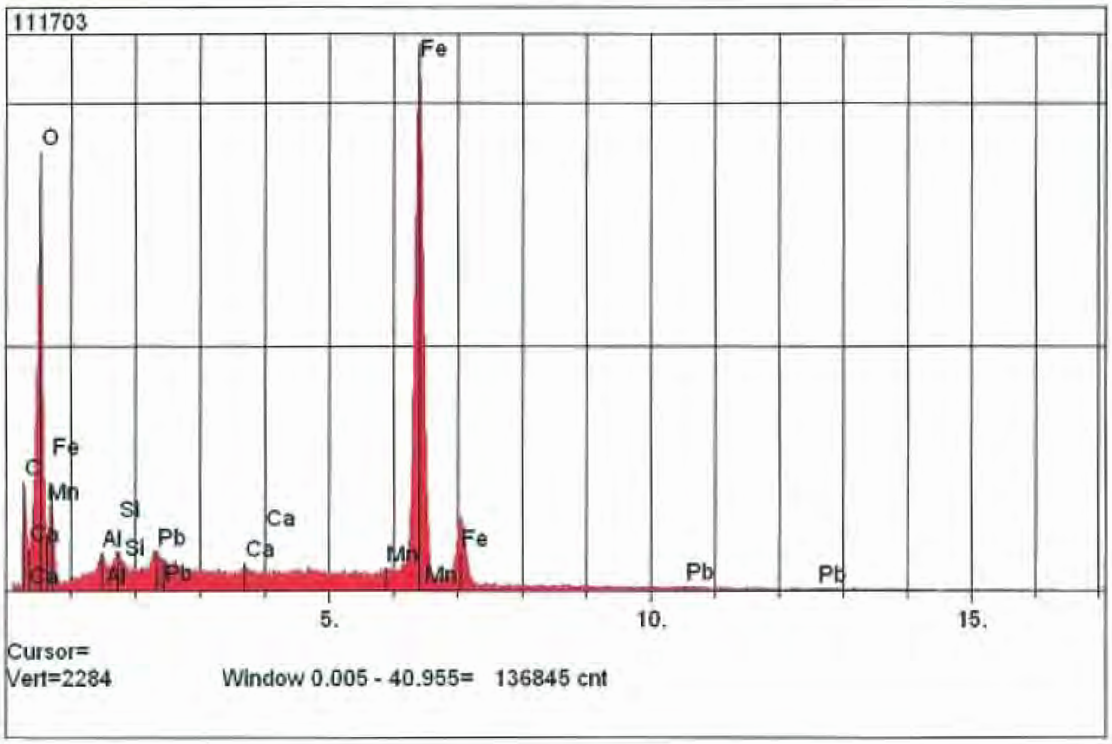

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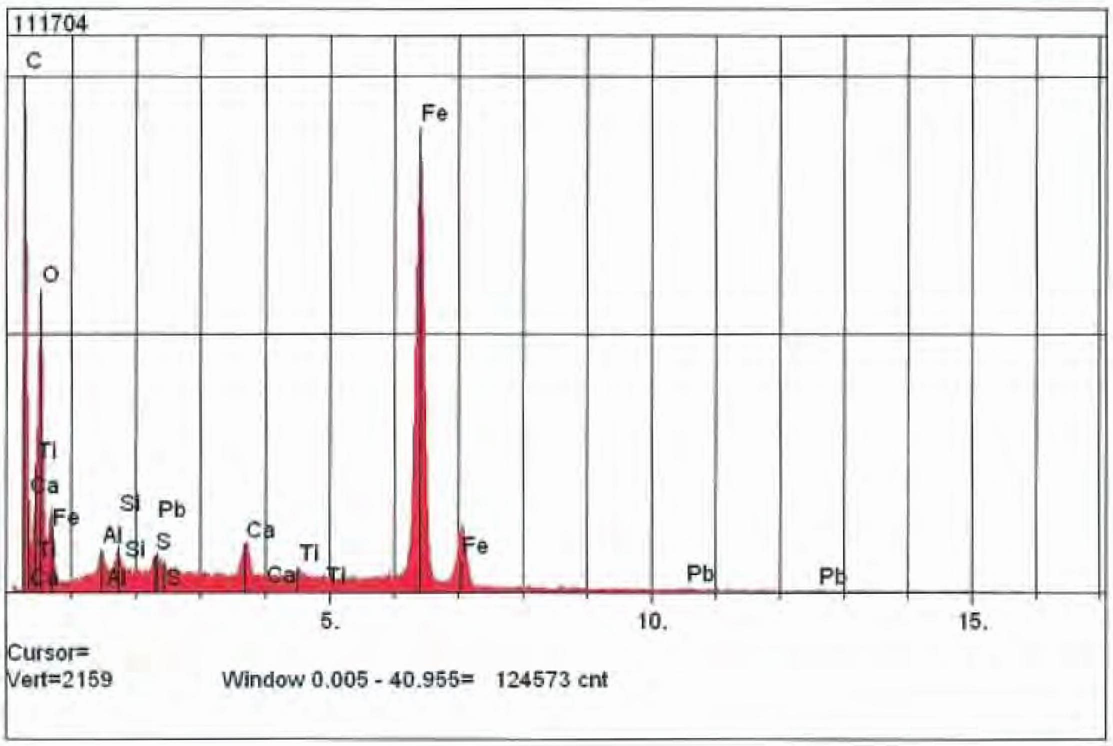

Thursday, December 31, 2009; 12:56:53 AM

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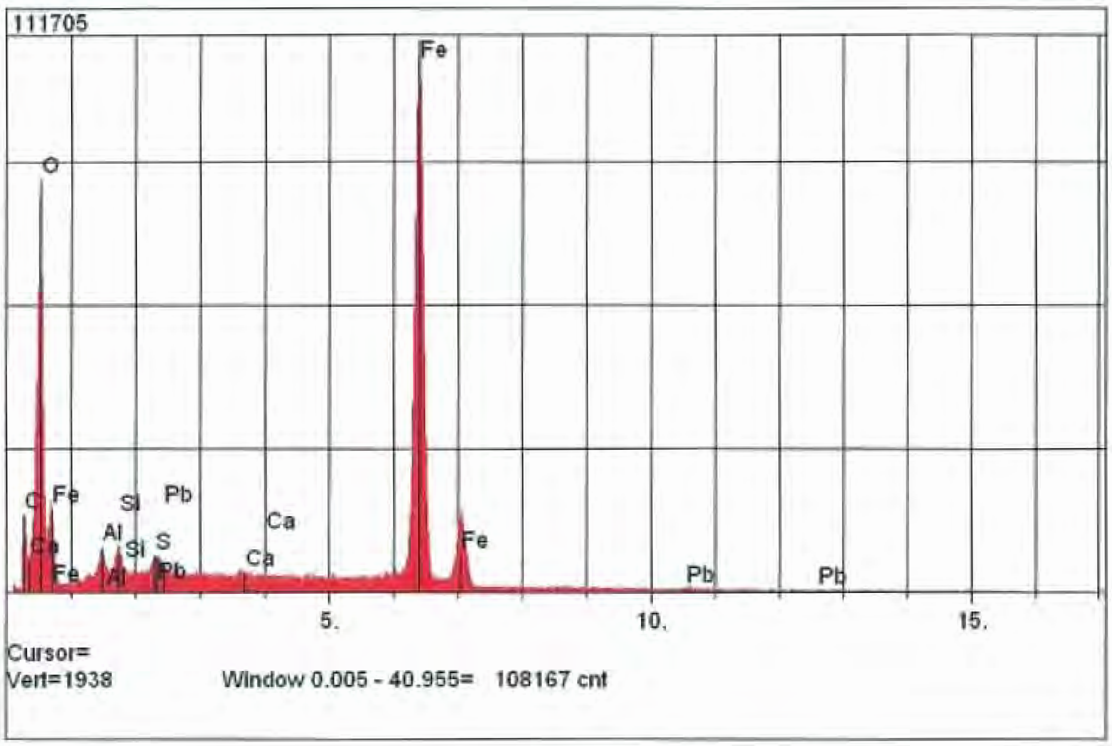
File: 111705	Job No.: 3543	Voltage: 20kV	Time: 100 Sec.

Sample I.D: Location 5



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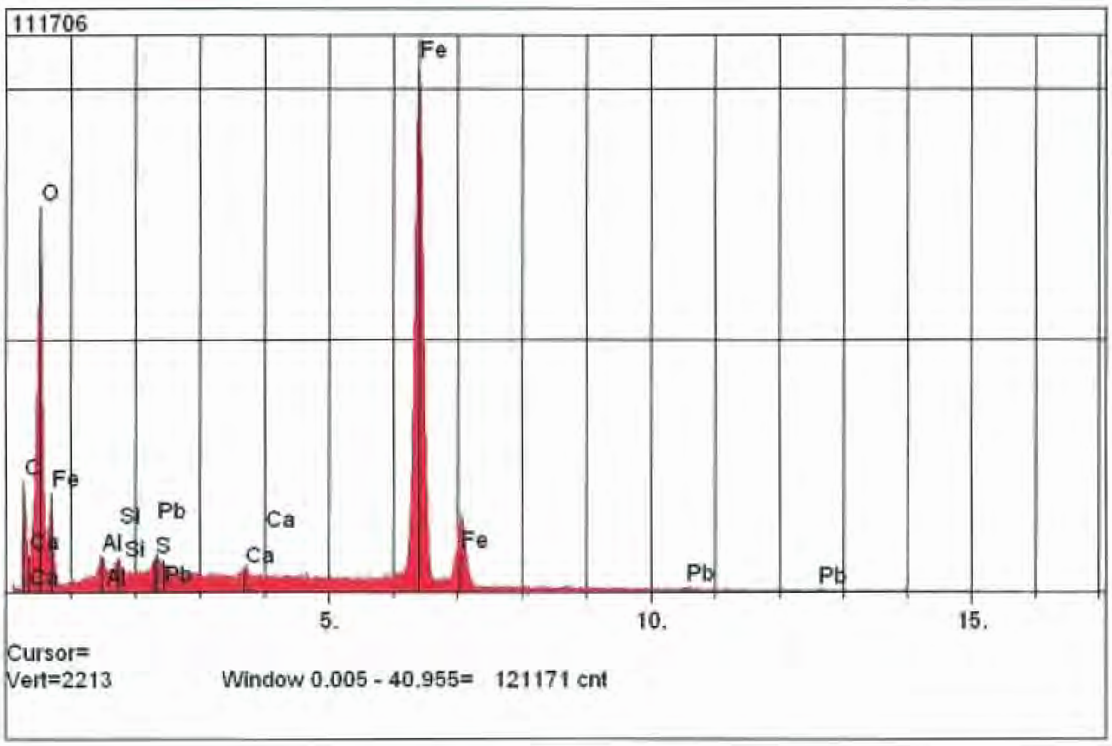

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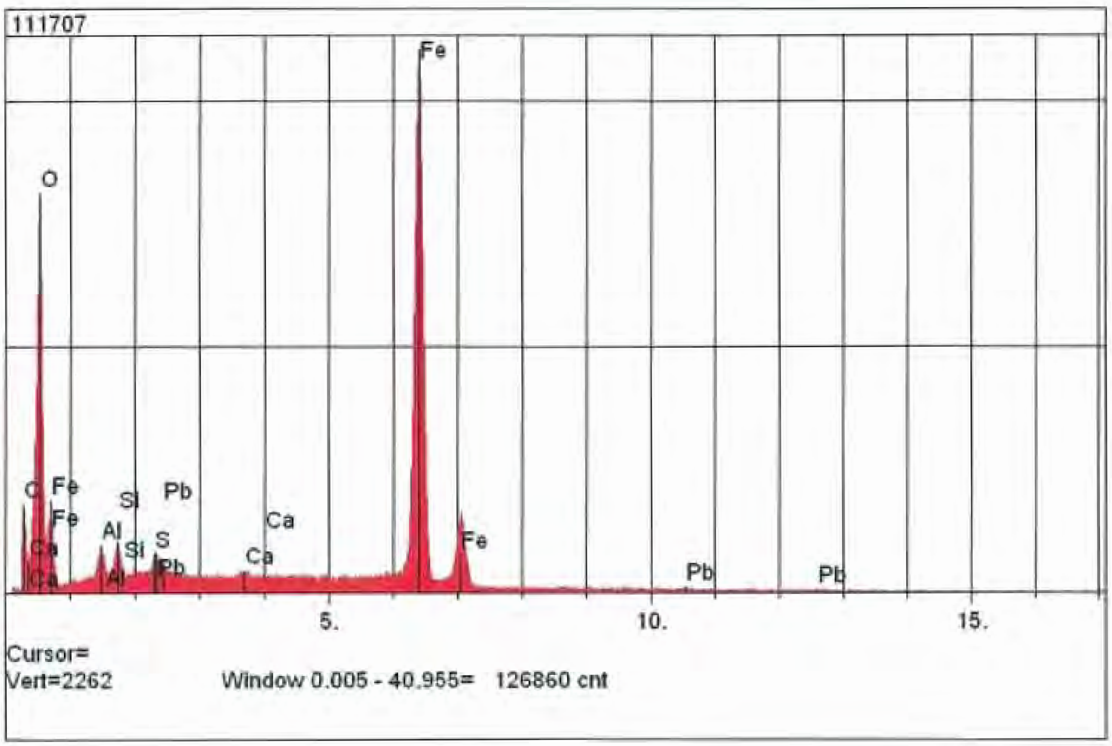

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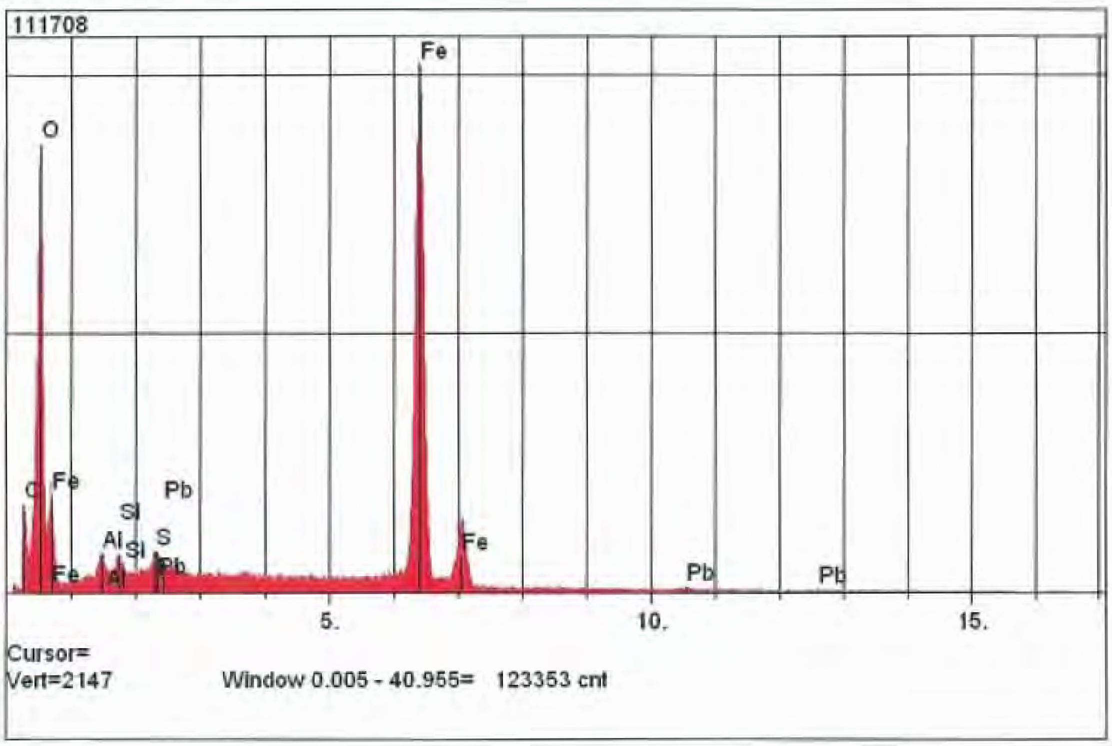

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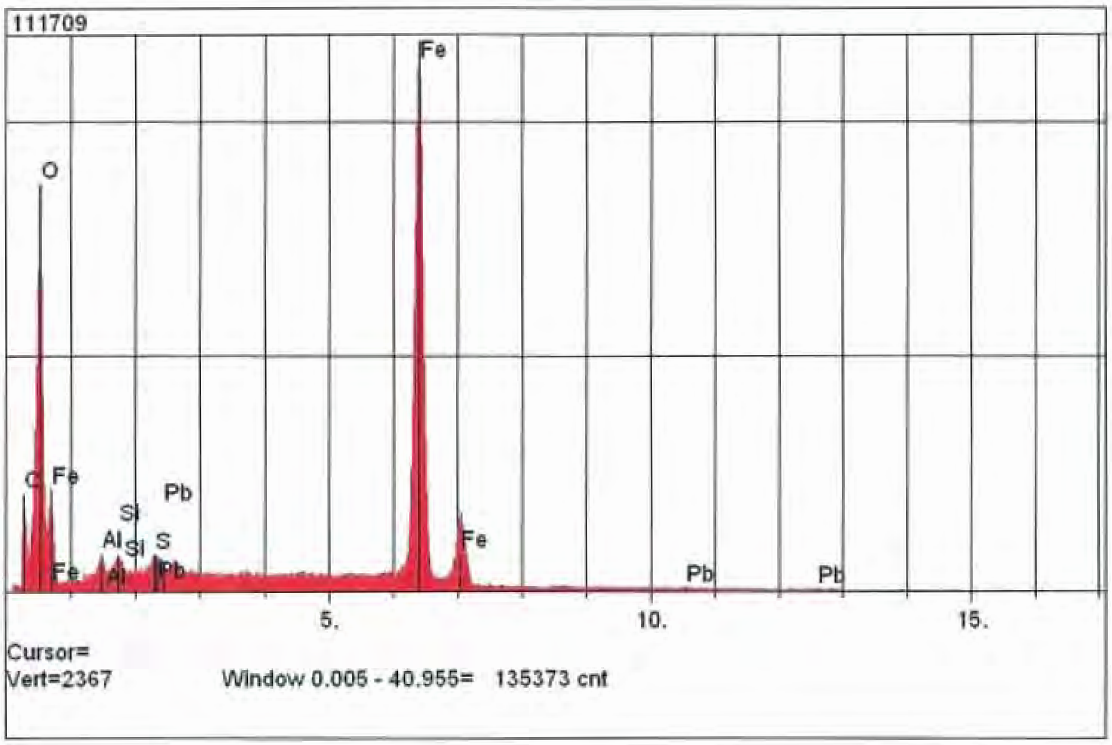

Thursday, December 31, 2009; 1:00:39 AM

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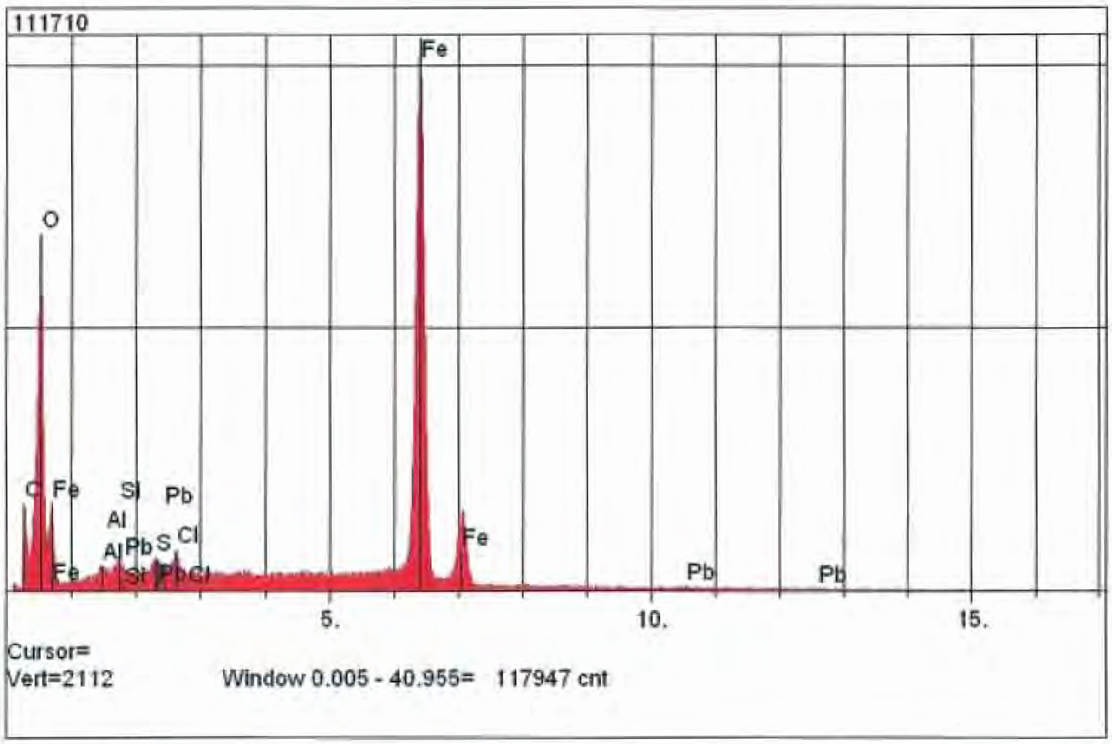
Sample I.D: Location 10



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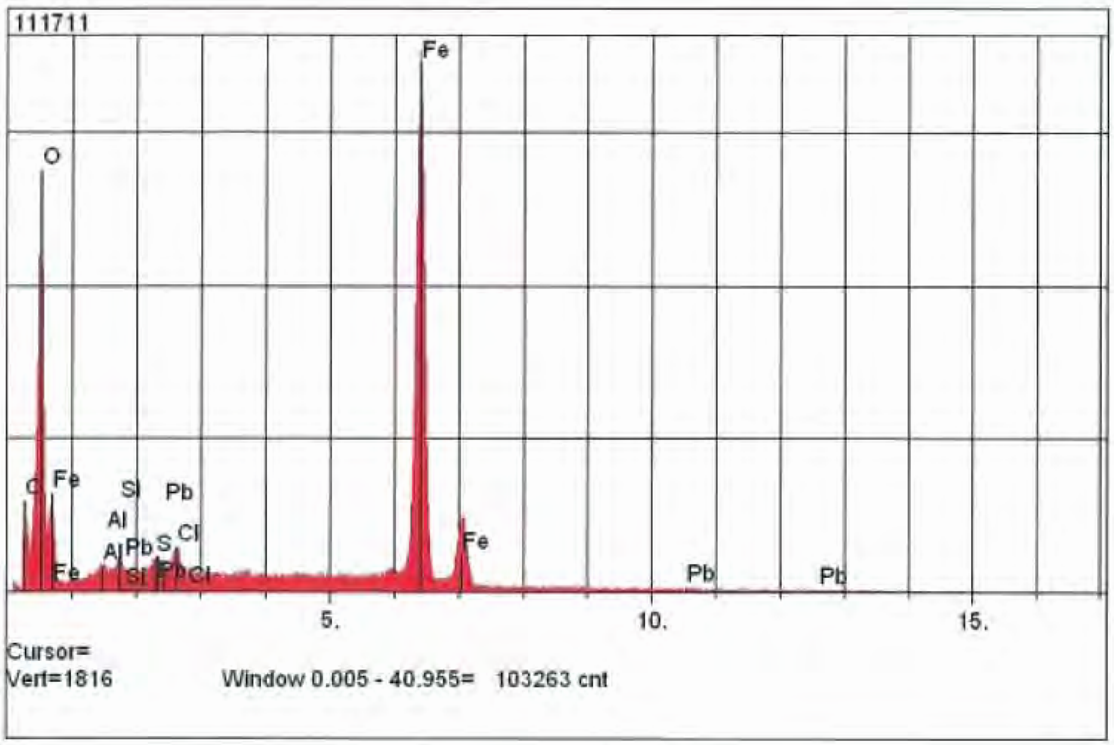

Thursday, December 31, 2009; 1:01:02 AM

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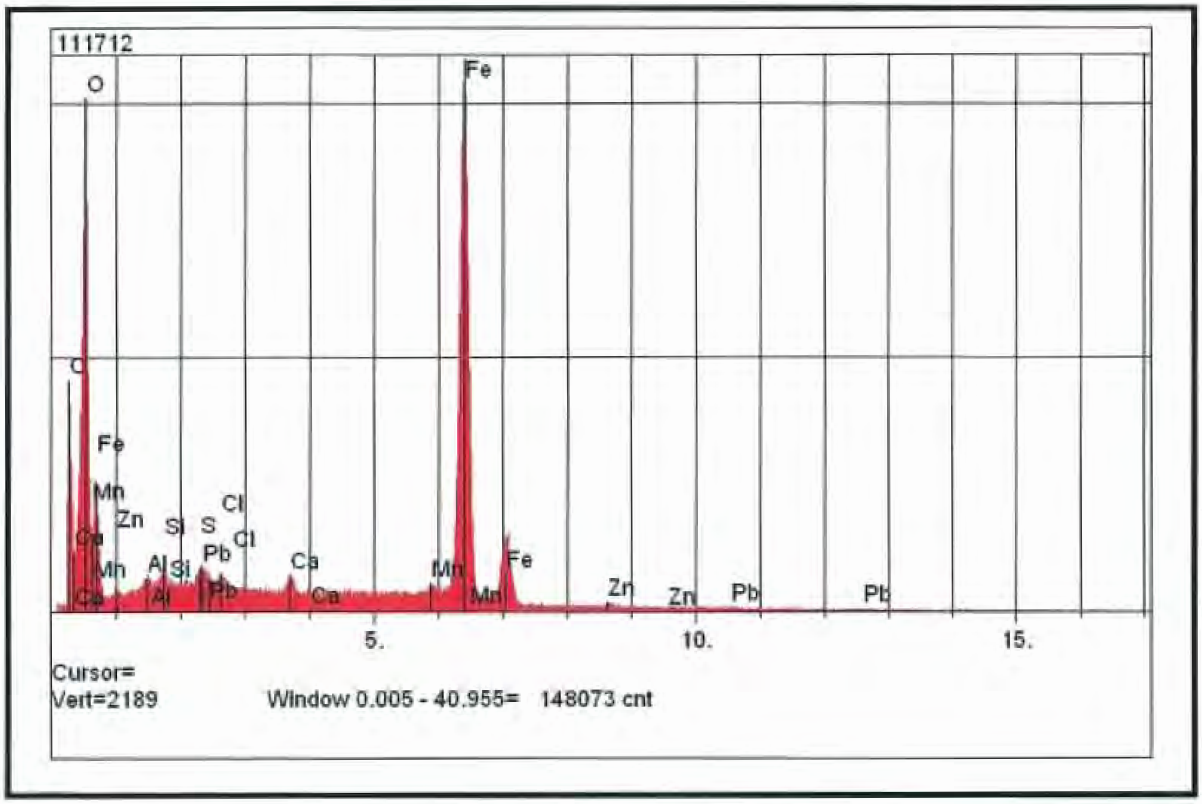
File:	111712	Job No.:	3543	Voltage:	20kV	Time:	100 Sec.

Sample I.D: Location 12



Thursday, December 31, 2009; 1:01:34 AM

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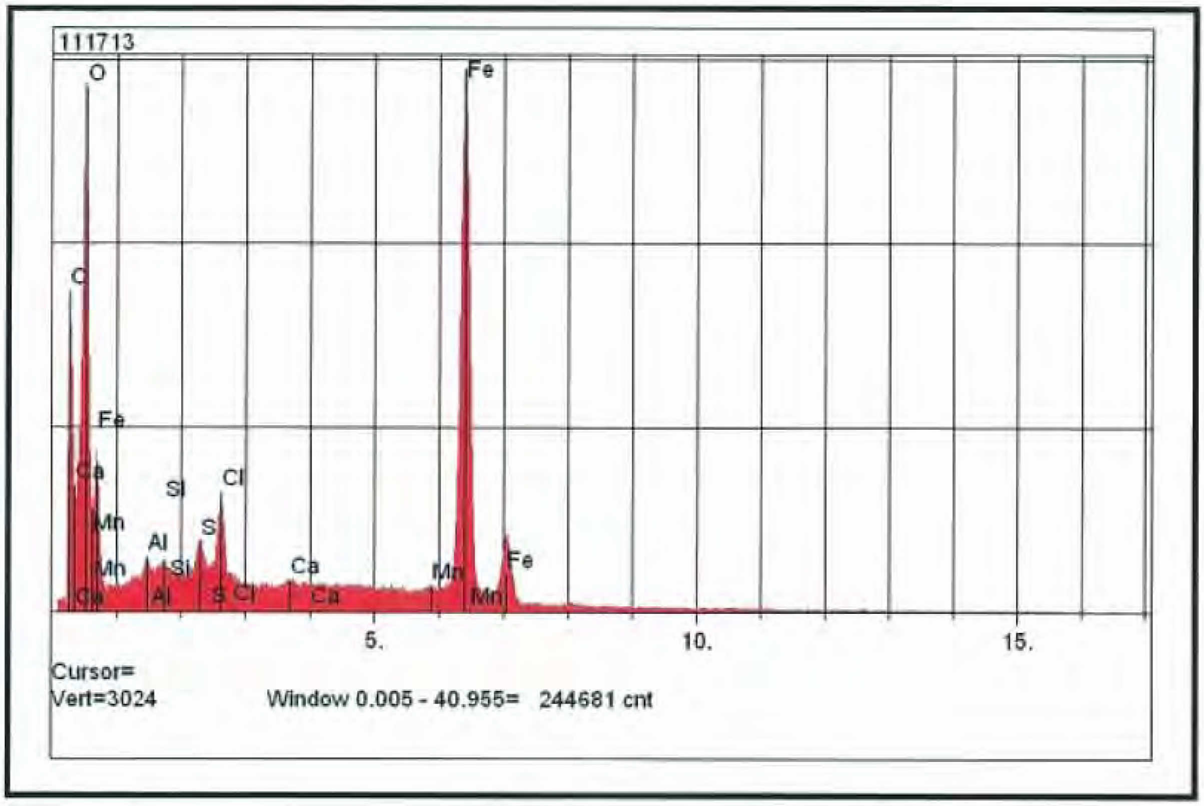
File: 111713	Job No.: 3543	Voltage: 20kV	Time: 100 Sec.

Sample I.D: Location 13



Thursday, December 31, 2009; 1:02:27 AM

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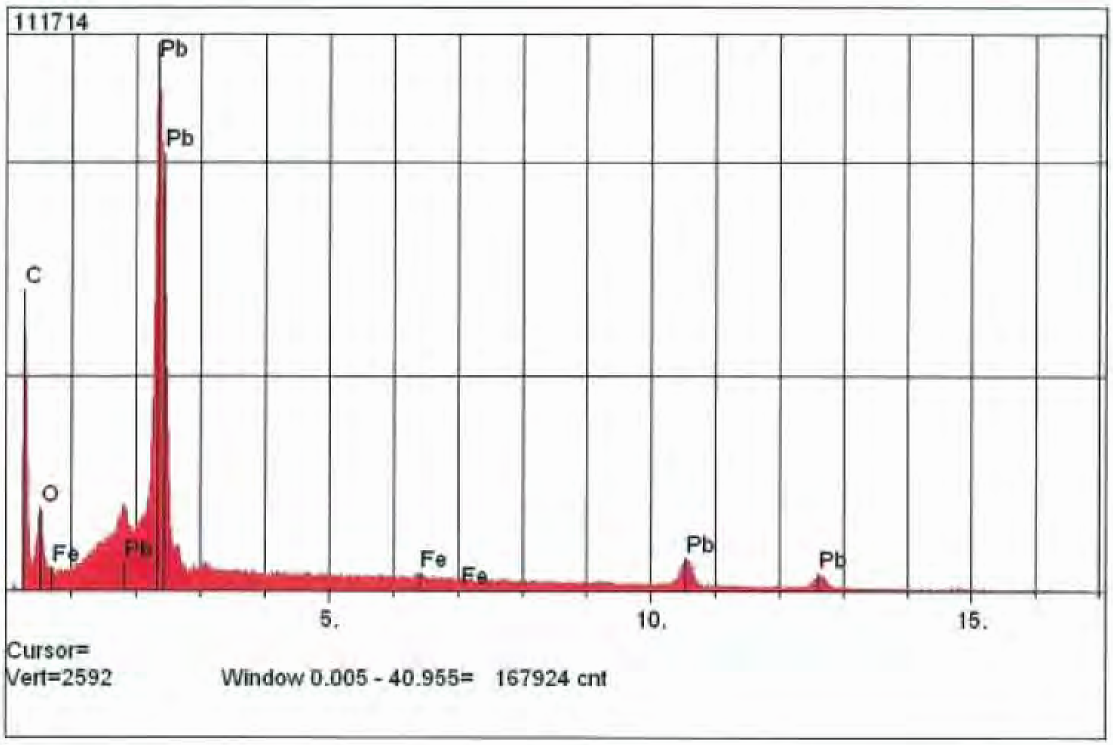
File: 111714	Job No.: 3543	Voltage: 20kV	Time: 100 Sec.

Sample I.D: Location 14



Thursday, December 31, 2009; 1:03:55 AM

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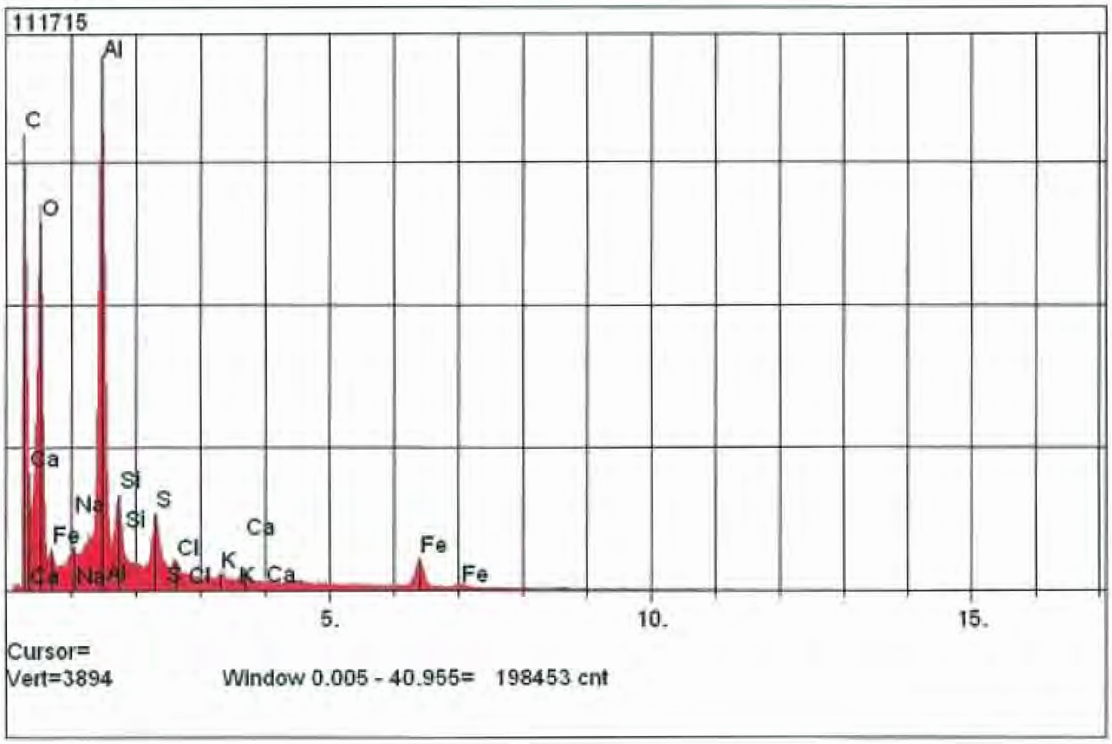
File: 111715	Job No.: 3543	Voltage: 20kV	Time: 100 Sec.

Sample I.D: Location 15



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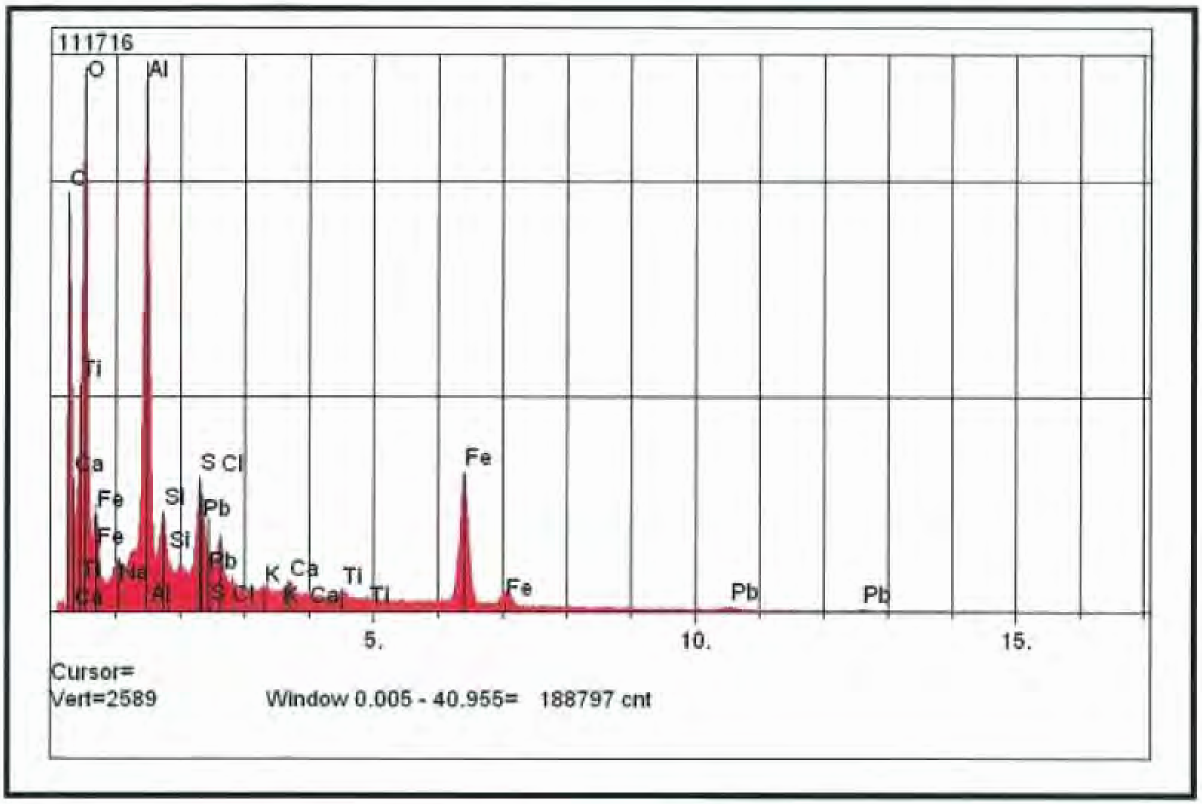
File: 111716	Job No.: 3543	Voltage: 20kV	Time: 100 Sec.

Sample I.D: Location 16



Thursday, December 31, 2009; 1:05:02 AM

Fig. 31 Overall photo of upper portion of fracture and lower portion of fracture. Opposite side.

Fig. 32 Outer edge of fracture.

Fig. 33 Outer edge of fracture. Opposite side.

Fig. 34 Outer edge of fracture. Arrow pointing to fracture origin.

Fig. 35 Mating fracture faces.

Fig. 36 Fracture face outer edge. Fracture origin at arrow location.

Fig. 37 Upper and lower portion of fractured eye bar.

Fig. 38 Upper and lower portion of fractured eye bar, opposite side.

Fig. 39 Inside diameter surface of eye bar pin location.

Fig. 40 Inside portion of fracture face, adjacent to pin location, after cleaning of oxide layer.

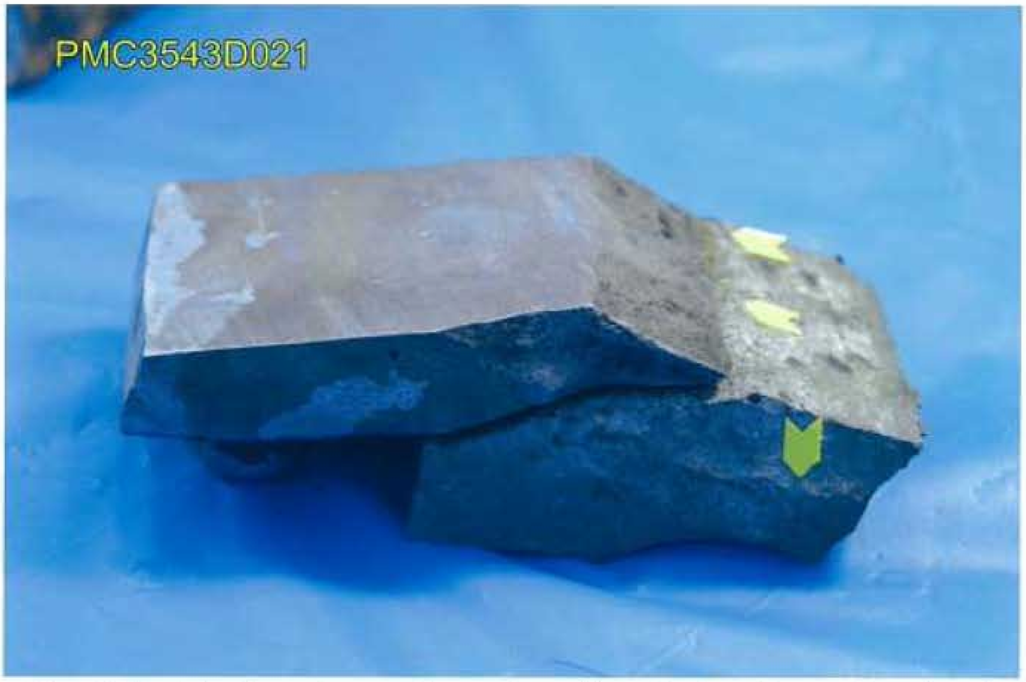
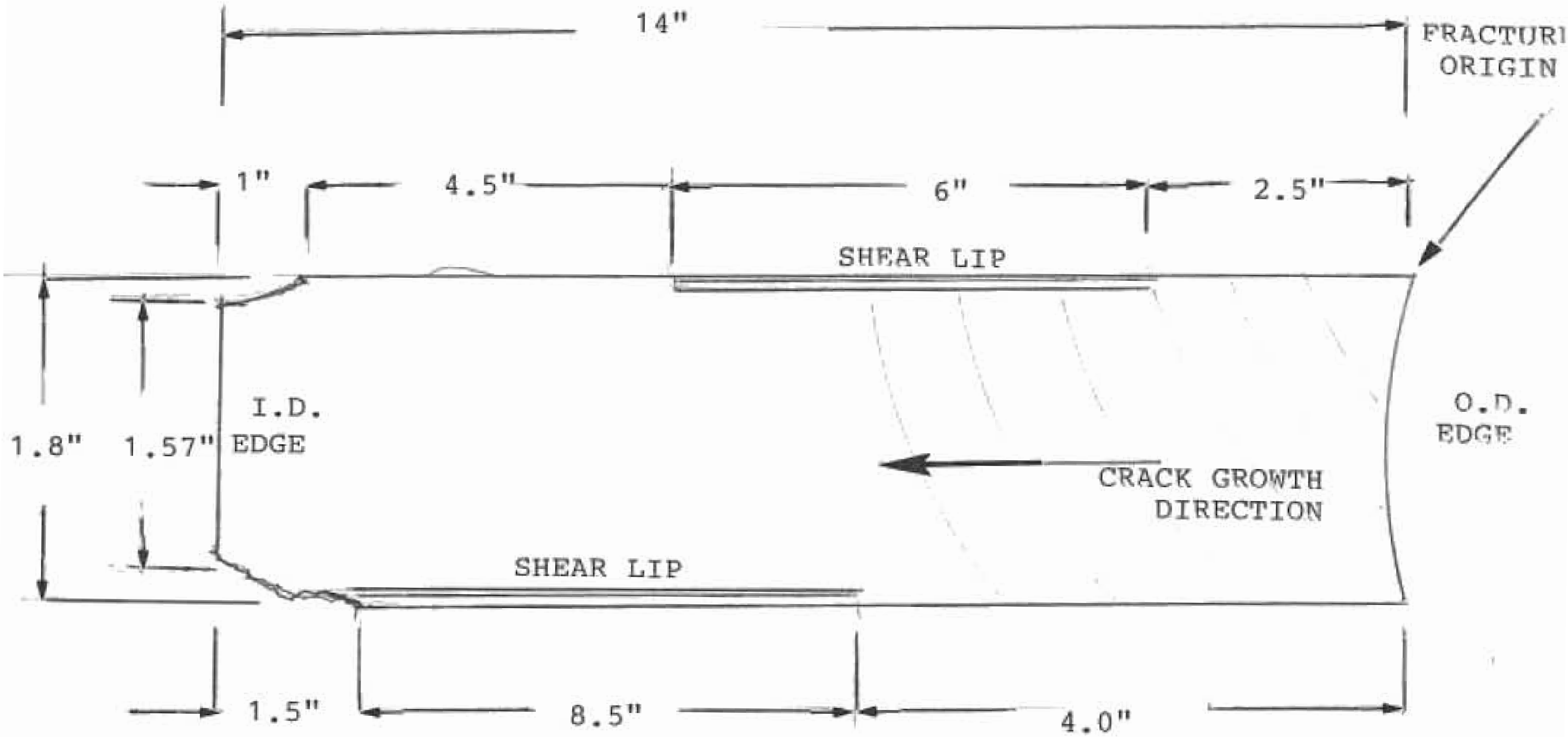


Fig. 41 Inside diameter surface of eye bar pin location, after cleaning of oxide layer.

Fig. 42 Inside diameter surface of eye bar pin location, after cleaning of oxide layer.

Fig. 43 Mating fracture faces of eye bar outboard from pin location, after cleaning of oxide layer.

Fig. 44 Fracture face of eye bar outboard from pin location, after cleaning of oxide layer.



SKETCH A
FRACTURE FACE PROFILE

SEM FRACTURE ANALYSES

SCANNING ELECTRON MICROSCOPY FRACTURE ANALYSES

Fig. 45 illustrates the fracture origin area corner of the eye bar. Higher magnifications photographs were taken at locations 6, 9, 4 and 1 as illustrated in Fig. 45. Fig. 46 illustrates the appearance of the fracture origin corner. Figs. 47 and 48 illustrate higher magnification views of the corner area. At this location the fracture face was cleaned of the oxide layer but no fracture features could be determined due to the etching effects of the removal of the oxide. There was however, evidence of significant rubbing damage in this corner area. Fig. 48 illustrates a higher magnification view of location 8, shown in Fig. 47. One can see that there is no evidence of intergranular or cleavage or dimple rupture. The features shown are strictly of etching effects from the removal of the oxide layer. Fig. 49 illustrates the appearance of the fracture at location 9 shown in Fig. 45 and Figs. 50, 51 and 52 show evidence of fatigue striations on the plane of fracture and evidence of rubbing. The fine lines shown in Figs. 49, 50, 51 and 52 definitely indicate fatigue crack propagation growth in this area. Fig. 51 illustrates the appearance of the fracture at a location approximately 3/8 of an inch from the corner area of the fracture face. Fig. 52 illustrates the appearance of evidence of fatigue at a location approximately 1" diagonally from the corner area of the fracture. Fig. 53 and 54 illustrate the appearance of the fracture at location 4 illustrated in Fig. 45. Even at this area there is evidence of slight fatigue crack growth on the plane of fracture. Figs. 55 and 56 illustrate the appearance of the fracture at arrow location 1 shown in Fig. 45 which again indicates some evidence of fatigue.

At this location there was no evidence of dimple rupture or intergranular fracture or cleavage fracture associated with the plane of fracture. The rest of the fracture in general area showed either heavy oxide and corrosion deposits and or etching effects from the cleaning of the oxide layer on the plane of fracture.

The second segment of the plane of fracture shown to the left in Fig. 35 was also placed in SEM after partial cleaning of the oxide layer and this examined for fracture mode. Fig. 57 illustrates a portion of the fracture face of this second segment, along the edge where there was evidence of cleaning of the oxide layer. At this location examination revealed etching effects but no clear evidence of fatigue or intergranular fracture or dimple rupture. Figs. 59 and 60 illustrates the appearance of the fracture in the central zone of the second segment which again showed no evidence of fatigue or intergranular of cleavage type fracture. There was extensive amount of rubbing and etch pitting in this area where the oxide had been cleaned. Figs. 61 and 62 illustrate the appearance of a shear lip area on the outer edge and at this location there was evidence of rubbing degradation and etch pitting from removal of oxide and slight evidence of dimple rupture. Fig. 63 and 64 showed additional views of the surface of the fracture in the second segment at the left hand edge which again shows evidence of edge pitting and oxidation and rubbing but no evidence of fatigue damage. There was also no evidence of intergranular, cleavage fracture or dimple rupture. In essence the clean areas where the oxide layer had been removed in this segment just showed etch pitted resulting form the removal of the oxide layer at random locations.

The fourth segment of the fracture face which is illustrated in Fig. 35 was also placed in the SEM. Figs. 65 and 66 illustrate the appearance of the fracture at the inside diameter edge of the eye bar close to the pin location where the fracture surface was relatively clean. This shows evidence of etch pitting and small traces of oxide on the plane of fracture. In the central portion of fracture segment No. 4 there were heavy oxide scale deposits which are illustrated in Figs. 67, 68, 69 and 70. In these photographs there was only slight evidence of dimple rupture and tensile overload. There was no evidence of fatigue, intergranular, fracture or cleavage.

Based on the overall analyses of the plane of fracture the results indicate that the fracture origin definitely was at the outside corner edge of the eye bar and at the inboard diagonally from this corner there was evidence of fatigue and inboard on the plane of fracture. On other areas of the fracture there was heavy oxidation and traces of dimple rupture from tensile over load. At none of the locations on the plane of fracture was there any evidence of intergranular fracture, or cleavage type fracture mode identified.

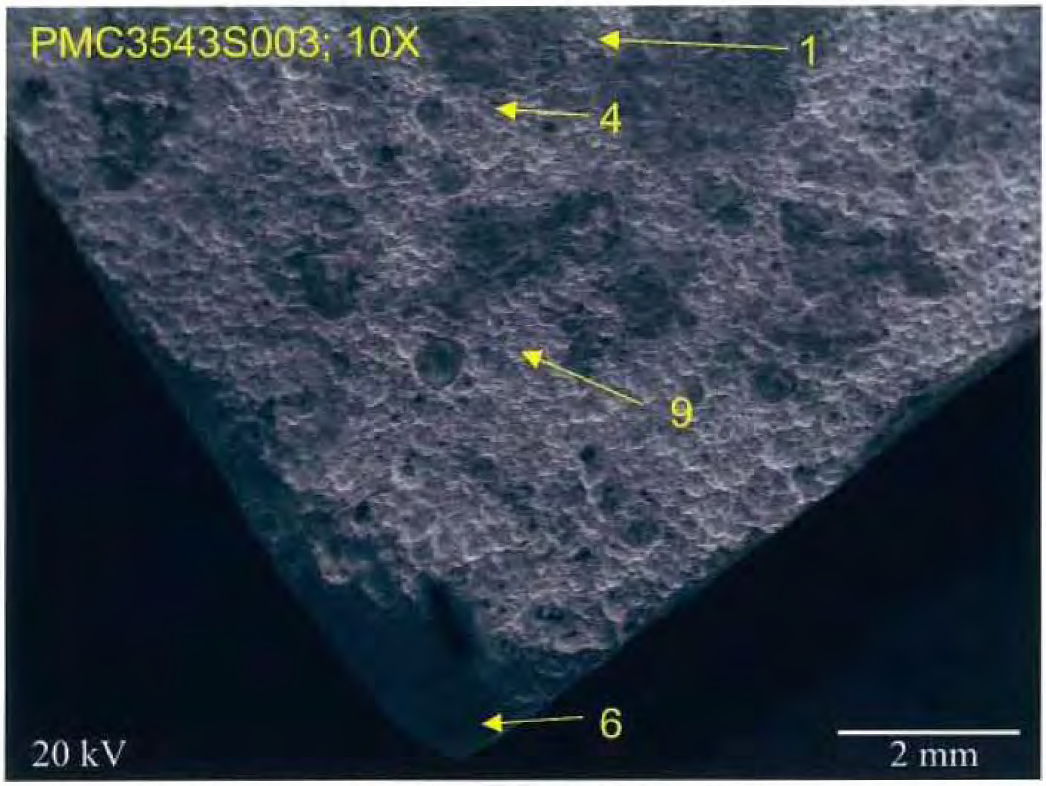


Fig. 45 S.E.M photo of eye bar fracture surface at fracture origin. 10X.

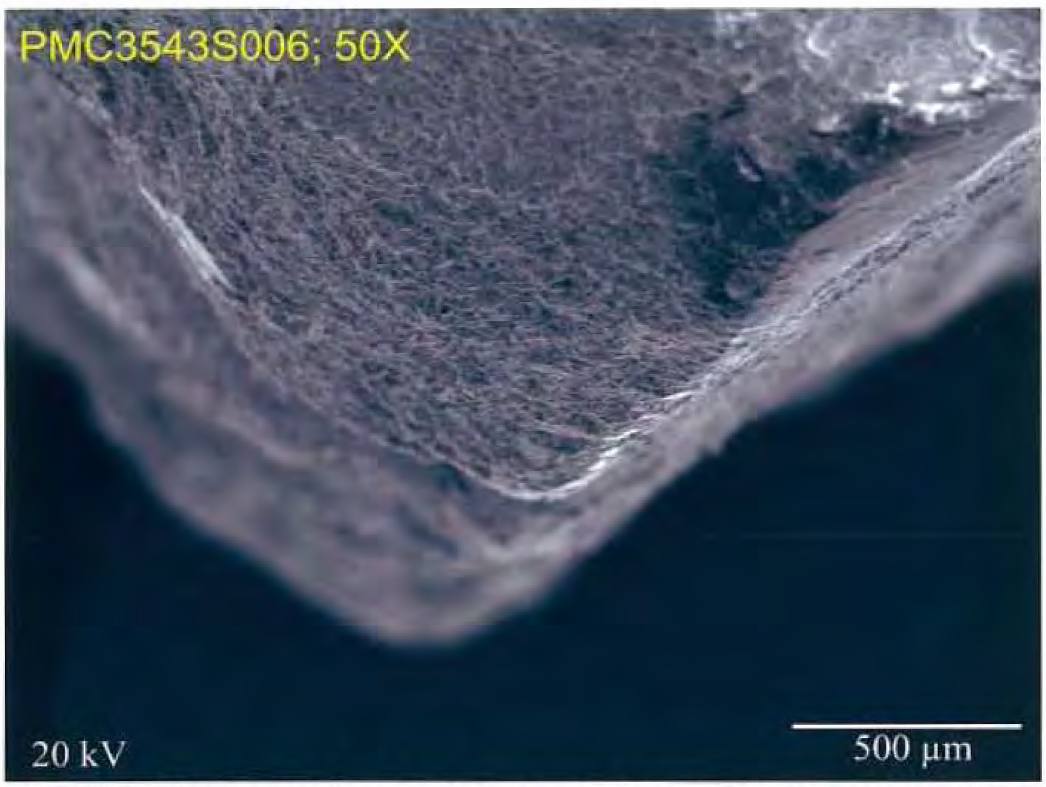


Fig. 46 S.E.M photo of eye bar fracture surface at fracture origin, location 6 in fig. 45. 50X.

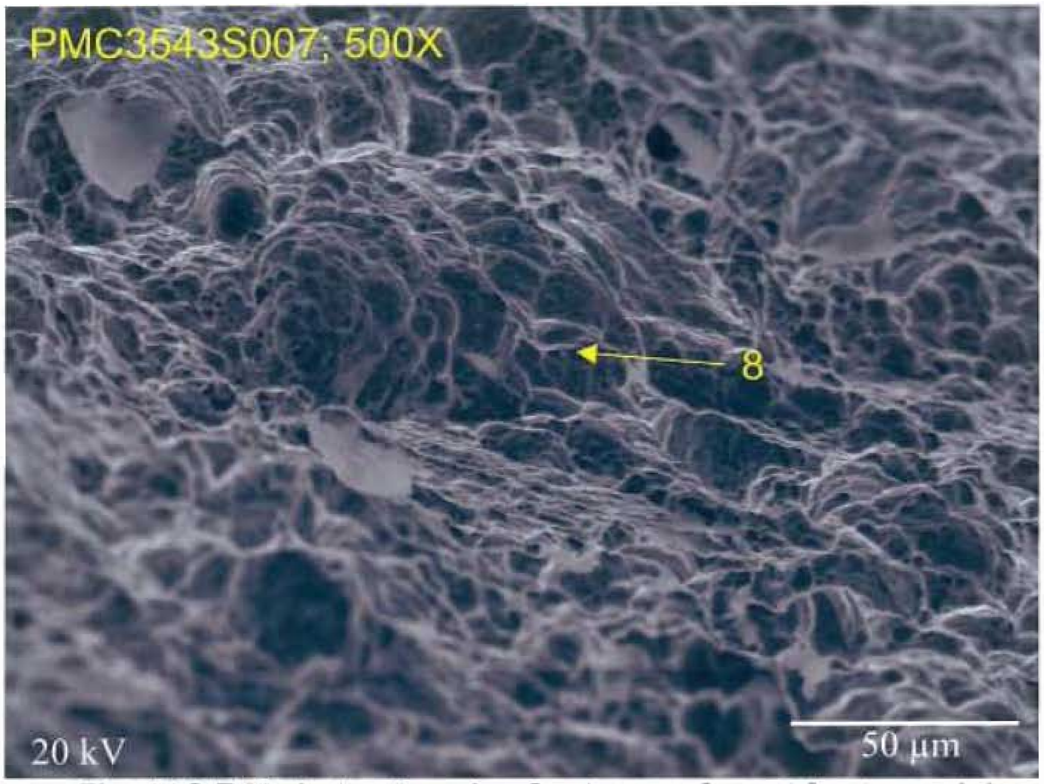


Fig. 47 S.E.M photo of eye bar fracture surface at fracture origin, in fig. 46. 500X.

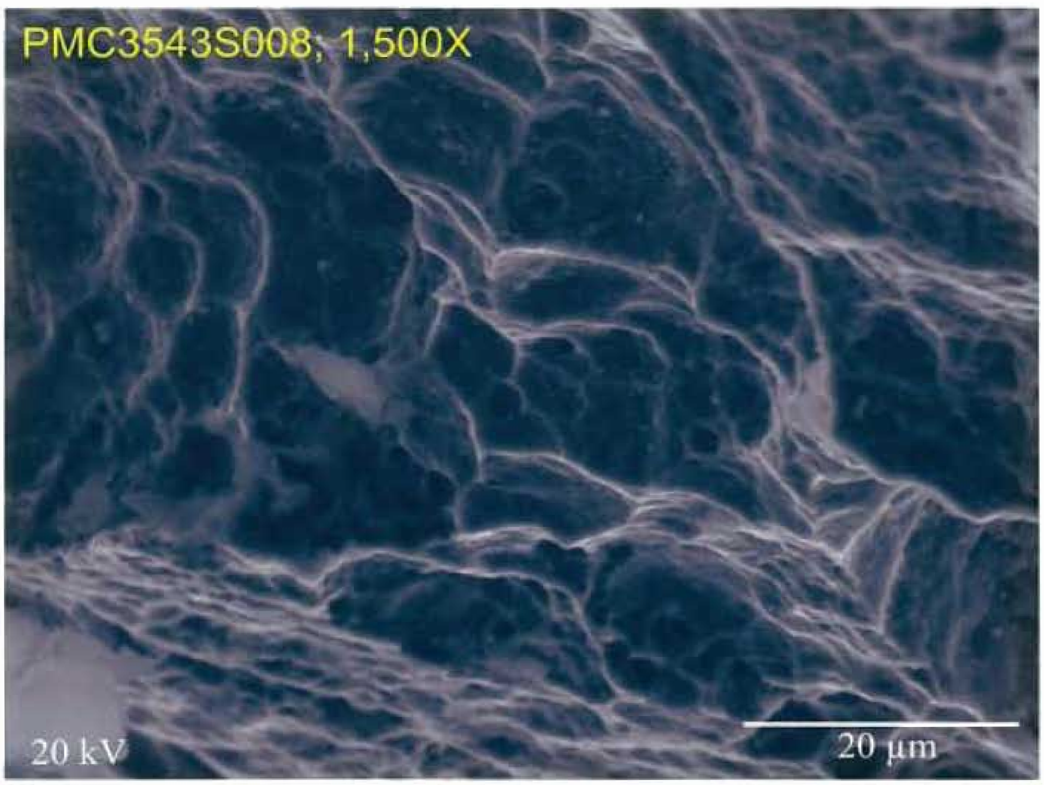


Fig. 48 S.E.M photo of eye bar fracture surface at fracture origin, location 8 in fig. 47. 1,500X.

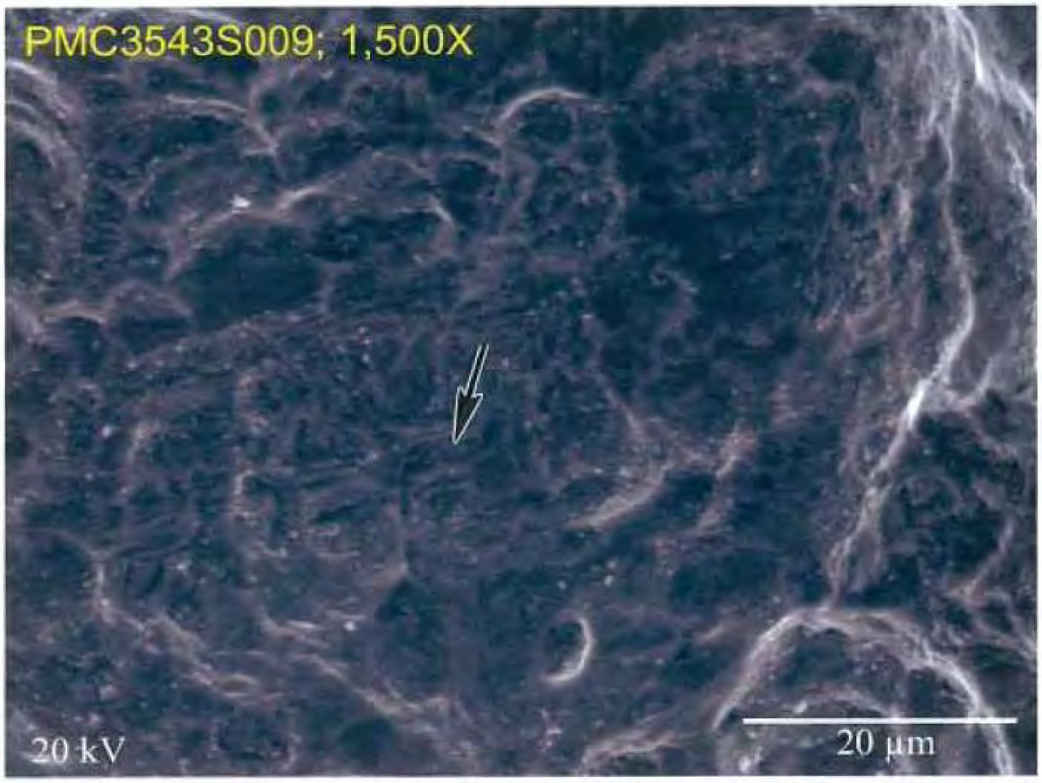


Fig. 49 S.E.M photo of eye bar fracture surface at fracture origin, location 9 in fig. 45. 1,500X.

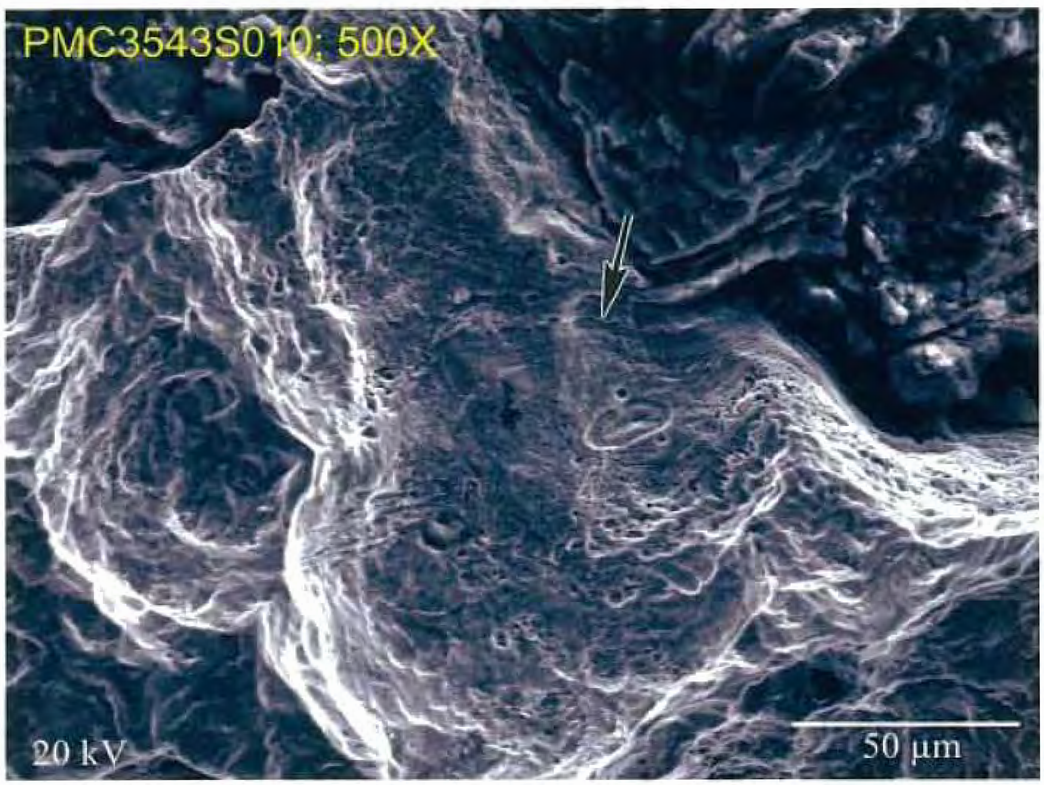


Fig. 50 S.E.M photo of eye bar fracture surface at fracture origin, in fig. 45. 500X.

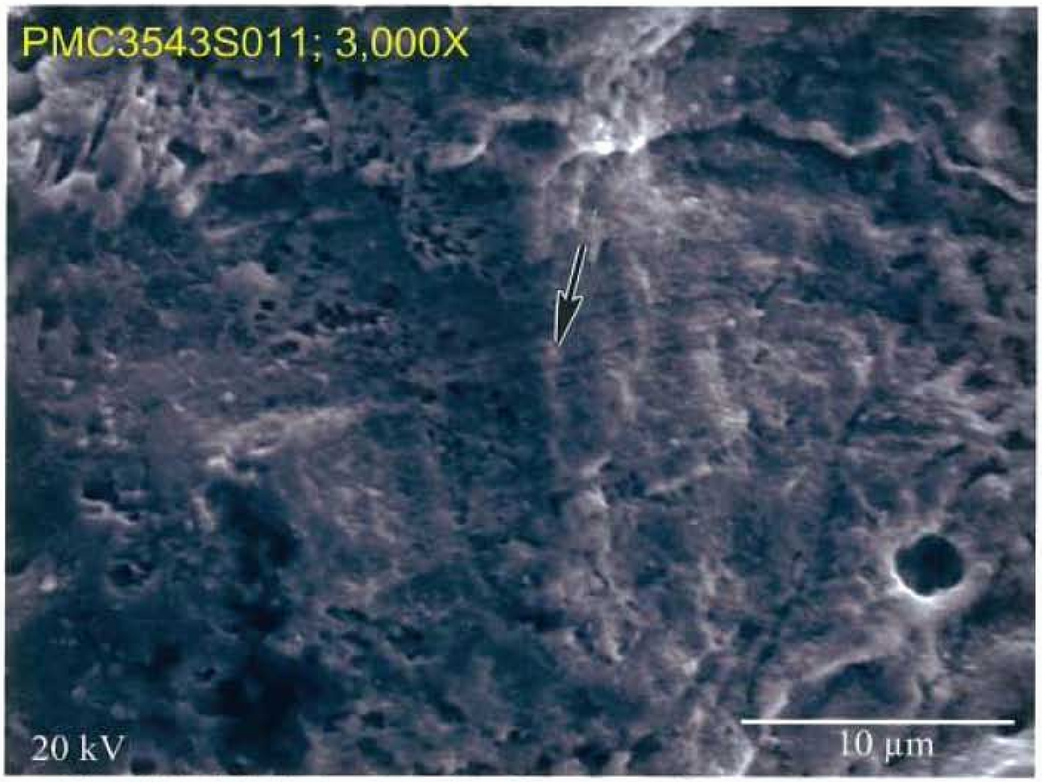


Fig. 51 S.E.M photo of eye bar fracture surface at fracture origin, in fig. 50. 3,000X

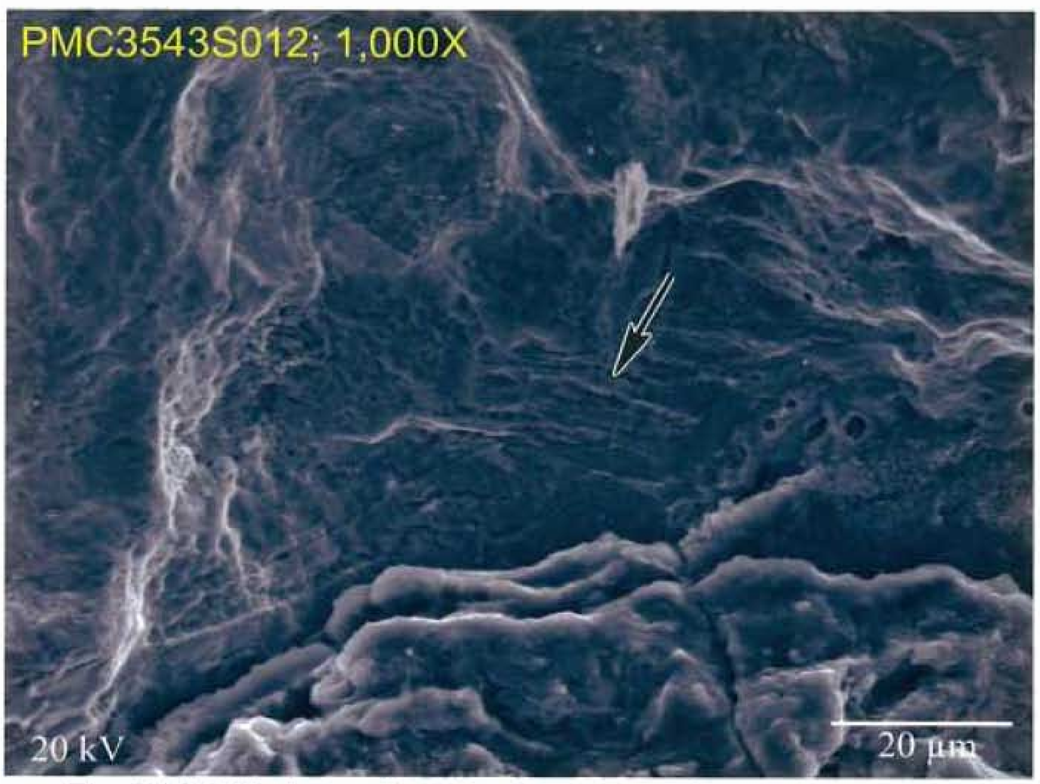


Fig. 52 S.E.M photo of eye bar fracture surface at fracture origin, in fig. 45. 1000X.

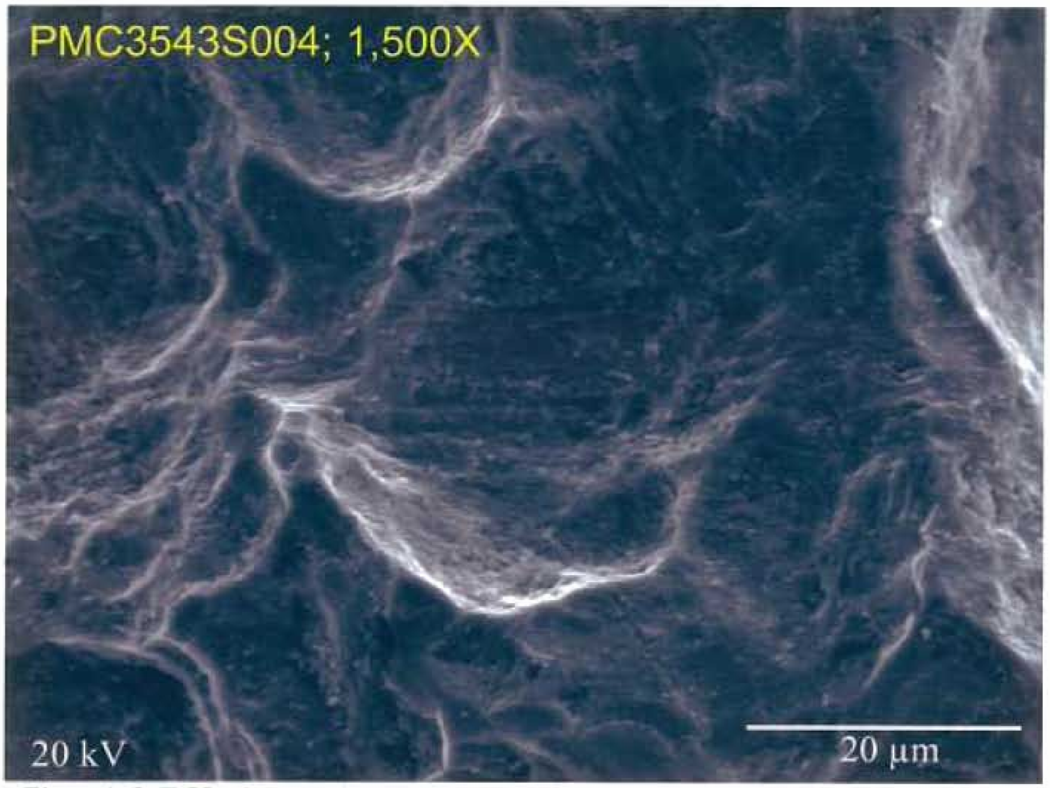


Fig. 53 S.E.M photo of eye bar fracture surface at fracture origin, location 4 in fig. 45. 1,500X.

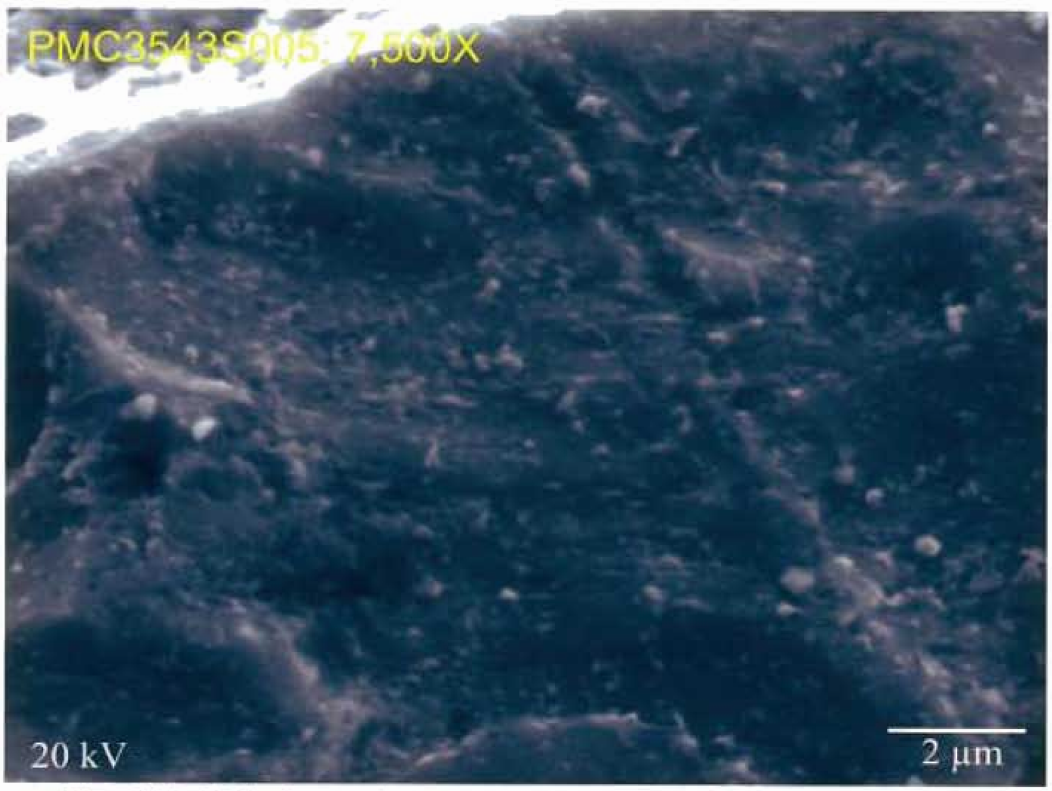


Fig. 54 S.E.M photo of eye bar fracture surface at fracture origin, in fig. 53. 7,500X.

Fig. 55 S.E.M photo of eye bar fracture surface at fracture origin, location 1 in fig. 45. 10X.

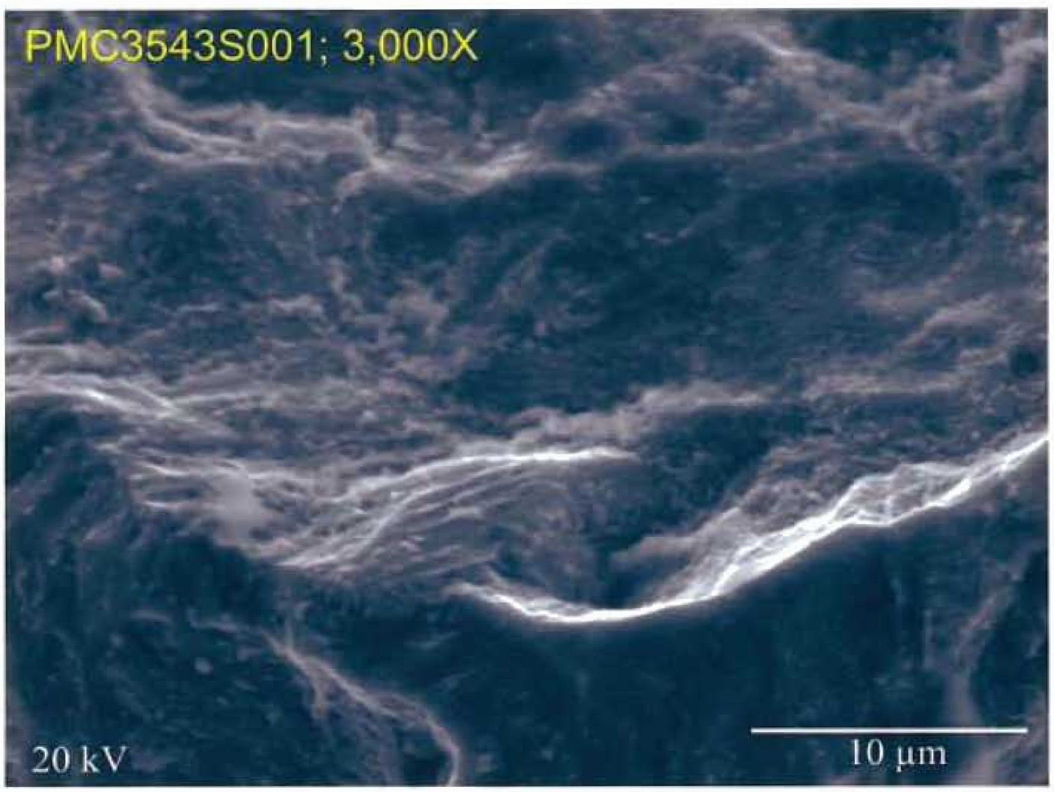


Fig. 56 S.E.M photo of eye bar fracture surface at fracture origin, location 1 in fig. 55. 3,000X.

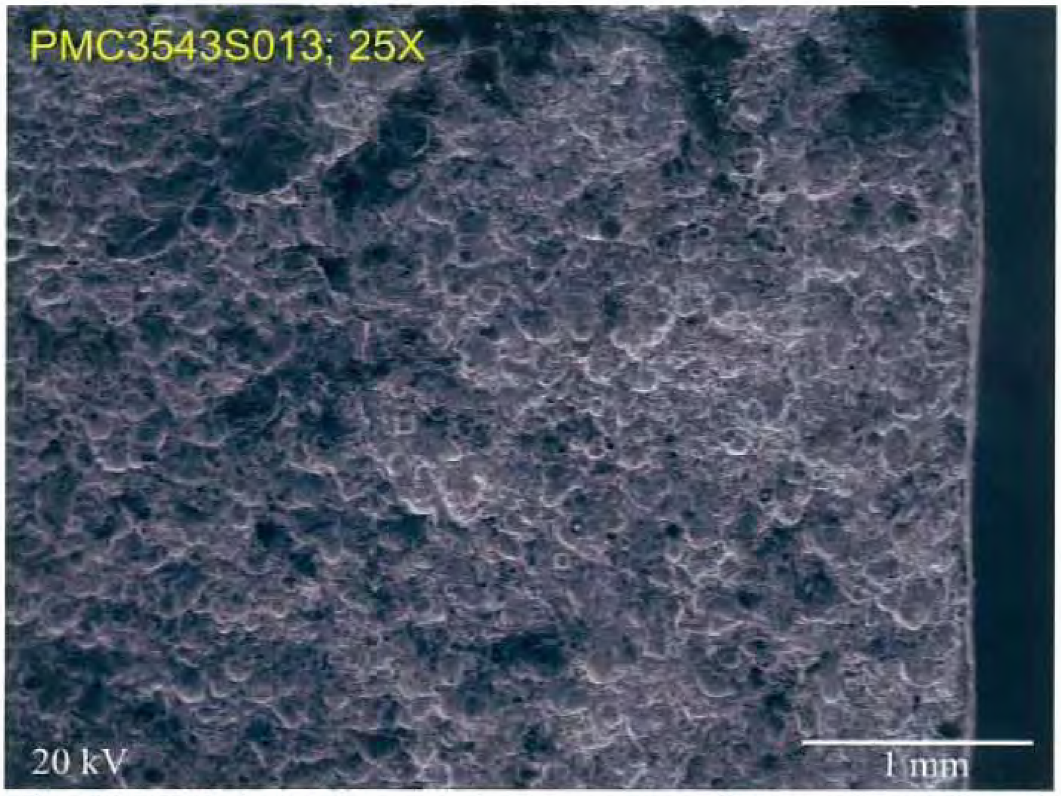


Fig. 57 S.E.M photo of eye bar fracture surface, 2nd segment in fig. 35 at location 2, right edge. 25X.

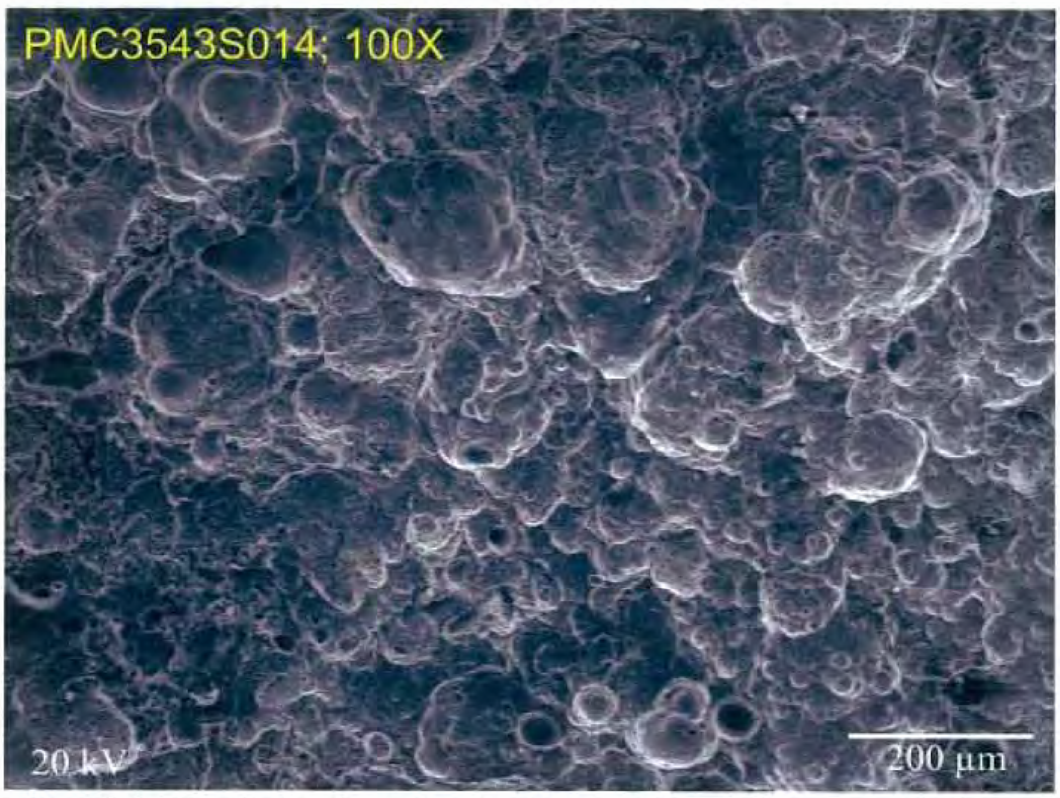


Fig. 58 S.E.M photo of eye bar fracture surface, 2nd segment in fig. 35 at location 2, right edge. 100X.

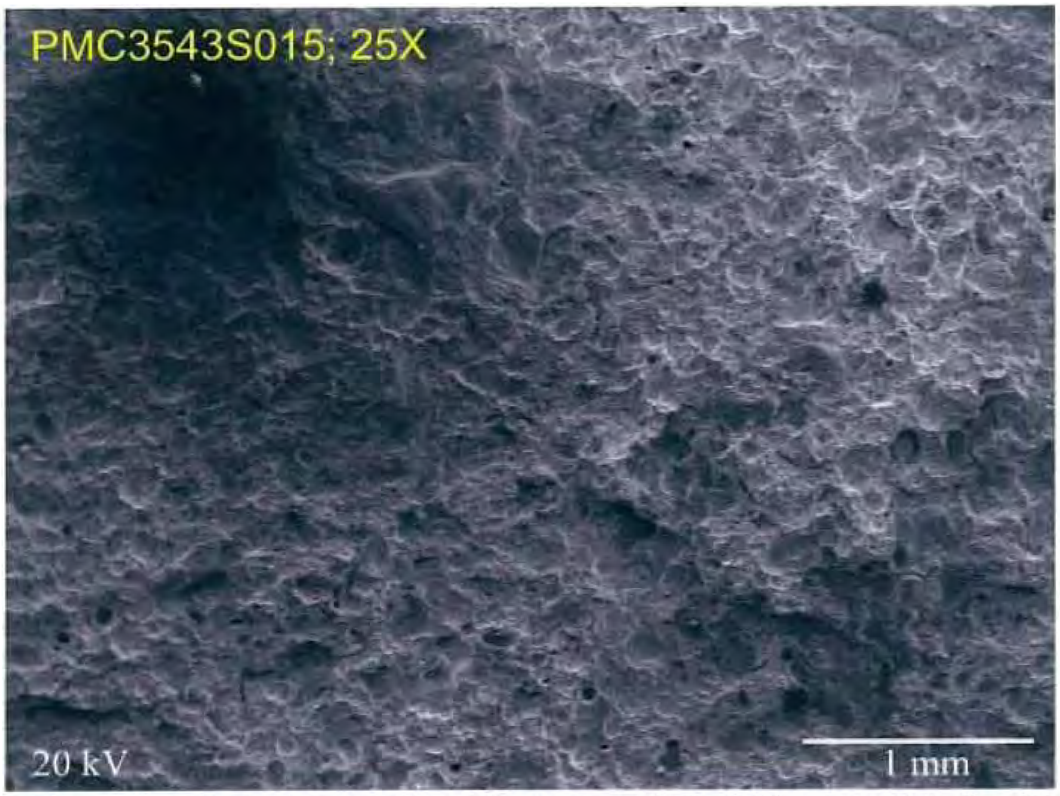


Fig. 59 S.E.M photo of eye bar fracture surface, 2nd segment in fig. 35 at location 2, Center zone. 25X.

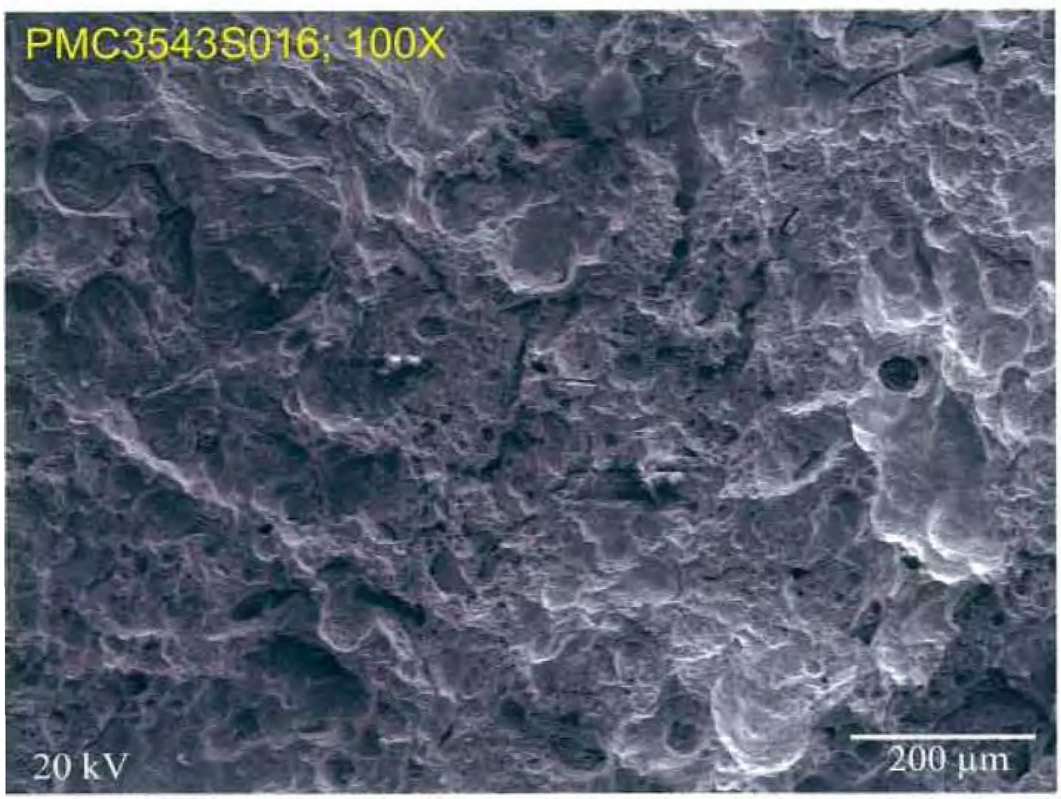


Fig. 60 S.E.M photo of eye bar fracture surface, 2nd segment in fig. 35 at location 2, Center zone. 100X.

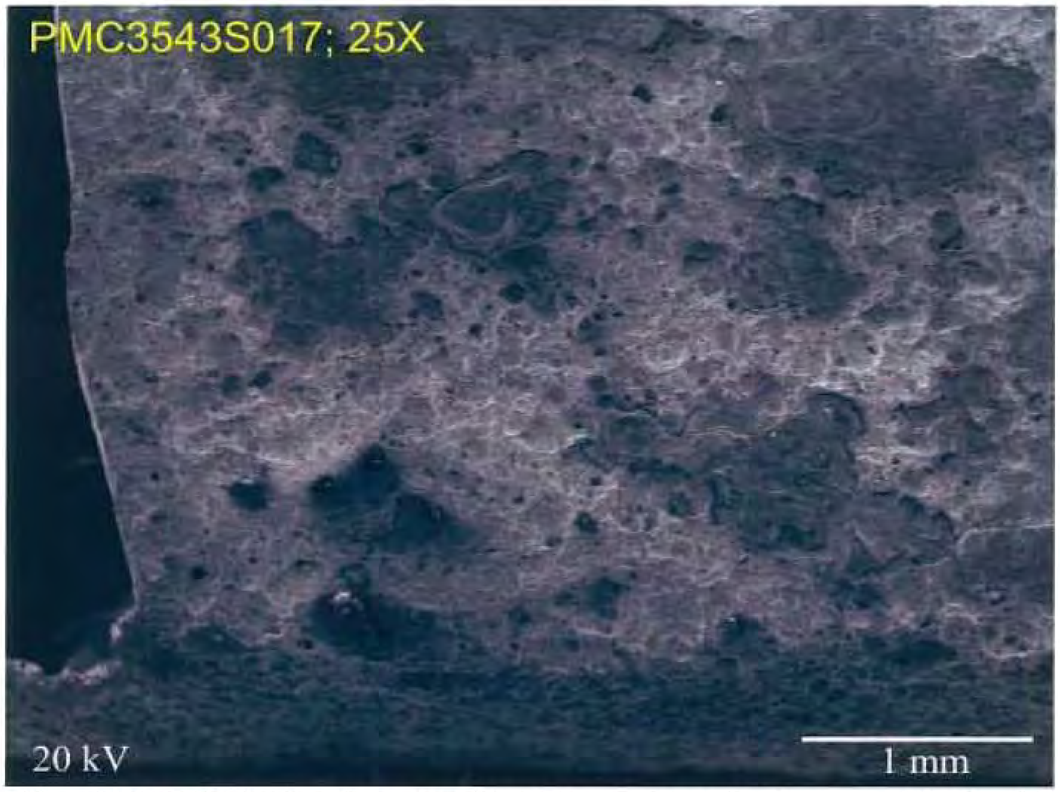


Fig. 61 S.E.M photo of eye bar fracture surface, 2nd segment in fig. 35 at location 2, Shear lip. 25X.

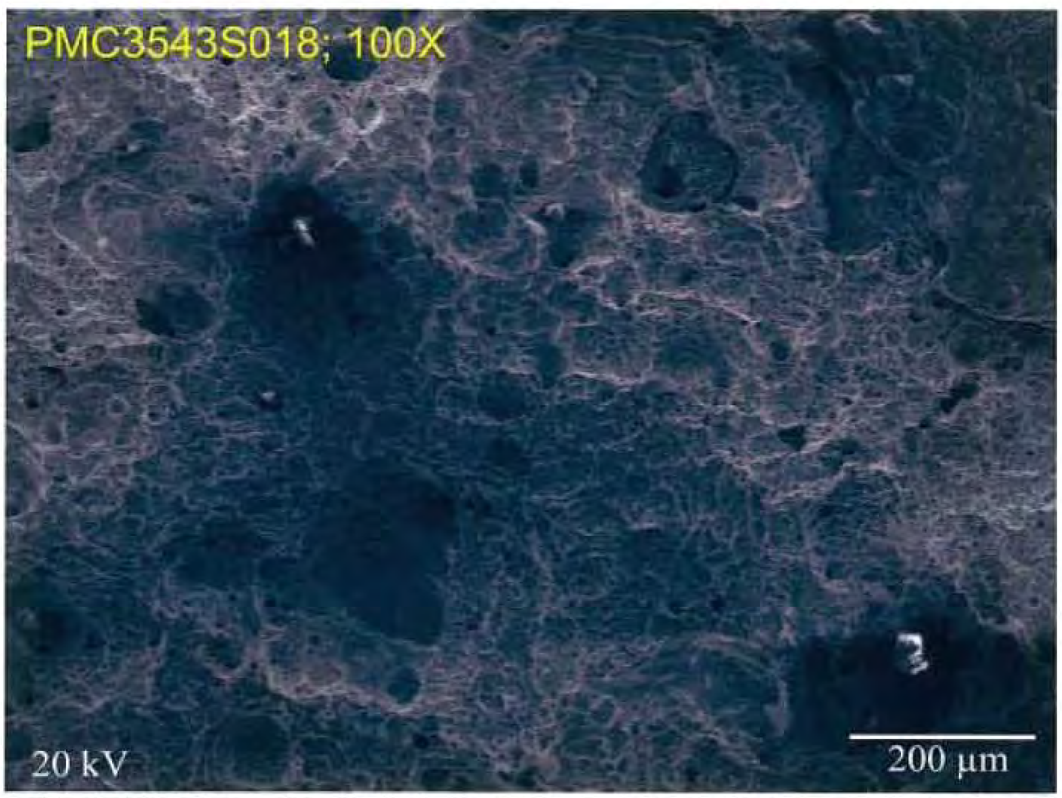


Fig. 62 S.E.M photo of eye bar fracture surface, 2nd segment in fig. 35 at location 2, shear lip. 100X.

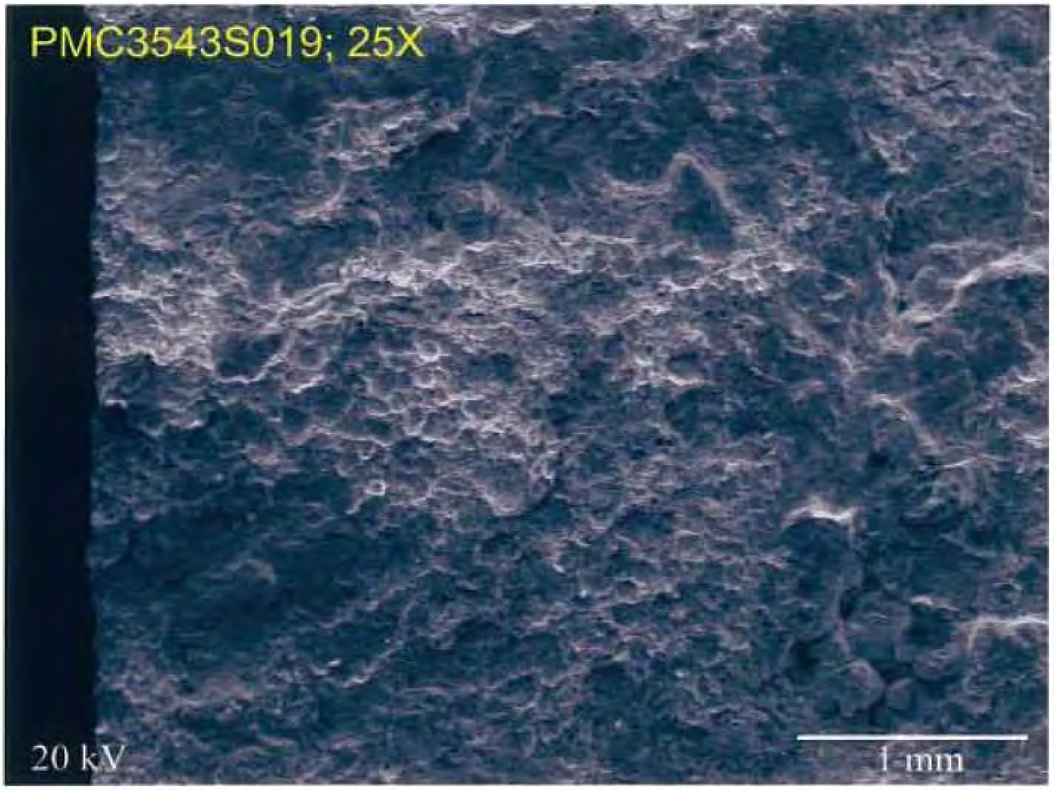


Fig. 63 S.E.M photo of eye bar fracture surface, 2nd segment in fig. 35 at location 2, left edge. 25X.

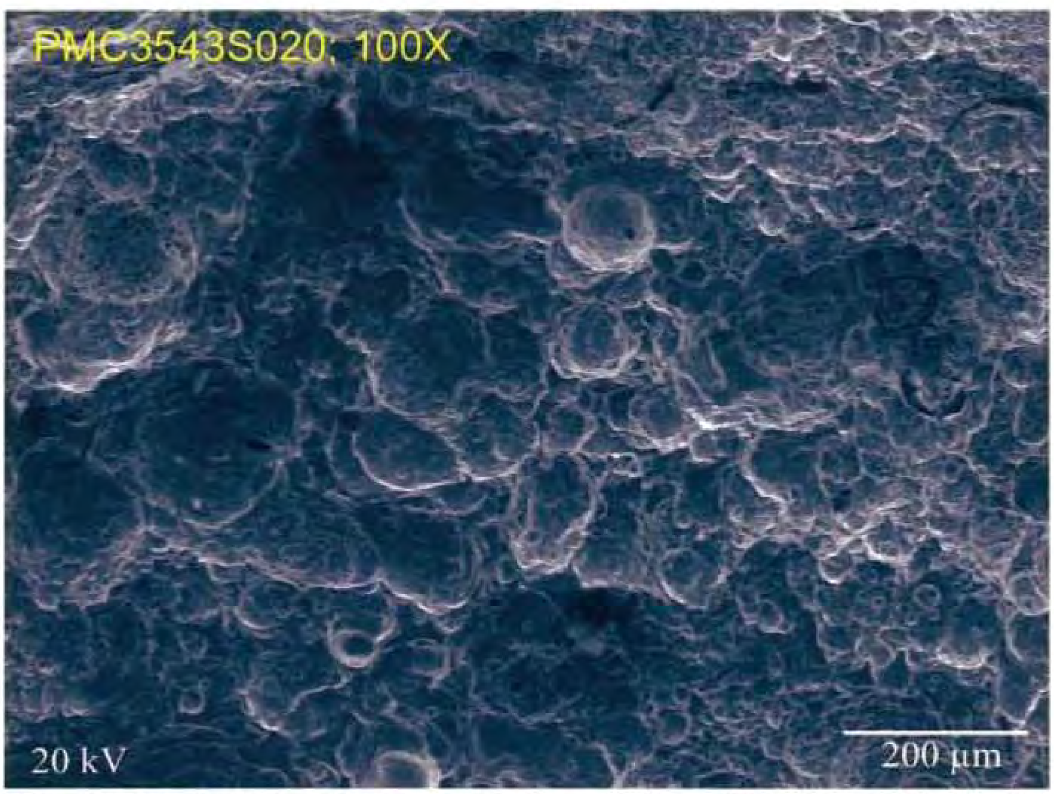


Fig. 64 S.E.M photo of eye bar fracture surface, 2nd segment in fig. 35 at location 2, left edge. 100X.

Fig. 65 S.E.M photo of eye bar fracture surface, 4th segment in fig. 35 at location 4, top edge, area 1. 10X.

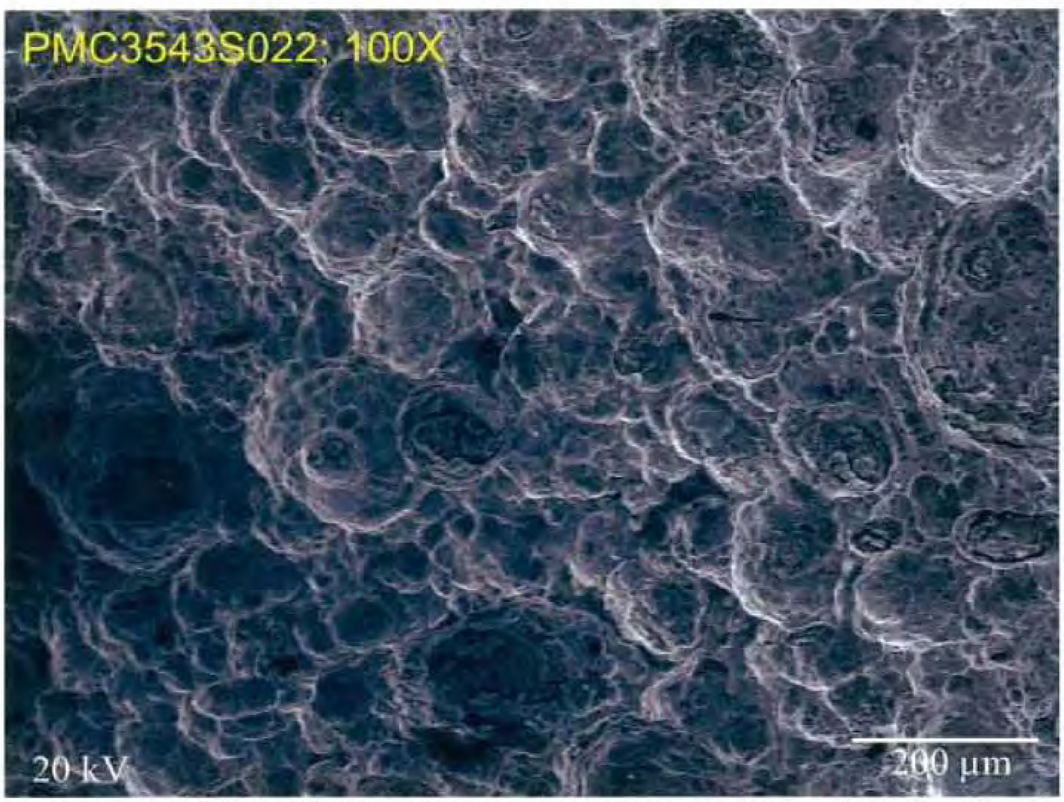


Fig. 66 S.E.M photo of eye bar fracture surface, 4th segment in fig. 35 at location 4, top edge, area 1. 100X.

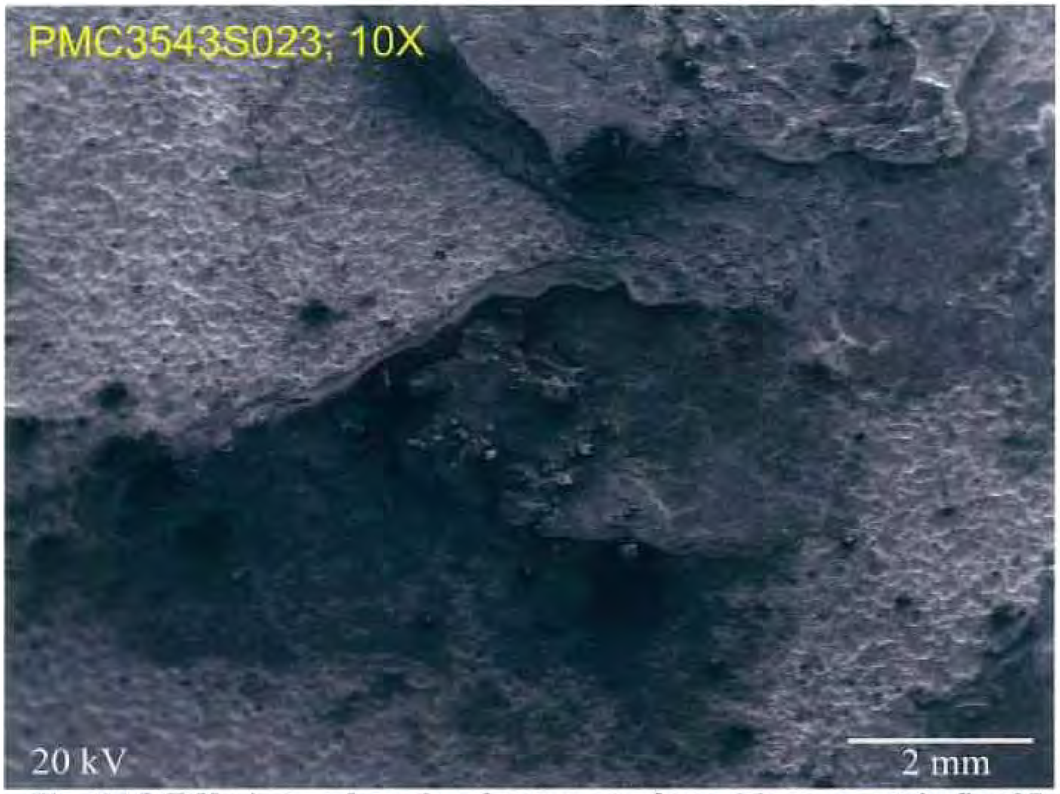


Fig. 67 S.E.M photo of eye bar fracture surface, 4th segment in fig. 35 at location 4, transition, area 2. 10X.

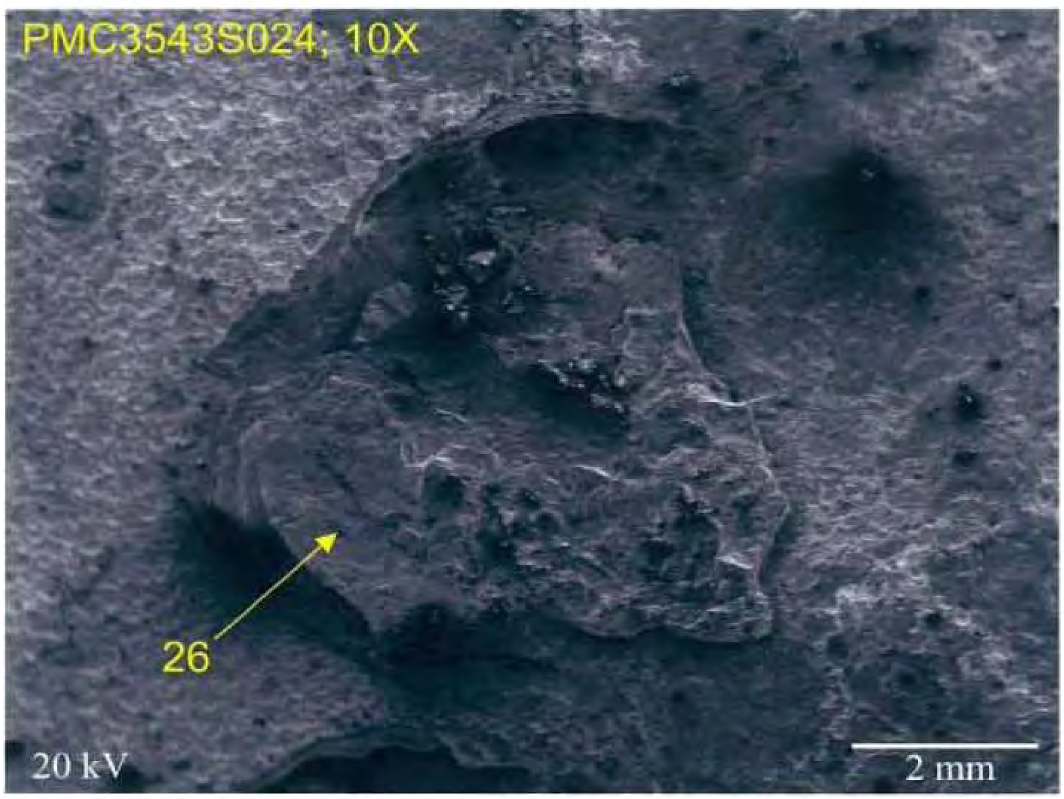


Fig. 68 S.E.M photo of eye bar fracture surface, 4th segment in fig. 35 at location 4, transition, area 2. 100X.

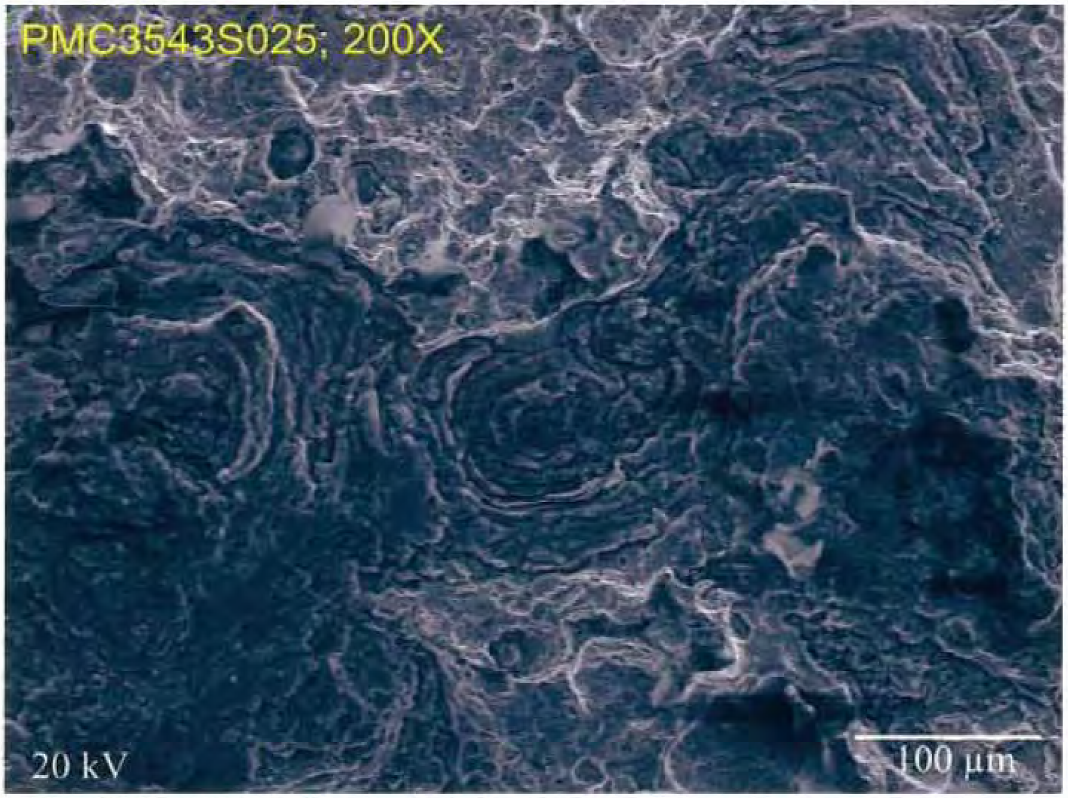


Fig. 69 S.E.M photo of eye bar fracture surface, 4th segment in fig. 35 at location 4, oxide on Fracture face, area 3. 200X.

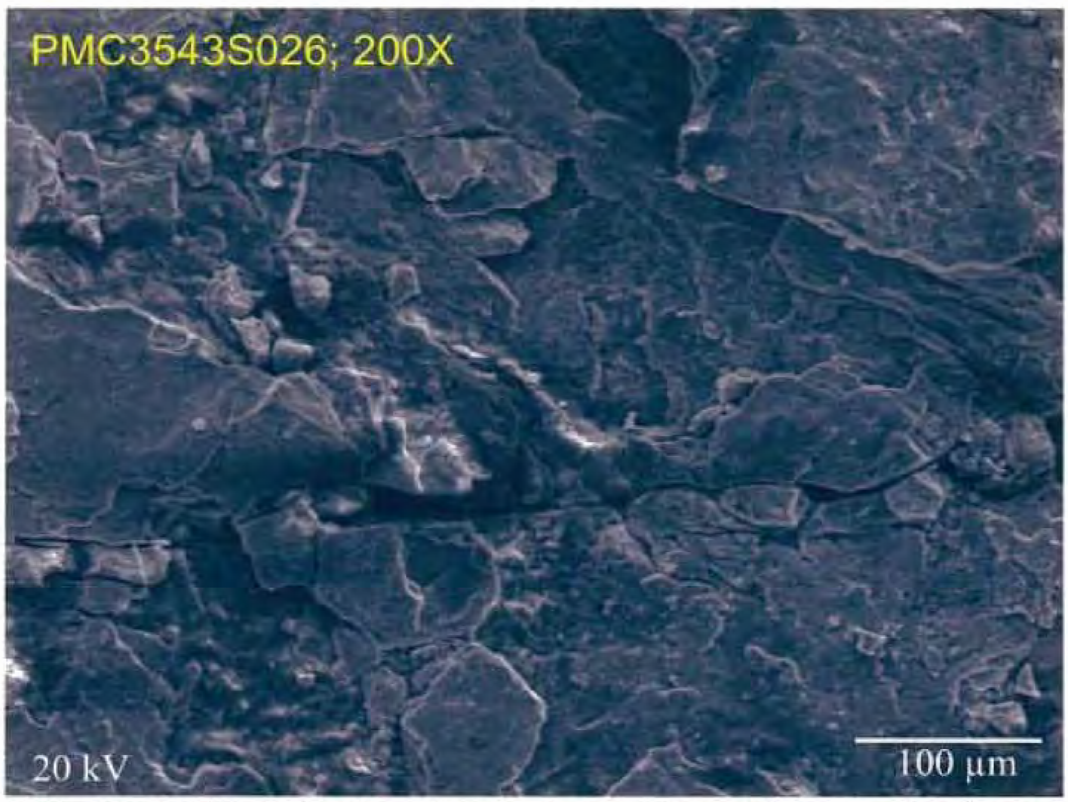


Fig. 70 S.E.M photo of eye bar fracture surface, 4th segment in fig. 35 at location 4, oxide layer in fig. 68. 200X.

MICROSTRUCTURE ANALYSES

MICROSTRUCTURE ANALYSES

The microsections prepared at the location indicated in Fig. 20 were examined for microstructure and hardness. Fig. 71 illustrates the microsection prepared at location 1 in Fig. 20. The outer edge of the eye bar at this location is shown to the left in the photograph. The outer edge of the eye bar has a concave configuration as is illustrated in Fig. 71. The arrow at the sharp corner at the top indicates where the fatigue fracture initiated in the eye bar. The microstructure near the top outer edge is shown in Fig. 72 and 73. The microstructure consists of highly tempered martensitic type structure. Inboard from this area the core microstructure consisted of martensitic grains surrounded by ferrite. This is illustrated in Figs. 74 and 75. Fig. 76 illustrates the microsection prepared at location 2 shown in Fig. 20. Fig. 77 illustrates the core microstructure of this specimen at 200X. Fig. 78 illustrates the microsection prepared at location 3 in Fig. 20. The area to the right represents the surface that is against the pin in the assembly. Figs. 79 and 80 illustrate the appearance of the top surface near the pin location which shows evidence of extensive oxidation and pitting. Fig. 81 illustrates the microstructure and the microsection prepared perpendicular to the plane of fracture at location 4 in Fig. 20. Examination of this specimen in the unetched condition revealed longitudinal oriented inclusions such as illustrated in Fig. 82. This identifies the principal roll direction or grain flow direction of the bar which is perpendicular to the plane of fracture and parallel to the long axes of the eye bar. Fig. 83 illustrates the microstructure near the top surface of this sample and which is tempered martensite and

Fig. 84 illustrates the appearance of the longitudinal elongated inclusion in the core area that exhibits a different microstructure. Fig. 85 illustrates the microstructure at the location of the inclusion which shows martensitic grains surrounded by ferrite. Fig. 86 illustrates the microsection at location 5. Fig. 87 shows an elongated inclusion running perpendicular to the plane of fracture in this section.

Fig. 88 illustrates the fracture face near the inboard side near the center pin location in the assembly. At this location there was heavy oxide scale on the plane of fracture which is illustrated in Fig. 88. A transverse microsection was prepared along the line showing on the specimen. Fig. 89 and 90 illustrate the nature of the large oxide scale at this location. Fig. 91 illustrates the cross section of the eye bar at this location and Figs. 92 and 93 illustrate the heavy oxide development on the plane of fracture at this location. Fig. 94 illustrates a cross section of the heavy oxide scale shown on the fracture face at this location. The microstructure under this oxide layer is illustrated in Figs. 95 and 96 which show that the microstructure consists of martensite grains surrounded by ferrite. There was no evidence of any decarburization layer associated with the plane of fracture or the location of the heavy oxide scale on the specimen. This indicates that the heavy oxidation was due to environmental corrosion after the fracture opened up and does not indicate that there was a longitudinal oriented heavy oxide scale in the eye bar at this location as manufactured.

Fig. 97 illustrates another section that was taken in the plane of the fracture thru the same oxide development and the sections removed are shown further in Fig. 98.

Figs. 99 and 100 illustrate the appearance of these microsections prepared in this direction. Fig. 101 illustrates the microsection along the plane of fracture and again shows no evidence of any decarburization layer or internal flaw below the oxide scale. Fig. 102 illustrates the etched microstructure which shows martensitic grains surrounded by ferrite. Figs. 103 and 104 show additional views of the microstructure which is consistent with the rest of the cross section. Fig. 105 illustrates the cross section taken at location B shown in Fig. 98 which again shows the plane of fracture and the oxidized fracture surface at the top portion.

Microhardness testing was conducted along the top outside edge of the eye bar on micro specimen No. 1 and these results are shown in table 1. Table No. 2 shows the hardness survey coming in from the fracture origin location and into the core. The surface at the corner was slightly harder than the core microstructure. The hardness at the corner was 20 to 23 RC and the core hardness was 94 RB. Microhardness was also conducted along the top edge on micro specimen No. 2. This is shown in Table 3. The microhardness survey conducted from the top edge of micro specimen No. 3 is shown in table 4. Table 5 illustrates the hardness conducted below the oxidized heavy scale deposit on the microsection shown in Fig. 98. One can see from the microhardness data that the hardness near the outer edges of the specimens are 20-23 RC and that proceeding from the surface the hardness decreases down to a core hardness of 94 RB. There was no indication of any hard brittle martensitic zones either at the surface or in the center sections of the cross sections.

The results of the chemical analyses of the eye bar conducted by Stork Laboratories were as follows:

Carbon		0.33
Manganese		0.65
Phosphorus		0.013
Sulfur		0.029
Silicon		0.15
Chromium		0.04
Nickel		0.03
Molybdenum	<	0.01
Copper		0.30
Iron		BAL

Results of the tensile test conducted at the tensile location shown in Fig. 20 showed the following results: near the top the ultimate tensile strength was 97,500psi, yield strength 64,000psi, elongation 23%, reduction of area 61%. At the center or core location the tensile strength was 85,000psi, the yield strength was 51,000psi, elongation 29%, percent reduction of area 63%. On the bottom side the ultimate tensile strength was 98,00psi, yield strength 64,500psi, elongation 26% and reduction of area 61%.

The results of the chemical analyses and the tensile strength properties are in conformance with the specifications for the eye bar as manufactured. (The specification requirements are shown in the addendum).

TABLE # 1

McKnight Laboratory Inc.

MICROHARDNESS MEASUREMENT

Job. No.: MEC091010 **Date:** 1/6/2010

Load: 500 gram **Recorder:** ______

Micro # 1 **EYEBAR**

Sample I.D.	Position (in)	Filar Units	Knoop Microhardness (KHN)	Hardness Converted From (KHN)
Top outside edge	0.002	353	229	95.5HRB
	0.004	361	219	94.0HRB
	0.006	334	255	21.0HRC
	0.008	339	248	99.0HRB
	0.010	348	235	97.0HRB
	0.012	344	241	98.0HRB
	0.015	346	238	97.5HRB
	0.020	336	252	20.0HRC
	0.025	336	252	20.0HRC
	0.030	340	246	99.0HRB
	0.040	336	252	20.0HRB
	0.050	347	237	97.0HRB
	0.070	357	224	95.0HRB
	0.100	346	238	97.5HRB
	0.150	347	237	97.0HRB
	0.200	381	196	89.0HRB
	0.300	353	229	95.5HRB
	Core	361	219	94.0HRB

McKnight Laboratory Inc.

MICROHARDNESS MEASUREMENT

Job. No.: MEC091010 **Date:** 1/6/2009

Load: 500 gram **Recorder:** ____________

Micro # 1

Sample I.D.	Position (in)	Filar Units	Knoop Microhardness (KHN)	Hardness Converted From (KHN)
Fracture Origin	0.002	340	246	20.0HRC
	0.004	331	260	22.0HRC
	0.006	331	260	22.0HRC
	0.008	328	265	23.0HRC
	0.010	331	260	22.0HRC
	0.012	328	265	23.0HRC
	0.015	323	273	24.0HRC
	0.020	320	278	25.0HRC
	0.025	313	291	27.0HRC
	0.030	324	271	24.0HRC
	0.040	326	268	23.5HRC
	0.050	329	263	22.5HRC
	0.070	335	254	20.5HRC
	0.100	338	249	20.0HRC
	0.150	334	255	21.0HRC
	0.200	338	249	20.0HRC
	0.300	341	245	99.0HRB
	Core	360	220	94.0HRB

McKnight Laboratory Inc.

MICROHARDNESS MEASUREMENT

Job. No.: MEC091010 **Date:** 1/6/2010

Load: 500 gram **Recorder:**

Micro # 2

Sample I.D.	Position (in)	Filar Units	Knoop Microhardness (KHN)	Hardness Converted From (KHN)
Top Edge	0.002	341	245	99.0HRB
	0.004	358	222	94.0HRB
	0.006	337	251	20.0HRC
	0.008	340	246	99.0HRB
	0.010	336	252	20.0HRC
	0.012	336	252	20.0HRC
	0.015	336	252	20.0HRC
	0.020	331	260	22.0HRC
	0.030	335	254	21.0HRC
	0.040	339	248	99.0HRB
	0.050	335	254	21.0HRC
	Core	372	206	91.0HRB

McKnight Laboratory Inc.

MICROHARDNESS MEASUREMENT

Job. No.: MEC091010 **Date:** 1/6/2010

Load: 500 gram **Recorder:**

Micro # 3

Sample I.D.	Position (in)	Filar Units	Knoop Microhardness (KHN)	Hardness Converted From (KHN)
Top Edge	0.002	418	163	80.0HRB
	0.004	333	257	21.0HRC
	0.006	331	260	22.0HRC
	0.008	321	276	24.5HRC
	0.010	321	276	24.5HRC
	0.012	321	276	24.5HRC
	0.015	329	263	22.0HRC
	0.020	348	235	97.0HRB
	Core	376	202	90.0HRB

McKnight Laboratory Inc.

MICROHARDNESS MEASUREMENT

Job. No.: MEC091010 **Date:** 1/6/2010

Load: 500 gram **Recorder:**

Micro # 3

Sample I.D.	Position (in)	Filar Units	Knoop Microhardness (KHN)	Hardness Converted From (KHN)
Near Fracture	Light Color Area	379	198	89.5HRB
Surface		395	183	86.0HRB
		382	195	89.0HRB
		382	195	89.0HRB
	Dark Color Area	389	188	87.0HRB
		386	191	88.0HRB
		389	188	87.0HRB
		369	209	91.0HRB
	Core	368	210	92.0HRB

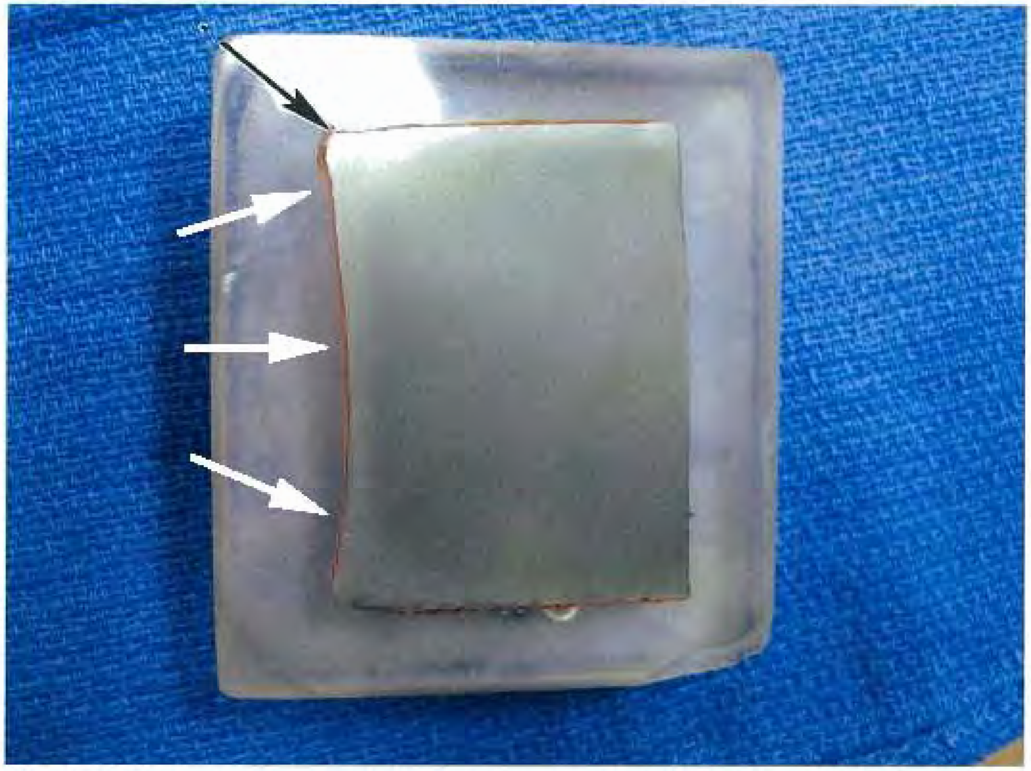


Fig. 71 Microsection made below fracture surface at location 1, in fig 20.

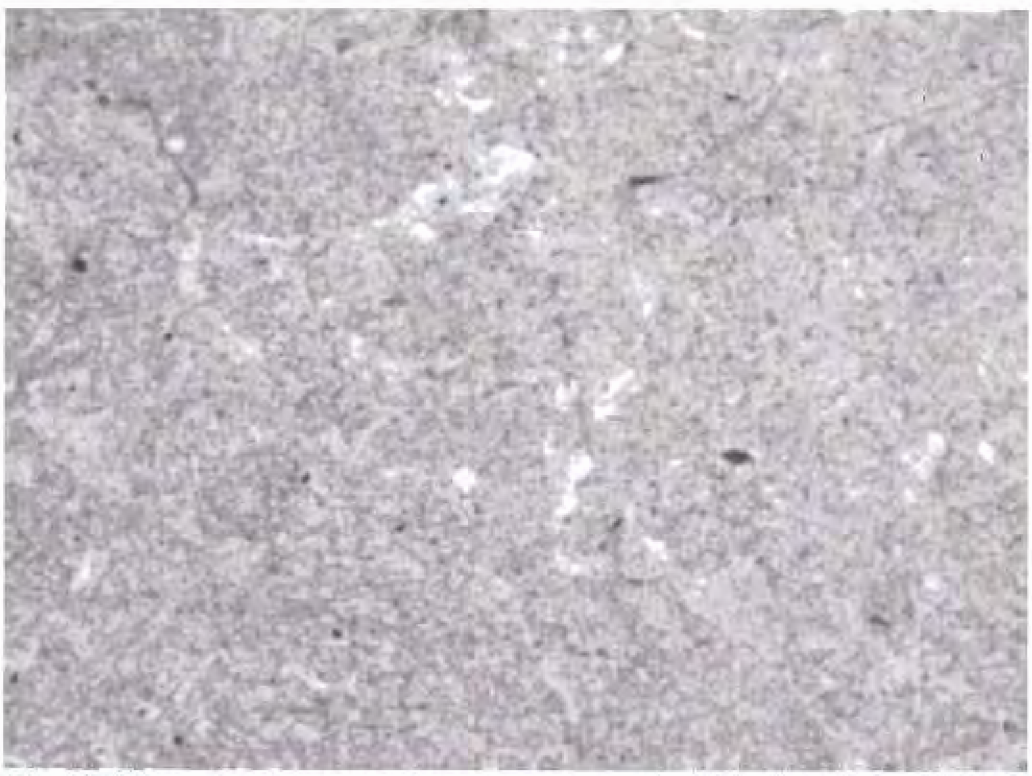


Fig. 72 Microstructure near top corner sample #1 in fig. 71. 200X Etched.

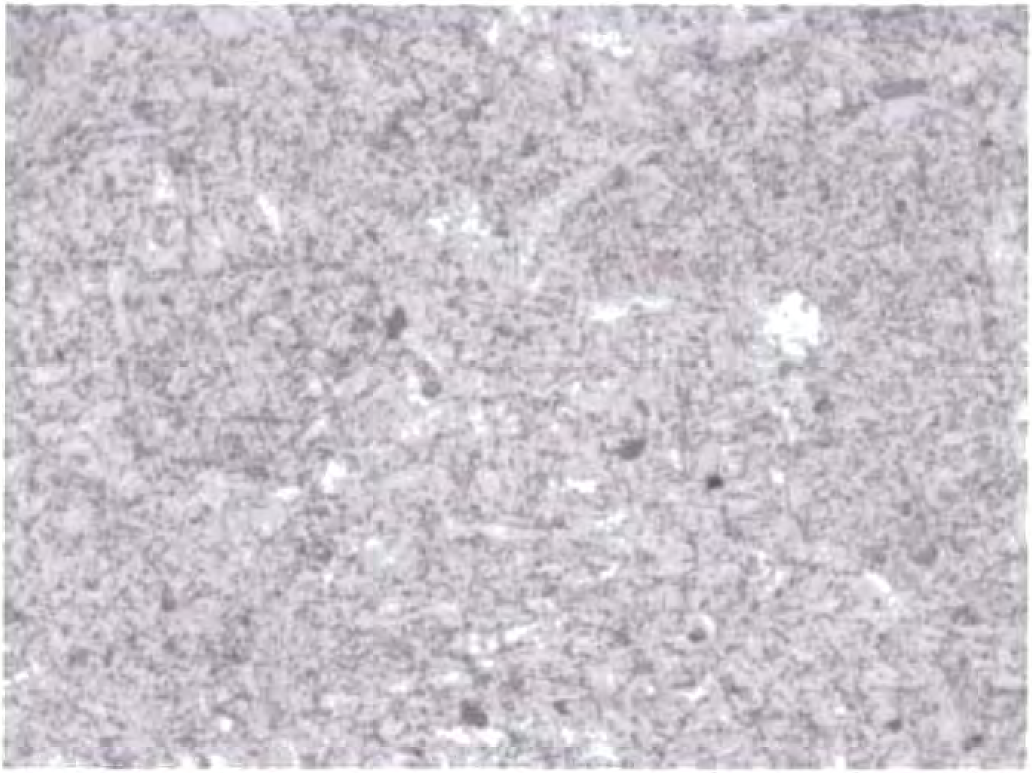


Fig. 73 Microstructure near top corner sample #1 in fig. 71. 500X Etched.

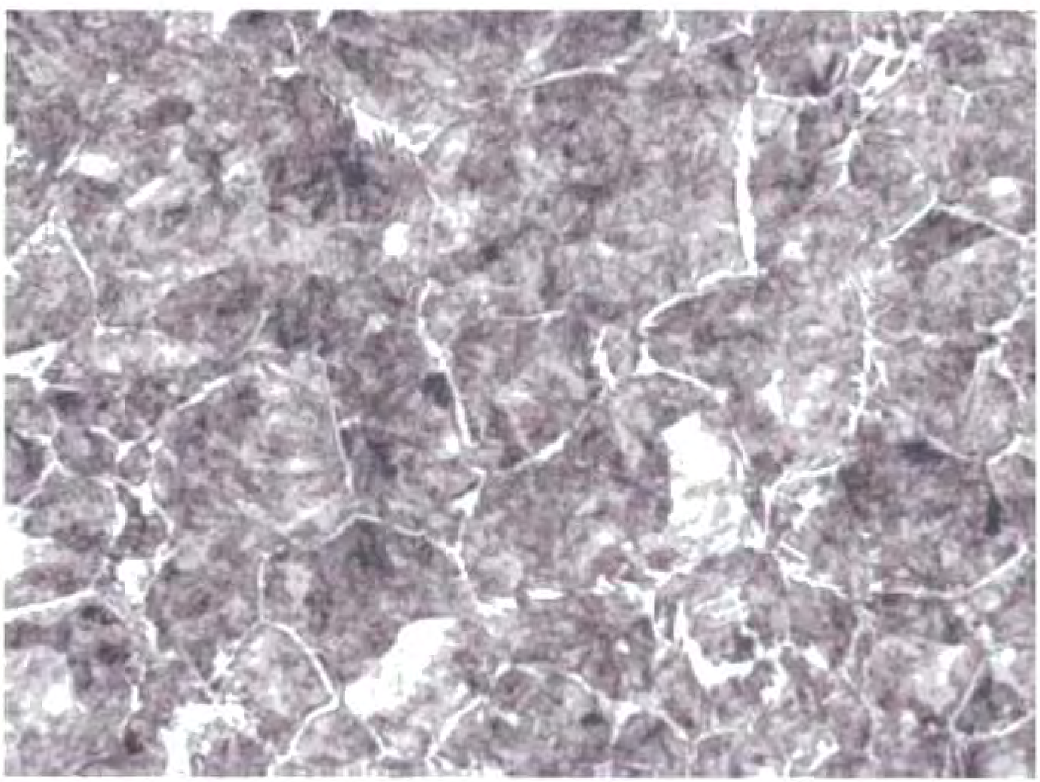


Fig. 74 Core microstructure of sample #1 in fig. 71. 200X Etched.

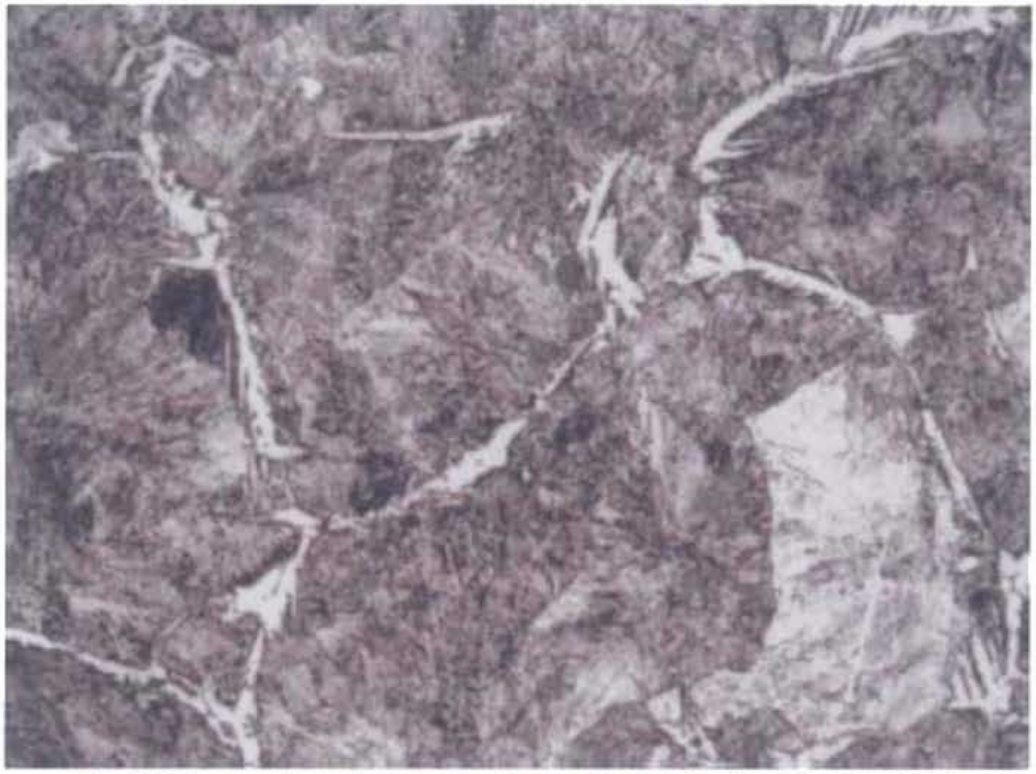


Fig. 75 Core microstructure of sample # 1 in fig. 71. 500X Etched.

Fig. 76 Microsection made below fracture surface at location 2 in fig. 20.

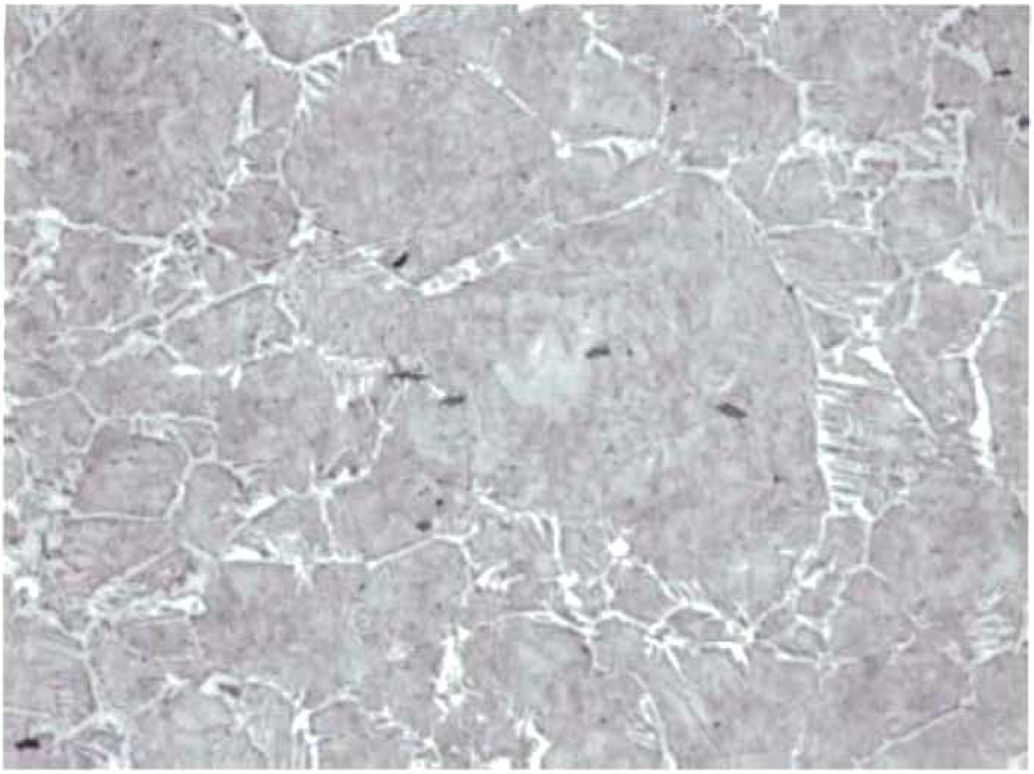


Fig. 77 Core microstructure of sample # 2 in fig. 76. 200X Etched.

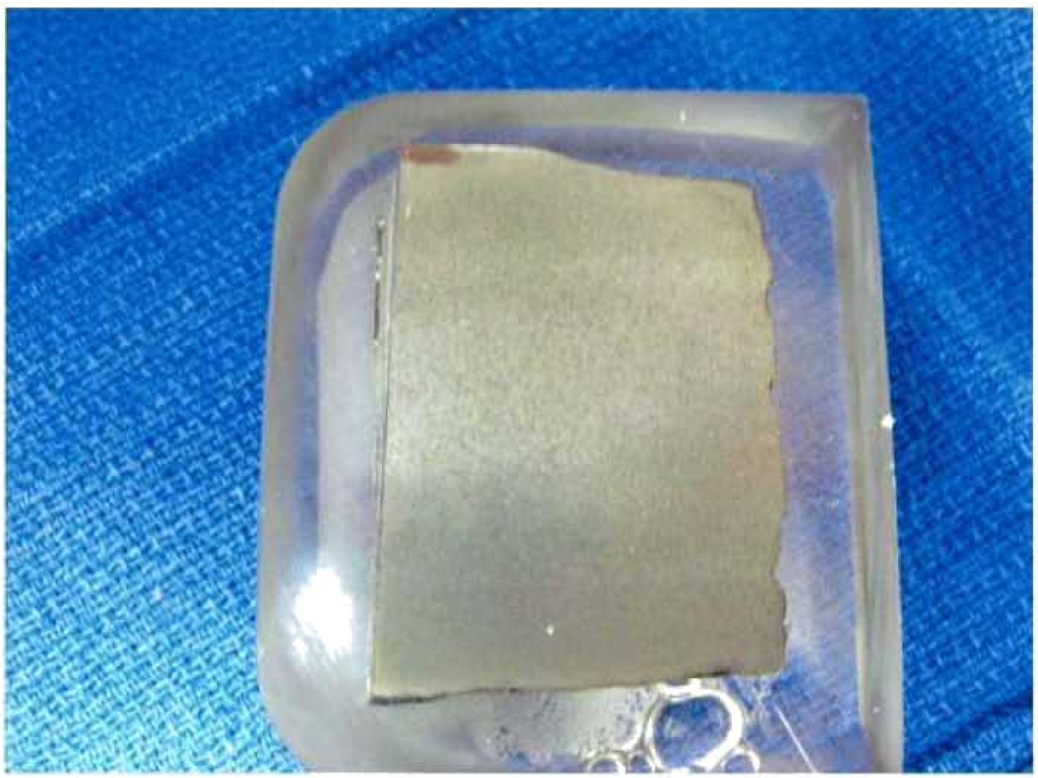


Fig. 78 Microsection made below fracture surface at location 3 in fig. 20.

Fig. 79 Top surface of sample # 3 in fig. 78. 50X Etched.

Fig. 80 Top surface of sample # 3 in fig. 78. 50X. Etched.

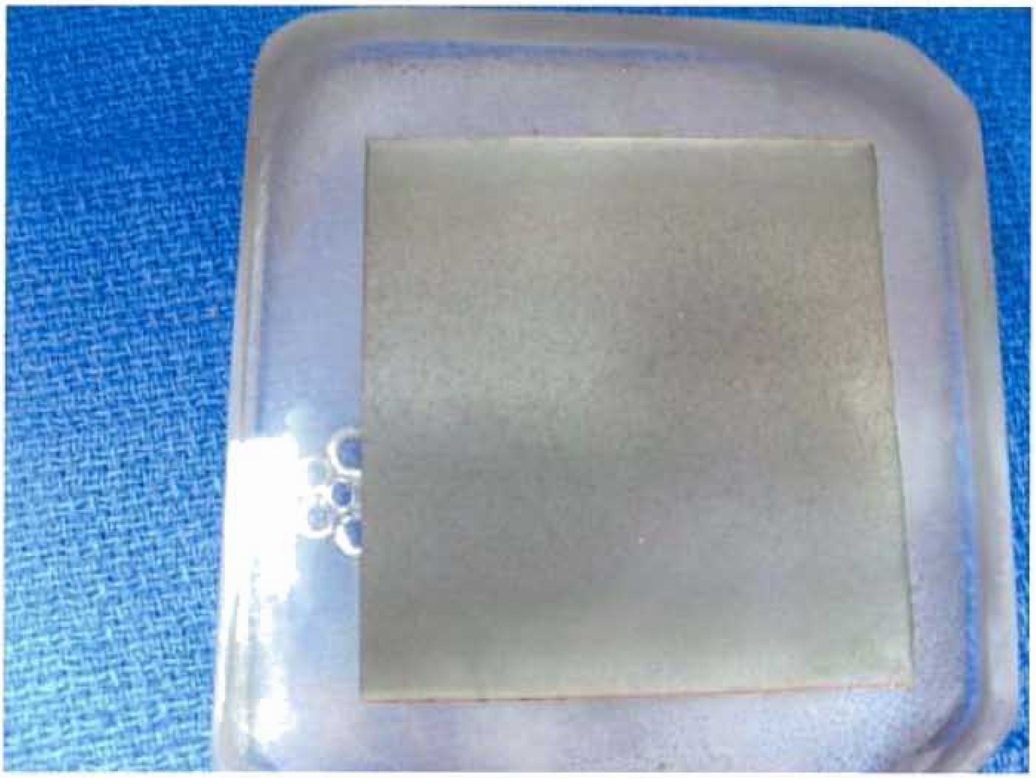


Fig. 81 Microsection made perpindicular to fracture surface at location 4 in fig. 20.

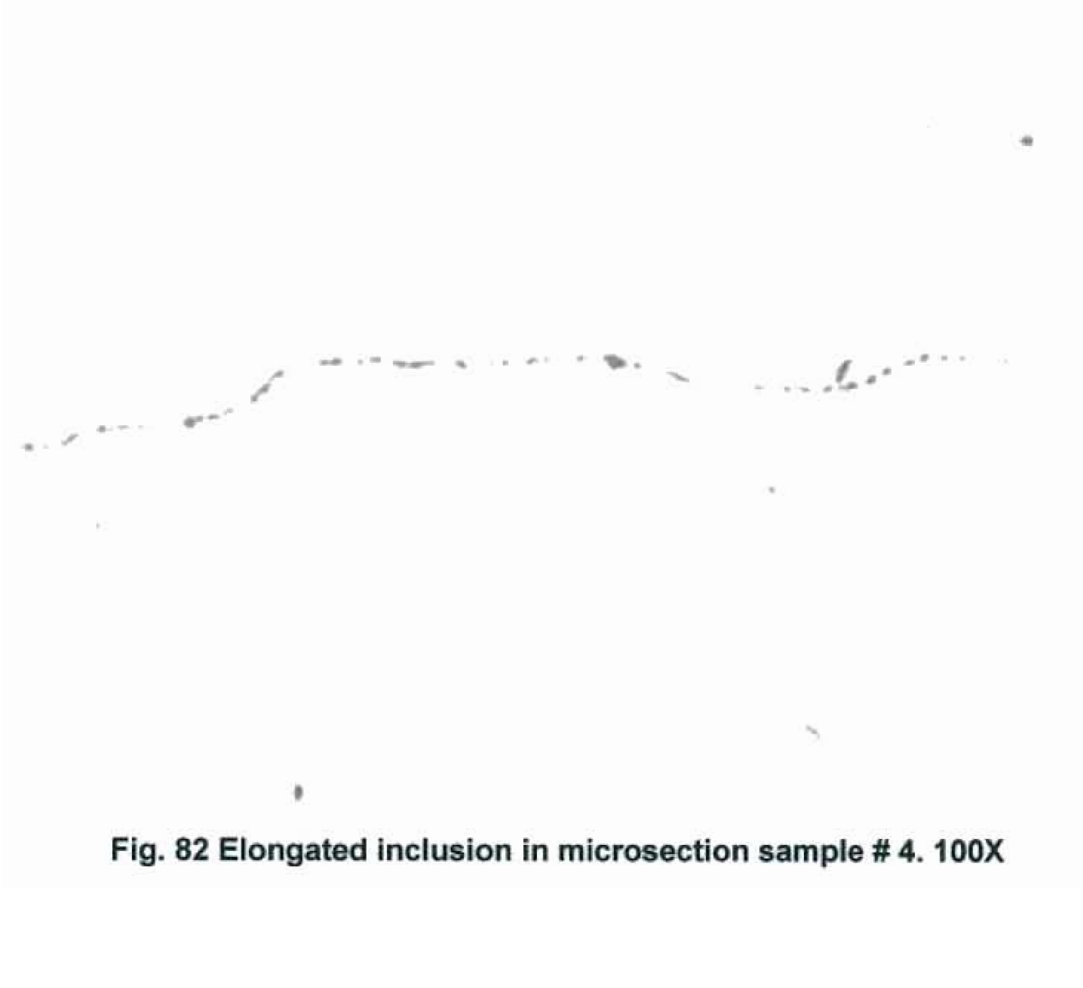


Fig. 82 Elongated inclusion in microsection sample # 4. 100X

Fig. 83 Microstructure near top surface of sample # 4, 200X. Etched.

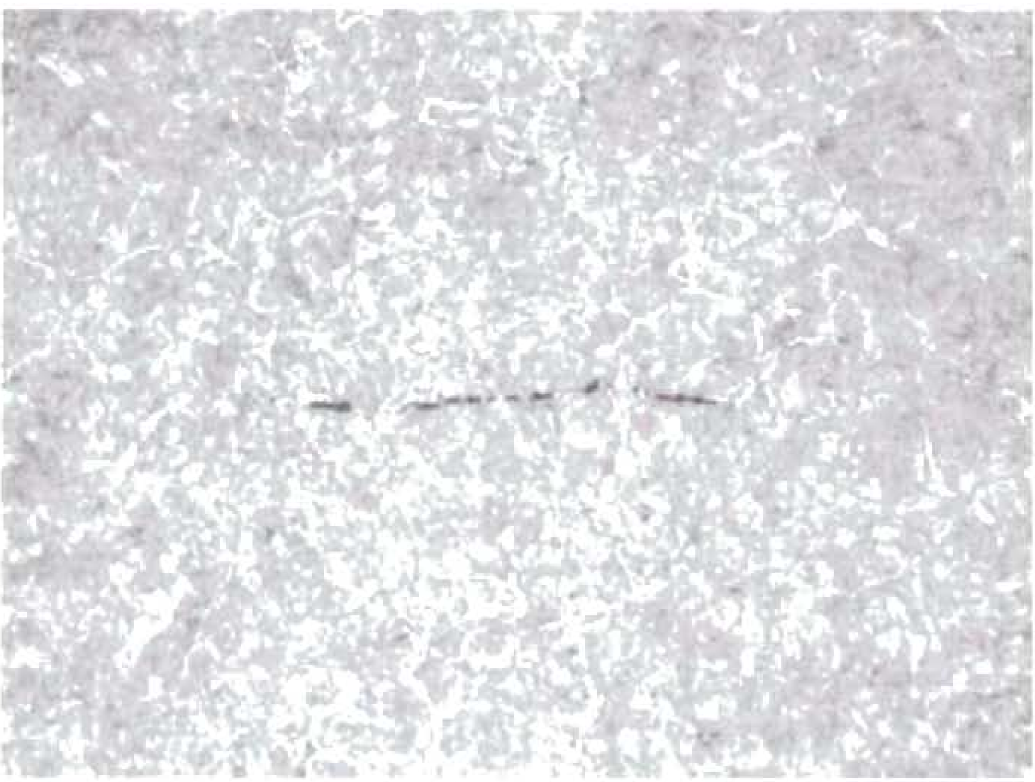


Fig. 84 Microstructure of sample # 4 showing elongated inclusion. 100X. Etched.

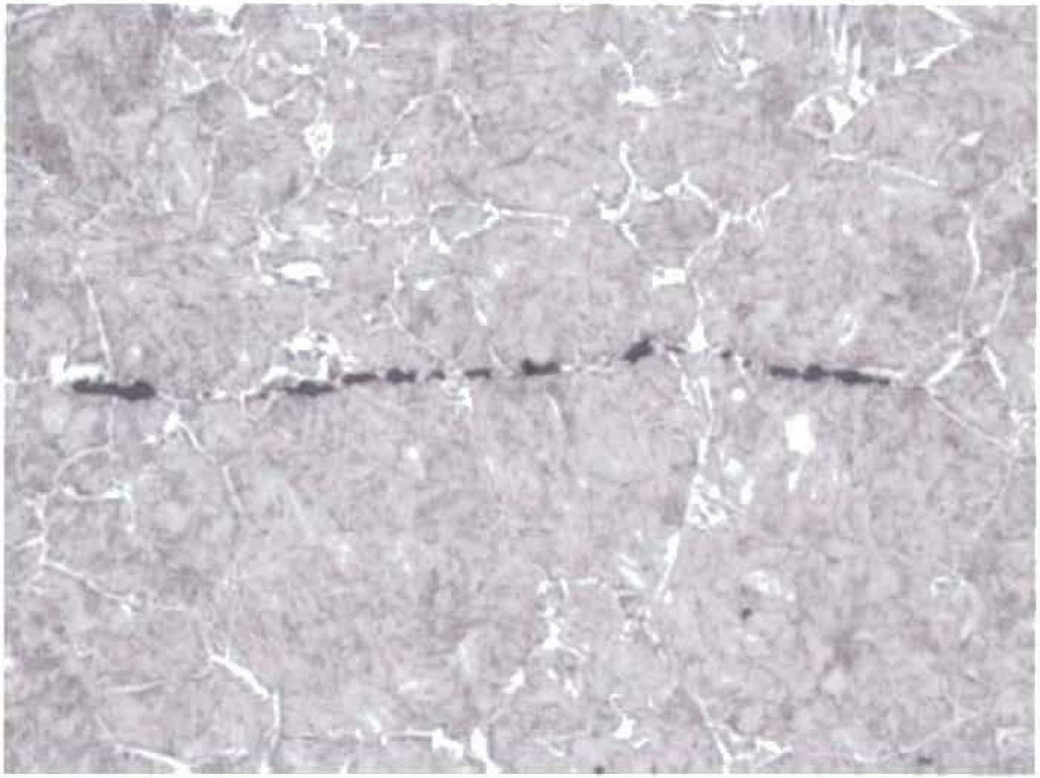


Fig. 85 Microstructure of sample # 4 showing elongated inclusion. 200X. Etched.

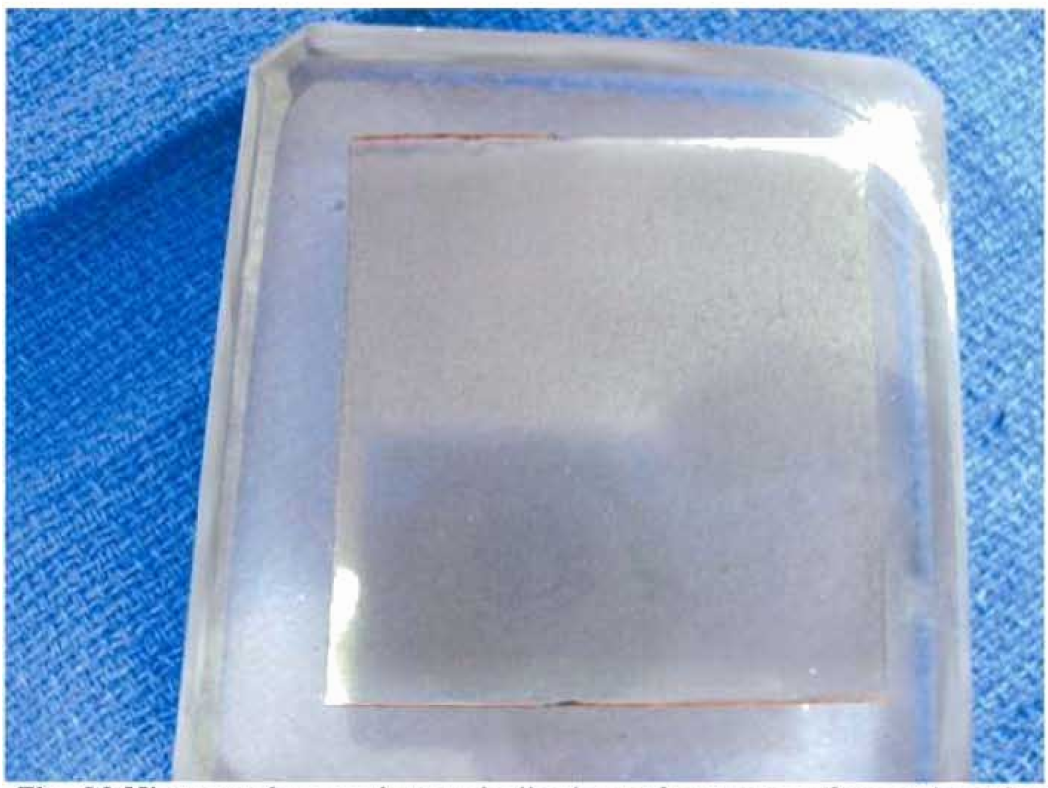


Fig. 86 Microsection made perpindicular to fracture surface at location 5 in fig. 20.

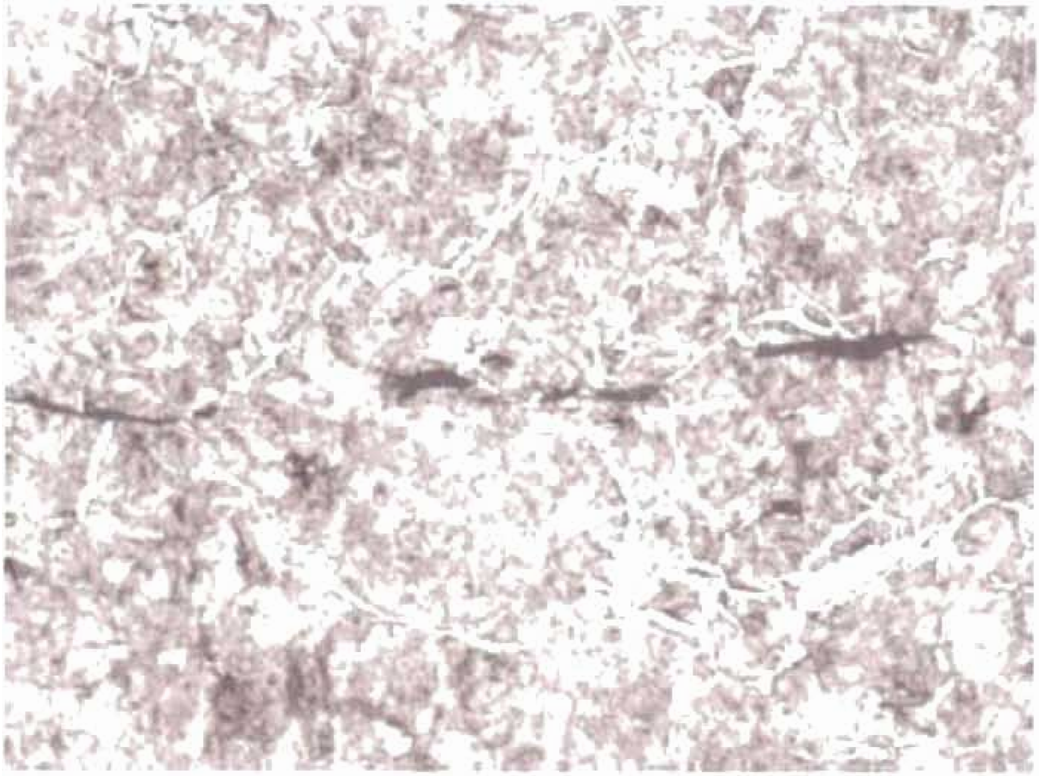


Fig. 87 Microstructure of sample # 5 200X. Etched.

Fig. 88 Transverse cross-section made of eye bar near the center pin location.

Fig. 89 Transverse cross-section made of eye bar near the center pin location.

Fig. 90 Scale on fracture surface of eye bar near the center pin location.

Fig. 91 Transverse cross-section made of eye bar near the center pin location.

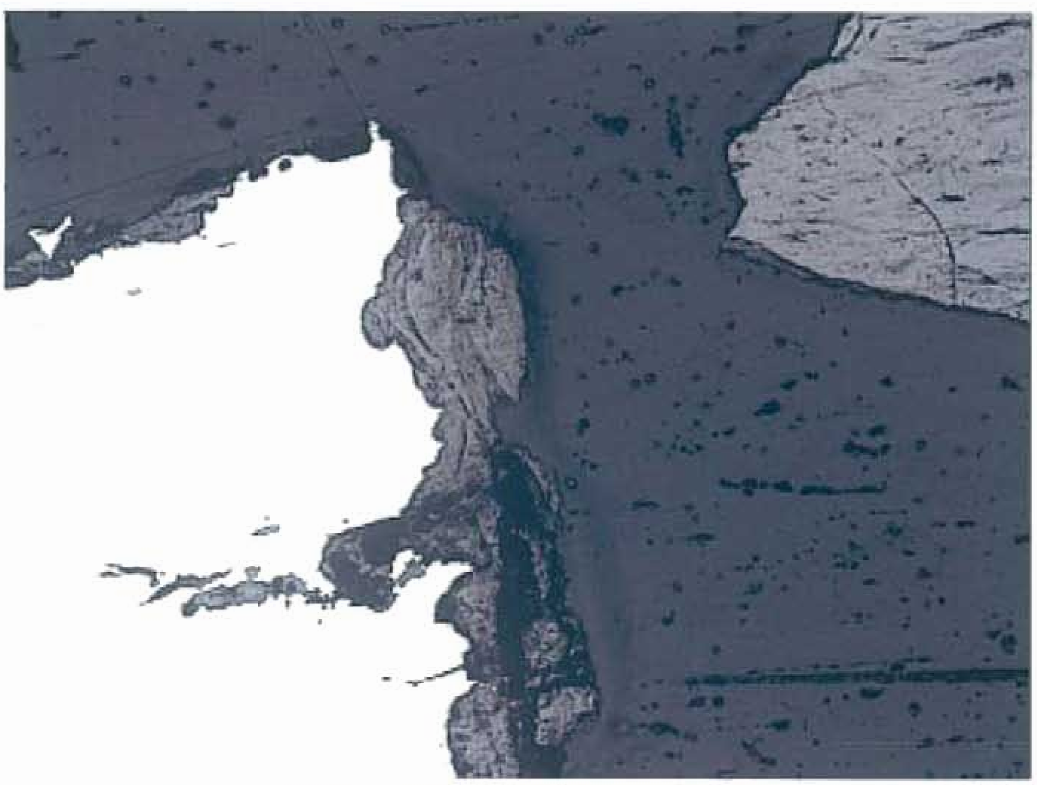


Fig. 92 Transverse cross-section made of eye bar near the center pin location, showing fracture face and scale. 100X.

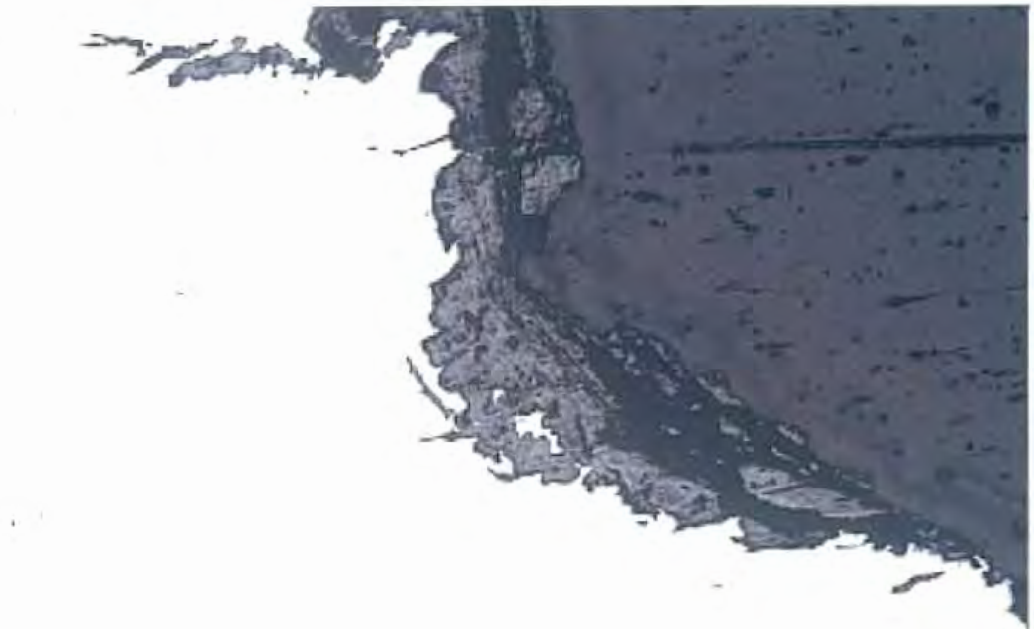


Fig. 93 Transverse cross-section made of eye bar near the center pin location, showing fracture face and scale. 100X.

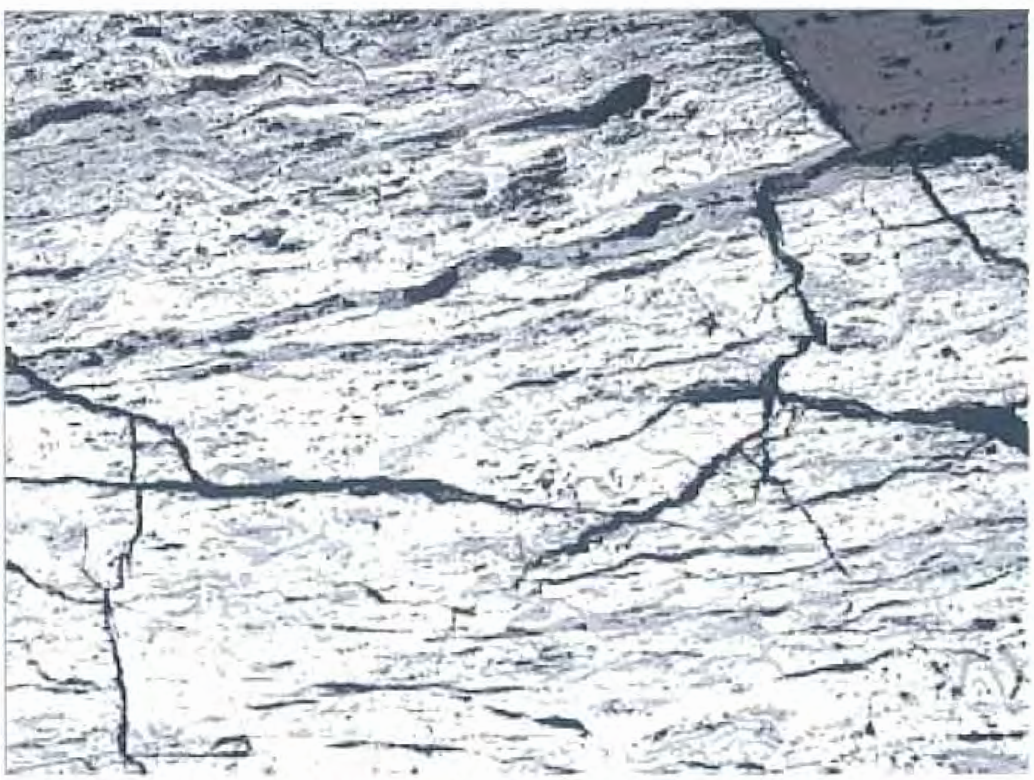


Fig. 94 Transverse cross-section made of eye bar near the center pin location, showing scale. 100X.

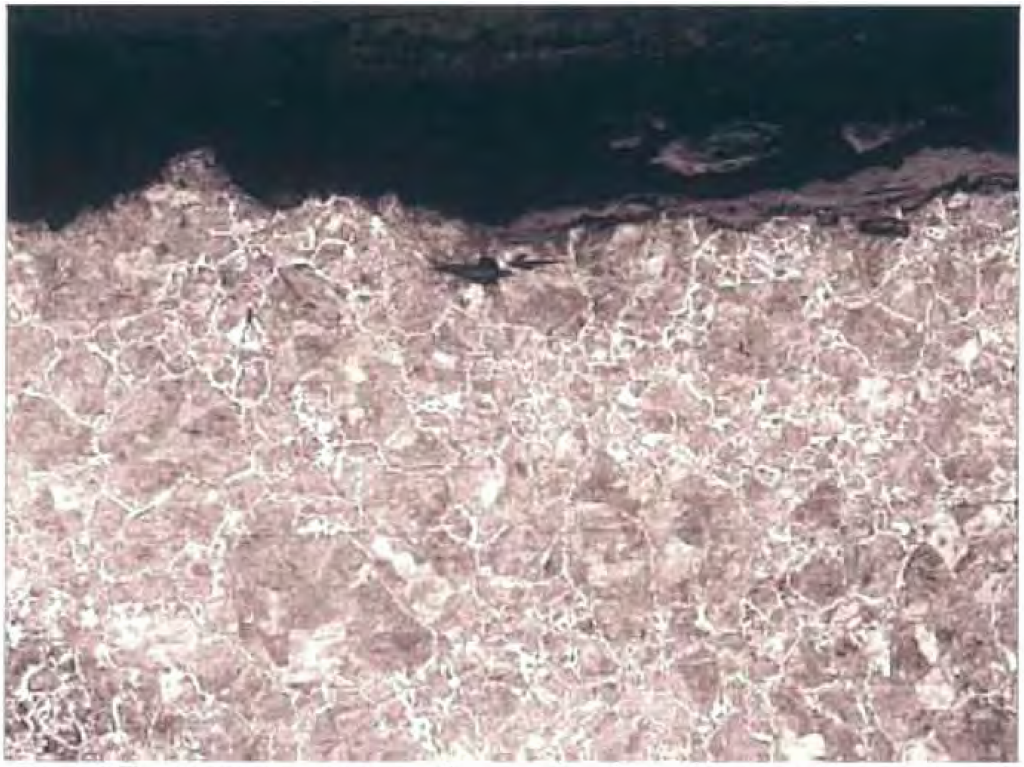


Fig. 95 Transverse cross-section made of eye bar near the center pin location, showing microstructure below fracture face. 100X. Etched.

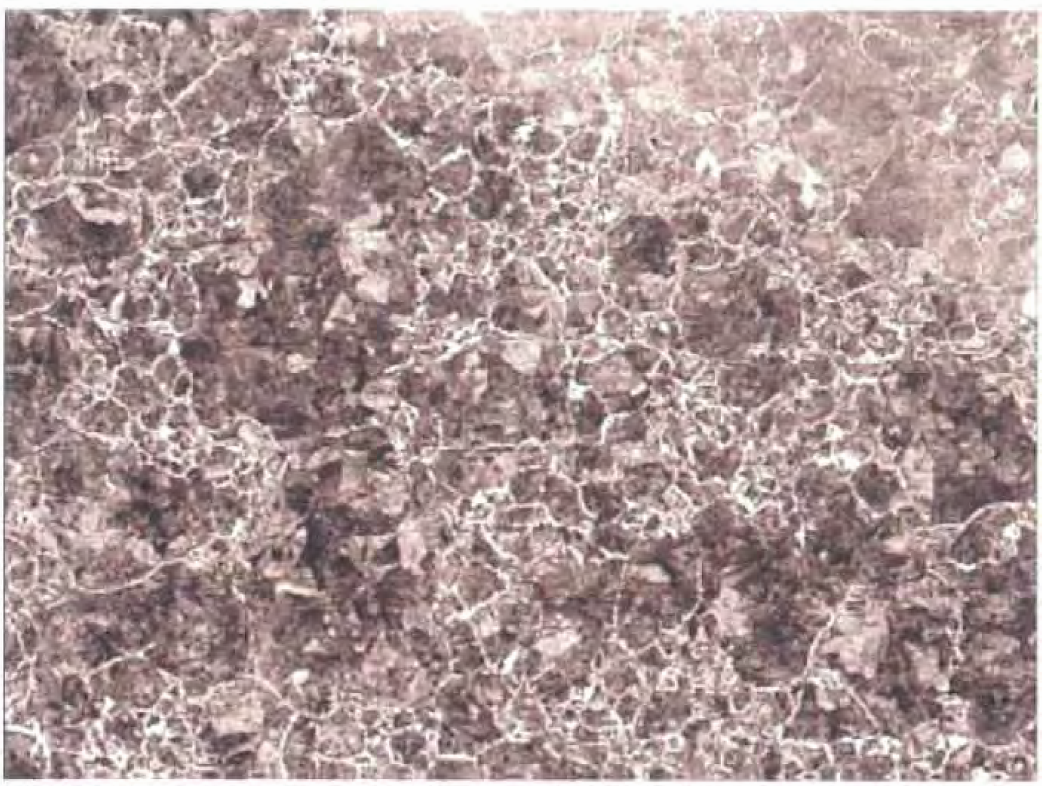


Fig. 96 Transverse cross-section made of eye bar near the center pin location, showing microstructure below fracture face. 100X. Etched.

Fig. 97 Location where longitudinal microsections were made of eye bar near the center pin location.

Fig. 98 Location where longitudinal microsections were made of eye bar near the center pin location.

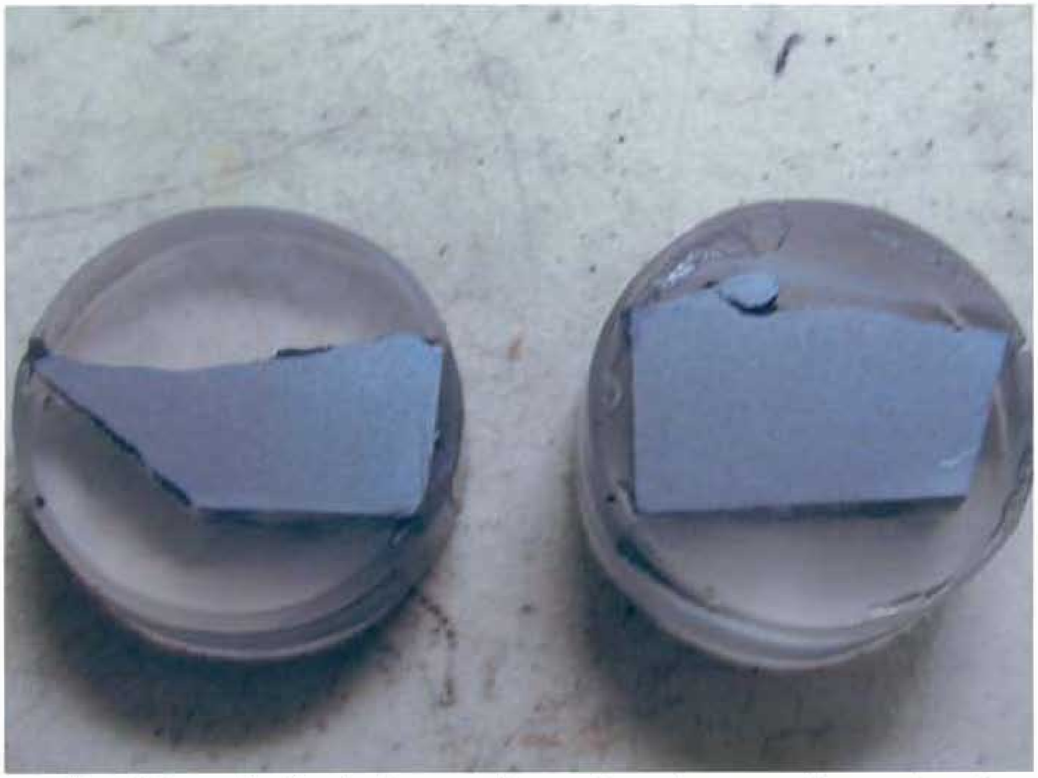


Fig. 99 Longitudinal microsections of eye bar near the center pin location, in fig. 98.

Fig. 100 Longitudinal microsection of eye bar near the center pin location, in fig. 98, location A.

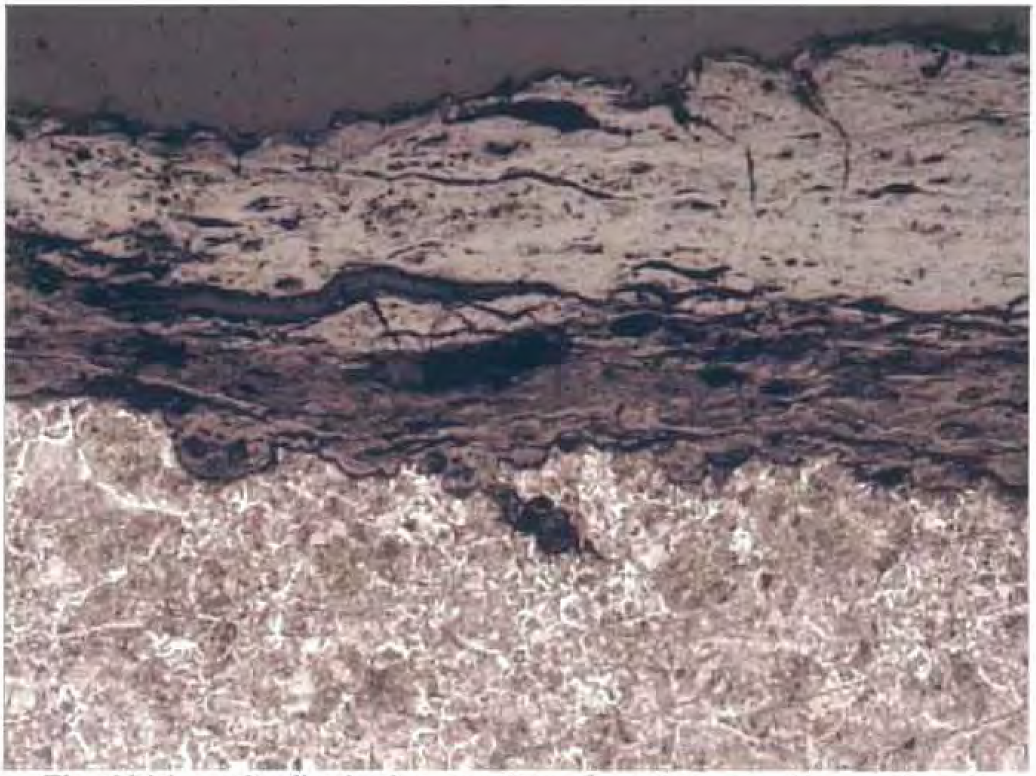


Fig. 101 Longitudinal microsection of eye bar near the center pin location, in fig. 98, location A, showing fracture surface. 50X. Etched.

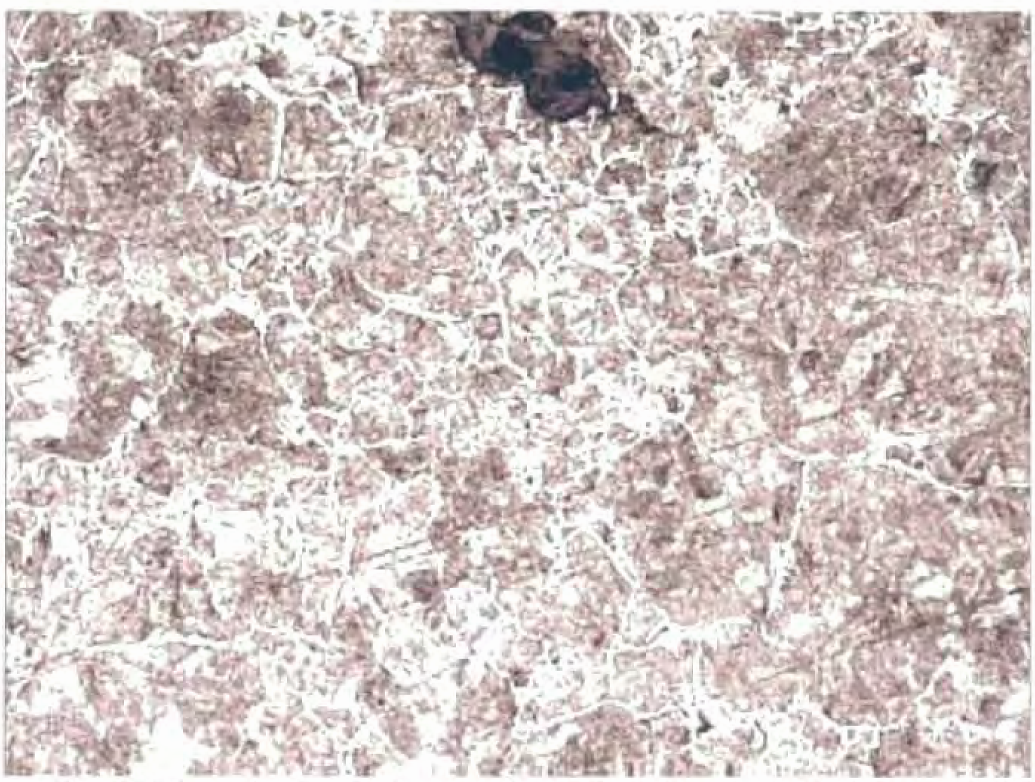


Fig. 102 Longitudinal microsection of eye bar near the center pin location, in fig. 98, location A, below fracture surface. 200X. Etched.

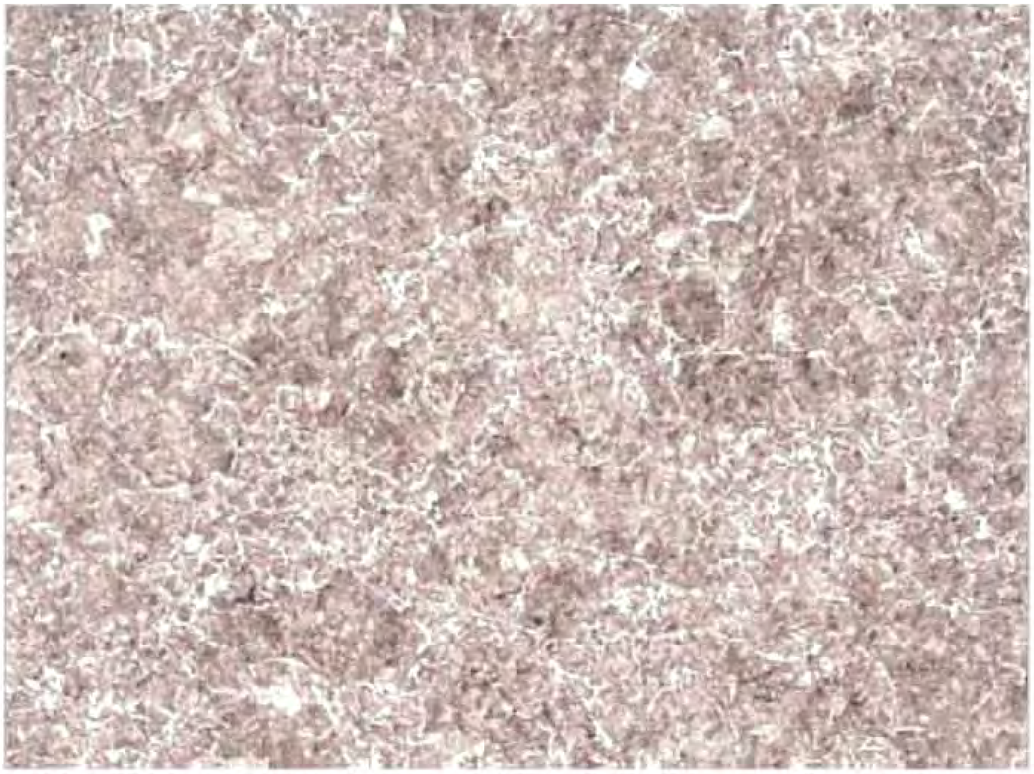


Fig. 103 Longitudinal microsection of eye bar near the center pin location, in fig. 98, location A, showing core microstructure. 50X.Etched.

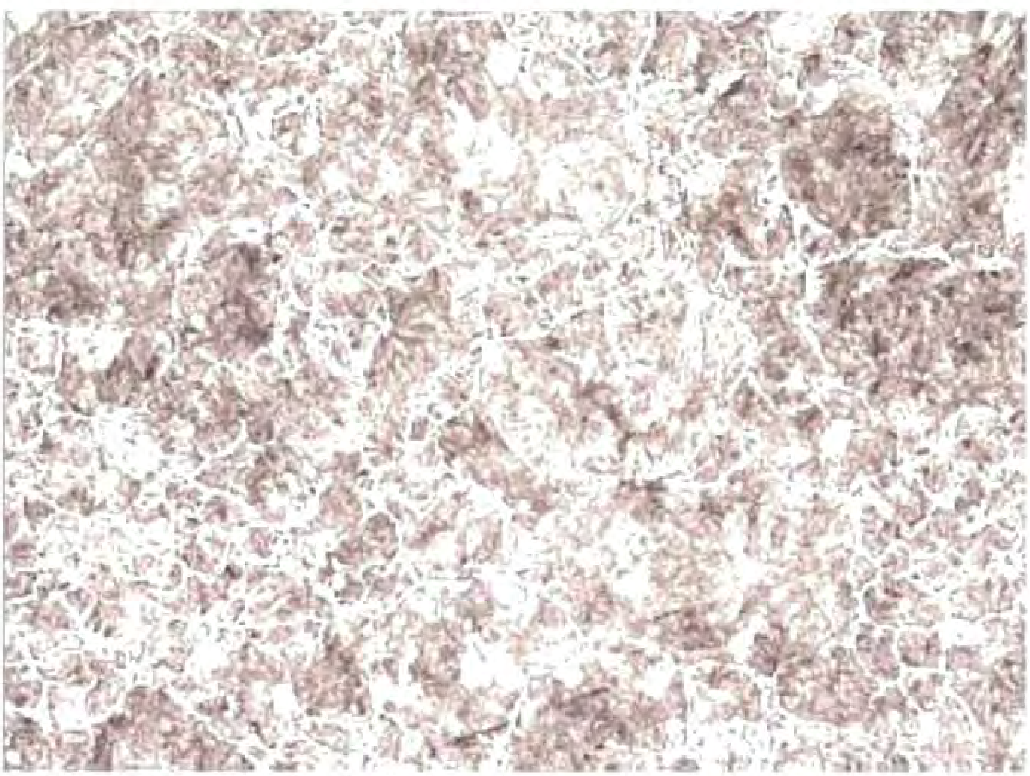


Fig. 104 Longitudinal microsection of eye bar near the center pin location, in fig. 98, location A, showing core microstructure. 200X.Etched.

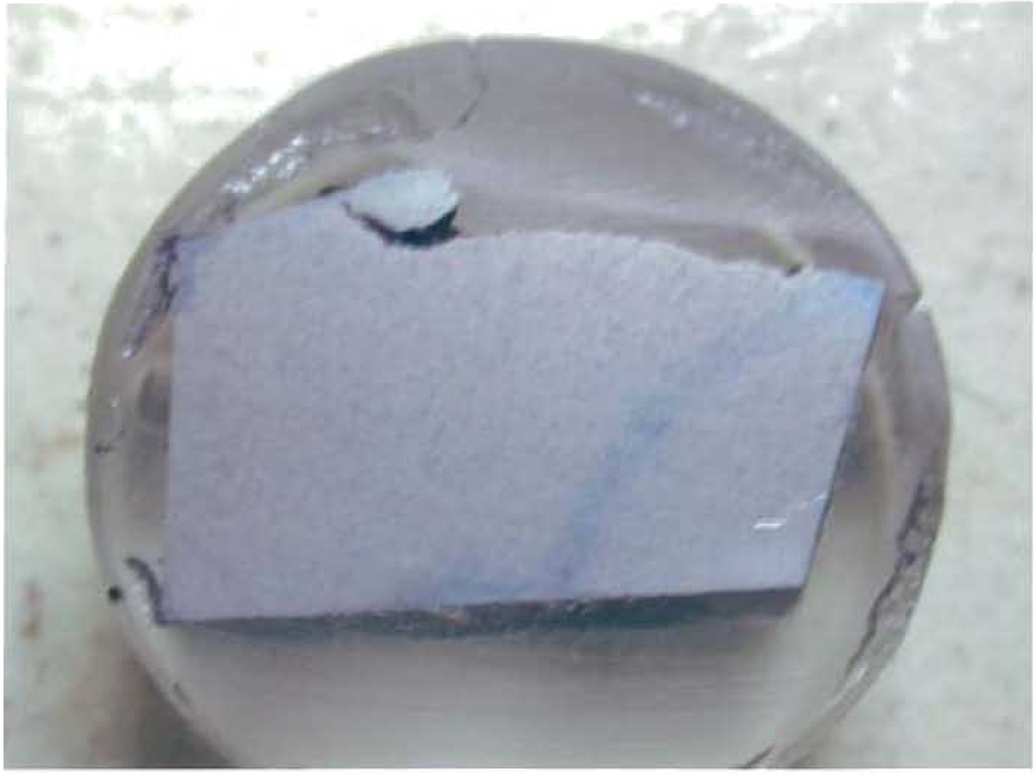


Fig. 105 Longitudinal microsection of eye bar near the center pin location, in fig. 98, location B.

Fig. 106 Test plan for mechanical properties from eye bar segments 1 and 2

ADDENDUM

STORK®
Materials Technology

Stork Materials Testing & Inspection

Material Testing and Non-Destructive Testing

Contact: Larry Mcknight
Mcknight Laboratory, Inc.
14555 Valley View Suite 1
SANTA FE SPRINGS, CA 90670

15062 Bolsa Chica
Huntington Beach, CA 92649

Telephone :(714) 892-1961
Telefax :(714) 892-8159
Website :www.storksmti.com

Date: 11/16/2009 **P.O. No.:** Verbal/Larry **W/O No.:** MCK002-11-12-56150

TEST CERTIFICATE

Description:	Eyebar Segments
Sample No.:	#7
Job No.:	MEC091010
Specification:	N/S (For information only)

Chemical Analysis Results

Element		Result %
C	=	0.33
Mn	=	0.65
P	=	0.013
S	=	0.029
Si	=	0.15
Cr	=	0.04
Ni	=	0.03
Mo	<	0.01
Cu	=	0.30
Fe	=	Balance

Chemical Analysis Performed by Optical Emission per SOP 2.02, Revision 9
Carbon and Sulfur by Combustion per SOP 7.00, Revision 5

FOR INFORMATION ONLY

Nadcap

Respectfully submitted

Andrea Dreyfuss

STORK®
Materials Technology

Stork Materials Testing & Inspection

Date: 11/16/2009 **P.O. No.:** Verbal/Larry **W/O No.:** MCK002-11-12-56150

Description:	Eyebar Segments
Sample No.:	#6 (Top, Center, Bottom)
Job No.:	MEC091010
Specification:	N/S (For information only)

Tensile Test Results

Test Method:	ASTM E 8 08					
Sample No.	**Tensile Strength**	**Yield Strength At 0.2% Offset**	**Elongation in 1.4"**	**Reduction of Area**	**Diameter**	**Area**
	Min. (psi)	**Min. (psi)**	**Min. (%)**	**Min. (%)**	**(in)**	**(in)**
#6 - Top	97,500	64,000	23	61	0.351	0.0968
#6 - Center	85,000	51,000	29	63	0.352	0.0973
#6 - Bottom	98,000	64,500	26	61	0.350	0.0962
Requirement:	N/S	N/S	N/S	N/S		

FOR INFORMATION ONLY

Nadcap A2LA

Respectfully submitted

Andrew Dreafall

MATERIALS

One of the outstanding features of the steel industry today is the development of high strength steels. At the beginning of the century the only steels generally available for structural purposes were rolled carbon steel and cold-drawn wire. In recent years both these materials have been improved, and by the use of alloys and heat-treatment new structural steels of greater strength have been produced. The designer thus has a variety of materials to work with, and can choose for each part of a structure the steel that is most suitable. In the San Francisco-Oakland Bay Bridge, for example, there are three grades of rolled structural steel, two grades of rivets, two grades of eyebars, and steel castings of many shapes and sizes. In the suspension spans, the cables and suspender ropes are made of cold drawn wire, which is described in the chapter on cables.

All of these steels are produced by Subsidiaries of United States Steel Corporation.

Rolled Structural Steel

The strongest of the rolled structural steels used in the San Francisco-Oakland Bay Bridge is nickel steel. It has a tensile strength not less than 90,000 lb. per sq. in., and a yield point not less than 55,000 lb. per sq. in. It owes its high strength to the presence of about three per cent of nickel. Nickel steel is used for the chords of the suspended span of the cantilever bridge, where the saving in weight causes a substantial decrease in the stresses throughout the structure. It is also used for large compression members in the cantilever bridge, where the members would otherwise be too large for good fabrication, and in the A-frames at the top of pier W4, where lack of room made it imperative to limit the size of the members.

Most of the structural members of the bridge are made of silicon steel, which has a tensile strength of 80,000 to 95,000 lb. per sq. in., and a yield point not less than 45,000 lb. per sq. in. Its high strength is due to the presence of more silicon, manganese, and carbon than are found in ordinary carbon steel. Less expensive than nickel steel, silicon steel is a high-strength material which is now used instead of carbon steel for the principal members in most long-span bridges, because of the resulting reduction of dead load. Because of the great distance of San Francisco from the centers of steel production, the lower weight of silicon steel members, as compared to carbon steel members of the same strength, resulted in a large saving in freight charges, which helped to offset the slightly greater cost of the material.

For small members, and for parts such as bracing and railway stringers, which were designed as much for stiffness as for strength, carbon steel is used. Carbon steel is also used for tie plates, lattice bars, and diaphragms, in members the main material of which is silicon or nickel steel. The carbon steel used for this bridge is of a slightly stronger and more expensive grade than the carbon steel ordinarily specified; its tensile strength is 62,000 to 70,000 lb. per sq. in., and its yield point is not less than 37,000 lb. per sq. in.

In general, carbon steel rivets were used both in shop and field. For some of the larger joints in the cantilever bridge, and at the A-frame in pier W4, manganese steel rivets were used. Their strength is about one-third more than that of carbon steel rivets.

Carnegie-Illinois Steel Corporation, a Subsidiary of United States Steel Corporation, furnished over one hundred thousand tons of rolled steel for use in the bridge.

Eyebars

Steel eyebars are used in the bridge for connecting the cables to their anchorages, and for truss members that are subject only to tension. Eyebars are flat bars of rectangular cross-section with a round forged head at each end. The heads are bored to receive steel pins, by which the eyebars are joined in chains or connected to other members. Eyebars are made with cross-sections up to 16 x 2 in. Several of them are usually grouped together to form a structural member.

The eyebars in the San Francisco-Oakland Bay Bridge are of two grades. For the San Francisco and Yerba Buena anchorages, and for anchoring the A-frames to pier W4, annealed eyebars are used. They have a yield point of 36,000 lb. per sq. in. and a tensile strength of 67,000 lb. per sq. in.

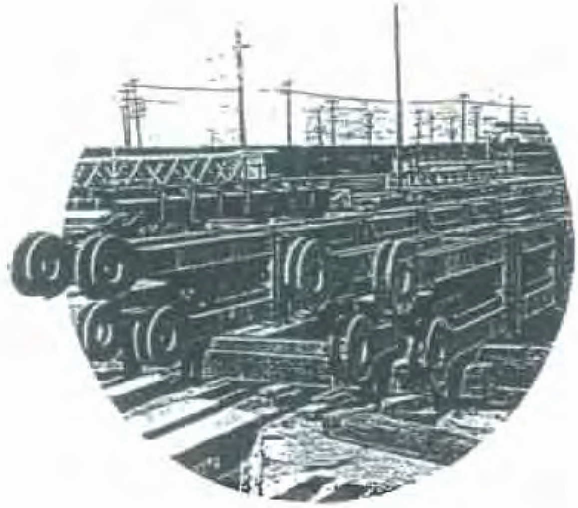
High tensile strength eyebars, with a yield point of 50,000 lb. per sq. in. and a tensile strength of 80,000 lb. per sq. in. are used as tension members throughout the cantilever bridge, and as bottom chords in the five 504-foot spans of the East Bay Crossing. In the suspension bridge they are used to connect the cables to the A-frame at the central anchorage (pier W4). High tensile strength bars are forged from carbon steel of a grade similar to that used for annealed bars. Their greater strength is obtained by a heat-treatment consisting of heating, quenching, tempering, and cooling in the air.

To make sure that the eyebars had the required strength, sample bars were selected by the inspector from the bars made for the bridge and were tested to destruction at the shops. The strength of all the bars in the bridge was determined by Brinnell hardness tests, which were compared with similar tests made on the bars that were tested to destruction.

The bridge contains 928 annealed eyebars, weighing 2200 tons, and 1844 high tensile strength eyebars, weighing 4500 tons, all of which were manufactured at the Ambridge plant of American Bridge Company, from steel rolled by Carnegie-Illinois Steel Corporation. Eyebars such as are used in this bridge are manufactured only by American Bridge Company.

Steel Castings

The bridge contains 1850 tons of steel castings, varying in size from collars weighing a few pounds, used to space the suspender ropes at the stiffening trusses, to the 46-ton saddle castings on the towers of the suspension bridge. In the suspension bridge cast steel was used for the cable saddles, strand shoes, cable bands, and splay castings, and for the shoes and bearings of the rocker posts at the ends of the stiffening trusses. On the East Bay Crossing cast steel was used only for the shoes of the 288-foot spans near the Oakland shore, which are supported directly on concrete piers. Cast steel was required to have a yield point not less than 35,000 lb. per sq. in., and a tensile strength not less than 65,000 lb. per sq. in.



B. Material

STRUCTURAL STEEL

(1) Process. - All structural steel shall be made by the open hearth process.

(2) Grades. - Four grades of structural steel will be used in the various parts of the superstructure and are designated on the Contract Drawings as Nickel Steel, Silicon Steel, Medium Carbon Steel and Mild Carbon Steel. Where the material is not otherwise specifically designated, Medium Carbon Steel shall be used.

Two grades of rivet steel will be used and are designated on the Contract Drawings as Manganese Rivets and Carbon Rivets. Where not otherwise specifically designated, Carbon Steel Rivets shall be used.

(3) Chemical Analysis. - An analysis to determine the quantity of the different elements in the steel shall be made by the manufacturer from a test ingot taken during the pouring of each melt. The drillings for this purpose shall be taken at least one-half (1/2) inch below the surface of the test ingot. A copy of this analysis, certified to by the manufacturer's chief chemist, shall be furnished to the Inspector immediately on the completion of such analysis. The various grades of steel shall not contain more than the following percentages of elements:

	Nickel Steel	Silicon Steel	Carbon Steel			Manganese Rivet Steel
			Medium	Rivet	Mild	
Carbon	0.40	0.40	. . . .	. . . .	. . . .	0.40
Manganese		1.00	. . . .	. . . .	. . . .	1.40
Silicon		0.45*	. . . .	. . . .	. . . .	0.25
Nickel	**					
Phosphorus						
Acid Process	0.06	0.06	0.06	0.04	0.06	0.04
Basic Process	0.04	0.04	0.04	0.04	0.04	0.04
Sulphur	0.05	0.05	0.05	0.045	0.05	0.05

* The percentage of silicon in silicon steel shall not be less than 0.20.

** The percentage of nickel in nickel steel shall not be less than 3.00.

The percentage of copper in all the above steels shall not be less than 0.20.

(4) Check Analyses. - Check analyses of the finished product may be made by the Engineer. The results of such check analyses shall not exceed the requirements specified for phosphorus and sulphur in the test ingot analysis by more than twenty-five (25) per cent, and for other elements the variation from the limits specified shall not be more than five (5) per cent.

(5) Discard. - A sufficient discard shall be made from each ingot to secure freedom from piping and undue segregation.

(6) Physical Properties. - Specimens cut from the finished material shall show the following physical properties:

	Nickel Steel	Silicon Steel	Carbon Steel			Manganese Rivet Steel
			Medium	Rivet	Mild	
Tensile Strength Pounds per Square Inch	90,000 Minimum	80,000/ /95,000	62,000/ /70,000	52,000/ /60,000	55,000/ /65,000	75,000/ /95,000
Yield Point, Minimum Pounds per Square Inch	55,000	45,000	37,000	30,000	30,000	45,000
Elongation in 8 Inches Minimum Per Cent	1,600,000[a] / Tensile Str	1,600,000[a] / Tensile Str	1,500,000[b] / Tensile Str	1,500,000 / Tensile Str	1,500,000 / Tensile Str	1,500,000 / Tensile Str
Reduction of Area Minimum	30%[c]	35%[c]	42%[d]	52%	50%	50%
Bend Test, Material 3/4 Inch or Less	180° around D = 1-1/2 T	180° around D = 1 T	180° around D = 1 T	180° flat	180° flat	180° flat
Material over 3/4 Inch to 1-1/4 Inches	180° around D = 2 T	180° around D = 1-1/2 T	180° around D = 1-1/2 T		180° around D = 1 T	

D = Inside diameter of bend.
T = Thickness of material.

a For silicon and nickel steel material over 3/4 inch thick, deduct one from percentage of elongation for each increase in thickness of 1/4 inch or fraction thereof, above 3/4 inch, but in no case shall the elongation be less than 14% for silicon steel or 12% for nickel steel.

b For medium steel material over 3/4 inch thick, deduct one from percentage of elongation for each increase in thickness of 1/8 inch or fraction thereof, above 3/4 inch, but in no case shall the elongation be less than 18%.

c For silicon and nickel steel material over 3/4 inch thick, deduct one from percentage of reduction of area for each increase in thickness of 1/8 inch, or fraction thereof, above 3/4 inch, but in no case shall the reduction of area be less than 24% for silicon steel or 20% for nickel steel.

d For medium steel material over 3/4 inch thick, deduct one from percentage of reduction of area, for each increase in thickness of 1/8 inch, or fraction thereof, above 3/4 inch, but in no case shall the reduction of area be less than 35%.

(7) Thick Material. - Tests from material of a thickness or diameter in excess of one and one-half (1-1/2) inches, shall show an ultimate strength and yield point equal to the minimum specified for its grade and an elongation in two (2) inches of $\frac{1,500,000}{\text{tens. str.}}$

(8) Bend Test for Angles. - All angles shall withstand being opened when tested cold, to an angle of one hundred fifty (150) degrees, or closed to an angle of thirty (30) degrees, without rupture.

(9) Identification. - All steel shall be made especially for this work and shall be subject to a system of identification approved by the Engineer and shall be handled by itself and isolated in such manner as to prevent the possibility of its becoming mixed with other kinds of steel. The Engineer may approve the use of stock material, for which certified copies of chemical and physical tests can be furnished by the manufacturer's chemist, for minor parts.

(10) Uniformity. - All steel shall be of uniform quality of each class. It shall be straight, without buckles or kinks, and free from injurious seams, flaws, cracks, excessive scale and pitting and other defects.

(11) Melt Number. - Every finished piece of steel shall be distinctly stamped with the melt number, and steel for pins shall have the melt number stamped on the ends. Rivet and lacing steel and small pieces of plates and shapes may be shipped in bundles securely wired together, with the melt number on a metal tag attached.

Universal plates and shapes shall be hot stamped. Sheared plates shall be stamped with steel dies after laying out. Painting heat numbers will not be allowed.

(12) Tolerances. - The cross-section or weight of each piece of steel shall not vary more than two and one-half (2-1/2) per cent from that specified, except in the case of plates wider than thirty-six (36) inches, for which allowance will be made in accordance with the specification of structural steel for bridges of the American Society for Testing Materials, serial designation A 7-29.

Mill Inspection

(13) Access. - The Engineer and his inspectors shall have free access, at all times, to all parts of the works where material for this Contract is being manufactured, handled or stored. The manufacturer shall extend to the Inspector, free of cost, all reasonable facilities to satisfy him that the material is being properly furnished in accordance with these Specifications.

(14) Notice. - The mills shall notify the Inspector at least eight (8) hours in advance when material for this work is to be rolled, giving him a schedule of sections. If not so notified, the Inspector may require the mills to handle the material for proper surface inspection before loading and shipping to the shops. In any case, the material shall be handled to the extent necessary to permit inspection of all surfaces.

(15) Approval before Shipment. - No material shall be loaded and shipped from the mills before the tests thereon have been completed and before the Inspector has approved the material in every respect as to quality as well as surface. Surface imperfections, except those which in the opinion of the Engineer do not impair the strength or appearance, will be cause for rejection.

Tests

(16) Number. - At least two (2) tension tests and one (1) bend test shall be made from each melt, or from each variety of product, such as plate, shape or bar, made therefrom. If material from any one (1) melt differs three-eighths (3/8) inch or more in thickness, one (1) tension and one (1) bend test from each variety of product shall be made from both the thickest and thinnest material rolled.

(17) Size of Specimens. - Specimens for tensile tests of rolled material less than one and one-half (1-1/2) inches thick, when machined, shall be of the full thickness of the material as rolled and shall have an area of at least one (1) square inch if cut from material one-half (1/2) inch thick or over and shall be at least two (2) inches wide if cut from material less than one-half (1/2) inch thick.

All bend test specimens of rolled material less than one and one-half (1-1/2) inches thick, shall be of the full thickness of material as rolled and shall be not less than two (2) inches wide. Bend test specimens shall withstand being bent cold without cracking on the outside of the bent portion. All successful bends shall be further closed in until broken or bent flat.

Test specimens from rolled or forged material of a thickness or diameter in excess of one and one-half (1-1/2) inches shall be cut from a point located midway between the surface and the center of the material. Tension test specimens shall be of one-half (1/2) inch diameter and two (2) inch gauge length.

(18) Speed of Test Machines. - The speed of the testing machine up to the yield point shall not exceed one and one-half (1-1/2) inches per minute for specimens with eight (8) inches gauge length, and shall be reduced on request of the Inspector so as to accurately determine the yield point. Beyond the yield point the speed may be increased to six (6) inches per minute until the specimen is broken.

(19) Determination of Yield Point. - The yield point shall be determined by the drop of the beam or halt of the gauge of the testing machine or by dividers, at the option of the Inspector. The testing machine shall not be stopped to obtain the drop of the beam or halt of the gauge.

(20) Type of Fracture. - All tension fractures shall be silky and of fine texture, free from coarse crystals. Square fractures shall be a sufficient cause for rejection.

(21) Retests. - In case the ultimate strength falls outside of the specified limits by less than one thousand (1000) pounds, all other requirements being filled, or in case the yield point falls below the specified minimum by less than one thousand (1000) pounds, all other requirements being filled, then two more tests may be taken from material of the same melt and thickness for each test thus failing and if both such retests fill all requirements the material will be accepted. All retest specimens shall be taken from the finished material rolled for this work and shall be stamped by the Inspector for identification, before being cut.

EYEBARS

(22) Chemical Properties. - Eyebar steel shall contain the following percentages of elements:

Carbon	.30 to .40
Manganese	.50 to .75
Phosphorus	not more than .04
Sulphur	not more than .05

(23) Specimen Tests. - The Contractor shall prepare two tension tests and one bend test from each heat of steel rolled for eyebars which tests shall be made in the presence of the Inspector and the results recorded for information regarding the physical properties of the material as rolled. These mill specimen tests shall be cut from the finished rolled material. They shall show a yield point of not less than forty thousand (40,000) pounds per square inch and an ultimate strength of not less than seventy thousand (70,000) pounds per square inch.

(24) Full Size Tests. - Eyebars tested to destruction from full sized bars fabricated for this work and selected from the finished bars by the Inspector, shall meet the following requirements:

	Annealed Carbon Bars	Heat Treated Bars
Minimum Yield Point, lbs. per sq. in.	36,000	50,000
Minimum Tensile Strength, lbs. per sq. in.	67,000	80,000
Minimum Elongation	10% in 20'-0"	8% in 18'-0"
Minimum Reduction of Area		35%

The number of full size tests will be determined by the Engineer but the number shall not be less than three (3) per cent and not more than five (5) per cent of the eyebars required for the bridge. Additional test bars required by reason of failures are not included in the above percentages.

Test bars, representing bars too long for the testing machine, shall be selected from the full length bar material after the heads on one end have been formed and shall have the second head formed upon them after being cut to the greatest length which can be tested.

No bars known to be defective in any way shall be taken for full size tests. Such defective bars shall be rejected. If tested by the manufacturer, the results shall in no way influence the acceptance or rejection of other bars. Full size eyebar tests will be required to break in the body. When a bar breaks in the head and develops the required elongation, another bar of the same size and lot shall be tested, the two (2) tests being counted as one (1). In case of the failure of full size eyebar tests, the Engineer may require additional tests to be made to assist him in arriving at a decision as to acceptance or rejection; or he may reject, without additional tests, all bars represented by the full size test made, or all bars of the same melt as the test so failing. The fracture of full size eyebar tests shall be silky, cupped or angular. A square, coarse, granular fracture shall be sufficient cause for rejection. Only the test bars which meet the requirements of these Specifications shall be paid for at the Contract unit price for eyebars.

(25) Brinnell Tests. - In addition to the above full size eyebar tests, the Contractor shall make two (2) Brinnell tests near the head of each heat treated bar, as well as make Brinnell tests every two (2) feet of the length of the full size test bars, which Brinnell tests shall be recorded and copies of the results furnished the Engineer and used as a check for the uniformity of the heat treatment of the eyebars. Bars from the same heat of steel showing a wide variation in the Brinnell results shall, upon request of the Engineer, be retreated.

PINS

(26) Chemical Properties. - The steel for pins shall contain not more than the following percentages of elements:

Phosphorus . . .	0.04
Sulphur	0.05

(27) Physical Properties. - Test specimens cut from the finished material shall show the following physical properties:

	Carbon Steel Pins	Heat Treated Pins
Minimum Yield Point, lbs. per sq. in.	35,000	60,000
Minimum Tensile Strength, lbs. per sq. in.	65,000	105,000
Minimum Elongation in 2 inches	1,600,000 / Tensile Str.	1,600,000 / Tensile Str.
Minimum Reduction in Area	42%	35%
Bend Test	180° around D - 1T	180° around D - 1T

(28) Tests. - Two (2) tension and one (1) bend test of pins, using standard one-half (1/2) inch diameter specimens shall be made from each melt. Test specimens shall be cut from a full sized prolongation of the pin, midway between the center and the outer surface. Tests shall be located and stamped by the Inspector for identification before the prolongations are removed. In the case of heat treated pins the prolongation shall not be removed until the heat treatment has been completed.

All tension fractures shall be silky and of fine texture, free from coarse crystals. Square fractures shall be a sufficient cause for rejection.

In case of failure to meet the specified requirements such additional specimens as required by the Engineer shall be selected from material of the same lot and tested and the entire lot may be rejected if the tests are not satisfactory to the Engineer.

AMERICAN BRIDGE COMPANY

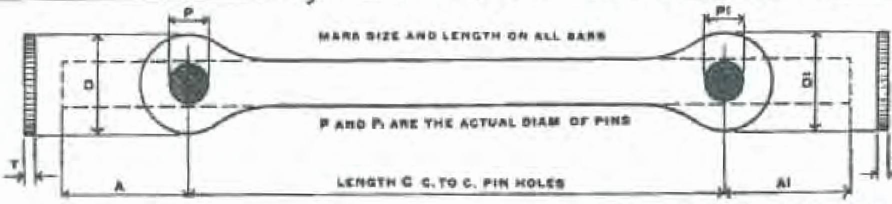
EYE BARS

DRAWINGS MADE BY Gary #1 DRAWING ROOM

WORK FABRICATED AT Ambridge PLANT

NAME OF STRUCTURE San Francisco-Oakland Bay Bridge

Eyebars for East Anchor Arm



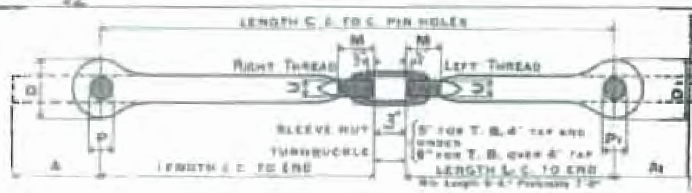
TEST BARS TO BE LISTED SEPARATELY AT BOTTOM OF BILL

NO. PCS.	SECTION	LENGTH C FT	LENGTH C INS	MARK	HEAD D PIN P	HEAD D DIA D	HEAD D THICK T	HEAD D ADD A	HEAD D1 PIN P1	HEAD D1 DIA D1	HEAD D1 THICK T1	HEAD D1 ADD A1	CALC. WT. FOR ONE SHIP. PCE.	ORDERED LENGTH FT	ORDERED LENGTH INS	ITEM	SHIPMENTS NO. PCS.	DATE	SCALE WEIGHT
	Heat Treated Eye Bars																		
8	12 x 1 15/16	69	1 15/16	M87-UA6	11½	28	1 15/16	4-2	13	29½	1 15/16	4-8	5949	78	0	121			
8	12 x 1 13/16	70	9 3/8	M87-UA6A	11½	28	1 13/16	4-2	13	29½	1 13/16	4-8	6077	79	7½	120			
4	12 x 1 5/8	65	0	LA4-M85	11½	28	1 5/8	4-2	11½	28	1 5/8	4-2	4699	7[illegible]	4	128			
4	12 x 1 11/16	65	0	LA4-M85A	11½	28	1 11/16	4-2	11½	28	1 11/16	4-2	4881	7[illegible]	4	125			
4	12 x 1 5/8	67	3 5/16	LA4-M83B	11½	28	1 5/8	4-2	11½	28	1 5/8	4-2	4520	70	7	129			
4	12 x 1 11/16	67	3 5/16	LA4-M83C	11½	28	1 11/16	4-2	11½	28	1 11/16	4-2	4694	70	7	126			
8	12 x 1 5/8	22	8 1/16	M83-MA3	11½	28	1 5/8	4-2	11½	28	1 5/8	4-2	1895	31	0	130			
8	12 x 1 11/16	22	8 1/16	M83-MA3A	11½	28	1 11/16	4-2	11½	28	1 11/16	4-2	1967	31	[illegible]	127			
16	12 x 1 13/16	65	0	M83-M82	11½	28	1 13/16	4-2	13	29½	1 13/16	4-8	5264	7[illegible]	[illegible]	123			
8	14 x 1 5/8	26	2 15/32	M82-MA2	13	33	1 5/8	4-10	15	34	1 5/8	5-5	2580	36	5½	119			
8	14 x 1 5/8	27	11 15/32	M82-MA2A	13	33	1 5/8	4-10	15	34	1 5/8	5-5	2715	3[illegible]	2½	118			
								PAGE TOTAL —					(328.784)						

See Sheet C10 for Test Bars

Eyebars on this sheet to be marked "East Anchor Arm"

DIAM. OF PIN HOLE — DIAM. OF PIN + 1/32



Made	Revision	App'd

APPROVED

Glenn B. Woodruff — Engr. of Design
Chas. E. Andrew — Bridge Engineer
C. H. Purcell — Chief Engineer
Approval Date 10-6-34

NOTE. L. P. D. & A. REFER TO SHORT END

TEST BARS TO BE LISTED SEPARATELY AT BOTTOM OF BILL

REQUIRED NO. PCS.	MARK	LENGTH C FT	LENGTH C INS	MATERIAL NO. PCS.	SECTION	LENGTH L.A.L. FT	LENGTH L.A.L. INS	END	HEAD PIN P1	HEAD THICK T T1	HEAD DIA D D1	HEAD ADD A A1	UPSET DIA U	UPSET LGTH M	UPSET ADD	CALC. WT FOR ONE SHIP PCE.	ORDERED LENGTH FT	ORDERED LENGTH INS	ITEM	SHIPMENTS NO. PCS.	DATE	SCALE WEIGHT
	All Eye Bars on this sheet to be Heat Treated																					
	Min Elastic Limit 50,000 #/□"																					
	All material to be copper Bearing Steel																					
	containing not less than 0.20% Copper																					
	Specifications Special by State of Cal. Dept of Public Works																					
	San Francisco-Oakland Bay Bridge - Contract No. 7																					

DIAM. OF PIN HOLE — DIAM. OF PIN

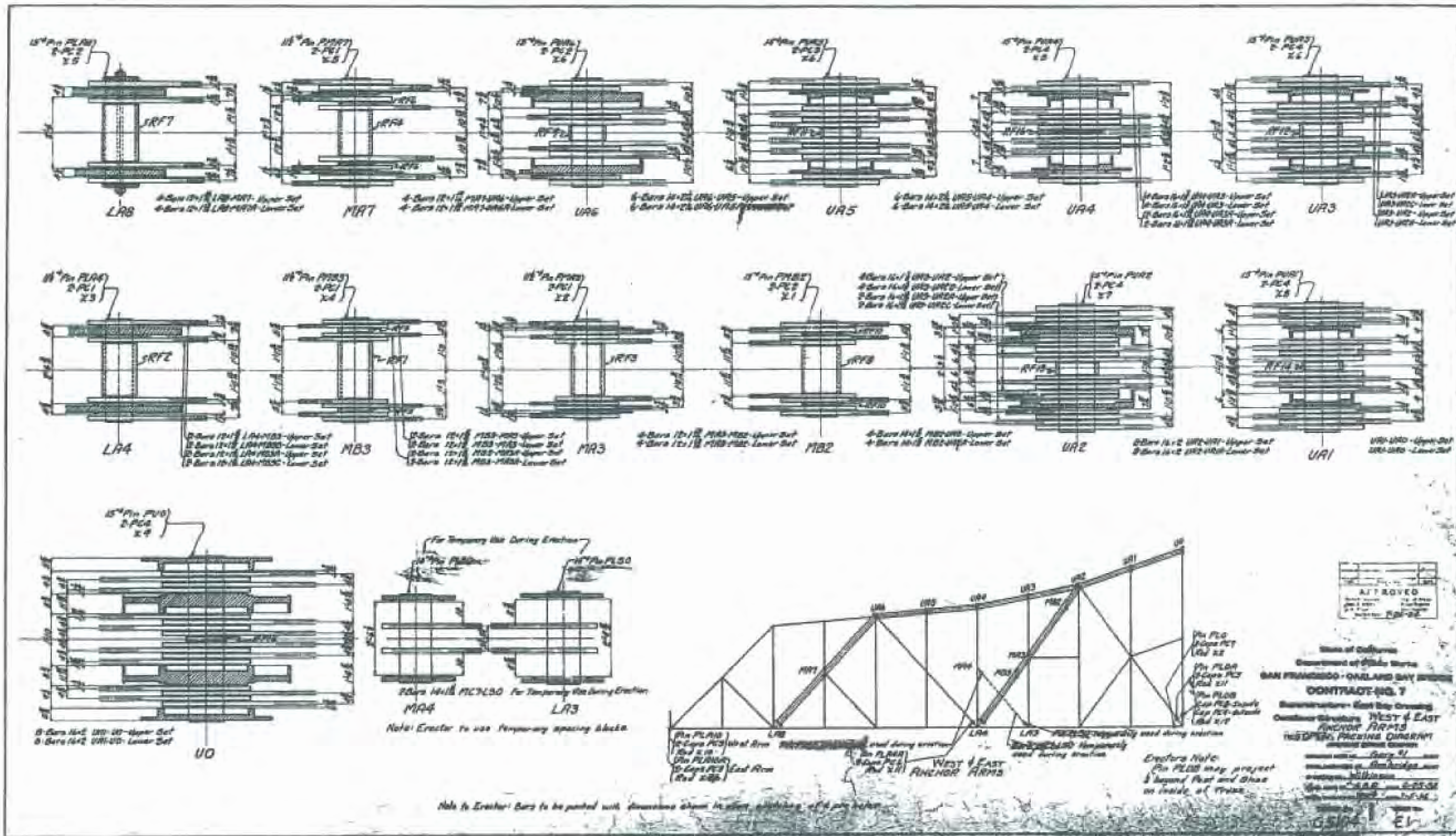
Rev. 8/28/35 E.K. [D]

MATERIAL INSPECTION

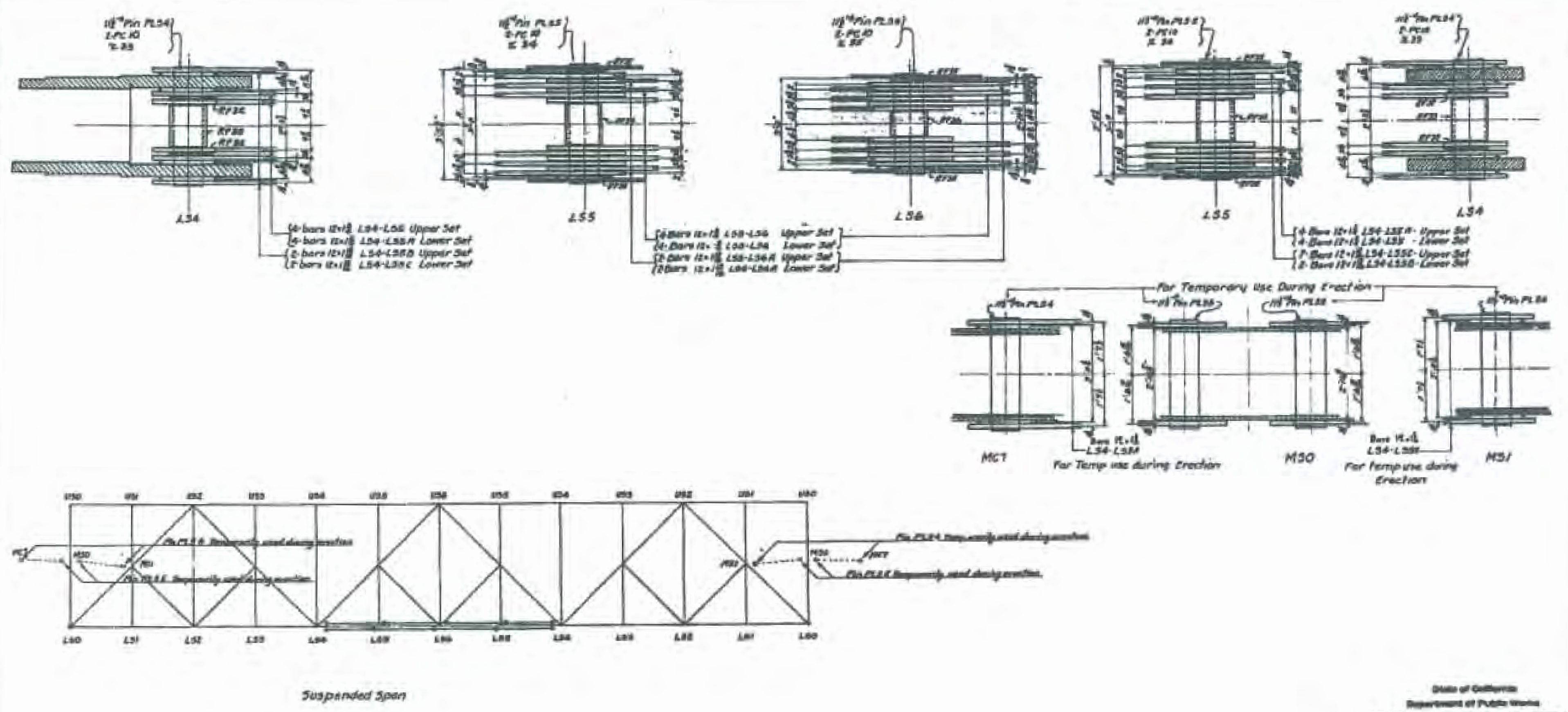
PAINT None, except Pin Holes to be coated with White Lead + Tallow

ORDER NO. 65104

SHEET NO. C 8



LA8
MA7
UA6
UA5
UA4
UA3
LA4
MB3
MA3
MB2
UA2
UA1
UO
MA4
LA3
Note: Erector to use temporary spacing blocks.
West & East Anchor Arms
Erectors Note:
Pin PL08 may project
beyond Post and Shoe
on inside of Truss.
APPROVED
State of California
SAN FRANCISCO - OAKLAND BAY BRIDGE
CONTRACT NO. 7
West & East
Anchor Arms
Packing Diagram
E1

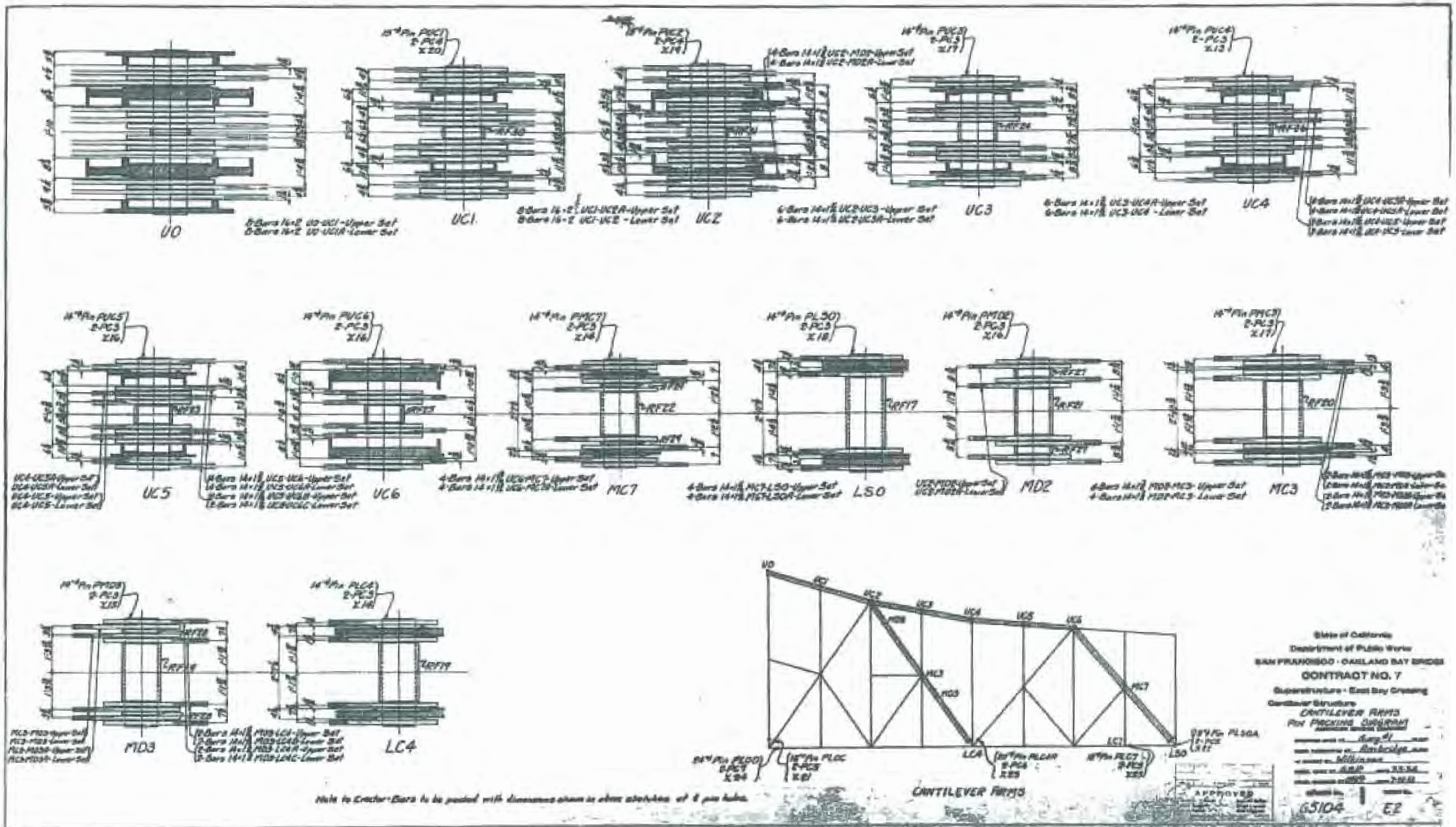


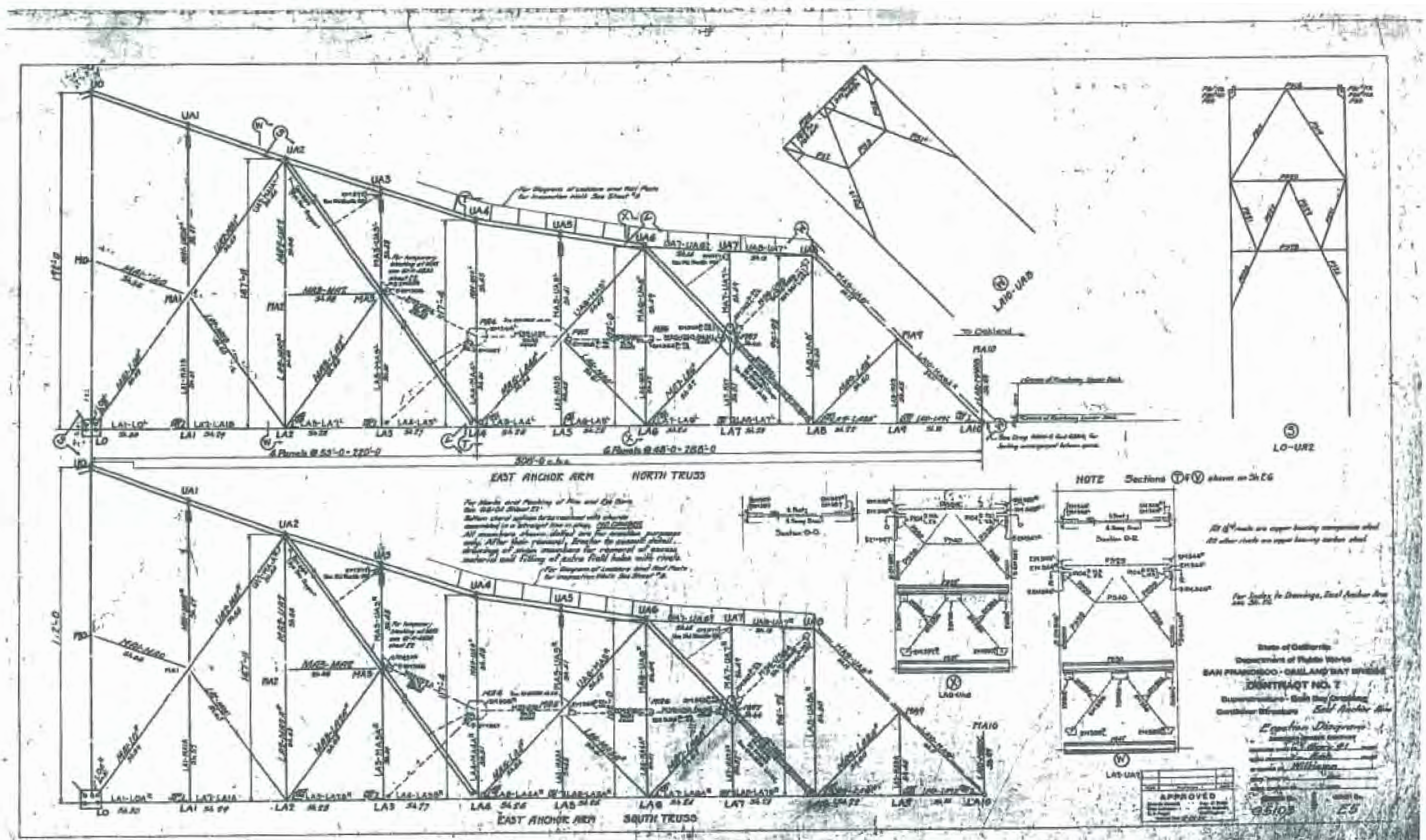
Note to Erector: Bars to be packed with dimensions shown in above sketches at ℄ Pin holes.

State of California
Department of Public Works
San Francisco - Oakland Bay Bridge
CONTRACT NO. 7
Superstructure - East Bay Crossing
Cantilever Elevation, Suspended Span
Pin Packing Diagram

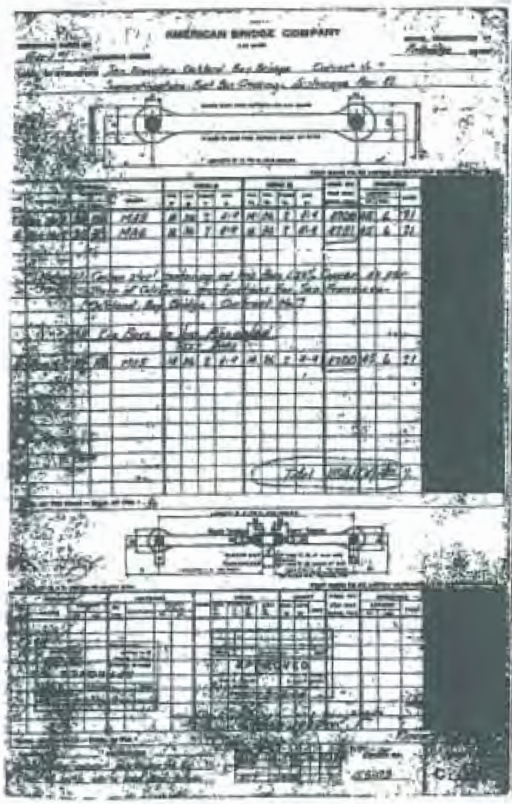
APPROVED

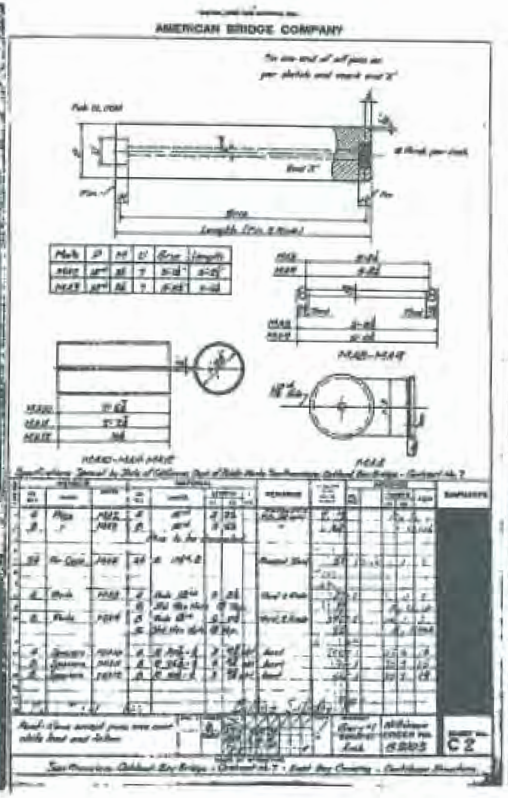
68109 E3

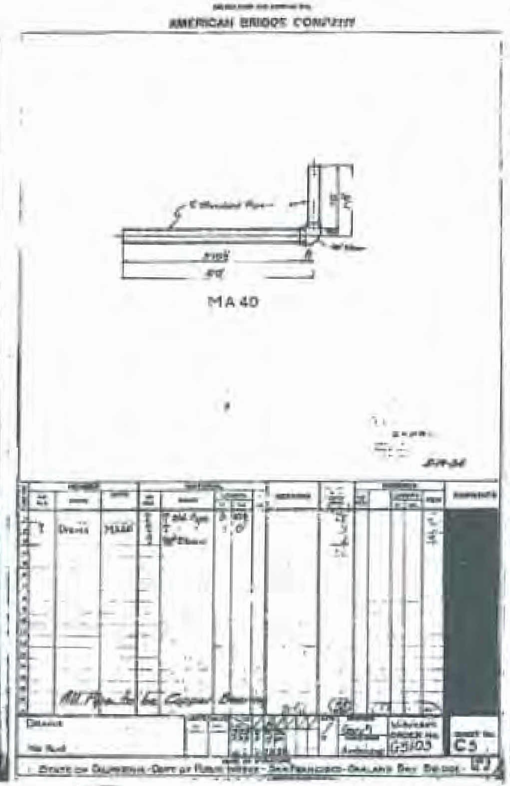

UO
UC1
UC2
UC3
UC4
UC5
UC6
MC7
LS0
MD2
MC3
MD3
LC4
CANTILEVER ARMS
State of California
Department of Public Works
SAN FRANCISCO - OAKLAND BAY BRIDGE
CONTRACT NO. 7
Superstructure - East Bay Crossing
Cantilever Structure
CANTILEVER ARMS
PIN PACKING DIAGRAM
APPROVED
G5104
E2

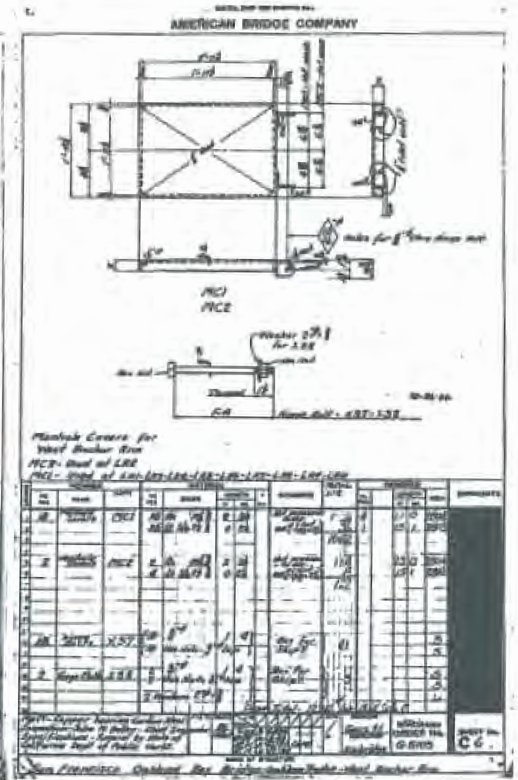


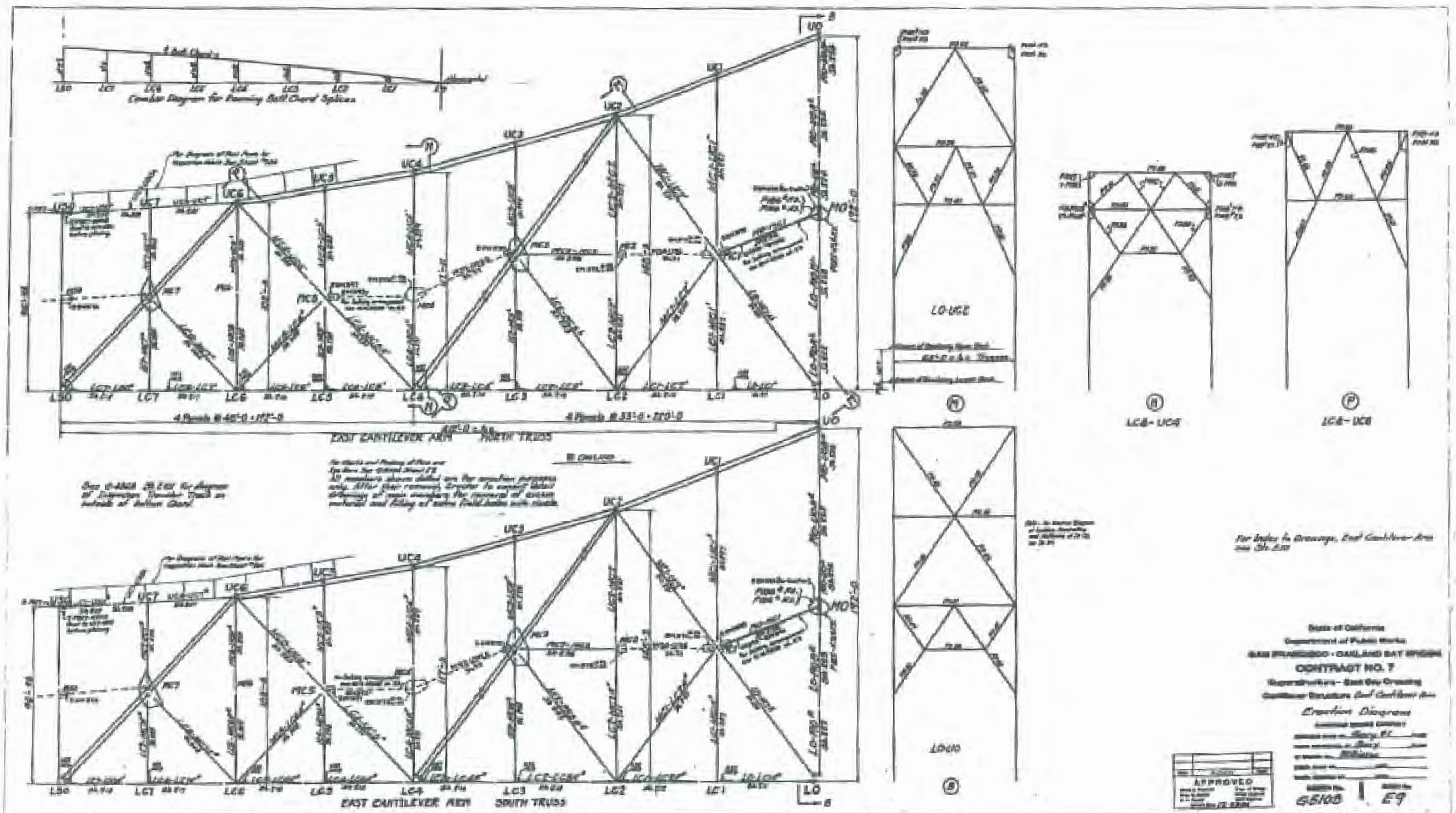
EAST ANCHOR ARM
NORTH TRUSS
EAST ANCHOR ARM
SOUTH TRUSS
LO-UR2
LA10-UA8
To Oakland
NOTE
State of California
Department of Public Works
SAN FRANCISCO - OAKLAND BAY BRIDGE
CONTRACT NO. 7
APPROVED
E5


AMERICAN BRIDGE COMPANY
APPROVED


AMERICAN BRIDGE COMPANY
MA8-MA9
C2


AMERICAN BRIDGE COMPANY
MA 40
G5103
C5


AMERICAN BRIDGE COMPANY
MC1
MC2
C6


Camber Diagram for Reaming Bott Chord Splices
EAST CANTILEVER ARM NORTH TRUSS
EAST CANTILEVER ARM SOUTH TRUSS
LO-UC2
LO-UO
LC6 - UC6
LC8 - UC8
State of California
Department of Public Works
SAN FRANCISCO - OAKLAND BAY BRIDGE
CONTRACT NO. 7
Superstructure - East Bay Crossing
Cantilever Structure East Cantilever Arm
Erection Diagram
APPROVED
G5108
E9

30-1

Index to Marks - G5103 - Cantilever and Anchor Arms

Description	Mark	Sheets
Bearing Bases	B	[illegible]
Diaphragms	DD	[illegible]
Diagonal Lacing	DL	[illegible]
Floor Beams	FB	[illegible]
Hangers	HG	[illegible]
Laterals	L	[illegible]
Ladders	LL	[illegible]
Members	MM	[illegible]
Member Covers	MC	[illegible]
Plates	P	[illegible]
Plates	FP	[illegible]
Pin Caps	PC	[illegible]
Portal Struts	PS	[illegible]
[illegible]	RF	[illegible]
[illegible]	RS	[illegible]
Stringer Bracing	SB	[illegible]
Top Laterals	T	[illegible]
[illegible]	X	[illegible]

Description	Mark	Sheets
Plates	P	[illegible]

Index to Marks - G5107 - Cantilever and Anchor Arms

Description	Mark	Sheets
[illegible]	DG	[illegible]
[illegible]	RR	[illegible]

Description	Mark	Sheets
[illegible]	DF	[illegible]
[illegible]	EJ	[illegible]
[illegible]	FS	[illegible]
Rail Plates	RP	[illegible]
Hand Rail	HR	[illegible]

Description	Mark	Sheets
[illegible]	DS	[illegible]
[illegible]	GS	[illegible]

Description	Mark	Sheets
[illegible]	LW	[illegible]
[illegible]	UW	[illegible]

G5104 Heat Treated Eye-Bars & Pins for Cantilever & Anchor Arms

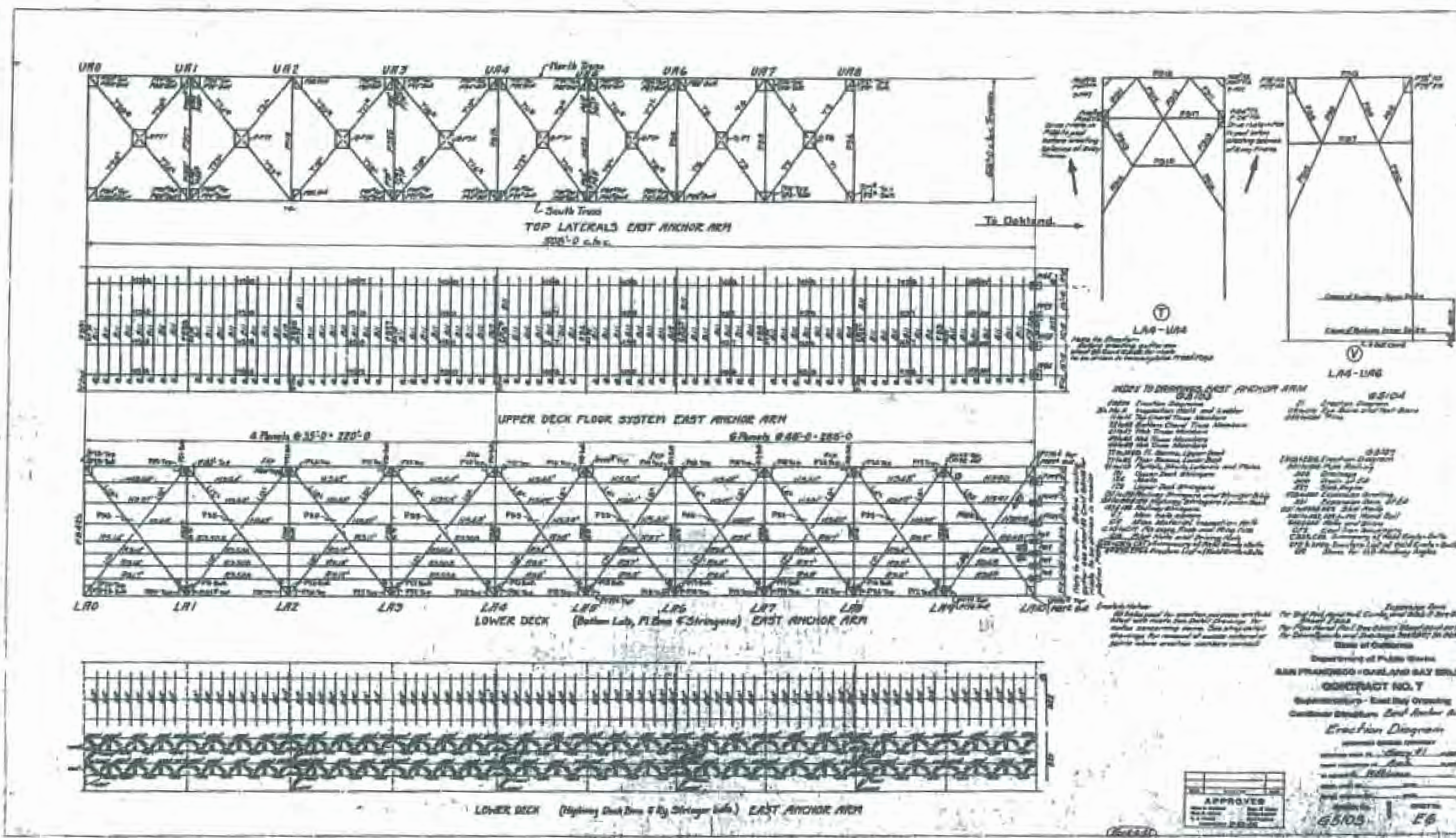
Description	Sheets
Eye-Bars - West Anchor Arm	[illegible]
" " - East " "	[illegible]
" " - West Cantilever "	[illegible]
" " - East " "	[illegible]
Test Eye Bars West Anchor Arm	[illegible]
" " " East " "	[illegible]
" " " West Cantilever "	[illegible]
" " " East " "	[illegible]
Pins - West Anchor Arm	[illegible]
" - East " "	[illegible]
" - West Cantilever Arm	[illegible]
" - East " "	[illegible]

G4868 - Inspection Traveler Track & Brackets for Cantilever & Anchor Arms

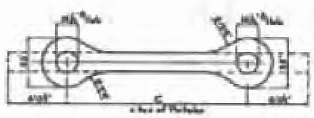
Description	Sheet
Track	[illegible]
Brackets	[illegible]

State of California
Department of Public Works
SAN FRANCISCO - OAKLAND BAY BRIDGE
CONTRACT NO. 7
Superstructure - East Bay Crossing
Cantilever Structure
Anchor and Cantilever Arms
Index to Marks

K1



UR0
UR1
UR2
UR3
UR4
UR6
UR7
UR8
North Truss
South Truss
TOP LATERALS EAST ANCHOR ARM
To Oakland
LA4-UA4
LA6-UA6
UPPER DECK FLOOR SYSTEM EAST ANCHOR ARM
LR0
LR1
LR2
LR3
LR4
LR6
LR7
LR8
LOWER DECK (Bottom Lats, Fl. Bms & Stringers) EAST ANCHOR ARM
LOWER DECK EAST ANCHOR ARM
APPROVED
CONTRACT NO. 7
Erection Diagram
65105
E6



[illegible] required for [illegible]

[illegible] Material

No. of Pieces	No. of Pieces	Mark		Size		[illegible]		[illegible] Length	
[illegible]	[illegible]	[illegible]	[illegible]	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
One	[illegible]	[illegible]	[illegible]	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
One	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Note:
Eye bars to be [illegible] Carbon Steel, Copper Bearing

[illegible] except pin holes which are to [illegible] [illegible] of Bar Longer

[illegible]	Remarks	[illegible]

APPROVED

[illegible] Engineer of Design
[illegible] Bridge Engineer
[illegible] Chief Engineer
[illegible]

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
SAN FRANCISCO-OAKLAND BAY BRIDGE
CONTRACT NO. 7
SUPERSTRUCTURE EAST BAY CROSSING
Eye Bars 504'0" Spans

McCLINTIC-MARSHALL CORPORATION
Pittsburgh [illegible] Pittsburgh [illegible]

CONTRACT C3 1580-7

MECHANICAL TESTING ON SPECIMENS FROM THE FRACTURED EYEBAR SFOBB EAST SPAN
Mactec Project: 5016050429-05.401

Report No. MEC091010

Prepared for:

CALTRANS

February 16, 2010

Prepared by:

McKNIGHT LABORATORY, INC.

Larry E. McKnight

Larry E. McKnight, P.E.
Principal Consulting Engineer

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  - **TENSILE TESTING……………………………………………………16-20**
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PROCEDURE

February 16, 2010

CALTRANS
Division of Maintenance
111 Grand Avenue, Room 10-400
Oakland, CA 94623

McKNIGHT LABORATORY, INC.
Report No. MEC091010

SUBJECT: MECHANICAL TESTING ON SPECIMENS FROM THE FRACTURED EYEBAR SFOBB EAST SPAN
Mactec Project: 5016050429-05.401

PROCEDURE

Larger segments of the eyebar were submitted to the laboratory for mechanical testing. Figure 1 illustrates the additional segments that were submitted and illustrates the layout of the locations of the test specimens. Segment 1 identifies the head section of the eyebar and segment 2 identifies the shank area of the eyebar. The nominal dimensions are shown in the photograph. The previous samples that were submitted for failure analysis are shown in the bottom center area as illustrated in the photograph. These specimens contain the original fracture of the eyebar that was analyzed and reported on January 6, 2010.

The layout of test specimens are identified on the segments 1 and 2. The block of specimens identified as F on segment 1 and segment 2 represent the section that was removed for possible fatigue testing. However no fatigue testing has been conducted at this time. The other specimens that are identified relate to the longitudinal tensile specimen in the head area of segment 1 and segment 2 and the fracture toughness test specimens prepared from the head and the shank in the longitudinal and transverse direction with the direction of the notch indicated on the specimens identified as K. The specimen identifications shown as G on the two segments represent the specimens that were removed for dynamic modulus testing. The two tensile specimens identified in the photograph were cut and removed from the one-quarter thickness location of the eyebar. In other words, the tensile specimen was located at a distance half way between the surface and the core of the eyebar. After the tensile tests were performed at these two locations the end of the tensile bar from the head area, segment 1, and an end of one of the tensile specimens from segment 2 in the shank were chemically analyzed. Figures 2 and 3 illustrate the tensile specimens prepared from the head and the shank area of the eyebar. Figure 4 illustrates the four fracture toughness specimens prepared prior to testing. Figures 5 and 6 illustrate the appearance of the fracture toughness specimens taken from the head segment of the eyebar after testing. These represent the 1-LT and 1-TL fracture toughness specimens from the head. Figures 7 and 8 illustrate the appearance of the fracture toughness specimens from the shank segment of the eyebar. These represent the 2-LT and 2-TL fracture toughness specimens. Figure 9 illustrates the appearance of the dynamic modulus specimens taken from the head portion of the eyebar. Two specimens were prepared in the longitudinal direction and two specimens in the transverse direction. One specimen was prepared at the top surface of the eyebar and the second was taken at the core of the eyebar in each direction. Figure 10 illustrates the two dynamic modulus specimens prepared from the shank area. One specimen was prepared in the transverse direction and one in the longitudinal direction. These particular specimens were made with the full thickness of the shank. The results of all of the testing are shown in the following enclosed lab reports.

SUMMARY
OF
TEST RESULTS

SUMMARY OF TEST RESULTS

The tensile results conform to the bridge specification requirement. In addition, the chemical analysis is also consistent with and conforms to the original bridge specification for the eyebar. Since the chemistry of the tensile specimen prepared from the head segment is virtually identical to the chemical analysis of the tensile specimen taken from the shank it's apparent that the shank and the head of the eyebar were made from the same steel. This indicates that the eyebar and shank were essentially one piece of the same steel as manufactured.

The results of the dynamic modulus tests show that the elastic modulus on the specimens taken from the head segment of the eyebar varied from 30.26 to 30.94; the modulus of rigidity varied from 11.81 to 12.07; the Poissons ratio varied from 0.266 to 0.289. For the eyebar shank segment 2 the elastic modulus varied from 29.97 to 30.25; the modulus of rigidity varied from 11.84 to 11.93; the Poissons ratio varied from 0.255 to 0.269. Based on these readings there was no significant variations in the dynamic modulus properties between the head and the shank area of the eyebar.

The results of the facture toughness testing on the four specimens showed that a number of the parameters on the validity checks for the determination of K_{IC} value were valid, however there were some invalid parameters on each of the specimens. In essence the true K_{IC} value cannot be reported due to the fact that the maximum specimen thickness that could be obtained from the eyebar was not large enough to produce a valid K_{IC}. In the validity note at the bottom of the report there is a quotation from ASTME-399-09 which says, "Variation in the value K_{IC} can be expected within the allowable range of specimen proportions, A/W and W/B. K_{IC} may also be expected to rise with increasing ligament size. This indicates that if a thicker ligament could have been available a valid K_{IC} could have been determined. The value K_Q may be considered to be an approximation of K_{IC}.

FIGURES

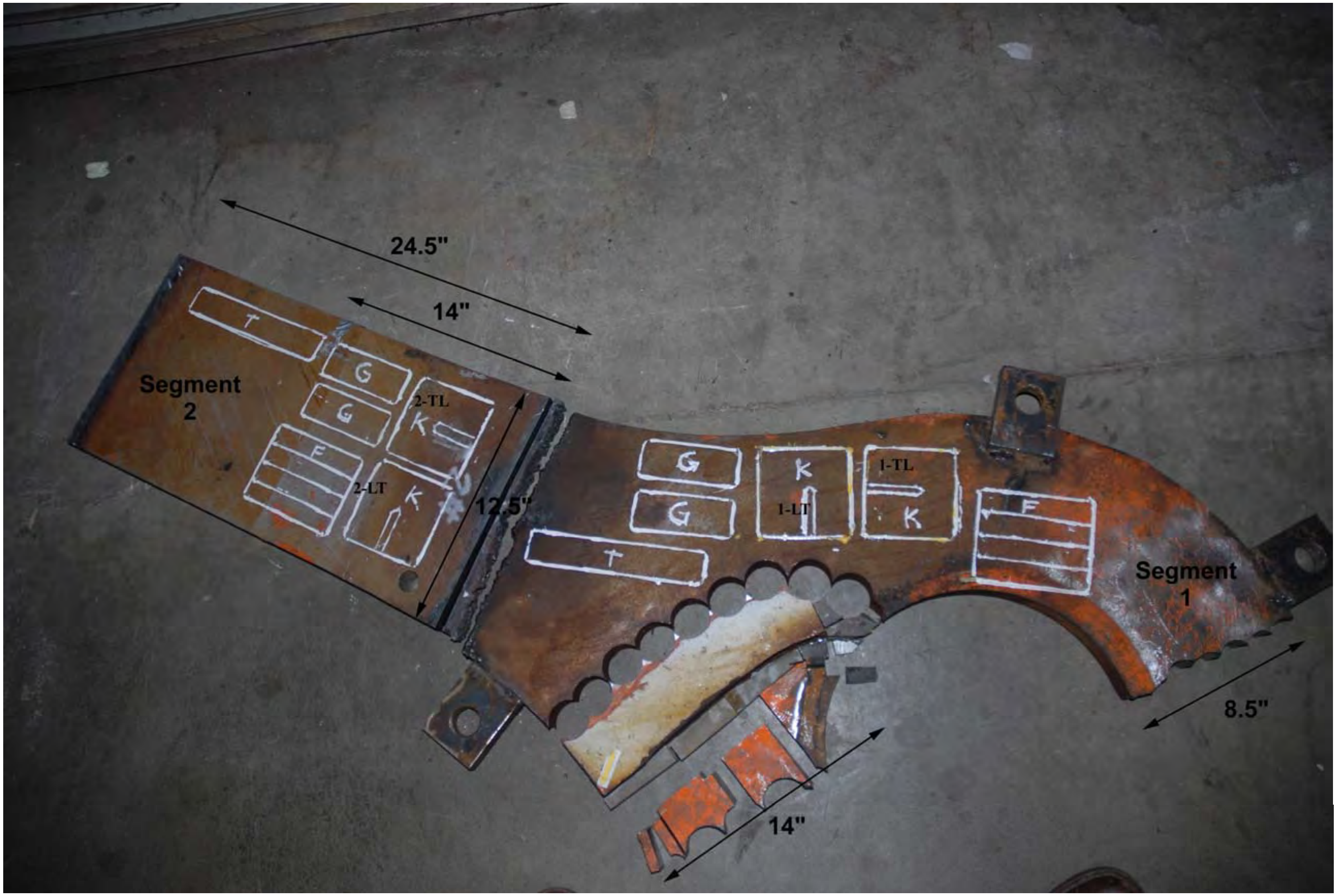

24.5"
14"
Segment 2
T
G
G
F
2-TL
K
2-LT
K
12.5"
G
G
K
1-TL
1-LT
K
T
F
Segment 1
8.5"
14"

Fig 1


EXOVA
10005 FREEMAN AVENUE
SANTA FE SPRINGS, CA 90670
TEL: (562) 946-1721 FAX: (562) 944-8389
Customer: MCKNIGHT LABORATORY, INC.
Date: 01/18/10 ES
H/N: NOT SUPPLIED, SEGMENT #1
HEAD
Dept: TENSILE
TB-A LAB # 493596
493596_2500001
ID TO BE PLACED ON SPECIMEN: 596 501
UPON COMPLETION OF MACHINING/PREPARATION
INITIAL HERE TO VERIFY THE SAMPLE ID

Fig 2


EXOVA
10005 FREEMAN AVENUE
SANTA FE SPRINGS, CA 90670
TEL: (562) 946-1721 FAX: (562) 944-8389
Customer: MCKNIGHT LABORATORY, INC.
PO/SO: 696557
Date: 01/18/10 ES
H/N: NOT SUPPLIED, SEGMENT #2
Item: 002
Material: STEEL
Specimen Size: R1, RTT
Direction: AS MARKED (T), Temp: RT
INFO ONLY. 2"GAUGE LENGTH REQD
Shank
Dept: TENSILE
TB-A LAB # 493596
493596_2500002
Round Specimen - Cut & ID By
G. Dia
G. Length
C.C.
Surf. Finish
Mach By
Insp By
Threads
ID TO BE PLACED ON SPECIMEN: 596 502
UPON COMPLETION OF MACHINING/PREPARATION
INITIAL HERE TO VERIFY THE SAMPLE ID

Fig 3

Fig 4

Fig 5

Fig 6

Fig 7

Fig 8

Fig 9

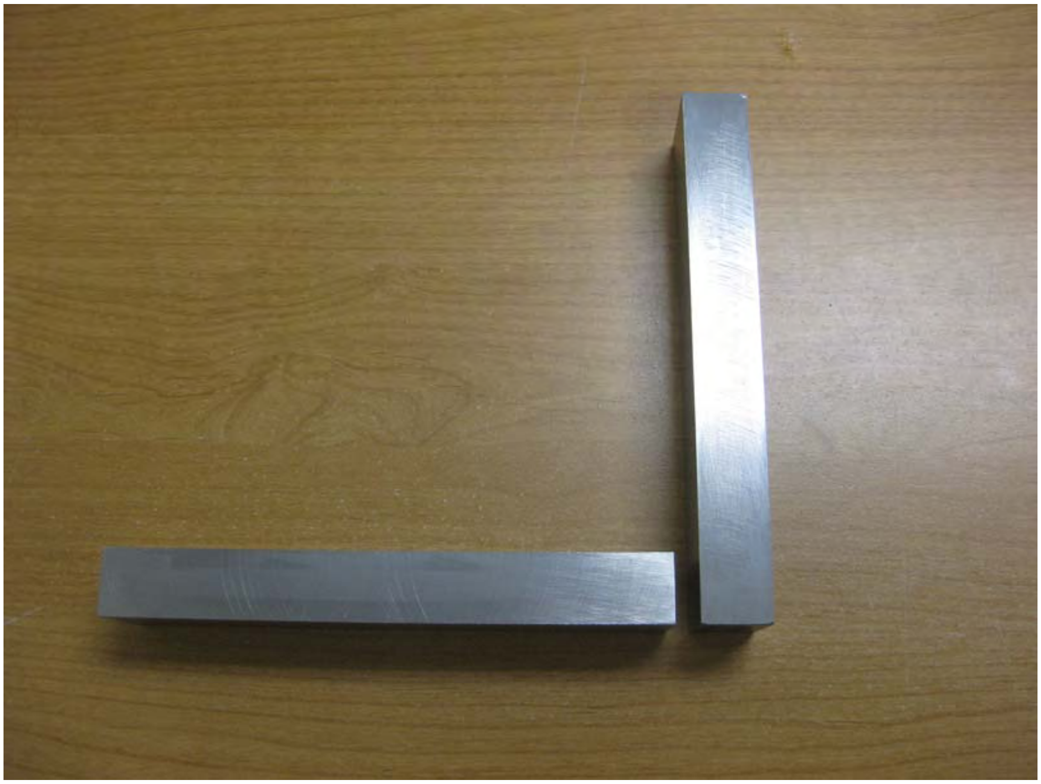


Fig 10

TENSILE TESTING

EXOVA
10005 Freeman Avenue, Santa Fe Springs, CA. 90670
Tel: (562) 946-1721 Fax: (562) 944-8389 www.exova.com

Exova

Customer: CALTRANS
5900 Folsom Road
Sacramento, CA
PO/SO: 696557
Lab No: 493596
Date: 02/11/10
Material: STEEL
P/N:
Heat Number: NOT SUPPLIED
Specification: INFO ONLY
Other: I BAR SEGMENTS
Seg #1 HEAD
Ref Job#: MEC091010, Misc.: OAKLAND BRIDGE

TEST RESULTS PREVIEW

METALLURGY	TENSILE TEST LOC/ORIENTATION	TEMP°F	STRESSED DIM	STRESSED AREA	TYS @ 0.2% OFF LBS	TYS @ 0.2% OFF KSI	TENSILE STRENGTH LBS	TENSILE STRENGTH KSI	ELONG (4D) IN	ELONG (4D) %	RED. OF AREA FIN. DIM.	RED. OF AREA %
	AS MARKED (T)	RT	.491 D	.1893	12111	64.0	18080	95.5	0.460	23.0	.320 D	57.5
	Information Only								2.0G			

This is not a certified test report.

Both yield strengths determined by yield point.
PARTIAL CERTIFICATION.

MEM PAGE: 1 of 6

Signed for and on behalf of Exova

Victor Landero, Operation Manager
EXOVA

Accredited Nadcap Materials Testing Laboratory

Exova Testing. Advising. Assuring.

RT 60K 2 in (2R) 0.2% OFFSET

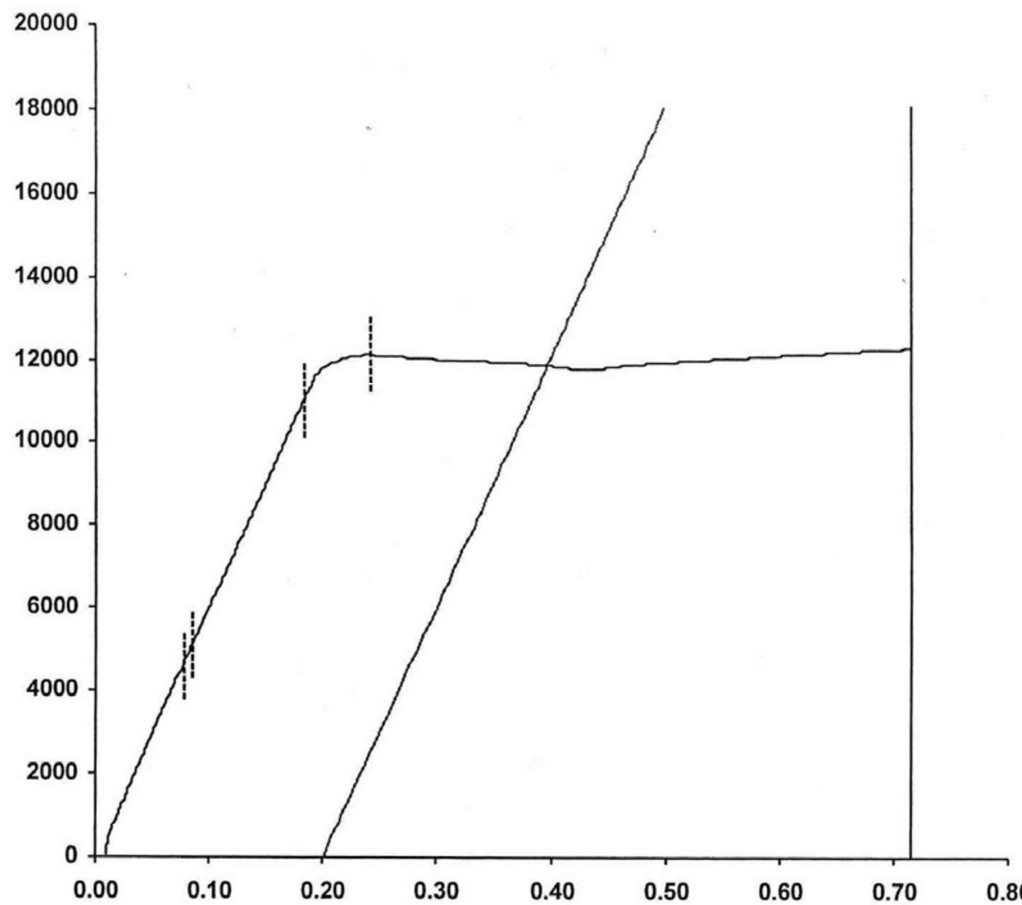
Test Number 51509
Report Number 19080
Test Date 1/21/2010 9:43:52 AM

Head Specimen ID	1
Original Gage (in)	2.0000
Diameter (inch)	0.4910
Modulus	31,823,730
0.2% Yield (Lbs)	12,111
Tensile (Lbs)	18,080
0.2% Yield (Psi)	64,000
Tensile (Psi)	95,500
Elongation (%)	-100.0
R.A. (%)	
Final Gage (In)	0.0000
Final Diameter (in)	0.0000
.5% EUL (lbs.)	11,943
Final Load (Lbs)	-19

By: ____________________ Date: __________

Testing Machine SFM-60	
Load Cell S/N (FM141-81), Units (Lbs)	60000
Preload Value (Lbs)	50
Crosshead Speed (Inches / min) or Rate	0.5
Extension or Position Measured by	EZ-0.1-2 (5053)

Force (Lbs) vs Extension (%)



LAB NUMBER 493596
HEAT NUMBER N/S
OPERATOR RM
ITEM NUMBER 1

Template No 103 04-Feb-10
EXOVA, Inc

EXOVA
10005 Freeman Avenue, Santa Fe Springs, CA. 90670
Tel: (562) 946-1721 Fax: (562) 944-8389 www.exova.com

Customer: CALTRANS
5900 Folsom Road
Sacramento, CA
Material: STEEL
Specification: INFO ONLY

PO/SO: 696557
P/N:

Lab No: 493596 Date: 02/11/10
Heat Number: NOT SUPPLIED
Other: I BAR SEGMENTS
Seg #2 SHANK

Ref Job#: MEC091010, Misc.: OAKLAND BRIDGE

TEST RESULTS PREVIEW

METALLURGY	TENSILE TEST	TEMP°F	STRESSED	STRESSED	TYS @ 0.2% OFF		TENSILE STRENGTH		ELONG (4D)		RED. OF AREA	
	LOC/ORIENTATION		DIM	AREA	LBS	KSI	LBS	KSI	IN	%	FIN. DIM.	%
	AS MARKED (T)	RT	.499 D	.1956	10932	55.9	16975	86.8	0.550	27.5	.307 D	62.2
	Information Only								2.0G			

This is not a certified test report.

Both yield strengths determined by yield point.
PARTIAL CERTIFICATION.

Signed for and on behalf of Exova

Victor Landero, Operation Manager
EXOVA

Accredited Nadcap Materials Testing Laboratory

RT 60K 2 in (2R) 0.2% OFFSET

Test Number 51510
Report Number 19081
Test Date 1/21/2010 10:01:35 AM

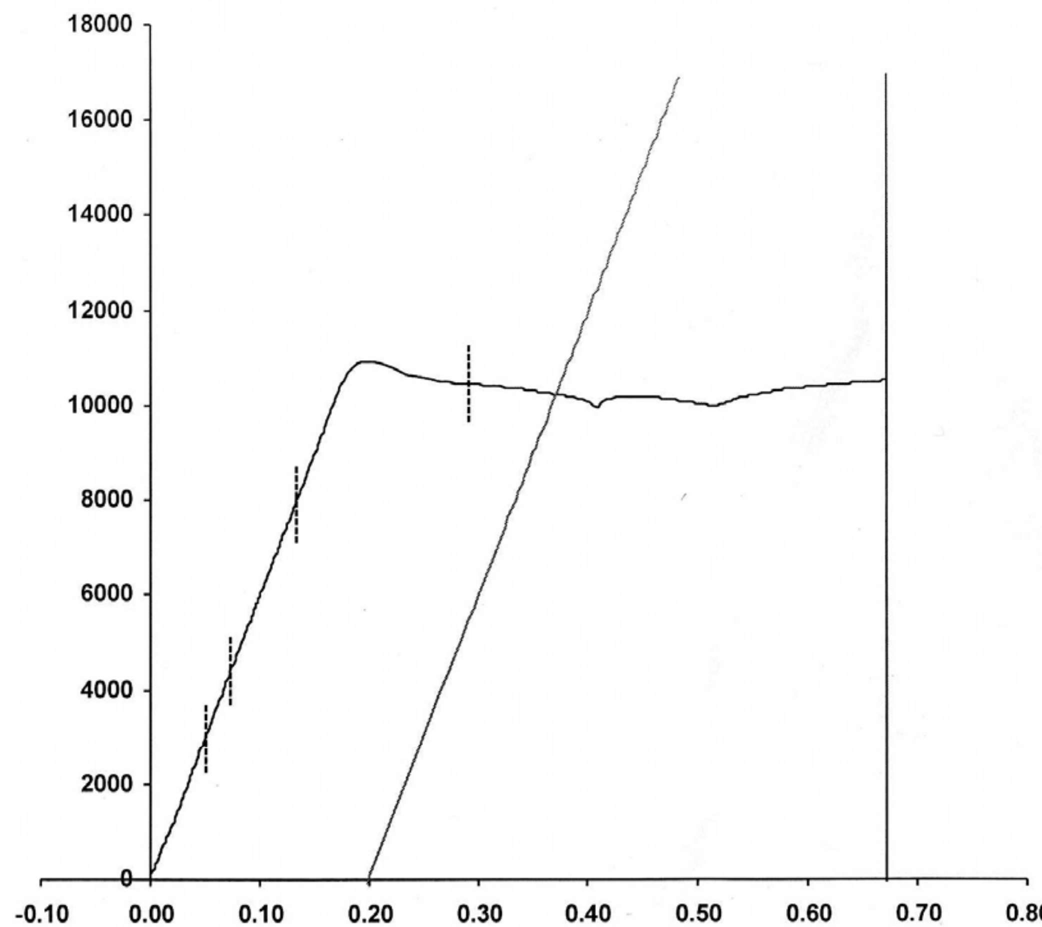
Shank	
Specimen ID	2
Original Gage (in)	2.0000
Diameter (inch)	0.4990
Modulus	30,536,590
0.2% Yield (Lbs)	10,932
Tensile (Lbs)	16,975
0.2% Yield (Psi)	56,000
Tensile (Psi)	87,000
Elongation (%)	-100.0
R.A. (%)	
Final Gage (In)	0.0000
Final Diameter (in)	0.0000
.5% EUL (lbs.)	10,042
Final Load (Lbs)	-20

By: ______________________ Date: __________

Testing Machine SFM-60

Load Cell S/N (FM141-81), Units (Lbs)	60000
Preload Value (Lbs)	50
Crosshead Speed (Inches / min) or Rate	0.5
Extension or Position Measured by	EZ-0.1-2 (5053)

Force (Lbs) vs Extension (%)



LAB NUMBER 493596
HEAT NUMBER N/S
OPERATOR RM
ITEM NUMBER

Template No 103 04-Feb-10
EXOVA, Inc

CHEMISTRY ANALYSIS

Material Testing and Non-Destructive Testing

15062 Bolsa Chica
Huntington Beach, CA 92649

Telephone :(714) 892-1961
Telefax :(714) 892-8159
Website :www.storksmti.com

Contact: Larry McKnight
Photometrics Inc.
15801 GRAHAM STREET

HUNTINGTON BEACH, CA 92649

Date: 2/8/2010 **P.O. No.:** 5749 **W/O No.:** PHO001-02-04-65032-1

TEST CERTIFICATE

Description:	Segment # 1 - Head

CHEMICAL ANALYSIS

Element		Result %
C	=	0.31
Mn	=	0.64
P	=	0.012
S	=	0.022
Si	=	0.15
Cr	=	0.03
Ni	=	0.02
Mo	<	0.01
Cu	=	0.27
Fe	=	Balance

Chemical Analysis Performed by Optical Emission per SOP 2.02, Revision 10
Carbon and Sulfur by Combustion per SOP 7.00, Revision 5

FOR INFORMATION ONLY

IMPORTANT NOTE REGARDING U.S. EXPORT LAWS:

Stork Materials Technology does not have on file an End Use Certificate from your company for the P.O./Part Number(s) or Program identified on this report. Therefore, we consider you to be the end user of any technical data and or services provided by Stork in connection with this order and fully responsible for compliance with the applicable export laws of the United States including the International Traffic in Arms Regulations and Export Administration Regulations.

Respectfully submitted

Rose Saplan
Senior Technician

Material Testing and Non-Destructive Testing

Contact: Larry McKnight
Photometrics Inc.
15801 GRAHAM STREET

HUNTINGTON BEACH, CA 92649

15062 Bolsa Chica
Huntington Beach, CA 92649

Telephone :(714) 892-1961
Telefax :(714) 892-8159
Website :www.storksmti.com

Date: 2/8/2010 **P.O. No.:** 5749 **W/O No.:** PHO001-02-04-65032-2

TEST CERTIFICATE

Description:	Segment # 2 - Shank

CHEMICAL ANALYSIS

Element		**Result %**
C	=	0.34
Mn	=	0.66
P	=	0.013
S	=	0.024
Si	=	0.15
Cr	=	0.03
Ni	=	0.02
Mo	<	0.01
Cu	=	0.27
Fe	=	Balance

Chemical Analysis Performed by Optical Emission per SOP 2.02, Revision 10
Carbon and Sulfur by Combustion per SOP 7.00, Revision 5

FOR INFORMATION ONLY

IMPORTANT NOTE REGARDING U.S. EXPORT LAWS:

Stork Materials Technology does not have on file an End Use Certificate from your company for the P.O./Part Number(s) or Program identified on this report. Therefore, we consider you to be the end user of any technical data and or services provided by Stork in connection with this order and fully responsible for compliance with the applicable export laws of the United States including the International Traffic in Arms Regulations and Export Administration Regulations.

Respectfully submitted

Rose Saplan
Senior Technician

FRACTURE TOUGHNESS TESTING

EXOVA
10005 Freeman Avenue, Santa Fe Springs, California 90670
Tel: (562) 946 1721 Fax: (562) 944-8389 www.exova.com

Exova

Customer:	CALTRANS	P.O.:	696557	Date:	2/11/2010
	5900 Folsom Road	Heat Number:	Not Supplied	Lab Number:	493596-001
	Sacramento, CA	Heat Code:		Part Number:	
Material:	STEEL	Serial Number:	I bar	Part Size:	
Specification:	INFO ONLY		Segment #1 Head		I BAR SEGMENTS
Ref Job#	MEC091010				
Misc.	OAKLAND BRIDGE				

CERTIFICATION OF FRACTURE TOUGHNESS TESTING PER ASTM E399-09

SUMMARY OF TEST RESULTS:

Configuration Code	C(T)(L-T)
Test Temperature (°F)	RT
K_Q (ksi x sqrt(in))	48.3
K_{Ic} (ksi x sqrt(in))	See Validity Note Below
K_{Ic} Min	0.0

SPECIMEN DESCRIPTION:

Description	As Received
Product Form	Test Piece
Specimen Type	Compact Specimen C(T)
Notch Type	Straight Through Notch

SPECIMEN DIMENSIONS:

B thickness (inches)	1.495
W width (inches)	3.000
an notch (inches)	1.359
D holes dia. (inches)	0.749
2H height (inches)	3.603

PRECRACKING DATA

Precrack Temp. (°F)	73
Relative Humidity (%)	37
K(max) (pounds)	6,000
K(max) (cycles)	48,000
a1 (inches)	1.527
a2 (inches)	1.572
a3 (inches)	1.590
a4 (inches)	1.591
a5 (inches)	1.529

FRACTURE DATA:

P_Q (pounds)	11,850
P_{max} (pounds)	13,350
Yield Strength (ksi)	64.0
Modulus of E (msi)	30.0
Strength Ratio	1.056
Fracture Appearance	13% Fraction Oblique

VALIDITY CHECKS FOR THE DETERMINATION OF THE K_{Ic} VALUE:

Valid — **ASTM E 399 Section 7.3.2.1:** Average crack length (a) shall be between 0.45 W and 0.55 W

Average Crack Length (a)	1.584
0.45 W	1.350
0.55 W	1.650

Valid — **ASTM E 399 Section 8.2.3 (Requirement 1):** The difference between any two of the three crack length measurements (a2, a3, a4) shall not exceed 10% of the average crack length (a).

Maximum Difference	0.019
10% Average Crack Length	0.158

Valid — **ASTM E 399 Section 8.2.3 (Requirement 2):** No part of the crack front (Side I, Side II) shall be closer to the machined starter notch than 2.5 % W or 0.050".

Side I Crack Front	0.168
Side II Crack Front	0.170
2.5% W	0.075

Valid — **ASTM E 399 Section 8.2.3 (Requirement 3):** Neither surface crack length (a1, a5) shall differ from the average length by more than 15%.

Surface Crack (a1)	1.527
Surface Crack (a5)	1.529
85% of Average Crack	1.347
115% of Average Crack	1.822

Valid — **ASTM E 399 Section 8.2.3 (Requirement 4):** The difference between the two surface measurements (a1, a5) shall not exceed 10 % of the average crack length (a).

Difference of a1 & a5	0.002
10% of Average Crack	0.158

Valid — **ASTM E 399 Section 8.2.4:** The plane of the crack shall be parallel to both the specimen width and thickness direction within 10° and there shall be no evidence of multiple cracking.

Crack Plane to Width	0
Crack Plane to Thickness	0

Valid — **ASTM E 399 Section 8.3:** Static testing load rate (K rate) shall be within the range from 30 to 150 ksi x sqrt(in) / min.

Loading rate (K rate)	85.6

Valid — **ASTM E 399 Section 8.4:** The initial slope (linear portion) of the loading curve shall be between 0.7 and 1.5

Slope of Loading Curve	1.37

Invalid — **ASTM E 399 Section 9.1.3:** The ratio of P_{max}/P_Q shall not exceed 1.10

P_{max}/P_Q Ratio	1.127

Invalid — **ASTM E 399 Section 9.1.4:** Specimen ligament size (W-a) shall be greater than $2.5(K_Q/YS)^2$

Specimen ligament (W-a)	1.416
2.5(KQ/YS)^2	1.425

Valid — **ASTM E 399 Section A8.3.3:** K_{max}/E shall not exceed 0.002 and K_{max} must not exceed 60% of the K_Q value.

K_{max}/E	0.0008
K_{max}	24.5
60% K_Q	29.0

Invalid — **ASTM E 399 Section A8.1.3:** The maximum Kmax during any stage must not exceed 80% of the KQ value.

Maximum K_{max}	44.86
80% K_Q	38.66

VALIDITY NOTE:

This test is NOT VALID per ASTM E-399.
ASTM E399 - 09, 5.1.1 Variation in the value of Klc can be expected within the allowable range of specimen proportions, a/W and W/B. Klc may also be expected to rise with increasing ligament size.

See Validity Note Above.

Partial Certification

Signed for and on behalf of Exova

Victor Landero, Q.M.
EXOVA

Accredited Nadcap Materials Testing Laboratory

EXOVA
10005 Freeman Avenue, Santa Fe Springs, California 90670
Tel: (562) 946 1721 Fax: (562) 944-8389 www.exova.com

Exova

Customer:	CALTRANS	P.O.:	696557	Date:	2/11/2010
	5900 Folsom Road	Heat Number:	Not Supplied	Lab Number:	493596-002
	Sacramento, CA	Heat Code:		Part Number:	
Material:	STEEL	Serial Number:	I bar	Part Size:	
Specification:	INFO ONLY		Segment #1 Head		I BAR SEGMENTS

Ref Job# MEC091010
Misc. OAKLAND BRIDGE

CERTIFICATION OF FRACTURE TOUGHNESS TESTING PER ASTM E399-09

SUMMARY OF TEST RESULTS:

Configuration Code	C(T)(T-L)
Test Temperature (°F)	RT
K_Q (ksi x sqrt(in))	70.4
K_{Ic} (ksi x sqrt(in))	See Validity Note Below
K_{Ic} Min	0.0

SPECIMEN DESCRIPTION:

Description	As Received
Product Form	Test Piece
Specimen Type	Compact Specimen C(T)
Notch Type	Straight Through Notch

SPECIMEN DIMENSIONS:

B thickness (inches)	1.496
W width (inches)	3.001
an notch (inches)	1.358
D holes dia. (inches)	0.751
2H height (inches)	3.603

PRECRACKING DATA

Precrack Temp. (°F)	73
Relative Humidity (%)	37
K(max) (pounds)	6,000
K(max) (cycles)	55,000
a1 (inches)	1.521
a2 (inches)	1.601
a3 (inches)	1.636
a4 (inches)	1.625
a5 (inches)	1.510

FRACTURE DATA:

P_Q (pounds)	16,600
P_{max} (pounds)	16,600
Yield Strength (ksi)	64.0
Modulus of E (msi)	30.0
Strength Ratio	1.387
Fracture Appearance	3% Fraction Oblique

VALIDITY CHECKS FOR THE DETERMINATION OF THE K_{Ic} VALUE:

Valid **ASTM E 399 Section 7.3.2.1:** Average crack length (a) shall be between 0.45 W and 0.55 W

Average Crack Length (a)	1.621
0.45 W	1.350
0.55 W	1.651

Valid **ASTM E 399 Section 8.2.3 (Requirement 1):** The difference between any two of the three crack length measurements (a2, a3, a4) shall not exceed 10% of the average crack length (a).

Maximum Difference	0.035
10% Average Crack Length	0.162

Valid **ASTM E 399 Section 8.2.3 (Requirement 2):** No part of the crack front (Side I, Side II) shall be closer to the machined starter notch than 2.5 % W or 0.050".

Side I Crack Front	0.163
Side II Crack Front	0.152
2.5% W	0.075

Valid **ASTM E 399 Section 8.2.3 (Requirement 3):** Neither surface crack length (a1, a5) shall differ from the average length by more than 15%.

Surface Crack (a1)	1.521
Surface Crack (a5)	1.510
85% of Average Crack	1.378
115% of Average Crack	1.864

Valid **ASTM E 399 Section 8.2.3 (Requirement 4):** The difference between the two surface measurements (a1, a5) shall not exceed 10 % of the average crack length (a).

Difference of a1 & a5	0.011
10% of Average Crack	0.162

Valid **ASTM E 399 Section 8.2.4:** The plane of the crack shall be parallel to both the specimen width and thickness direction within 10° and there shall be no evidence of multiple cracking.

Crack Plane to Width	0
Crack Plane to Thickness	0

Valid **ASTM E 399 Section 8.3:** Static testing load rate (K rate) shall be within the range from 30 to 150 ksi x sqrt(in) / min.

Loading rate (K rate)	89.0

Valid **ASTM E 399 Section 8.4:** The initial slope (linear portion) of the loading curve shall be between 0.7 and 1.5

Slope of Loading Curve	1.32

Valid **ASTM E 399 Section 9.1.3:** The ratio of P_{max}/P_Q shall not exceed 1.10

P_{max}/P_Q Ratio	1.000

Invalid **ASTM E 399 Section 9.1.4:** Specimen ligament size (W-a) shall be greater than $2.5(K_Q/YS)^2$

Specimen ligament (W-a)	1.380
2.5(KQ/YS)^2	3.022

Valid **ASTM E 399 Section A8.3.3:** K_{max}/E shall not exceed 0.002 and K_{max} must not exceed 60% of the K_Q value.

K_{max}/E	0.0008
K_{max}	25.4
60% K_Q	42.2

Valid **ASTM E 399 Section A8.1.3:** The maximum Kmax during any stage must not exceed 80% of the KQ value.

Maximum K_{max}	46.63
80% K_Q	56.29

VALIDITY NOTE:

This test Is NOT VALID per ASTM E-399.
ASTM E399 - 09, 5.1.1 Variation in the value of Klc can be expected within the allowable range of specimen proportions, a/W and W/B. Klc may also be expected to rise with increasing ligament size.

See Validity Note Above.

Partial Certification

Signed for and on behalf of Exova

Victor Landero, Q.M.
EXOVA

Accredited Nadcap Materials Testing Laboratory

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10005 Freeman Avenue, Santa Fe Springs, California 90670
Tel: (562) 946 1721 Fax: (562) 944-8389 www.exova.com

Exova

Customer: CALTRANS
5900 Folsom Road
Sacramento, CA
Material: STEEL
Specification: INFO ONLY

P.O.: 696557
Heat Number: Not Supplied
Heat Code:
Serial Number: I bar
Segment #2 Shank

Date: 2/11/2010
Lab Number: 493596-003
Part Number:
Part Size:
I BAR SEGMENTS

Ref Job# MEC091010
Misc. OAKLAND BRIDGE

CERTIFICATION OF FRACTURE TOUGHNESS TESTING PER ASTM E399-09

SUMMARY OF TEST RESULTS:

Configuration Code	C(T)(L-T)
Test Temperature (°F)	RT
K_Q (ksi x sqrt(in))	68.1
K_{Ic} (ksi x sqrt(in))	See Validity Note Below
K_{Ic} Min	0.0

SPECIMEN DESCRIPTION:

Description	As Received
Product Form	Test Piece
Specimen Type	Compact Specimen C(T)
Notch Type	Straight Through Notch

SPECIMEN DIMENSIONS:

B	thickness (inches)	1.495
W	width (inches)	3.000
an	notch (inches)	1.358
D	holes dia. (inches)	0.751
2H	height (inches)	3.604

PRECRACKING DATA

Precrack Temp.	(°F)	73
Relative Humidity	(%)	37
K(max)	(pounds)	6,000
K(max)	(cycles)	43,000
a1	(inches)	1.522
a2	(inches)	1.585
a3	(inches)	1.609
a4	(inches)	1.590
a5	(inches)	1.524

FRACTURE DATA:

P_Q	(pounds)	16,500
P_{max}	(pounds)	16,850
Yield Strength	(ksi)	55.9
Modulus of E	(msi)	30.0
Strength Ratio		1.551
Fracture Appearance		8% Fraction Oblique

VALIDITY CHECKS FOR THE DETERMINATION OF THE K_{Ic} VALUE:

Valid — **ASTM E 399 Section 7.3.2.1:** Average crack length (a) shall be between 0.45 W and 0.55 W

Average Crack Length (a)	1.595
0.45 W	1.350
0.55 W	1.650

Valid — **ASTM E 399 Section 8.2.3 (Requirement 1):** The difference between any two of the three crack length measurements (a2, a3, a4) shall not exceed 10% of the average crack length (a).

Maximum Difference	0.024
10% Average Crack Length	0.159

Valid — **ASTM E 399 Section 8.2.3 (Requirement 2):** No part of the crack front (Side I, Side II) shall be closer to the machined starter notch than 2.5 % W or 0.050".

Side I Crack Front	0.164
Side II Crack Front	0.166
2.5% W	0.075

Valid — **ASTM E 399 Section 8.2.3 (Requirement 3):** Neither surface crack length (a1, a5) shall differ from the average length by more than 15%.

Surface Crack (a1)	1.522
Surface Crack (a5)	1.524
85% of Average Crack	1.355
115% of Average Crack	1.834

Valid — **ASTM E 399 Section 8.2.3 (Requirement 4):** The difference between the two surface measurements (a1, a5) shall not exceed 10 % of the average crack length (a).

Difference of a1 & a5	0.002
10% of Average Crack	0.159

Valid — **ASTM E 399 Section 8.2.4:** The plane of the crack shall be parallel to both the specimen width and thickness direction within 10° and there shall be no evidence of multiple cracking.

Crack Plane to Width	0
Crack Plane to Thickness	0

Valid — **ASTM E 399 Section 8.3:** Static testing load rate (K rate) shall be within the range from 30 to 150 ksi x sqrt(in) / min.

Loading rate (K rate)	86.6

Valid — **ASTM E 399 Section 8.4:** The initial slope (linear portion) of the loading curve shall be between 0.7 and 1.5

Slope of Loading Curve	1.35

Valid — **ASTM E 399 Section 9.1.3:** The ratio of P_{max}/P_Q shall not exceed 1.10

P_{max}/P_Q Ratio	1.021

Invalid — **ASTM E 399 Section 9.1.4:** Specimen ligament size (W-a) shall be greater than 2.5(KQ/YS)^2

Specimen ligament (W-a)	1.405
2.5(KQ/YS)^2	3.705

Valid — **ASTM E 399 Section A8.3.3:** K_{max}/E shall not exceed 0.002 and K_{max} must not exceed 60% of the K_Q value.

K_{max}/E	0.0008
K_{max}	24.7
60% K_Q	40.8

Valid — **ASTM E 399 Section A8.1.3:** The maximum Kmax during any stage must not exceed 80% of the KQ value.

Maximum K_{max}	45.37
80% K_Q	54.44

VALIDITY NOTE:

This test is NOT VALID per ASTM E-399.
ASTM E399 - 09, 5.1.1 Variation in the value of Klc can be expected within the allowable range of specimen proportions, a/W and W/B. Klc may also be expected to rise with increasing ligament size.

See Validity Note Above.

Partial Certification

Signed for and on behalf of Exova

Victor Landero, O.M.
EXOVA

Accredited
Nadcap
Materials Testing Laboratory

EXOVA
10005 Freeman Avenue, Santa Fe Springs, California 90670
Tel: (562) 946 1721 Fax: (562) 944-8389 www.exova.com

Exova

Customer:	CALTRANS	P.O.:	696557	Date:	2/11/2010
	5900 Folsom Road	Heat Number:	Not Supplied	Lab Number:	493596-004
	Sacramento, CA	Heat Code:		Part Number:	
Material:	STEEL	Serial Number:	I bar	Part Size:	
Specification:	INFO ONLY		Segment #2 Shank		I BAR SEGMENTS
Ref Job#	MEC091010				
Misc.	OAKLAND BRIDGE				

CERTIFICATION OF FRACTURE TOUGHNESS TESTING PER ASTM E399-09

SUMMARY OF TEST RESULTS:

Configuration Code	C(T)(T-L)
Test Temperature (°F)	RT
K_Q (ksi x sqrt(in))	61.3
K_{Ic} (ksi x sqrt(in))	See Validity Note Below
K_{Ic} Min	0.0

SPECIMEN DESCRIPTION:

Description	As Received
Product Form	Test Piece
Specimen Type	Compact Specimen C(T)
Notch Type	Straight Through Notch

SPECIMEN DIMENSIONS:

B thickness (inches)	1.496
W width (inches)	2.998
an notch (inches)	1.359
D holes dia. (inches)	0.750
2H height (inches)	3.603

PRECRACKING DATA

Precrack Temp. (°F)	73
Relative Humidity (%)	37
K(max) (pounds)	6,000
K(max) (cycles)	42,000
a1 (inches)	1.517
a2 (inches)	1.601
a3 (inches)	1.625
a4 (inches)	1.612
a5 (inches)	1.535

FRACTURE DATA:

P_Q (pounds)	14,550
P_{max} (pounds)	14,550
Yield Strength (ksi)	55.9
Modulus of E (msi)	30.0
Strength Ratio	1.380
Fracture Appearance	10% Fraction Oblique

VALIDITY CHECKS FOR THE DETERMINATION OF THE K_{Ic} VALUE:

Valid — **ASTM E 399 Section 7.3.2.1:** Average crack length (a) shall be between 0.45 W and 0.55 W

Average Crack Length (a)	1.613
0.45 W	1.349
0.55 W	1.649

Valid — **ASTM E 399 Section 8.2.3 (Requirement 1):** The difference between any two of the three crack length measurements (a2, a3, a4) shall not exceed 10% of the average crack length (a).

Maximum Difference	0.024
10% Average Crack Length	0.161

Valid — **ASTM E 399 Section 8.2.3 (Requirement 2):** No part of the crack front (Side I, Side II) shall be closer to the machined starter notch than 2.5 % W or 0.050".

Side I Crack Front	0.158
Side II Crack Front	0.176
2.5% W	0.075

Valid — **ASTM E 399 Section 8.2.3 (Requirement 3):** Neither surface crack length (a1, a5) shall differ from the average length by more than 15%.

Surface Crack (a1)	1.517
Surface Crack (a5)	1.535
85% of Average Crack	1.371
115% of Average Crack	1.855

Valid — **ASTM E 399 Section 8.2.3 (Requirement 4):** The difference between the two surface measurements (a1, a5) shall not exceed 10 % of the average crack length (a).

Difference of a1 & a5	0.018
10% of Average Crack	0.161

Valid — **ASTM E 399 Section 8.2.4:** The plane of the crack shall be parallel to both the specimen width and thickness direction within 10° and there shall be no evidence of multiple cracking.

Crack Plane to Width	0
Crack Plane to Thickness	0

Valid — **ASTM E 399 Section 8.3:** Static testing load rate (K rate) shall be within the range from 30 to 150 ksi x sqrt(in) / min.

Loading rate (K rate)	88.4

Valid — **ASTM E 399 Section 8.4:** The initial slope (linear portion) of the loading curve shall be between 0.7 and 1.5

Slope of Loading Curve	1.35

Valid — **ASTM E 399 Section 9.1.3:** The ratio of P_{max}/P_Q shall not exceed 1.10

P_{max}/P_Q Ratio	1.000

Invalid — **ASTM E 399 Section 9.1.4:** Specimen ligament size (W-a) shall be greater than $2.5(K_Q/YS)^2$

Specimen ligament (W-a)	1.385
2.5(KQ/YS)^2	3.003

Valid — **ASTM E 399 Section A8.3.3:** K_{max}/E shall not exceed 0.002 and K_{max} must not exceed 60% of the K_Q value.

K_{max}/E	0.0008
K_{max}	25.3
60% K_Q	36.8

Valid — **ASTM E 399 Section A8.1.3:** The maximum Kmax during any stage must not exceed 80% of the KQ value.

Maximum K_{max}	46.32
80% K_Q	49.02

VALIDITY NOTE:

This test is NOT VALID per ASTM E-399.
ASTM E399 - 09, 5.1.1 Variation in the value of Klc can be expected within the allowable range of specimen proportions, a/W and W/B. Klc may also be expected to rise with increasing ligament size.

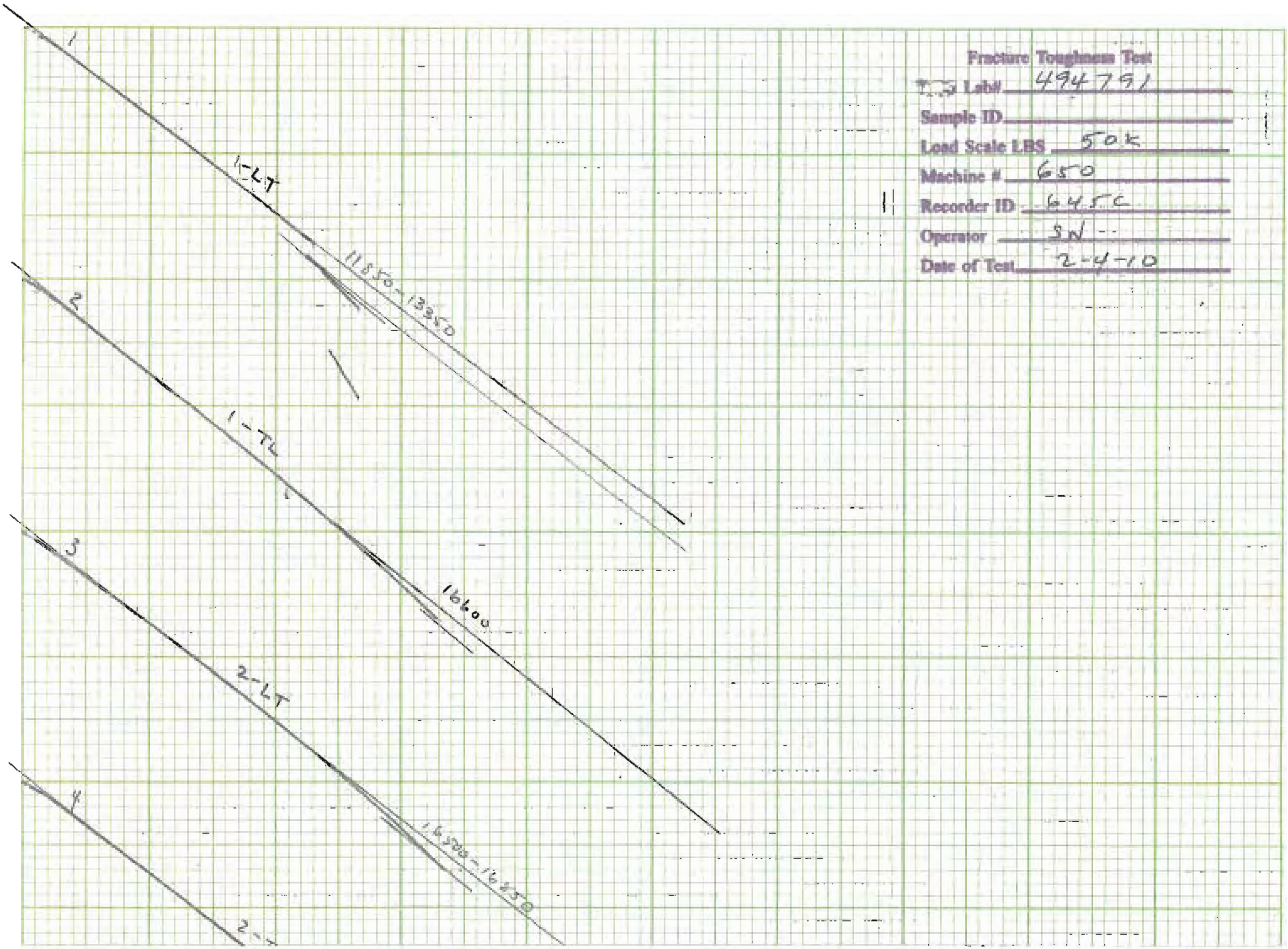
See Validity Note Above.

Partial Certification

Signed for and on behalf of Exova

Victor Landero, O.M.
EXOVA

Accredited Nadcap Materials Testing Laboratory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Load Scale LBS 50K
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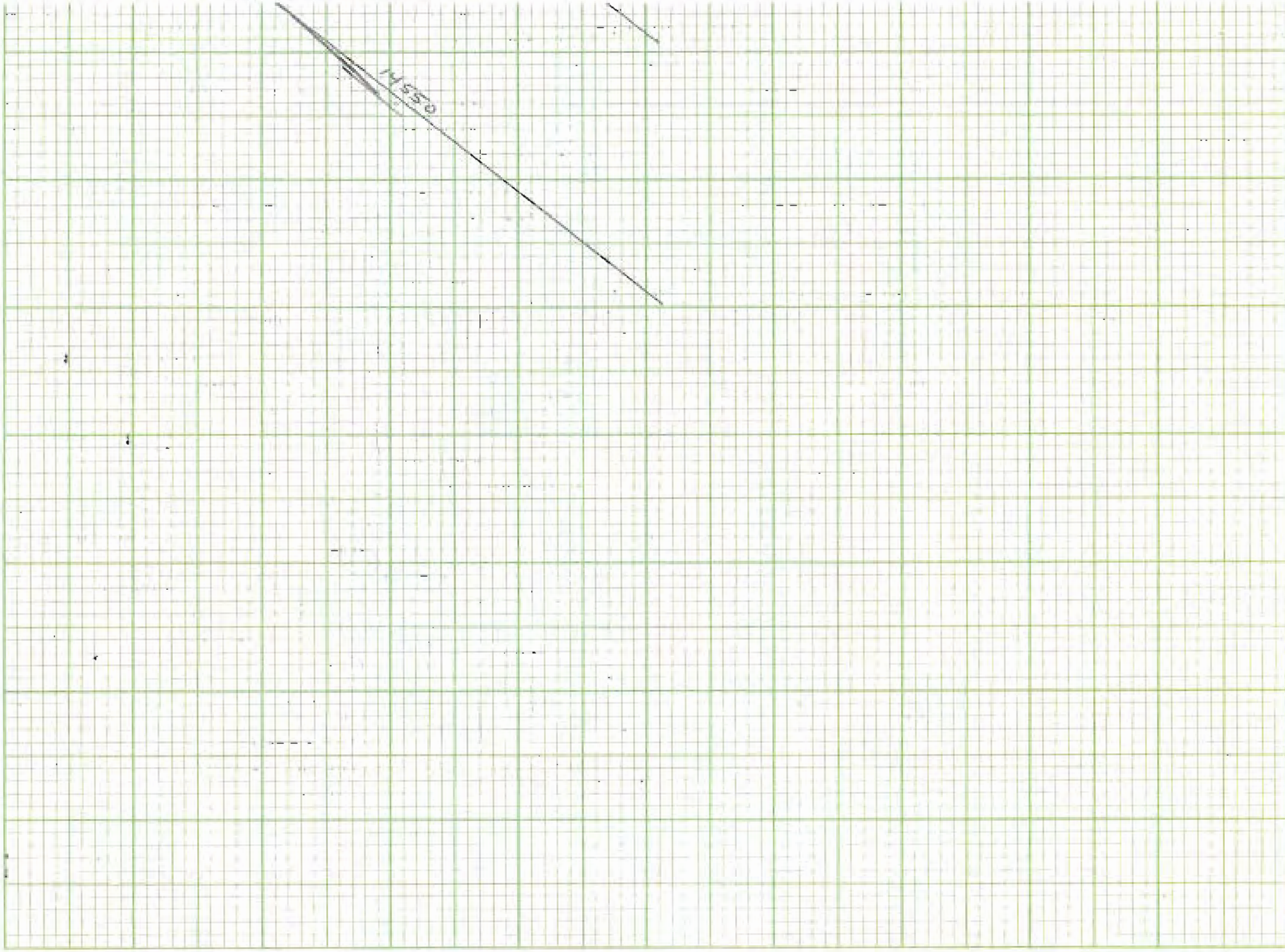
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DYNAMIC MODULUS TESTING

RH Gassner, CNJ
2324 Camon Escondido
Fullerton, CA 92833

MCK325											
Eyebar - Head Segment - 1											
	SAMPLE ID	E	G	POISSONS	LENGTH	DIM2	DIM3	MASS	DENSITY	FLEX	TORS
		(msi)	(msi)	RATIO	(mils)	(mils)	(mils)	(gms)	(lbs/cu in)	(hz)	(hz)
Surface Flexure	596 402F	30.44	11.81	0.289	3259	125.8	1000.3	52.6	0.283	2469	4731
Core Flexure	596 403F	30.70	11.98	0.281	3253	125.6	1000.8	52.6	0.284	2481	4758
Core Flexure	596 404F	30.94	12.02	0.287	3258	124.8	1000.3	52.3	0.283	2468	4732
Surface Flexure	596 405F	30.90	12.07	0.280	3250	125.8	999.6	52.6	0.284	2497	4790
Surface Flexure Transverse	596 405FT	30.30	12.02	0.261	3255	999.6	125.8	52.3	0.282	15590	4790
Core Flexure Transverse	596 404FT	30.58	12.02	0.273	3258	1000	124.8	52.3	0.283	15580	4732
Core Flexure Transverse	596 403FT	30.39	11.98	0.268	3253	1001	125.6	52.6	0.284	15580	4758
Surface Flexure Transverse	596 402FT	30.47	11.81	0.290	3259	1000	125.8	52.6	0.283	15540	4731
Surface Flexure Longitudinal	596 405L	30.42	12.02	0.266	3255	999.6	125.8	52.3	0.282	31230	4790
Core Flexure Longitudinal	596 404L	30.58	12.02	0.272	3258	1000	124.8	52.3	0.283	31190	4732
Core Felxure Longitudinal	596 403L	30.39	11.98	0.268	3253	1001	125.6	52.6	0.284	31130	4758
Surface Flexure Longitudinal	596 402L	30.26	11.81	0.281	3259	1000	125.8	52.6	0.283	31060	4731

MCK800											
Eyebar - Shank Segment - 2											
	SAMPLE ID	E	G	POISSONS	LENGTH	DIM2	DIM3	MASS	DENSITY	FLEX	TORS
		(msi)	(msi)	RATIO	(mils)	(mils)	(mils)	(gms)	(lbs/cu in)	(hz)	(hz)
Full Section Longitudinal	596 408	29.98	11.93	0.257	7967	988.4	1694.3	1719	0.284	3072	6426
Full Section Longitudinal	596 408	29.97	11.93	0.256	7967	1694	988.4	1719	0.284	4853	6426
Full Section Longitudinal	596 408	30.09	11.93	0.261	7967	988.4	1694.3	1719	0.284	12670	6426
Full Section Transverse	596 409	30.05	11.84	0.269	7961	986.9	1694.7	1719	0.285	3072	6395
Full Section Transverse	596 409	30.01	11.95	0.255	7961	1695	986.9	1719	0.285	4859	6426
Full Section Transverse	596 409	30.25	11.95	0.265	7961	986.9	1694.7	1719	0.285	12700	6426

E - Elastic Modulus

G - Rigidity Modulus

Poisson Ration - Ratio of transverse to longitudinal strain in a material under tension

GrindoSonic

A non-destructive materials testing system

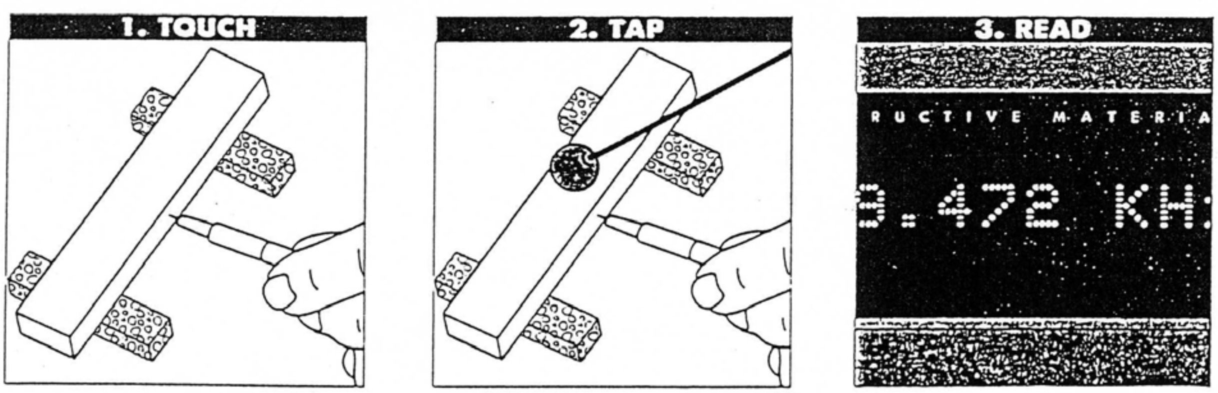
Meets **ASTM C 1259** $1376
Test Method for Dynamic Young's Modulus,
Shear Modulus, and Poisson's Ratio
for Advanced Ceramics by Impulse
Excitation of Vibration.

Measure Resonant Frequency Accurately in Seconds.
Use to Calculate Modulus. Correlate Variations in
Frequency or Modulus with Other Variables
e.g., mechanical properties, microstructure, composition.

How Does It Work?

It "listens" to the vibrations resulting from a simple tap, filters out the noise and harmonics, and displays th fundamental resonant frequency. The tapper may be a plastic bead on a stick or a screwdriver handle. For "listening", a supersensitive piezo-electric (contact) probe is furnished. An alternate device (optional) is a (non-contacting) microphone with equivalent sensitivity.

Modulus is calculated by the optional computer program after input of frequency, dimensions, and weight. the torsional frequency is entered along with that of either the flexural or the longitudinal mode of vibration the program will determine the values of modulus of elasticity (E), modulus of rigidity (G), and Poisson's Ratio (PR).



What Is It Good For?

Obviously, to determine E, G, & PR for design and stress analysis purposes, unconstrained by specimen size limits or hostile environments. Other applications range from process control through design and development to exotic research. Use of the correlations is valid, even when frequency differences are very small, due to the phenomenal precision of the GrindoSonic readings.

It can be used on all rigid materials: metals, ceramics, glass, refractories, cement, concrete, composites, graphite, plastics, wood, rock. Samples range from tiny bars with square or circular cross sections to quarter-dollar size discs to 20 foot long beams.

McKnight Laboratory Inc.

FAILURE ANALYSES SADDLE BAR SUPPORT FOR THE EAST SPAN

Report No. MEC091110

Prepared for:

CALTRANS

November 18, 2009

Prepared by:

McKNIGHT LABORATORY, INC.

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November 18, 2009

CALTRANS
SMI Toll Bridges
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McKNIGHT LABORATORY, INC.
Report No. MEC091110

SUBJECT: FAILURE ANALYSES SADDLE BAR SUPPORT FOR THE EAST SPAN

PROCEDURE

One piece of the saddle bar support rod was submitted to the laboratory for failure analyses. The part submitted was approximately 22" long and exhibited a fracture face on one end of the bar. The bar was photographed in the as received condition and then a section cut thru the bar at approximately ½" below the fracture face so that the fracture face could be examined in the Scanning Electron microscope. In addition, a longitudinal section was prepared below the fracture location and this was examined for microstructure and hardness. In addition, two tensile coupons were prepared, one near the surface of the bar and one at the center of the bar and these were tested for tensile properties. A chemical analyses was also conducted of the bar. In addition, three sets of charpy impact specimens were prepared. One set near the surface of the bar and one at the center of the bar. These were subsequently machined and tested at room temperature to determine the impact strength of the material.

The fracture face was placed in the Scanning Electron microscope and examined to determine the fracture origin and the fracture mode.

EXECUTIVE SUMMARY AND CONCLUSIONS

1. The fracture surface of the saddle bar exhibited a fatigue thumbnail crack at one location on the perimeter of the cross section of the bar. The fatigue crack measured .404" inboard on the plane of fracture and had a length of 1.056". Beyond the fatigue fracture zone the remaining portion of the cross section of the fracture face showed a complete cleavage type fracture which is indicative of brittle fracture over load.

2. The fact that there was one single fatigue thumbnail present on the fracture face indicates that the bar experienced sever unilateral bending stress. This indicates that either the bar was bent during installation or was bearing some place against the blocks or the fixture and put this particular bar in bending. As a result of the unilateral bending stress and vibration on the bar the combination of these two factors caused the fatigue crack just below the radius of the rib on the bar where it interfaced with the fastener or nut in the assembly.

3. The results of the chemical analysis indicated that the steel bar was comparable to AISI 1075 type carbon steel. The chemical analyses results are also consistent with ASTM A-722 which was the governing specification for the bar. However, in the ASTM A-722 specification the chemical analyses only specifies a limitation on the phosphorous of 0.40 and a limitation on the sulfur of .050%. The ASTM A-722 specification covers uncoated high strength steel bars for pre stressing concrete and the only requirements for chemistry is that the material

should have capabilities of developing, based on the chemical composition, the mechanical properties of the finished bar made by the manufacturer. The other stipulation is that the finished bar should have a minimum ultimate tensile strength of 150,000 PSI. The specification also requires yield of 80% of the tensile strength and 7% minimum elongation.

4. Tensile tests conducted on the bar showed that the ultimate tensile strength was 164 to 156,000 PSI which conforms to the requirements of an ASTM A-722.
5. The results of the impact test conducted near the surface of the bar and also the center of the bar yielded an average of 3.5 ft-lbs. at the center of the bar and near the surface of the bar the charpy impact had an average of 8.5 ft-lbs. All of the impact specimens showed complete cleavage fracture and no evidence of any % shear on the plane of fracture on the impact specimens and very low lateral expansion. This is indicative of a relatively brittle material. The fracture mode on the impact specimen was identical to the fracture mode on the overload portion of the bar that failed.
6. Examination of the microstructure of the bar at the fracture origin revealed no indication of any metallurgical defects associated with the plane of fracture or the fracture origin. The microstructure was martensitic and the core hardness was 31 RC. At the surface of the bar at the fracture origin the hardness 34½ to 37 RC.
7. One additional test is to be performed at the Department of Transportation in Sacramento by Rosme Aguilar. The straight piece of one of the bars is to be notched to simulate the fatigue crack on the surface of the bar and pulled in

tension. This information will indicate the level of stress that was on the bar at the time that it fractured.

RESULTS

Fig. 1 illustrates the bar support that was submitted for analyses. Fig. 2 illustrates the end of the bar with the fracture face illustrated at the right side as shown in the photograph. The fracture origin was identified as the 12 O'clock position. Fig. 3 illustrates the appearance of the side of the bar at the 12 O'clock position. Figs. 4, 5, and 6 illustrates the markings on the bar along its length. Fig. 7 illustrates the appearance of the bar at the 3 O'clock position and Fig. 8 illustrates the bar at the 6 O'clock position. The markings on the left side of the protrusions or the ribs on the outside of the bar suggest that the marks made are from interaction with the fastening nut on the assembly. Fig. 9 illustrates the appearance of the bar at the 9 O'clock position. Fig. 10 illustrates the appearance of the fracture face and Figs. 11 and 12 show additional views of the fracture face. The fracture at the origin shows the appearance of the thumbnail shape of the fracture which is indicative of a fatigue failure. This fracture face was later examined in the Scanning Electron microscope. Fig. 14 illustrates the location of two transverse cuts that were made in the bar. The cut to the right was made to remove the fracture face portion and the second cut was made to remove a longitudinal oriented microsection thru the entire bar. These sections are further shown in Fig. 15. Figs. 16, 17 and 18 show additional views of the fracture origin and the appearance of oxidation and discoloration over the depth of the fatigue crack. The fatigue crack depth at this location measured .404" inboard on plane of fracture and the length of the fatigue crack zone measured 1.065". At this location the diameter of the bar at the plane of fracture measured 1.844". The arrow in Fig. 18 illustrates the primary fatigue crack origin location. One can see radiating beach marks propagating away from this particular point. A small secondary fatigue crack is indicated by the small arrow shown in the left in Fig. 18. Fig. 19 illustrates an additional view of the fatigue fracture origin area. Figs. 20, 21 and 22 illustrate the appearance of the markings at the corner of the rib coincident with the fracture origin location. The oxide in this area was chipped and cracked apparently due to the interaction with the thread zone in the nut. Figs. 23, 24, 25 and 26 illustrate the appearance of the mill scale oxide and the cracking of the mill scale below the fracture origin location. This was caused by bearing against the threads of the nut. Fig. 27 illustrates the fracture origin location which shows evidence of rubbing degradation and also rubbing on the plane of fracture. Fig. 28 illustrates the appearance of the fracture origin. Fig. 29 illustrates the appearance of the fracture surface which shows evidence of rubbing and oxidation. Fig. 30 illustrates the appearance of the fracture inboard from the fracture origin which again shows significant evidence of rubbing degradation and oxidation. Fine fatigue striations could not be identified in this area although the fracture mode is fatigue. The first zone at the plane of fracture origin is shown in Fig. 17 and Fig. 31. Fig. 32 illustrates the appearance of the fracture in zone 2 which is the second step in the fatigue zone. Fig. 33 and 34 illustrate definite evidence of fatigue cracking damage in this area. Fig. 35

illustrates the transition from the end of the fatigue zone and progressing into the overload region, zone 3, on the fracture. One can see a line running across the photograph which defines the end of the fatigue zone. Fig. 36 illustrates the appearance of the fatigue fracture towards the end of the fatigue crack and Figs. 37 and 38 show additional higher magnification views of the fatigue zone which shows evidence of cracking and fatigue striations. Figs. 39 and 40 illustrate progressively the appearance of the fracture moving from the end of the fatigue zone across the plane of fracture and Fig. 41 illustrate the appearance of the fracture approximately ¾ of the way across the fracture face on the overload region. The fracture mode in the overload region was clearly cleavage fracture which indicates brittle propagation beyond the fatigue zone. At the other side of the cross section 180° away from the fatigue fracture origin there was evidence of a very small shear lip which exhibited dimple rupture. This is illustrated in Fig. 42.

MICROSTRUCTURE ANALYSES

Fig. 43 illustrates cross section of the bar below the plane of fracture showing the ribs on the two sides. Photographs of the microstructure were taken at locations 1, 2 and 3 as illustrated in Fig. 43 and these are illustrated in Figs. 44, 45 and 46. In all cases the microstructure was martensitic but the microstructure near the surface was more fully martensitic and contains less ferrite than the microstructure at location 2 and 3. Microhardness test were conducted along the rib area near the outside surface and at these locations the hardness was 33-35.5 RC. In the radius area of the rib the hardness was RC 36. In addition, a microhardness survey was conducted from the surface inboard from the flat area between the ribs progressing across the section. The hardness at a depth .002" was 27 RC and at .006" the hardness was 38 RC. At a depth of .050" the hardness was RC 39 and at a depth of approximately .800" the hardness was RC 33.

A microsection was also prepared exactly at the fracture origin location and 90° to the plane of fracture. Fig. 47 illustrates the fracture origin at 50X and Fig. 48 illustrates the appearance of the fracture origin in the unetched condition at 500X. There was no indication of any metallurgical defects or cracks within the bar and there were no secondary cracks below the plane of fracture in the material. Figs. 49 and 50 illustrate the appearance of the martensitic microstructure at the fracture origin which again shows no evidence of any metallurgical defects. The hardness at the origin was checked by microhardness technique and showed a hardness of 37 to 34.5 RC. At the center of the bar the minimum core hardness was 31 RC.

The fatigue fracture was also analyzed by EDS technique and spectrums 1, 2, and 3 illustrate the analyses of the surface of the fatigue fracture in zone 1 and zone 2 and zone 3 which is the overload portion of the fracture. In the oxidized and rubbed area of the fatigue zone there was evidence of iron and manganese attributed to the base metal and also trace amounts of Aluminum , silicon, sulfur, chlorine, potassium which would be elements of contamination on the plane of fracture during fatigue crack propagation.

CHEMICAL ANALYSES

A chemical analysis of the bar was also conducted. The results of the chemistry are listed below:

Carbon	0.73
Manganese	0.7
Phosphorus	0.016
Sulfur	0.019
Silicon	0.26
Chromium	0.02
Nickel	0.02
Molley	0.01
Copper	0.04
Iron	BAL

This analyses is consistent with the analyses of a typical AISI 1075 type material and appears to be consistent with the ASTM A-722 which was identified as the specification for the bar.

The results of the tensile test and the impact test are shown in the attached document from Stork Laboratory. Near the surface of the bar the ultimate tensile strength was 164 KSI and at the center of the bar the ultimate tensile strength was 156 KSI. The Charpy impact test results showed impact strengths of 3.5 to 4 ft-lbs. in the center area of the bar and near the surface of the bar the impacts strengths vary from 7.5 to 10 with an average of 8.5 ft-lbs. There was no evidence of any % shear failure on the impact specimen and the lateral expansion was extremely low on both specimens. This is indicative of brittle low impact strength steel. These values of the impact test definitely indicate that the material is very notch sensitive and explains why there was a very large brittle over load area on the plane of fracture that resulted after the development of a relatively shallow fatigue fracture zone. The fracture in this case is indicative of the fact that there was an unilateral bending stress imposed on the bar at the time that the fatigue crack initiated and propagated.

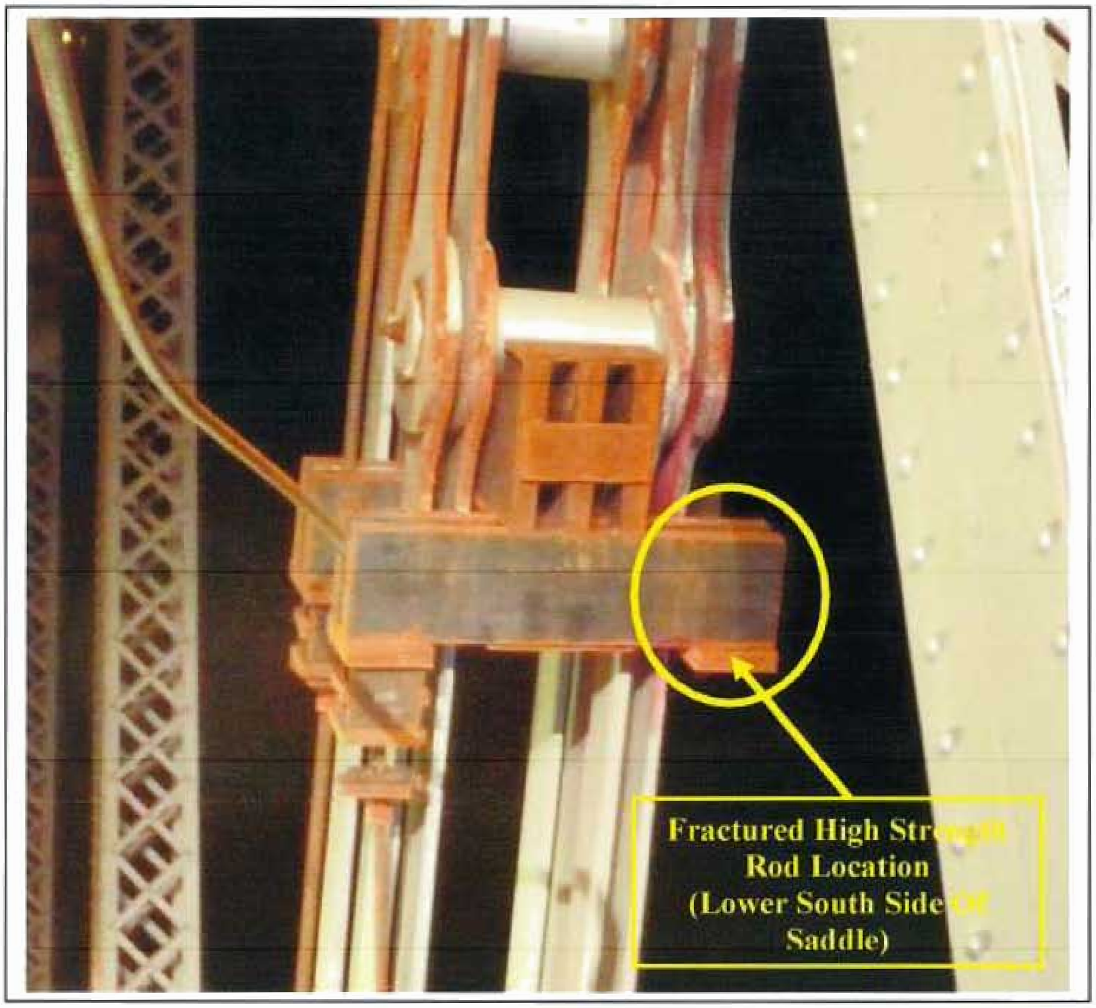


Fig. A Fractured Rod location.

Fig. 1 As received failed support rod from east span.

Fig. 2 As received failed support rod from east span. 12 O'clock position, fracture origin.

Fig. 3 As received failed support rod from east span. 12 O'clock position, fracture origin.

Fig. 4 As received failed support rod from east span. 12 O'clock position, fracture origin.

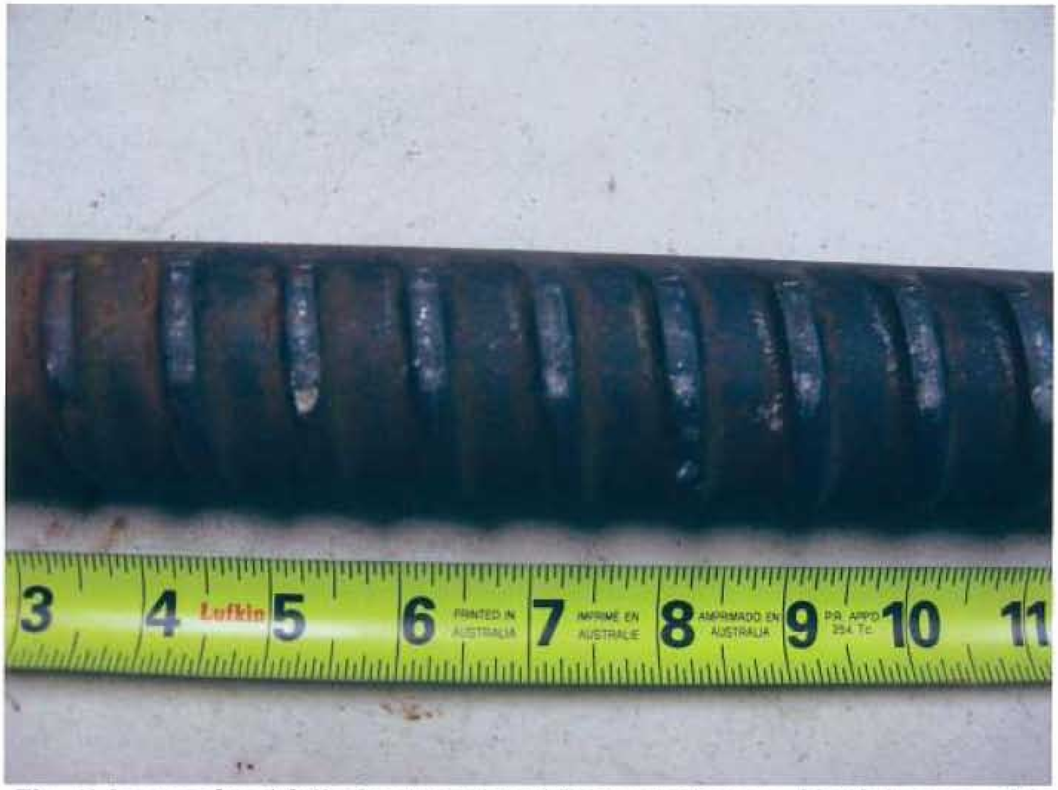


Fig. 5 As received failed support rod from east span. 12 O'clock position.

Fig. 6 As received failed support rod from east span. 12 O'clock position.

Fig. 7 As received failed support rod from east span. 3 O'clock position.

Fig. 8 As received failed support rod from east span. 6 O'clock position.

Fig. 9 As received failed support rod from east span. 9 O'clock position.

Fig. 10 As received failed support rod from east span. Fracture sureface.

Fig. 11 As received failed support rod from east span. Fracture sureface.

Fig. 12 As received failed support rod from east span. Fracture sureface.

Fig. 13 As received failed support rod from east span. Fracture sureface.

Fig. 14 As received failed support rod from east span. Location where longitudinal microsection was made.

Fig. 15 As received failed support rod from east span. Location where longitudinal microsection was made.

Fig. 16 As received failed support rod from east span. Fracture surface.

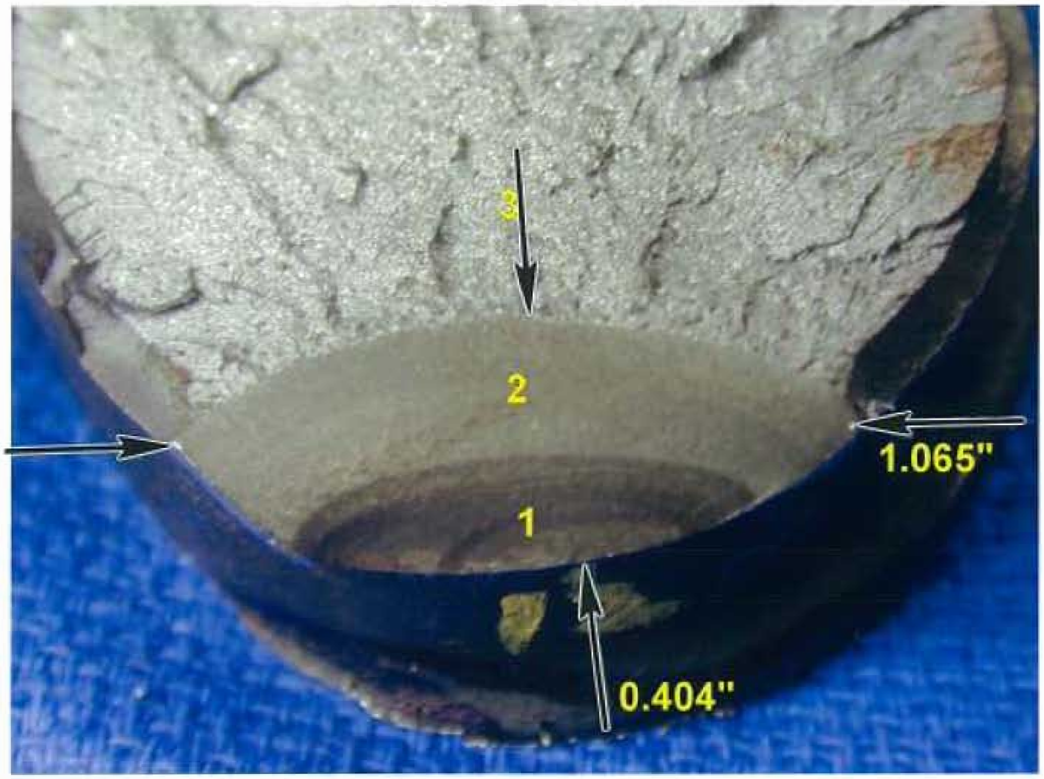


Fig. 17 As received failed support rod from east span. Fracture origin.

Fig. 18 As received failed support rod from east span. Fracture origin.

Fig. 19 As received failed support rod from east span. Fracture origin.

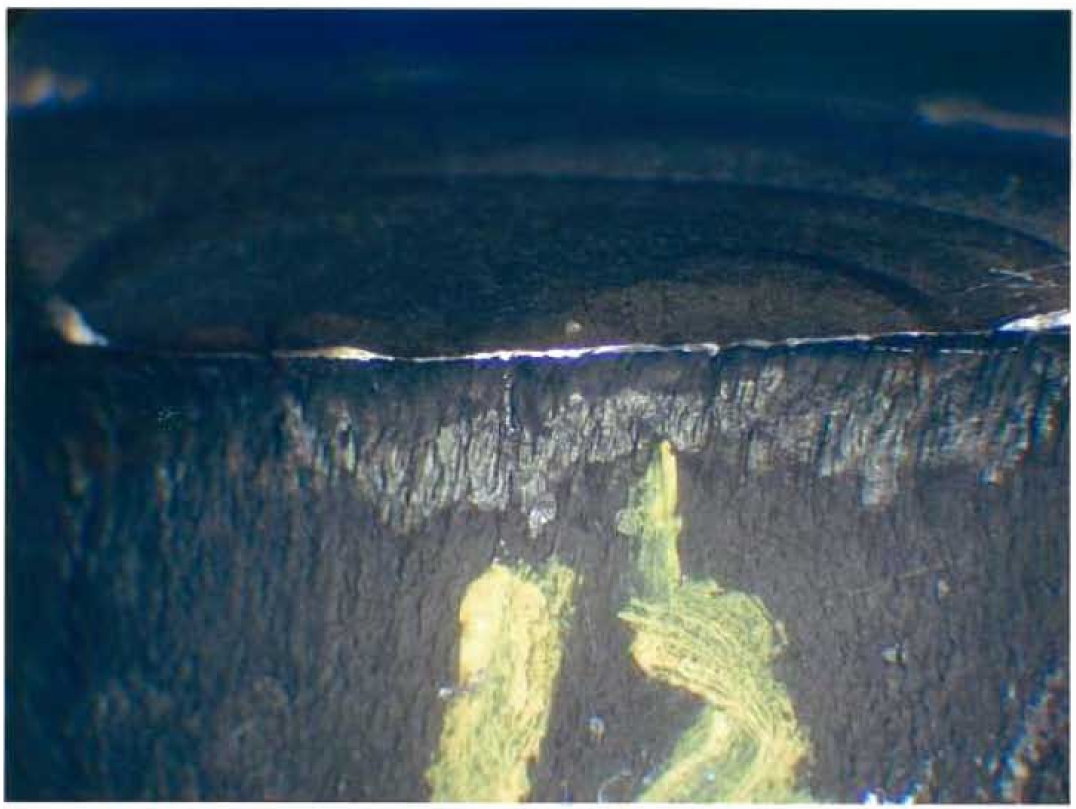


Fig. 20 As received failed support rod from east span. Fracture origin.

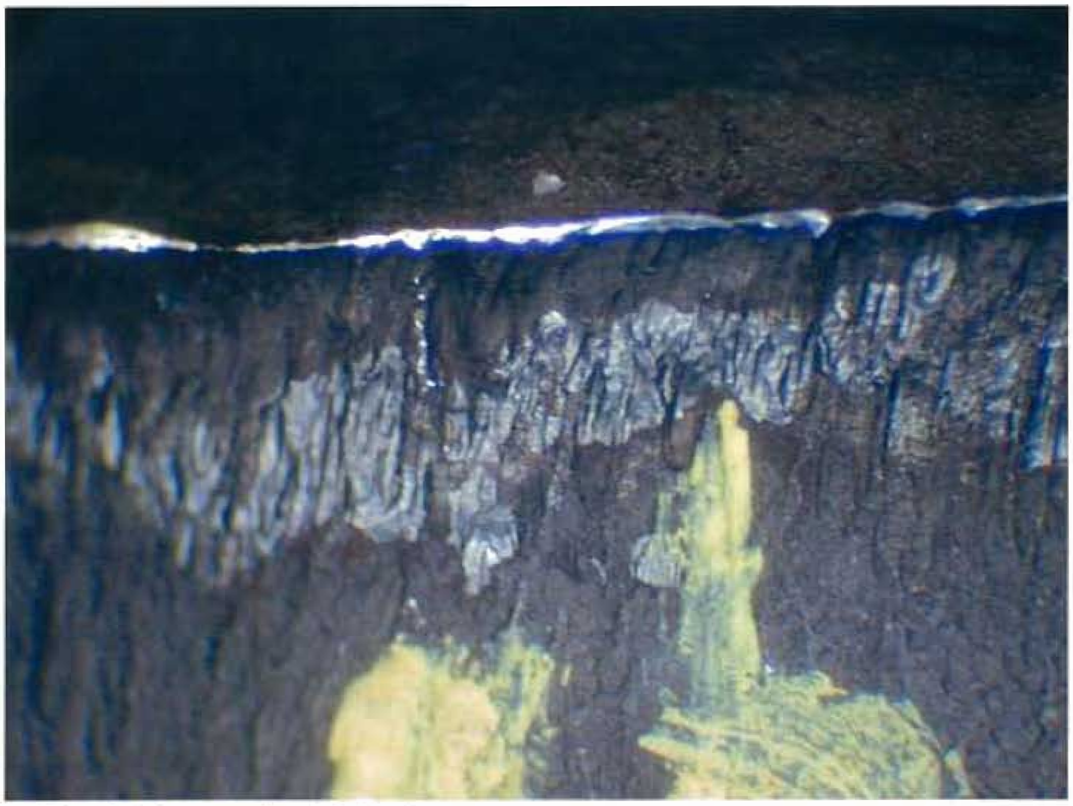


Fig. 21 As received failed support rod from east span. Fracture origin.

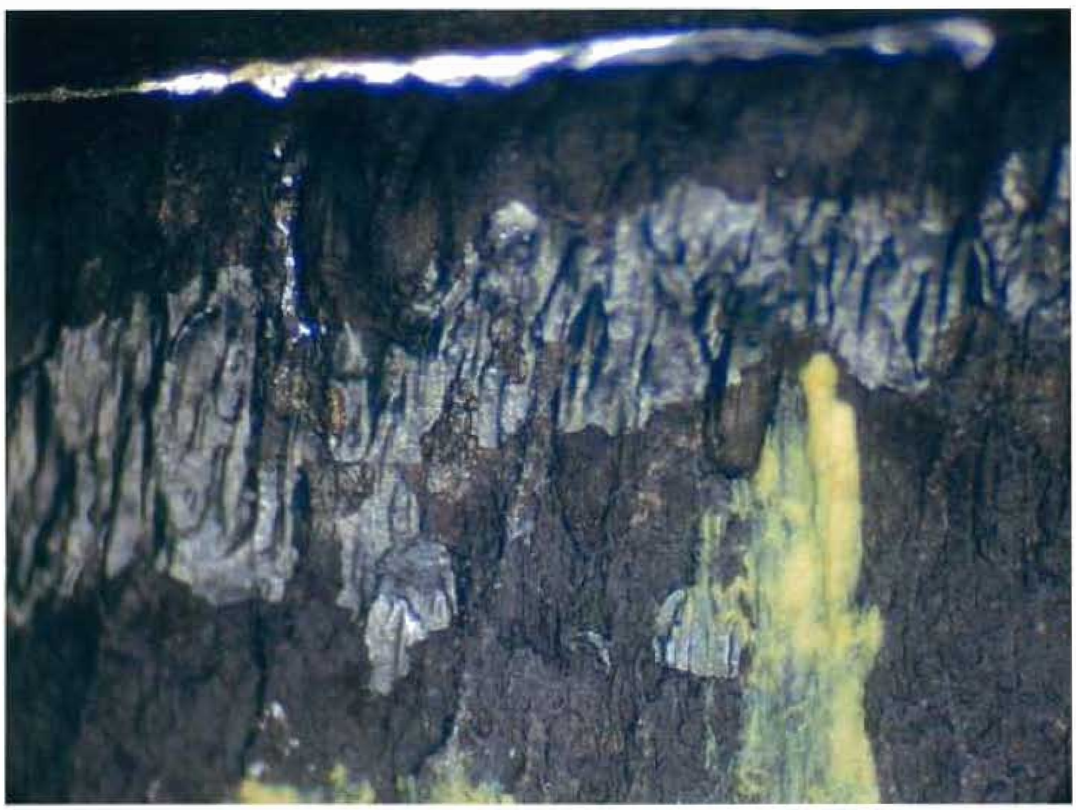


Fig. 22 As received failed support rod from east span. Fracture origin.

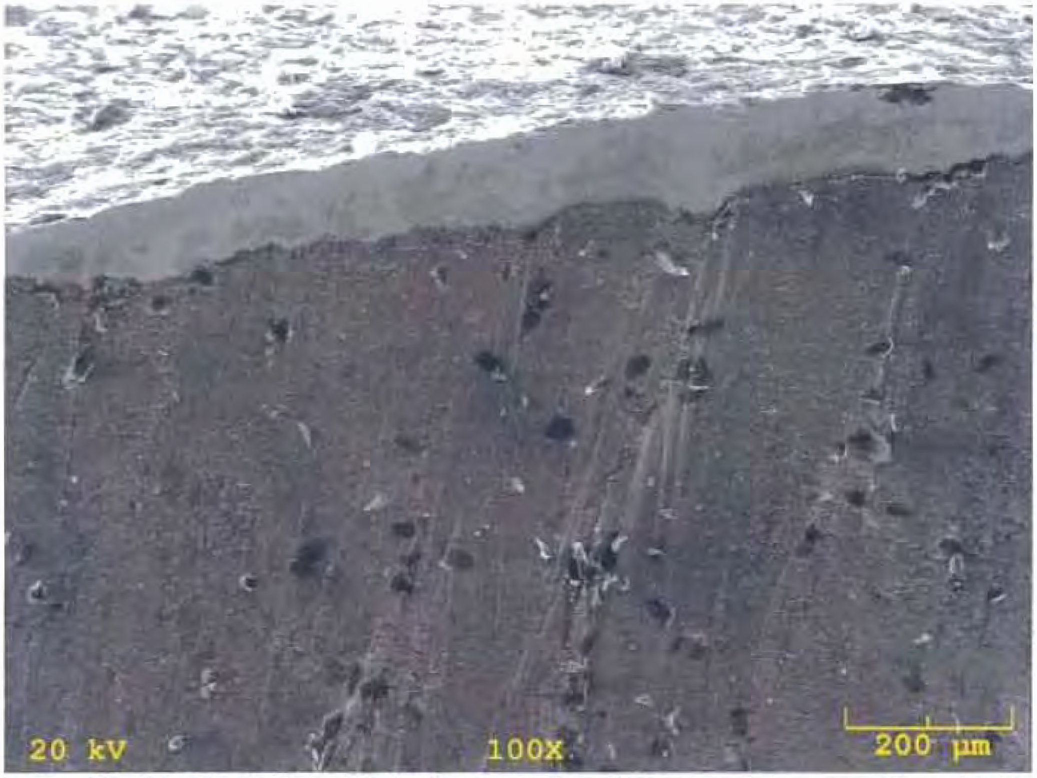


Fig. 23 S.E.M photo of failed support rod from east span. Edge, below fracture origin. 100X.

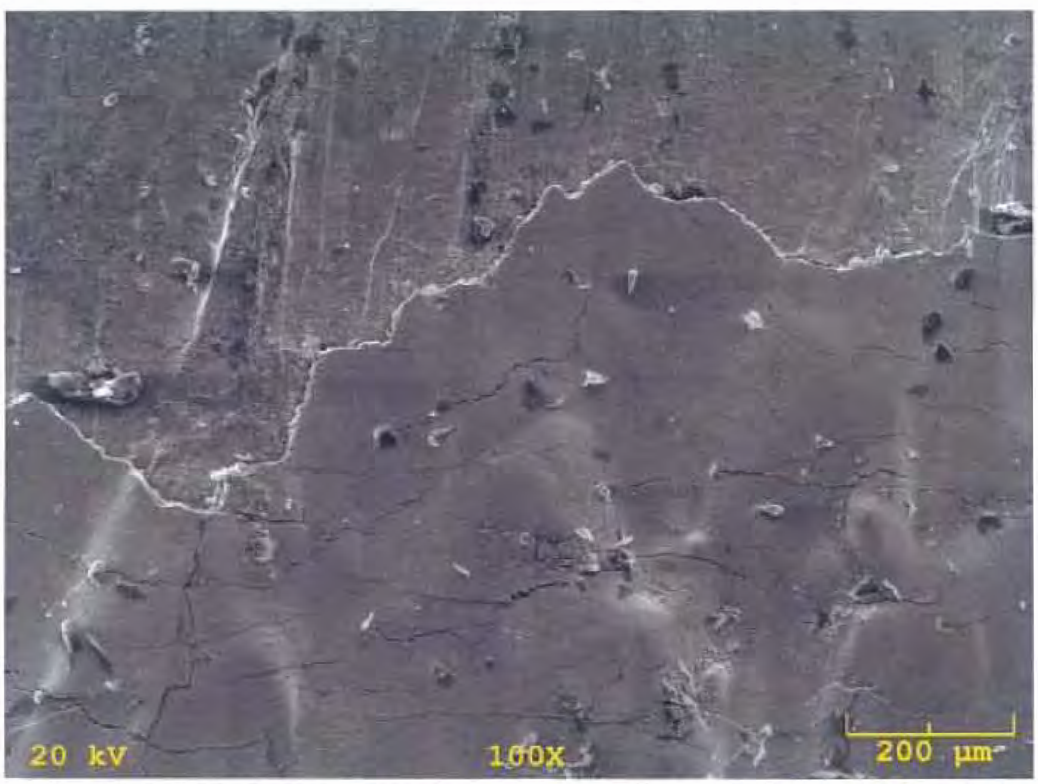


Fig. 24 S.E.M photo of failed support rod from east span. Edge, below fracture origin. 100X.

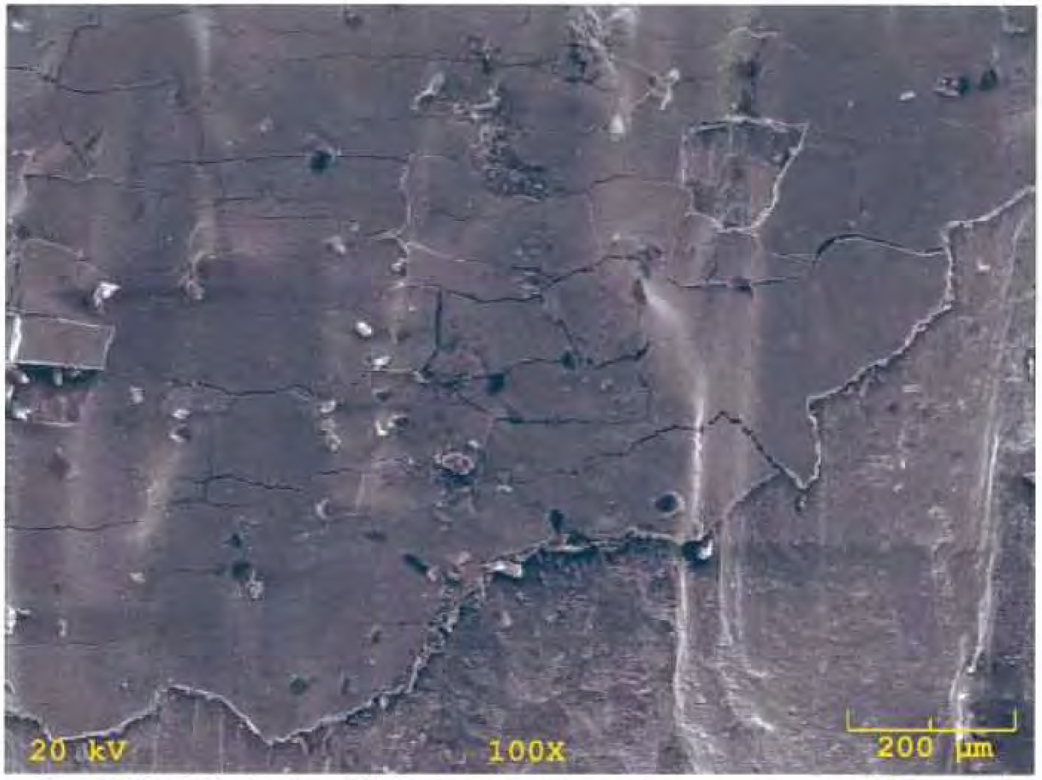


Fig. 25 S.E.M photo of failed support rod from east span. Edge, below fracture origin. 100X.

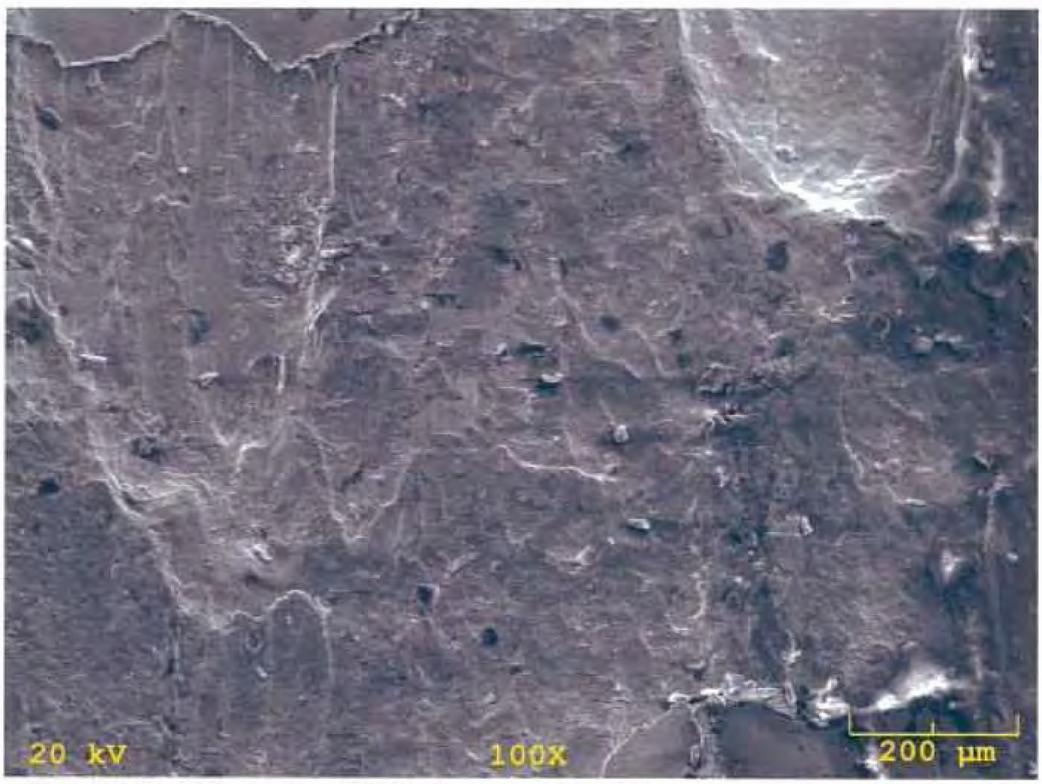


Fig. 26 S.E.M photo of failed support rod from east span. Edge, below fracture origin. 100X.

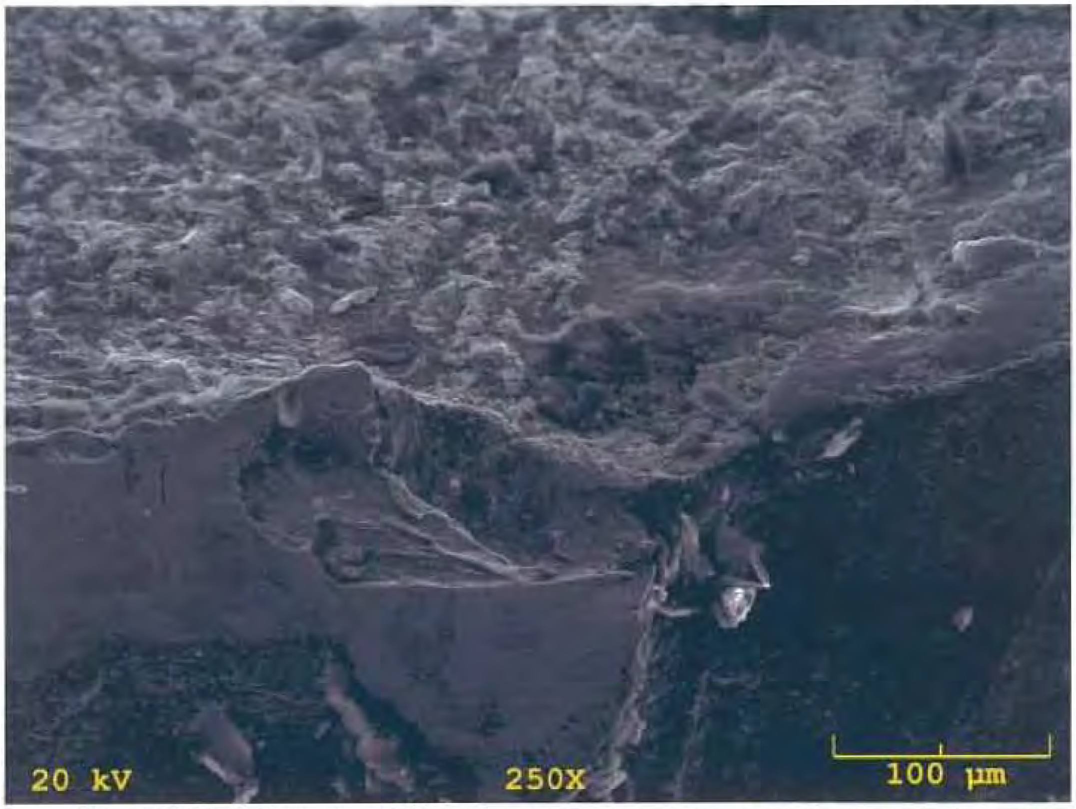


Fig. 27 S.E.M photo of failed support rod from east span. Edge, at fracture origin. 250X.

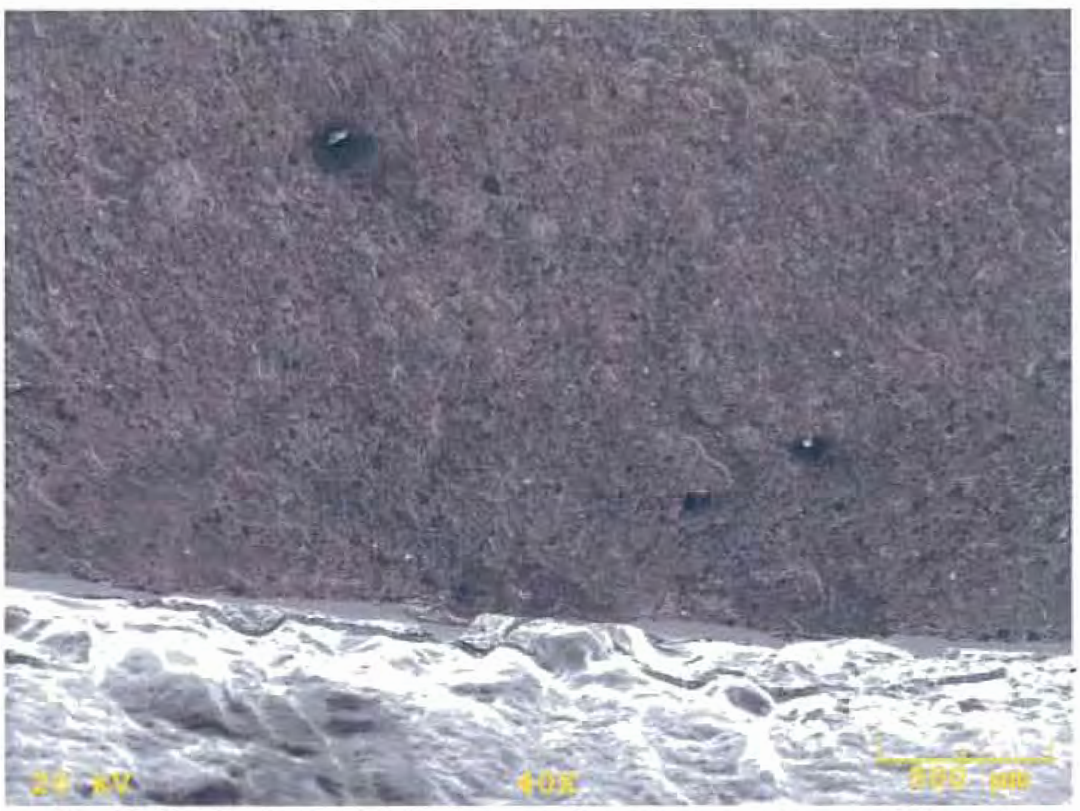


Fig. 28 S.E.M photo of failed support rod from east span. Edge, at fracture origin. 40X.

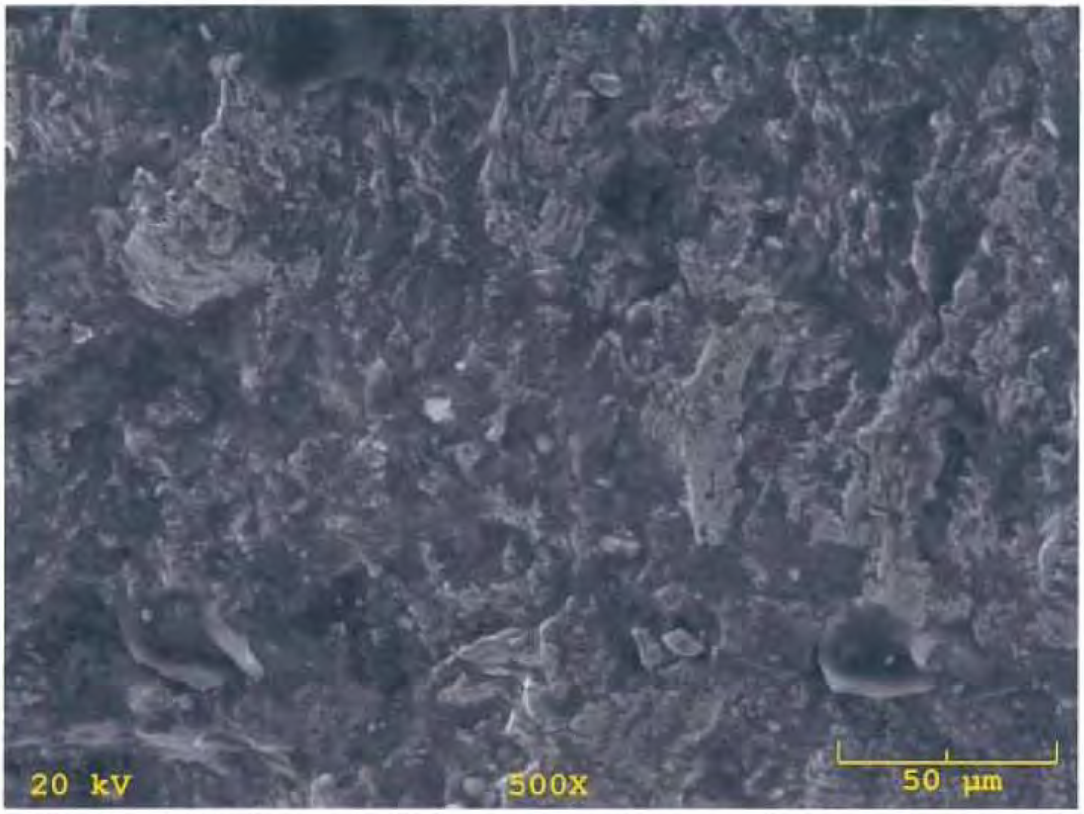


Fig. 29 S.E.M photo of failed support rod from east span at fracture origin. 500X.

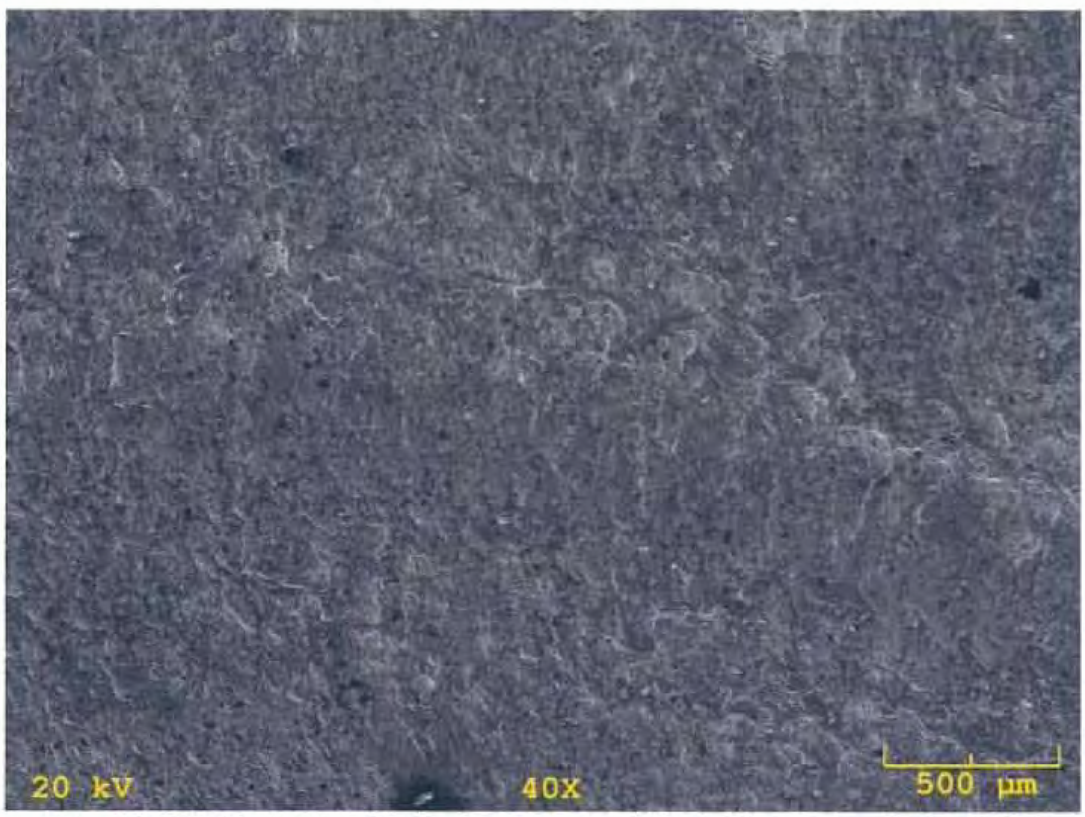


Fig. 30 S.E.M photo of failed support rod from east span. inboard from fracture origin. 40X.

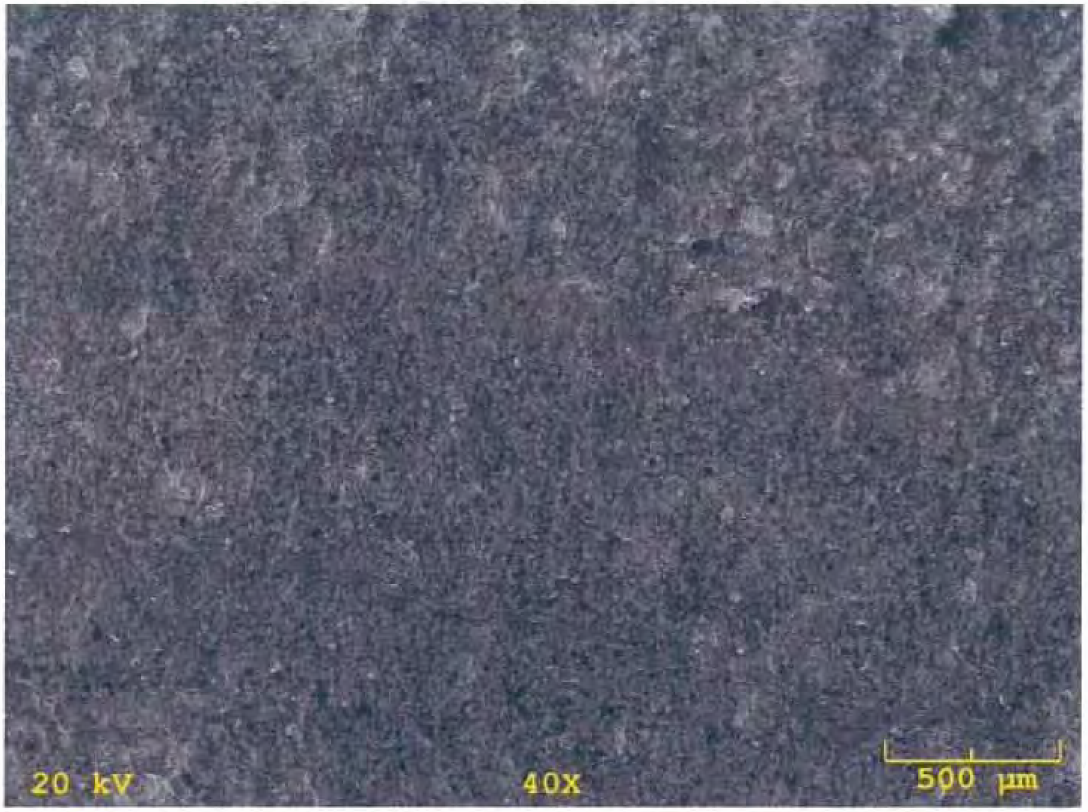


Fig. 31 S.E.M photo of failed support rod from east span at fracture origin. Zone 1. 40X.

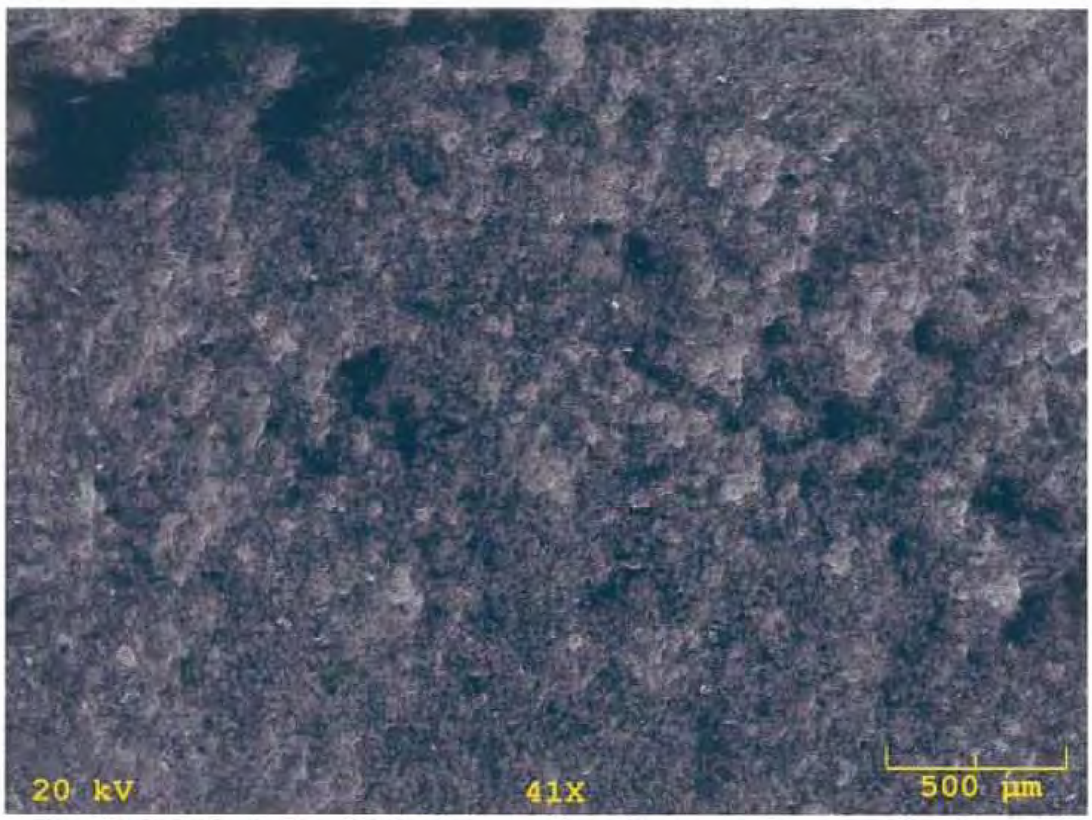


Fig. 32 S.E.M photo of failed support rod from east span at fracture origin. Zone 2. 41X.

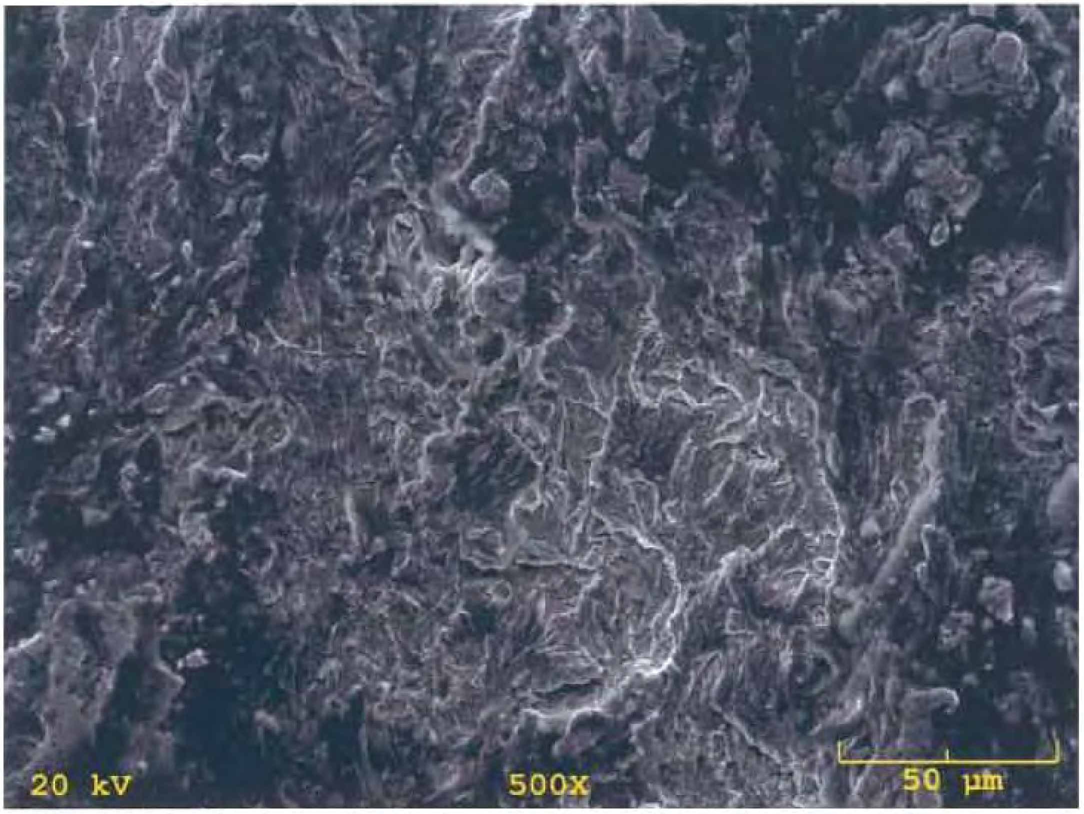


Fig. 33 S.E.M photo of failed support rod from east span at fracture origin. Zone 2. 500X.

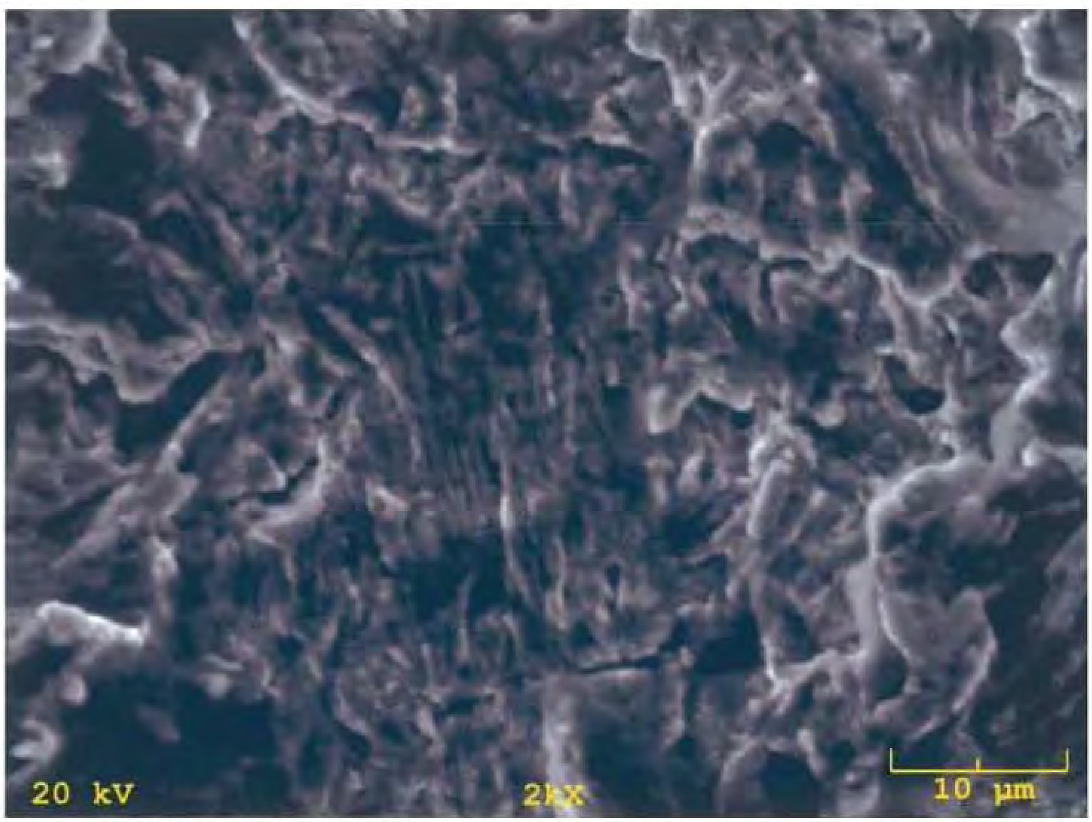


Fig. 34 S.E.M photo of failed support rod from east span at fracture origin. Zone 2. 2000X.

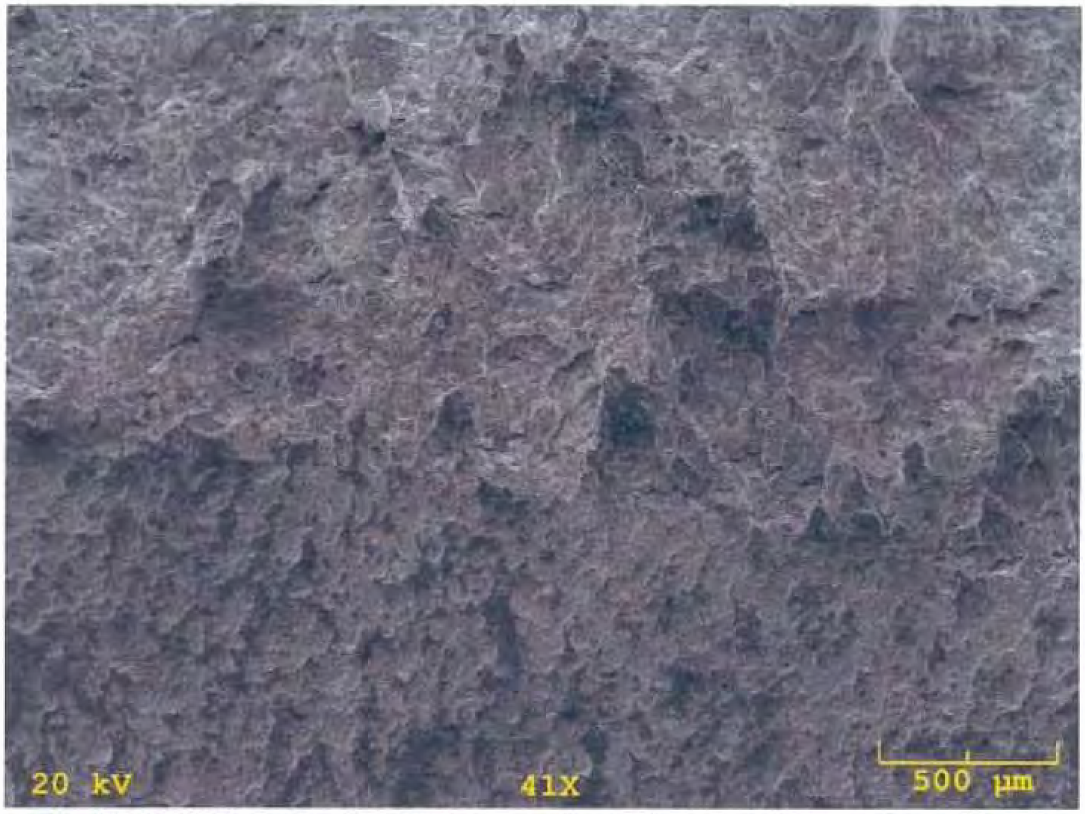


Fig. 35 S.E.M photo of failed support rod from east span. Transition Zone 2-3. 41X.

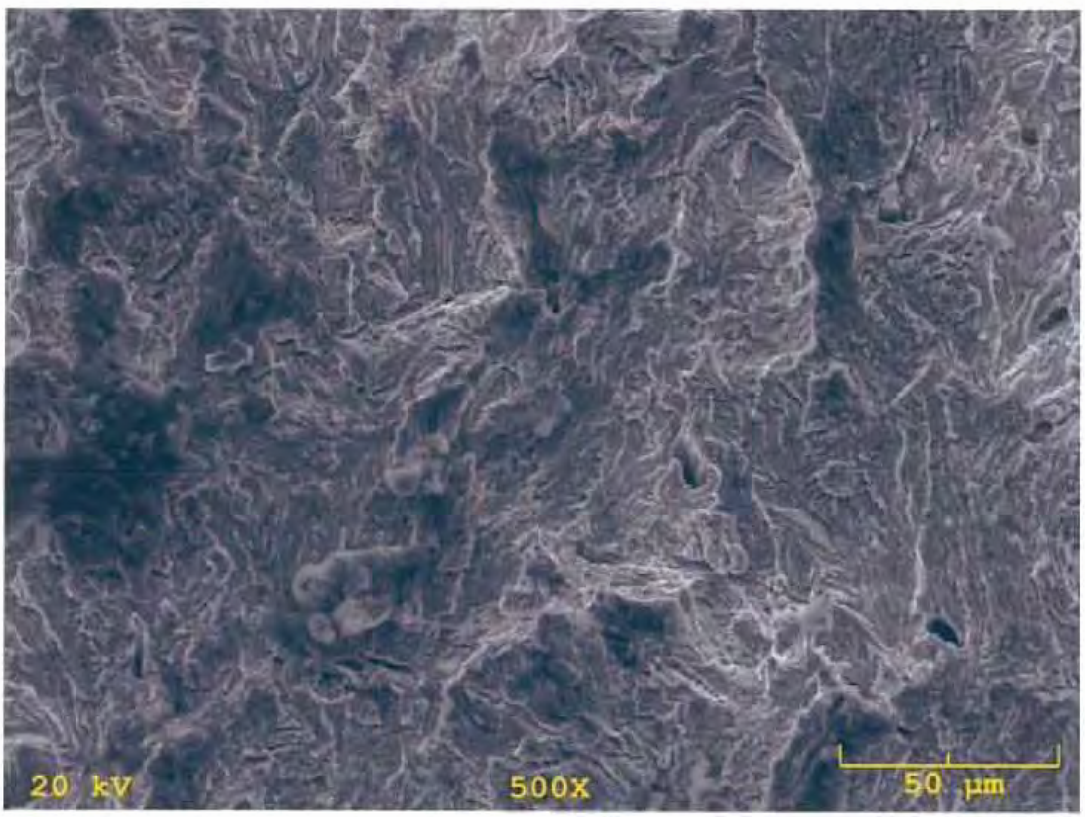


Fig. 36 S.E.M photo of failed support rod from east span at fracture surface. Fatigue. Zone 2. 500X.

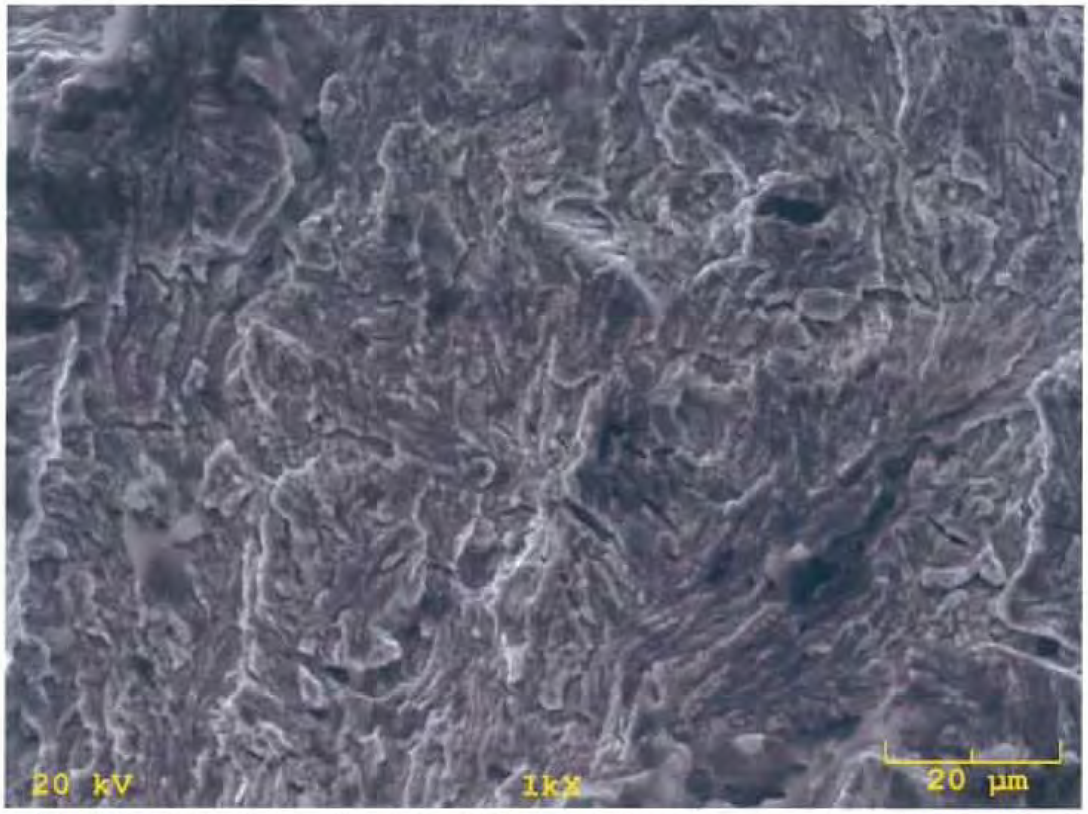


Fig. 37 S.E.M photo of failed support rod from east span at fracture surface. Fatigue. Zone 2. 1000X.

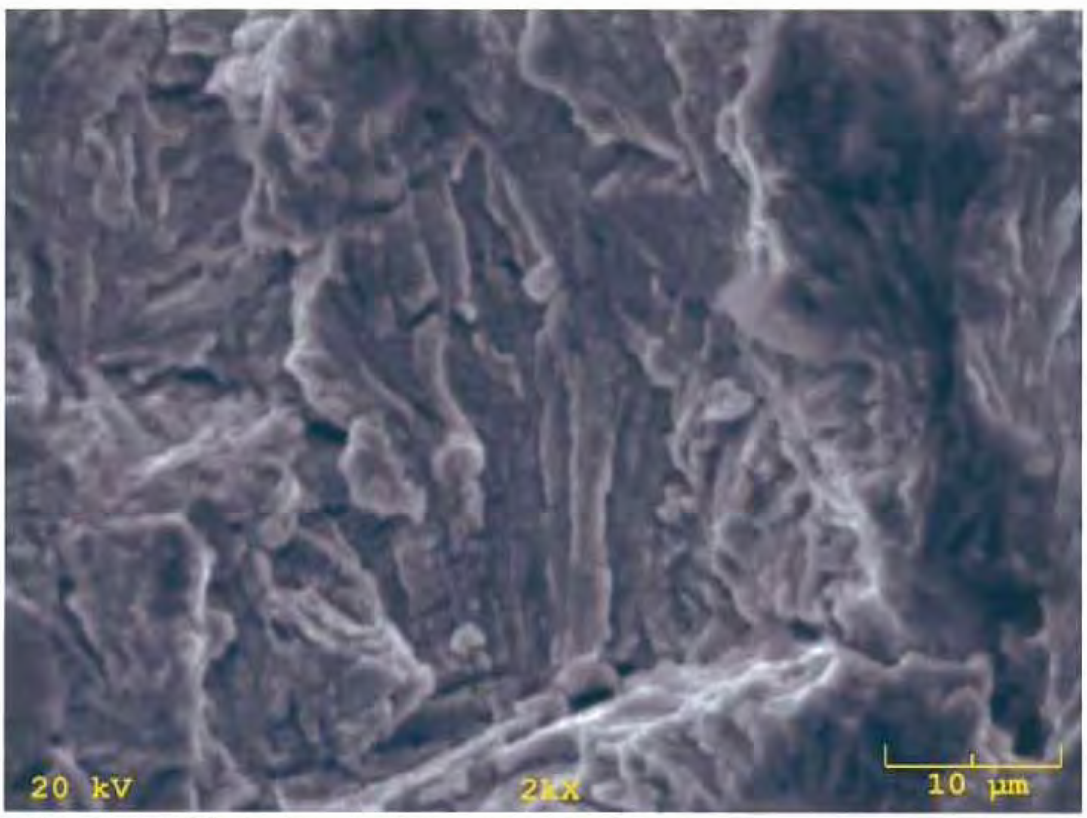


Fig. 38 S.E.M photo of failed support rod from east span at fracture surface. Fatigue. Zone 2. 2000X.

Fig. 39 S.E.M photo of failed support rod from east span on fracture surface. Above zone 2 in zone 3. 500X.

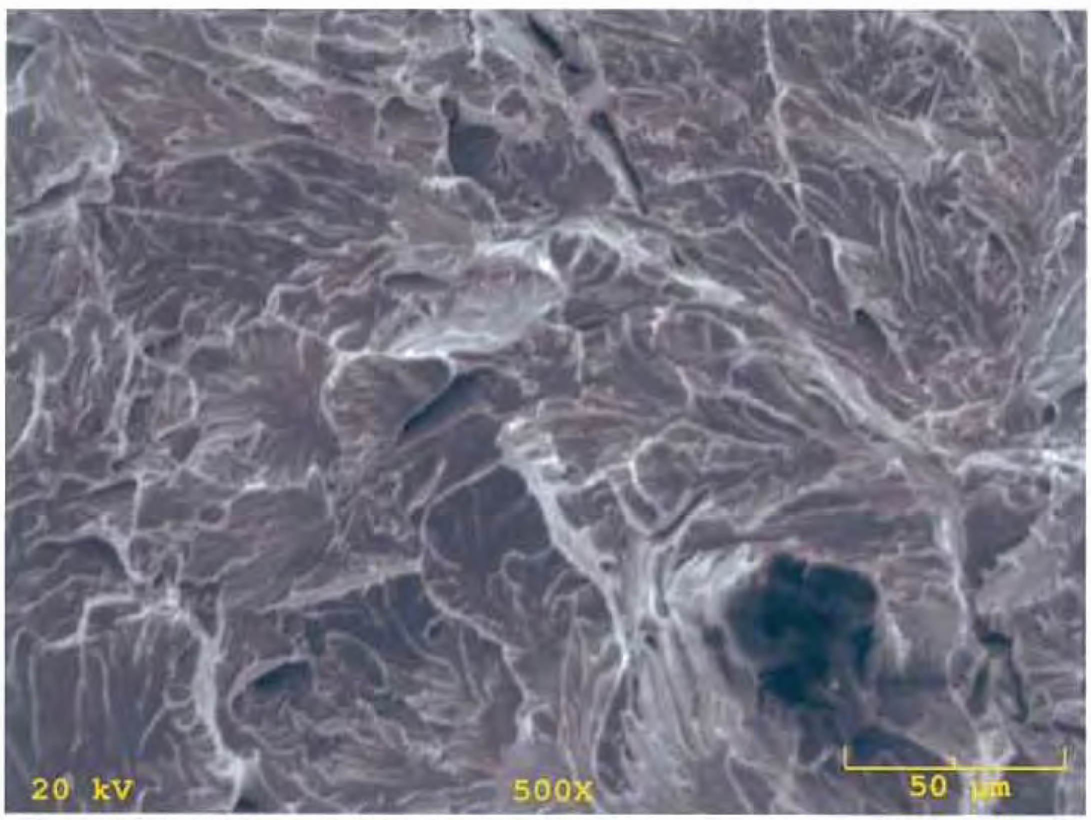


Fig. 40 S.E.M photo of failed support rod from east span middle of fracture surface. 500X.

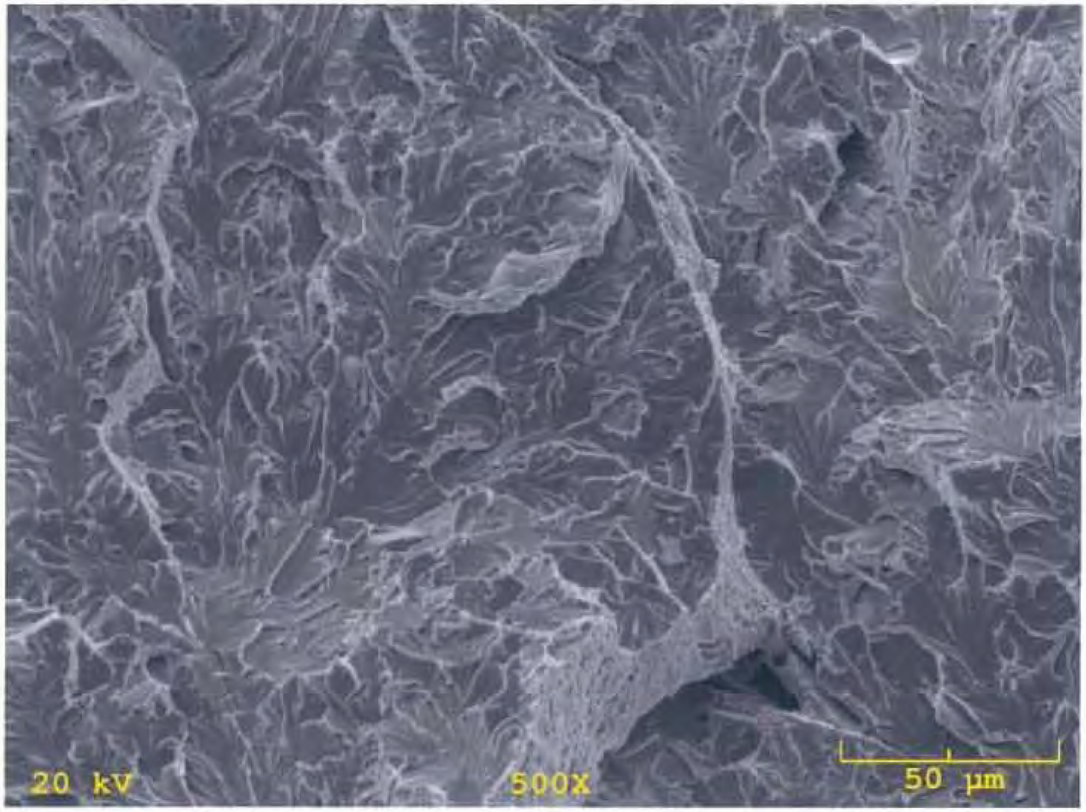


Fig. 41 S.E.M photo of failed support rod from east span 3/4 across on fracture surface. 500X.

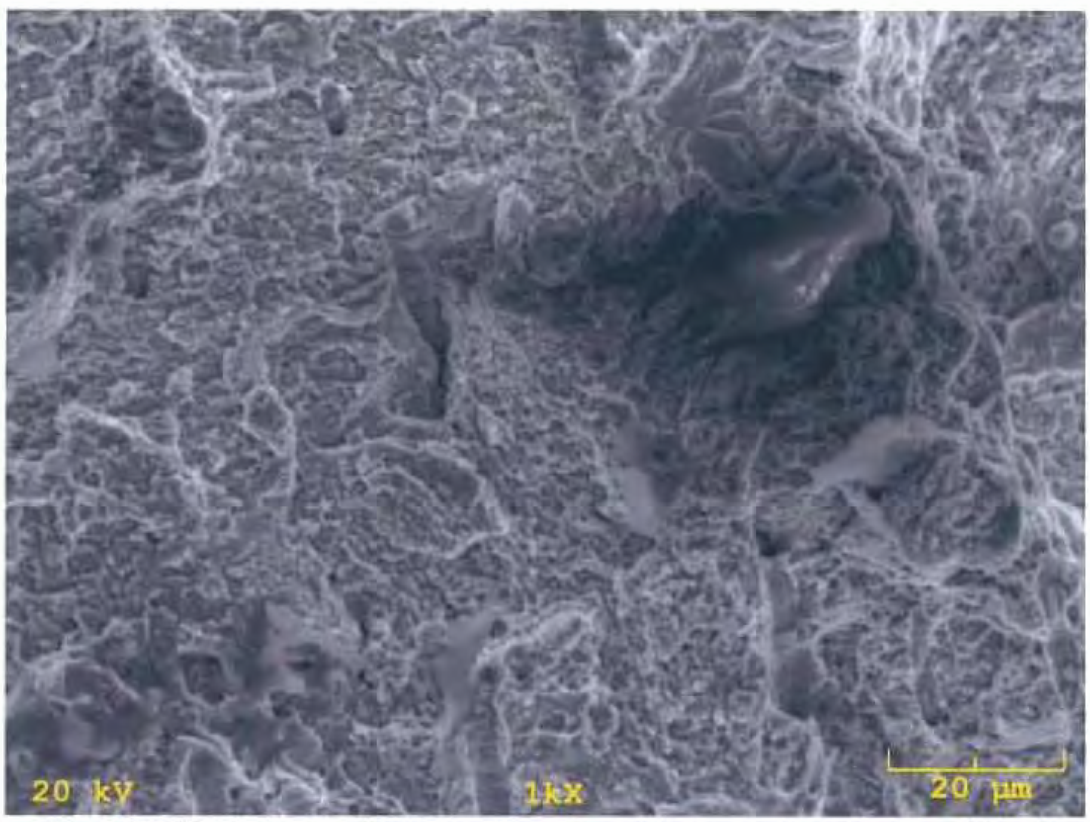


Fig. 42 S.E.M photo of failed support rod from east span shear lip edge, 1000X.

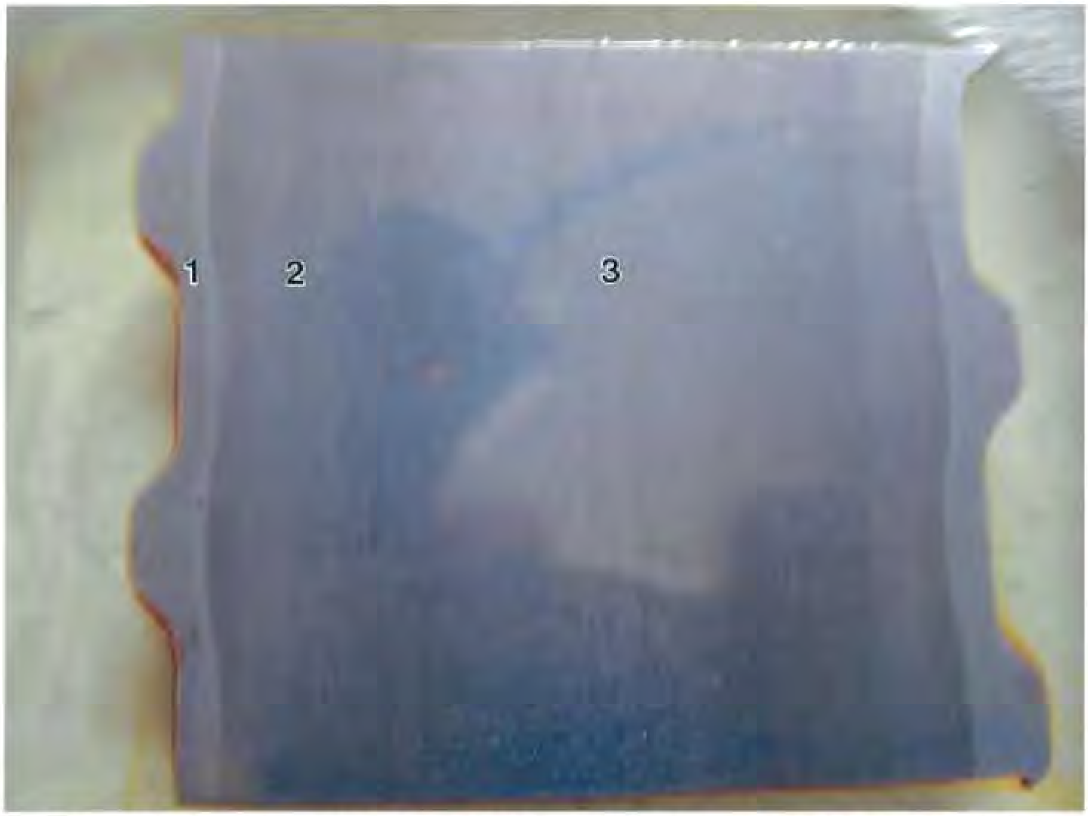


Fig. 43 Longitudinal cross-section of failed support rod from east span. Section taken out below fracture origin shown in fig. 15.

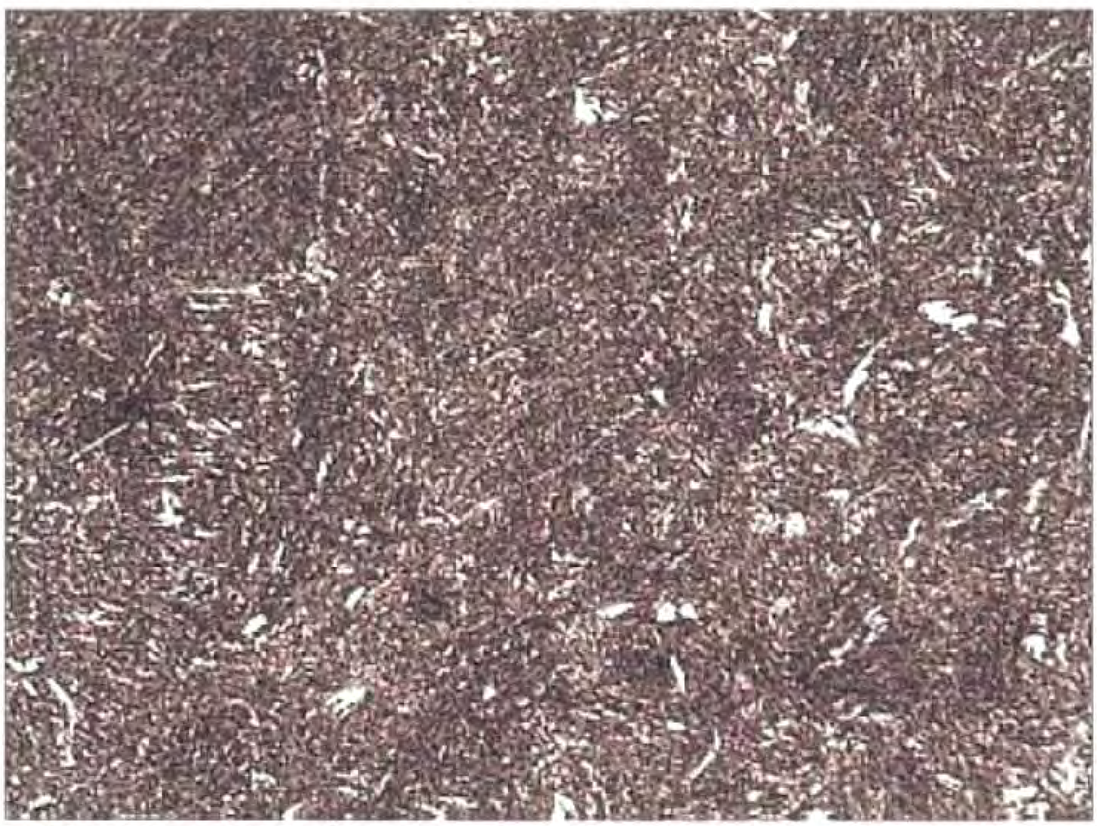


Fig. 44 Longitudinal cross-section of failed support rod from east span. Microstructure at location 1 in fig. 43. 500X. Etched.

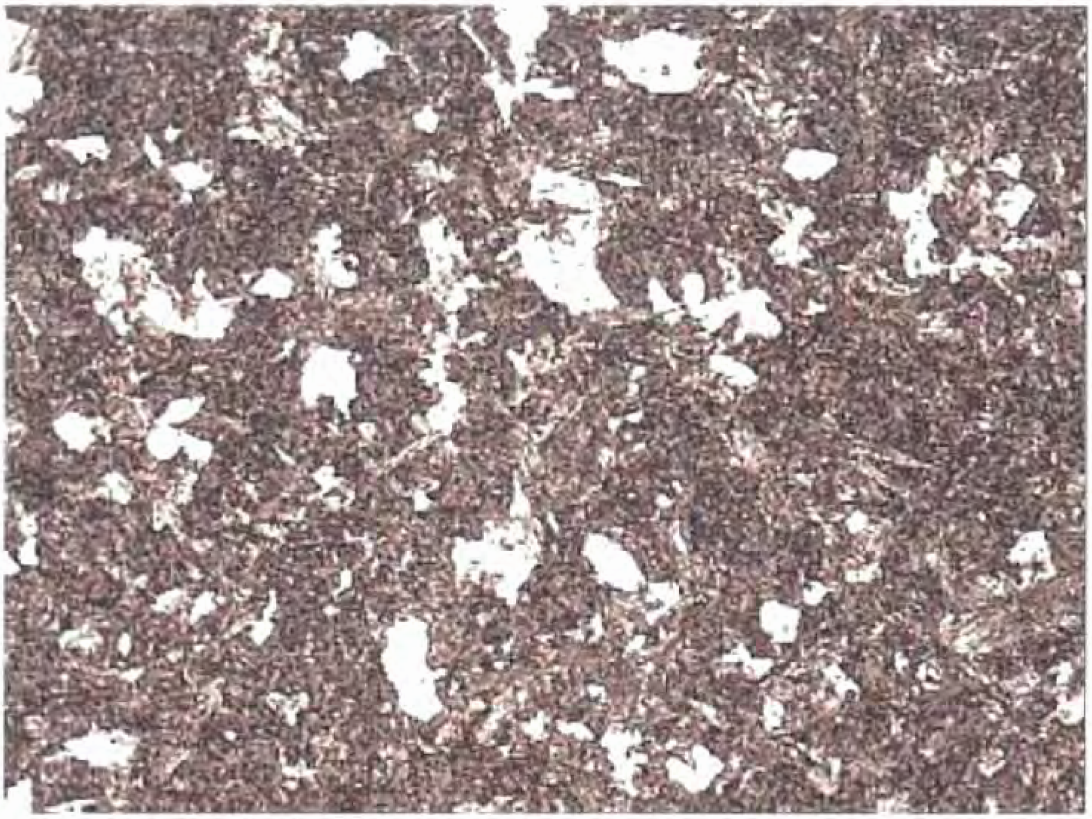


Fig. 45 Longitudinal cross-section of failed support rod from east span. Microstructure at location 2 in fig. 43. 500X. Etched.

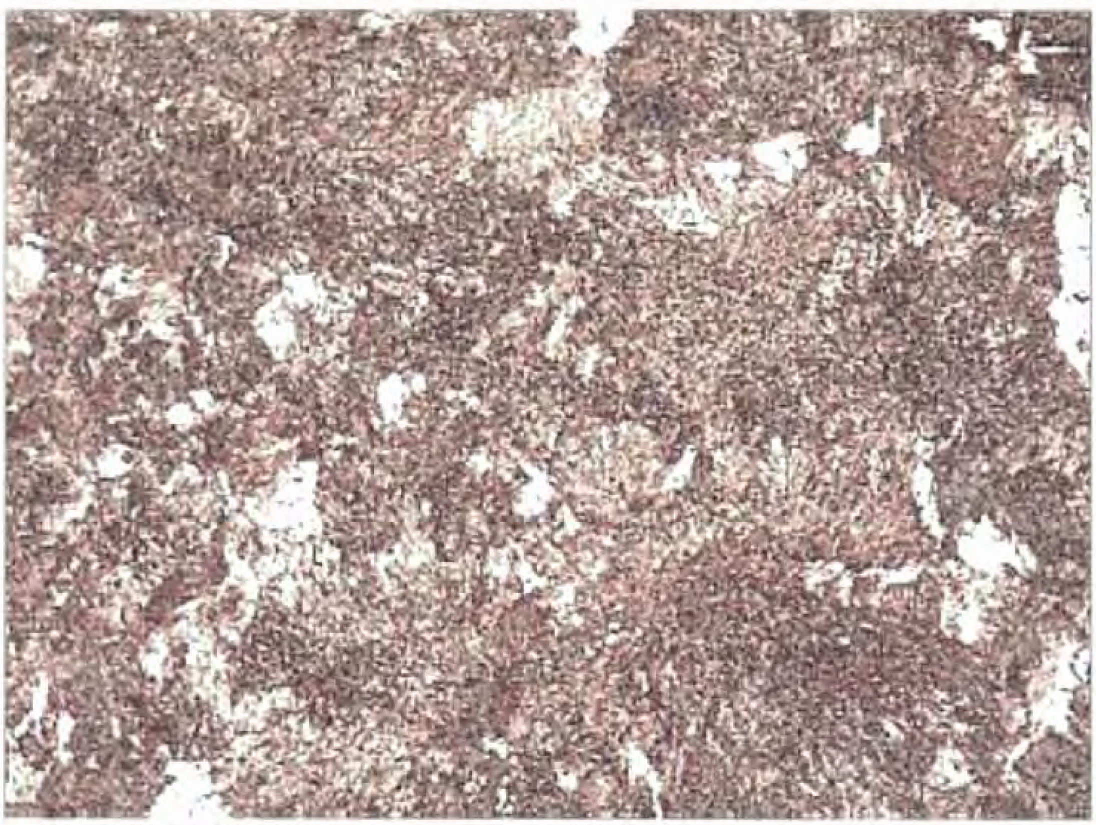


Fig. 46 Longitudinal cross-section of failed support rod from east span. Microstructure at location 3 in fig. 43. 500X. Etched.

Fig. 47 Cross-section of failed support rod from east span at fracture origin in fig. 16. 50X.

Fig. 48 Cross-section of failed support rod from east span at fracture origin in fig. 16. 500X.

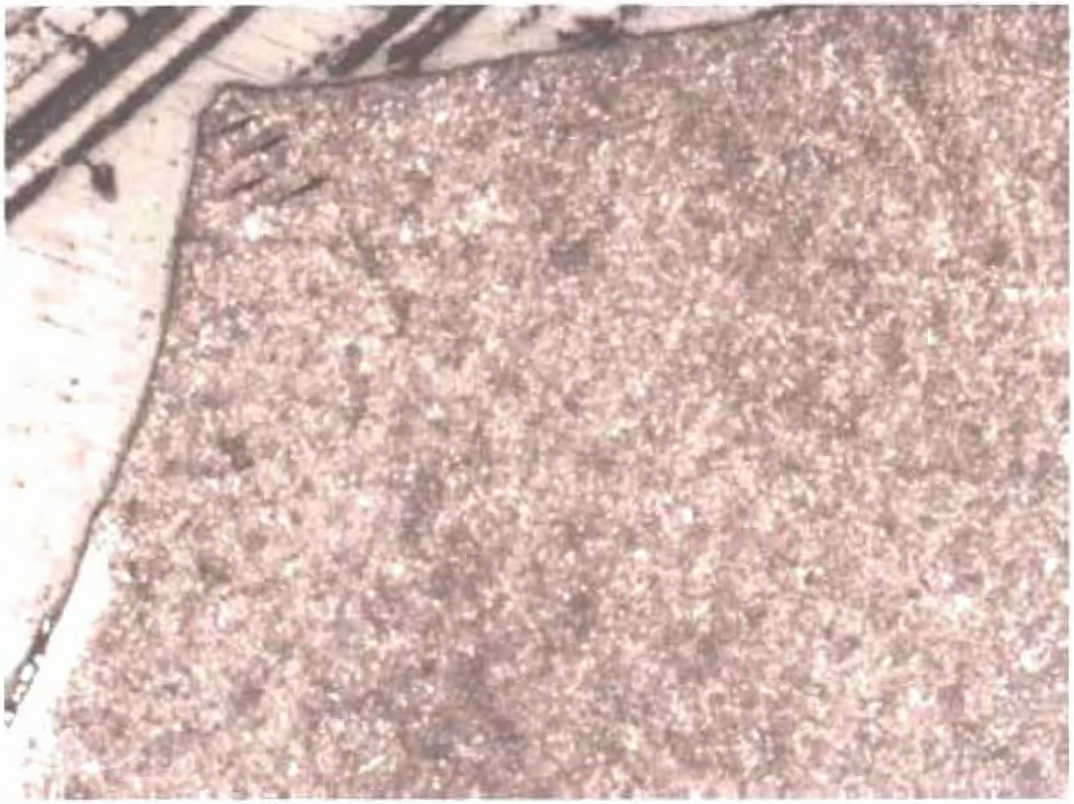


Fig. 49 Cross-section of failed support rod from east span at fracture origin in fig. 16. 50X. Etched.

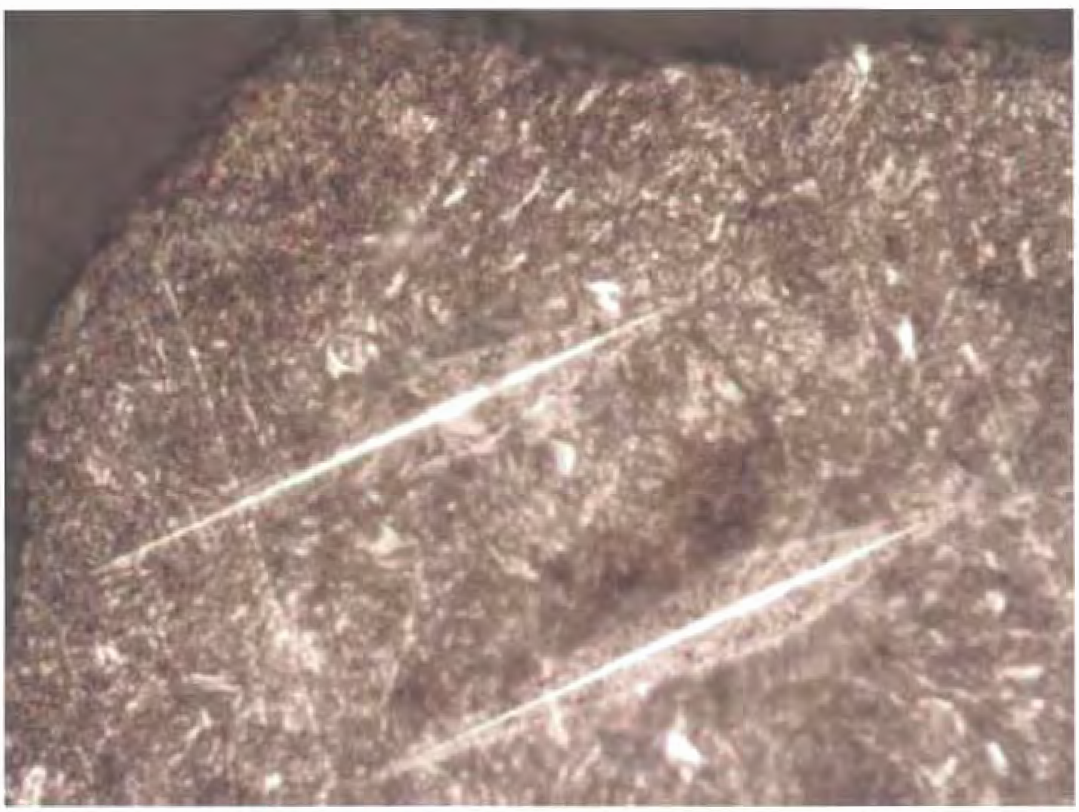
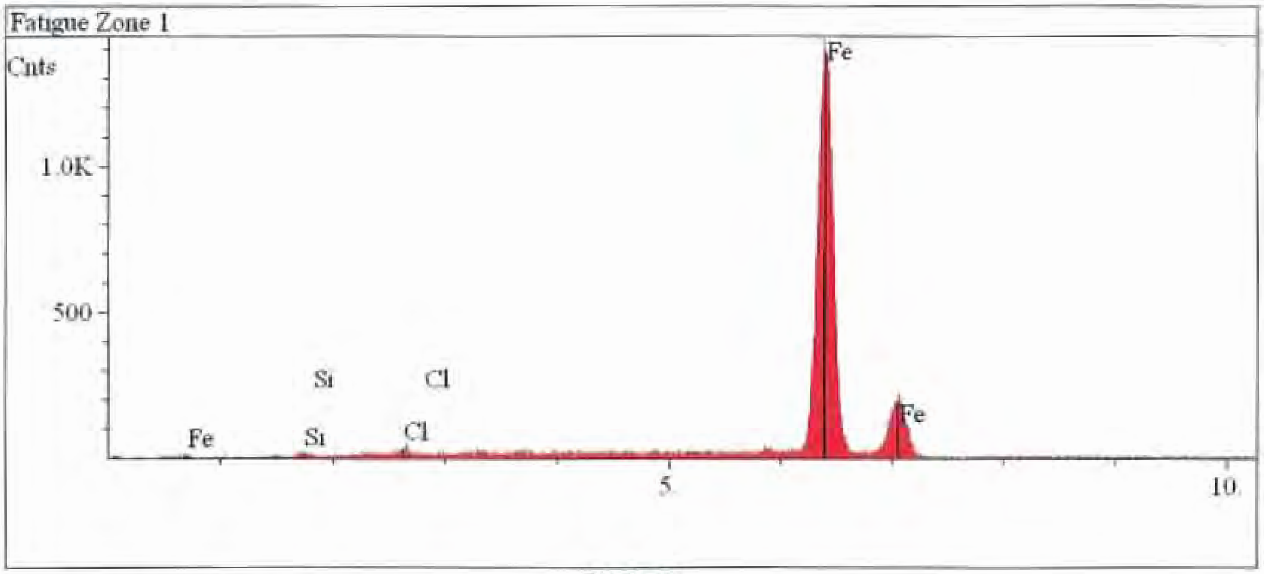


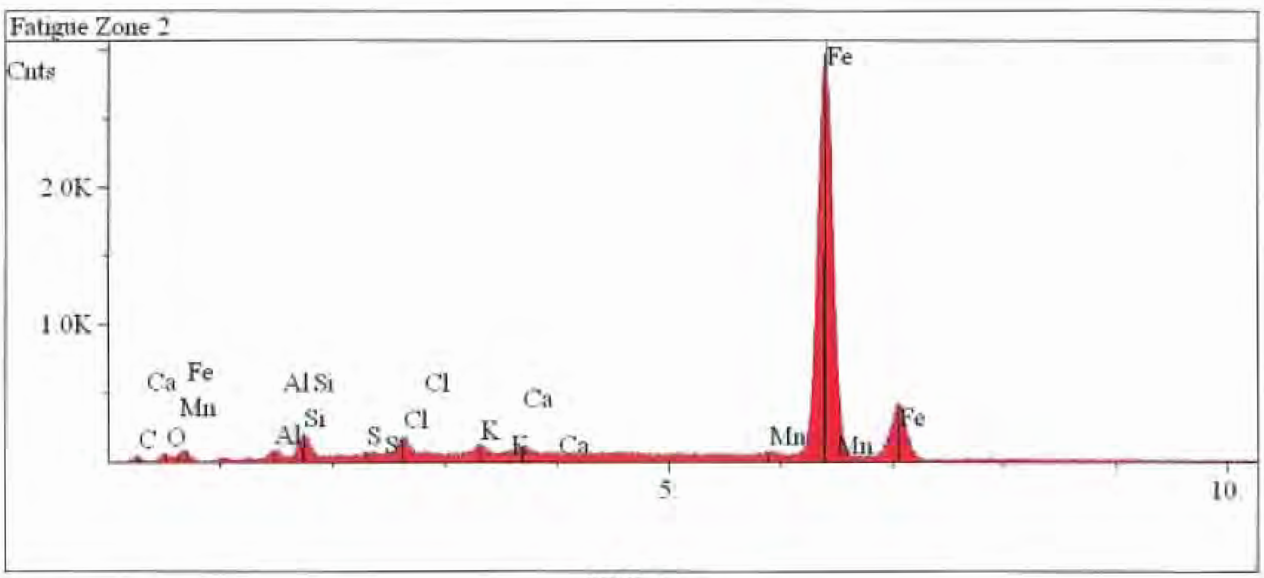
Fig. 50 Cross-section of failed support rod from east span at fracture origin in fig. 16. 500X. Etched.

PhotoMetrics, Inc.
THE MATERIALS CHARACTERIZATION LAB
15801 GRAHAM ST., HUNTINGTON BEACH, CA 92649
(714) 895-4465 • FAX (714) 893-4682



Spectrum No. 1

20 KeV



Spectrum No. 2

20 KeV

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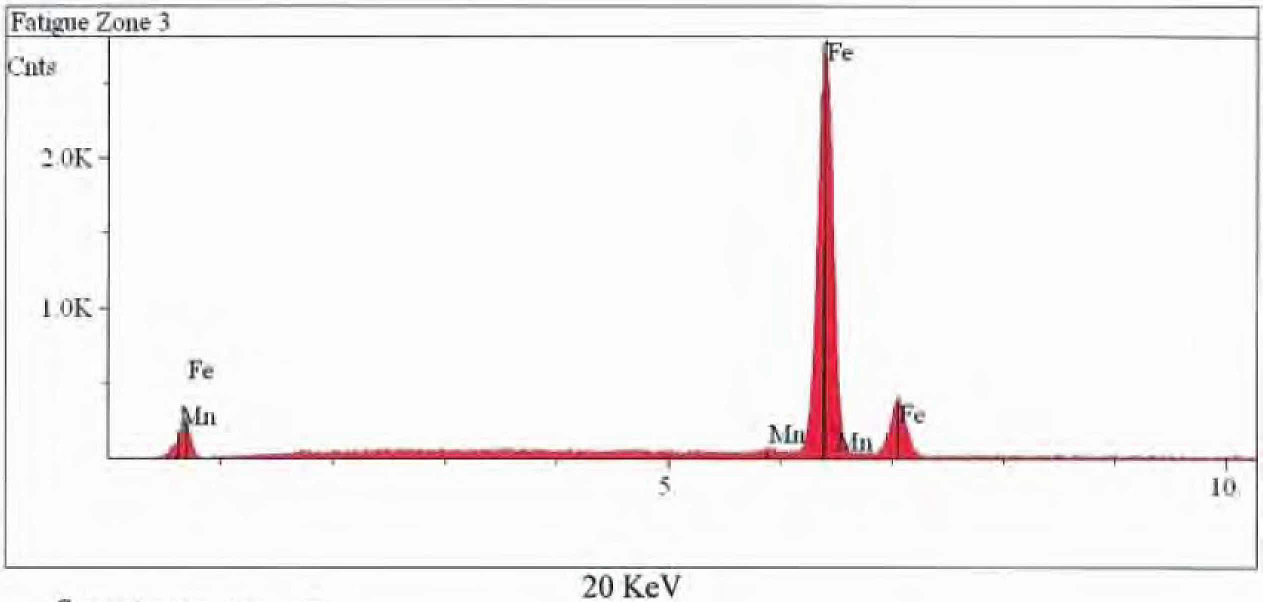

Spectrum No. 3

STORK®
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Stork Materials Testing & Inspection

Material Testing and Non-Destructive Testing

15062 Bolsa Chica
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Telephone :(714) 892-1961
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Website :www.storksmti.com

Contact: Larry McKnight
McKnight Laboratory, Inc.
14555 Valley View Suite 1

SANTA FE SPRINGS, CA 90670

Date: 11/6/2009 **P.O. No.: 203441** **W/O No.:** MCK002-11-05-55421-1

TEST CERTIFICATE

Description	1.7" Bar Segment
Job No.	MEC091110

Chemistry for customer information only. The chemical composition met the chemistry requirements for 1075 carbon steel as shown below.

		Bar Material	1075 Reqt's	
Element		**Result %**	**Min %**	**Max %**
C	=	0.73	0.70	0.80
Mn	=	0.70	0.40	0.70
P	=	0.016	0.000	0.040
S	=	0.019	0.000	0.050
Si	=	0.26	0.00	NS
Cr	=	0.02	0.00	NS
Ni	=	0.02	0.00	NS
Mo	<	0.01	0.00	NS
Cu	=	0.04	0.00	NS
Fe	=	Balance	Balance	Balance

Chemical Analysis Performed by Optical Emission per SOP 2.02, Revision 9
Carbon and Sulfur by Combustion per SOP 7.00, Revision 5

Respectfully submitted

Kelly Nguyen
Senior Quality Administrator

Accredited Nadcap Materials Testing Laboratory   A2LA ACCREDITED

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Date: 11/10/2009 **P.O. No.:** 203443 **W/O No.:** MCK002-11-06-55561-1

TEST CERTIFICATE

Description:	Bar Stock
Job Ref.:	EAC091110

TENSILE

Specification:	For Information Only					
Test Method:	ASTM A 370 09a					
Requirement:	None supplied					
Location	**Tensile Strength**	**Yield Strength At 0.2% Offset**	**Elongation in 1.4"**	**Reduction of Area**	**Diameter**	**Area**
	Min. (psi)	**Min. (psi)**	**Min. (%)**	**Min. (%)**	**(in)**	**(in)**
Center of Bar	156,000	135,000	14	37	0.351	0.0968
Near Surface	164,000	143,000	15	40	0.353	0.0979
Requirement:	**N/S**	**N/S**	**N/S**	**N/S**		

CHARPY IMPACT

Specification:	For Information Only					
Test Method:	ASTM A 370-09a					
Requirement:	None supplied					
Test Temperature:	Room Temperature (+70 Degrees F)					
Sample	**Notch Depth**	**Width of Notch Side**	**Offset Width**	**Ft-lbs.**	**%Shear**	**Lateral Expansion (Mils)**
Center of Bar #1	.0790	.3948	.3945	3.5	0	1
Center of Bar #2	.0786	.3948	.3942	3.5	0	2
Center of Bar #3	.0789	.3948	.3943	4	0	2
			Average:	3.5		
Near Surface #1	.0788	.3941	.3945	10	5	5
Near Surface #2	.0787	.3940	.3942	7.5	0	6
Near Surface #3	.0791	.3943	.3949	7.5	0	5
			Average:	8.5		

FOR INFORMATION ONLY

Respectfully submitted

Kelly Nguyen
Senior Quality Administrator

Designation: A 722/A 722M – 07

Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete[1]

This standard is issued under the fixed designation A 722/A 722M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers uncoated high-strength steel bars intended for use in pretensioned and post-tensioned prestressed concrete construction or in prestressed ground anchors. Bars are of a minimum ultimate tensile strength level of 1035 MPa (150 000 psi).

1.2 Two types of bars are provided: Type I bar has a plain surface and Type II bar has surface deformations.

1.3 Supplementary requirements of an optional nature are provided. They shall apply only when specified by the purchaser.

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 700 Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment

E 30 Test Methods for Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron[3]

2.2 *Government Standards:*[4]

MIL-STD-129 Marking for Shipment and Storage

2.3 *U.S. Federal Standards:*[4]

Fed. Std. 123 Marking for Shipment (Civil Agencies)

3. Ordering Information

3.1 Orders for material under this specification should include the following information:

3.1.1 Quantity,

3.1.2 Name of material (uncoated high-strength bars for prestressing concrete),

3.1.3 ASTM designation and year of issue,

3.1.4 Size and length,

3.1.5 Type,

3.1.6 Special inspection requirements, if desired (see Section 12),

3.1.7 Special preparation for delivery, if desired (see Section 11),

3.1.8 Load-elongation curve, if required (see Section 15), and

3.1.9 Supplementary requirements, if desired.

NOTE 1—A typical ordering description is as follows: 50 uncoated high-strength steel bars for prestressing concrete to ASTM A 722/A 722M – __; 26 mm diameter, 12.20 m long, Type II; packed in accordance with A 700; meeting supplementary bending properties.

4. Materials and Manufacture

4.1 The bars shall be rolled from properly identified heats of ingot cast or strand cast steel. The standard sizes and dimensions of Type I and II bars shall be those listed in Table 1 and Table 2, respectively.

4.2 The bars shall be subjected to cold-stressing to not less than 80 % of the minimum ultimate strength, and then shall be stress-relieved, to produce the prescribed mechanical properties.

5. Chemical Composition

5.1 An analysis of each heat of steel shall be made by the manufacturer from test samples taken during the pouring of each heat.

5.1.1 Choice and use of chemical composition and alloying elements, to produce the mechanical properties of the finished bar prescribed in 6.2, shall be made by the manufacturer, subject to the limitations in 5.1.2.

5.1.2 On heat analysis, phosphorus and sulfur shall not exceed the following:

Phosphorus	0.040 %
Sulfur	0.050 %

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.05 on Steel Reinforcement.

Current edition approved March 1, 2007. Published March 2007. Originally approved in 1975. Last previous edition approved in 2005 as A 722/A 722M – 06.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn.

[4] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, http://www.dodssp.daps.mil.

*A Summary of Changes section appears at the end of this standard.

TABLE 1 Dimensions for Type I (Plain) Bar

Nominal Diameter		Nominal Mass (Weight)		Nominal Area[A]	
mm	in.	kg/m	lb/ft	mm²	in.²
19	¾	2.23	1.50	284	0.44
22	⅞	3.04	2.04	387	0.60
25	1	3.97	2.67	503	0.78
29	1⅛	5.03	3.38	639	0.99
32	1¼	6.21	4.17	794	1.23
35	1⅜	7.52	5.05	956	1.48

[A] The nominal area is determined from the nominal diameter in inches. Values have been converted from inch-pound units to metric units.

TABLE 2 Dimensions for Type II (Deformed) Bar

Nominal Diameter[A]		Nominal Mass (Weight)		Nominal Area[B]	
mm	in.	kg/m	lb/ft	mm²	in.²
15	⅝	1.46	0.98	181	0.28
20	¾	2.22	1.49	271	0.42
26	1	4.48	3.01	548	0.85
32	1¼	6.54	4.39	806	1.25
36	1⅜	8.28	5.56	1019	1.58
46	1¾	13.54	9.10	1664	2.58
65	2½	27.10	18.20	3331	5.16

[A] Nominal diameters are for identification only. Values have been converted from metric to inch-pound units.

[B] The nominal area is determined from the bar weight less 3.5 % for the ineffective weight of the deformations.

5.2 A product analysis may be made by the purchaser from the finished bar representing each cast or heat of steel. The phosphorus and sulfur contents thus determined shall not exceed the limits specified in 5.1.2 by 0.008 %.

5.3 Test Methods E 30 shall be used for referee purposes.

6. Mechanical Properties

6.1 All testing for mechanical properties shall be performed in accordance with the requirements of Test Methods and Definitions A 370.

6.2 *Tensile Properties*:

6.2.1 Finished bars shall have a minimum ultimate tensile strength of 1035 MPa (150 000 psi).

6.2.2 The minimum yield strength of Type I and Type II bars shall be 85 % and 80 %, respectively, of the minimum ultimate tensile strength of the bars. The yield strength shall be determined by either of the methods described in Test Methods and Definitions A 370; however, in the extension under load method, the total strain shall be 0.7 %, and in the offset method the offset shall be 0.2 %.

6.2.3 The minimum elongation after rupture shall be 4.0 % in a gage length equal to 20 bar diameters, or 7.0 % in a gage length equal to 10 bar diameters.

6.3 *Test Specimens*—Tension tests shall be made using full-size bar test specimens. Machined reduced section test specimens are not permitted. All unit stress determinations shall be based on the nominal area shown in Table 1 or the effective area shown in Table 2.

6.4 *Number of Tests*—The number of tensile specimens tested shall be one from each 36 Mg (39 tons) or fraction thereof, of each size of bar rolled from each heat but not less than two from each heat. The specimens shall be randomly selected following the final processing operation.

6.5 *Retests*:

6.5.1 If any tensile property of any tension test specimen is less than that specified, and any part of the fracture is outside the middle third of the gage length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

6.5.2 If the results of an original tension test fail to meet specified requirements, two additional tests shall be made on samples of bar from the same heat and bar size, and if failure occurs in either of these tests, the bar size from that heat shall be rejected.

6.5.3 If any test specimen fails because of mechanical reasons such as failure of testing equipment, it shall be discarded and another specimen taken.

6.5.4 If any test specimen develops flaws, it shall be discarded and another specimen of the same size bar from the same heat substituted.

7. Requirements for Deformations

7.1 Material furnished as Type II bar shall have deformations spaced uniformly along the length of the bar. The deformations on opposite sides of the bar shall be similar in size and shape. The average spacing or distance between deformations on both sides of the bar shall not exceed seven tenths of the nominal diameter of the bar.

7.2 The minimum height and minimum projected area of the deformations shall conform to the requirements shown in Table 3.

7.3 *Mechanical Coupling*—For those bars having deformations arranged in a manner to permit coupling of the bars with a screw-on type coupler, it shall be the responsibility of the finished-bar manufacturer to demonstrate that a bar cut at any point along its length may be coupled to any other length of bar and that a coupled joint supports the minimum specified ultimate tensile strength of the coupled bars. The coupler type shall be provided or designed by the finished-bar manufacturer.

8. Measurements of Deformations

8.1 The average spacing of deformations shall be determined by dividing a measured length of the bar specimen by the number of individual deformations and fractional parts of deformations on any one side of the bar specimen. A measured length of the bar specimen shall be considered the distance

TABLE 3 Deformation Dimensions for Type II Bar

Nominal Diameter		Deformation Dimensions					
		Maximum Average Spacing		Minimum Average Height		Minimum Projected Area[A]	
mm	in.	mm	in.	mm	in.	mm²/mm	in.²/in.
15	⅝	11.1	0.44	0.7	0.03	2.4	0.09
20	¾	13.3	0.52	1.0	0.04	3.4	0.13
26	1	17.8	0.70	1.3	0.05	4.4	0.17
32	1¼	22.5	0.89	1.6	0.06	5.4	0.21
36	1⅜	25.1	0.99	1.8	0.07	6.1	0.24
46	1¾	30.1	1.19	2.2	0.09	7.3	0.29
65	2½	44.5	1.75	2.9	0.11	9.7	0.38

[A] Calculated from equation, min projected area = $0.75\pi d\ h/s$

where:

d = nominal diameter,

h = minimum average height, and

s = maximum average spacing.

from a point on a deformation to a corresponding point on any other deformation on the same side of the bar.

8.2 The average height of deformations shall be determined from measurements made on not less than two typical deformations. Determinations shall be based on three measurements per deformation: one at the center of the overall length, and the other two at the quarter points of the overall length.

8.3 To indicate adequately the conformity to the dimensional requirements, measurements shall be taken at random from one bar from each 30 Mg (33 tons) of each lot or fraction thereof.

8.4 Insufficient height, insufficient projected area, or excessive spacing of deformations shall not constitute cause for rejection unless it has been clearly established by determinations on each lot that typical deformation height or spacing does not conform to the minimum requirements prescribed in Section 7. No rejection shall be made on the basis of measurements if fewer than ten adjacent deformations on each side of the bar are measured.

NOTE 2—The term "lot" shall mean all bars of the same nominal mass (weight) per metre (linear foot) contained in an individual shipping release or shipping order.

9. Permissible Variation in Size or Weight

9.1 For Type I bars, the permissible variation from the nominal diameter specified in Table 1 shall not exceed +0.75, –0.25 mm (+0.030, –0.010 in.).

9.2 For Type II bars, the permissible variation from the nominal weight specified in Table 2 shall not exceed +3 %, –2 %.

10. Finish

10.1 The bars shall be free of defects injurious to the mechanical properties and shall have a workmanlike finish.

11. Packaging and Package Marking

11.1 Packaging, marking, and loading for shipment shall be in accordance with Practices A 700.

11.2 When specified in the contract or order, and for direct procurement by or direct shipment to the U.S. government, marking for shipment, in addition to requirements specified in the contract or order, shall be in accordance with MIL-STD-129 for military agencies and with Fed. Std. No. 123 for civil agencies.

11.3 Unless otherwise specified in the contract or order, bars shall be grouped by size. Each bundle or lift shall be tagged showing the heat number, bar size, specification number (Specification A 722/A 722M), and the identity of the finished bar manufacturer. The tags shall display the following statement "High Strength Prestressing Bars". Both ends of each bar shall be painted yellow.

12. Inspection

12.1 The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests (except product analysis) and inspection, shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

12.2 If specified in the purchase order, the purchaser shall reserve the right to perform any of the inspection set forth in the specification where such inspections are deemed necessary to assure that the material furnished conforms to prescribed requirements.

12.3 If outside inspection is waived, the finished-bar manufacturer's certification that the material has been tested in accordance with, and meets the requirements of, this specification, shall be the basis of acceptance of the material.

13. Rejection

13.1 Unless otherwise specified, any rejection based on tests made in accordance with 5.2 shall be reported to the manufacturer within 5 working days from the receipt of samples by the purchaser.

13.2 Material that shows injurious defects subsequent to its acceptance at the manufacturer's works shall be subject to rejection, and the manufacturer shall be notified.

14. Rehearing

14.1 Samples tested in accordance with 5.2 that represent rejected material shall be preserved for two weeks from the date rejection is reported to the manufacturer. In case of dissatisfaction with the results of the tests, the manufacturer shall be permitted to make claim for a rehearing within that time.

15. Certification

15.1 If outside inspection is waived, a manufacturer's certification that the material has been tested in accordance with and meets the requirements of this specification shall be the basis of acceptance of the material. The certification shall include the specification number, year-date of issue, and revision letter, if any.

15.2 The manufacturer shall, when required in the order, furnish a representative load-elongation curve for each size and type of bar shipped.

15.3 A modulus of elasticity value of 205 GPa (29 700 000 psi) shall be used for the purpose of elongation calculation for Type II bars.

NOTE 3—Experience has shown that plotted load-elongation curves from mill tests on Type II bars vary excessively and are not sufficiently reliable for use in calculating modulus of elasticity values.

15.4 A material test report, certificate of inspection, or similar document printed from or used in electronic form from an electronic data interchange (EDI) transmission shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document must meet the requirements of the invoked ASTM standard(s) and conform to any existing EDI agreement between the purchaser and the supplier. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

NOTE 4—The industry definition as invoked here is: EDI is the computer-to-computer exchange of business information in a standard format such as ANSI ASC X12.

16. Keywords

16.1 deformed bars; high-strength steel bars; plain bars; post-tensioning; prestressed concrete

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified in the purchase order or contract:

S1. Bending Properties

S1.1 The bend test specimen shall withstand being bent, at ambient temperature but in no case less than 15°C (59°F), around a pin without cracking on the outside of the bent portion. The requirements for degree of bending and sizes of pins are prescribed in Table S1.1.

S1.2 The bend test shall be made on full-size specimens of sufficient length to ensure free bending and with an apparatus that provides the following:

S1.2.1 Continuous and uniform application of force throughout the duration of the bending operation.

S1.2.2 Unrestricted movement of the specimen at points of contact with the apparatus and bending around a pin free to rotate or bending about a central pin on a simple span with end supports free to rotate.

TABLE S1.1 Supplementary Bend Test Requirements

Nominal Bar Diameters		Diameter of Pin for 135° Bend[A]
mm	in.	
15	⅝	$d = 6t$
20	¾	$d = 6t$
26	1	$d = 6t$
32	1¼	$d = 8t$
36	1⅜	$d = 8t$
46	1¾	$d = 10t$
65	2½	$d = 10t$

[A] d = diameter of pin around which specimen is bent.
t = nominal diameter of bar.

S1.2.3 Close wrapping of the specimen around the pin during the bending operation.

S1.3 Other methods of bend testing shall be permitted, but failures due to such methods shall not constitute a basis for rejection.

S1.4 The number of bend test specimens shall be one from each 20 Mg (22 tons), or fraction thereof, of each size of bar rolled from each heat but not less than two from each heat. The specimens shall be randomly selected following the final processing operation.

S1.5 If a bend test fails for reasons other than mechanical reasons or flaws in the specimen as described in 6.5.3 and 6.5.4, a retest shall be permitted on two random specimens from the quantity of the finished bar product for each bar size in S1.4. If the results of both test specimens meet the specified requirements, the bars shall be accepted. The retest shall be performed on test specimens that are at air temperature but not less than 15°C (59°F).

S2. Reduction of Area

S2.1 The minimum reduction of area from the effective area shall be 20 % for Type I plain bars.

S3. Chemical Requirements

S3.1 The chemical composition determined as specified in 5.1 shall be reported to the purchaser or his representative.

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since the last issue (A 722/A 722M – 06) that may impact the use of this standard. (Approved March 1, 2007.)

(1) Revised 15.2 and added new paragraph 3.1.8.

Committee A01 has identified the location of selected changes to this standard since the last issue (A 722/A 722M – 05) that may impact the use of this standard. (Approved Sept. 1, 2006.)

(1) Section 11 was revised.

(2) Sections 2.2 and 2.3 were added.

ANALYSIS OF SADDLE BAR SUPPORT EAST SPAN NOTCHED AND UN-NOTCHED TENSILE TESTS

Report No. MEC091110

Prepared for:

CALTRANS

February 9, 2010

Prepared by:

McKNIGHT LABORATORY, INC.

Larry E. McKnight

Larry E. McKnight, P.E.
Principal Consulting Engineer

February 9, 2010

CALTRANS
SMI Toll Bridges
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Oakland, CA 94623

McKNIGHT LABORATORY, INC.
Report No. MEC091110

SUBJECT: ANALYSIS OF SADDLE BAR SUPPORT EAST SPAN NOTCHED AND UN-NOTCHED TENSILE TESTS

PROCEDURE

One piece of a saddle bar was tensile tested at CALTRANS and a second notched bar was tested at CALTRANS. The results of the tensile test were provided by Rosme Aguilar. After the tests were performed a sample of the fracture face from the notched bar and the sample of the un-notched bar were submitted to the laboratory for examination. The two fractures were photographed in the as received condition and then the fracture mode on the two bars was determined and photographs taken to document the fracture mode.

RESULTS

The appearance of the un-notched fracture face is shown in figure 1 and fracture face of the notched bar is shown in figure 2. The two fractures were placed in the Scanning Electron Microscope (SEM) and fracture mode determined. Figures 3, 4 and 5 illustrate the fracture mode in the un-notched bar and figures 6, 7, and 8 illustrate the fracture mode in the notched bar. In both cases the fracture mode was found to be cleavage as documented in SEM photographs. These results are exactly comparable to the overload portion of the fracture on the saddle bar that had the fatigue crack in it and which had broken on the bridge.

Fig 1

Fig 2

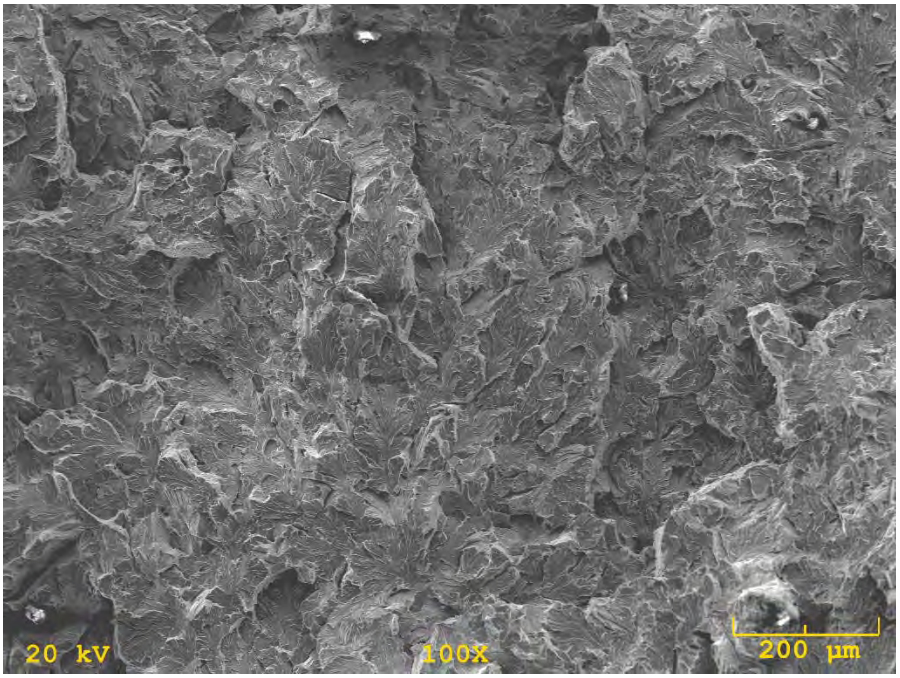

Fig 3

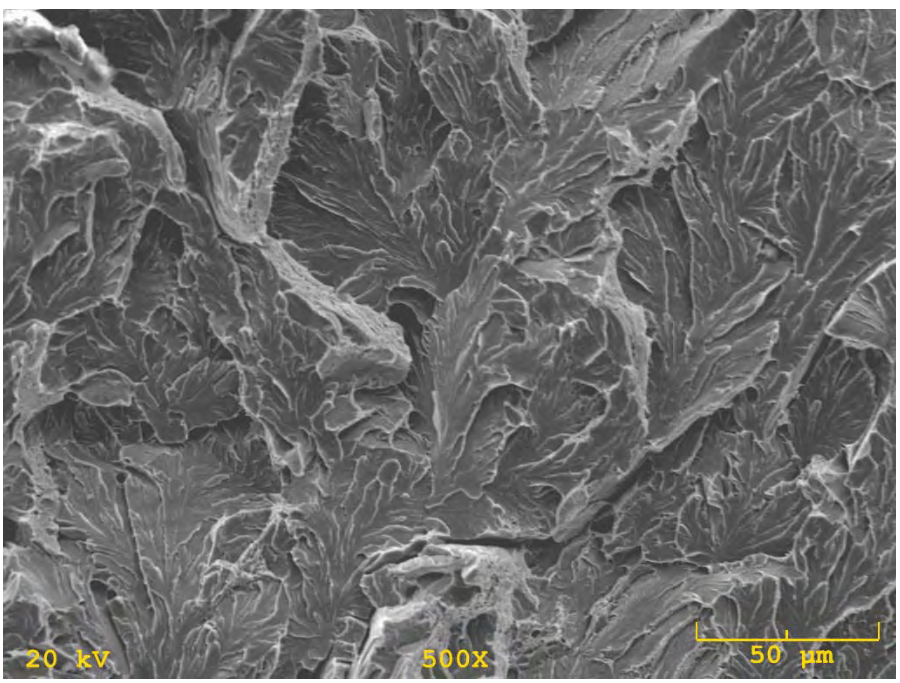

Fig 4

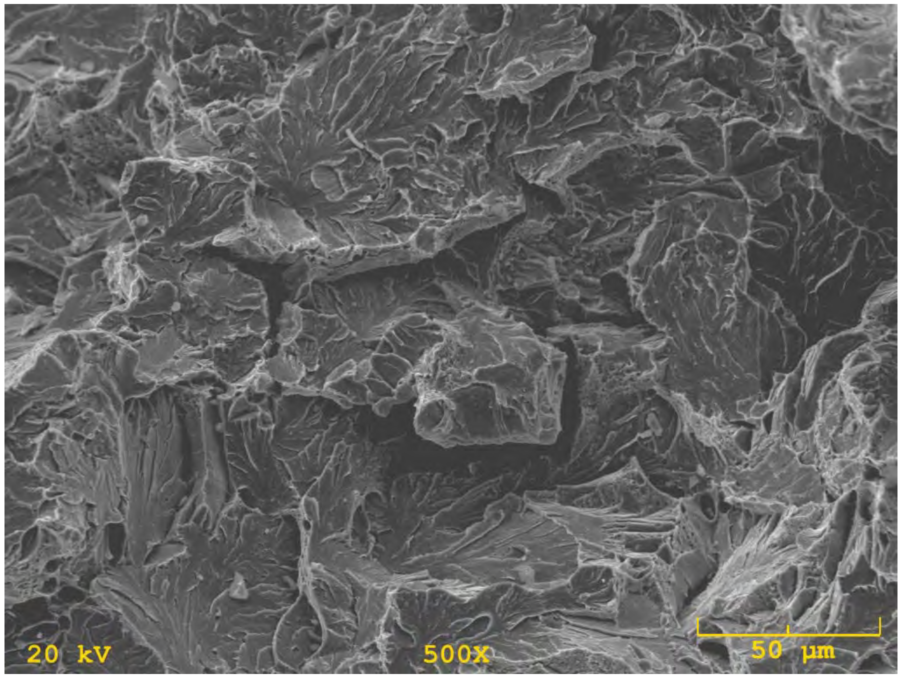

Fig 5

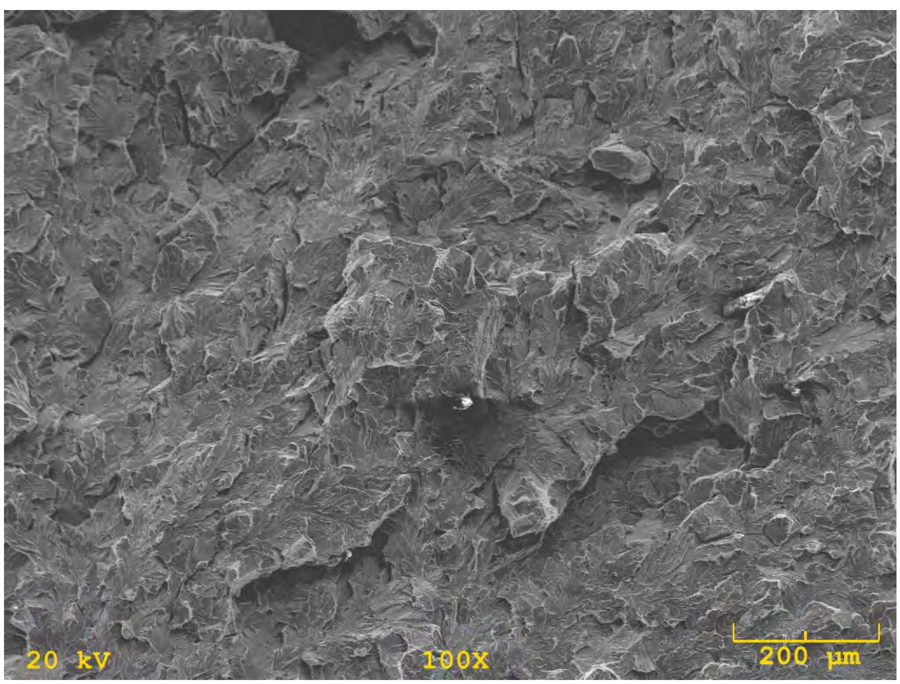

Fig 6

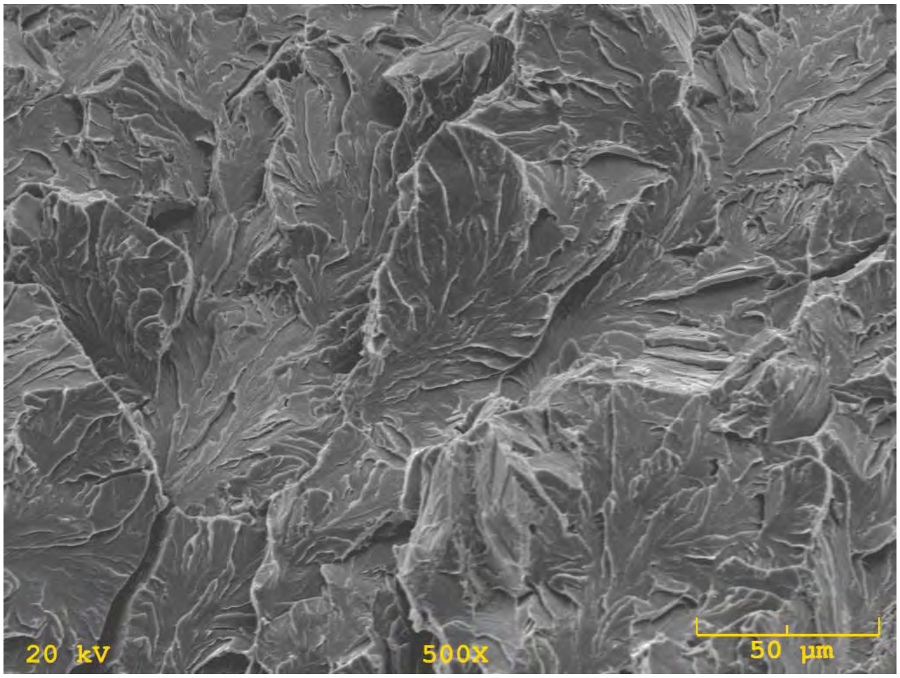

Fig 7

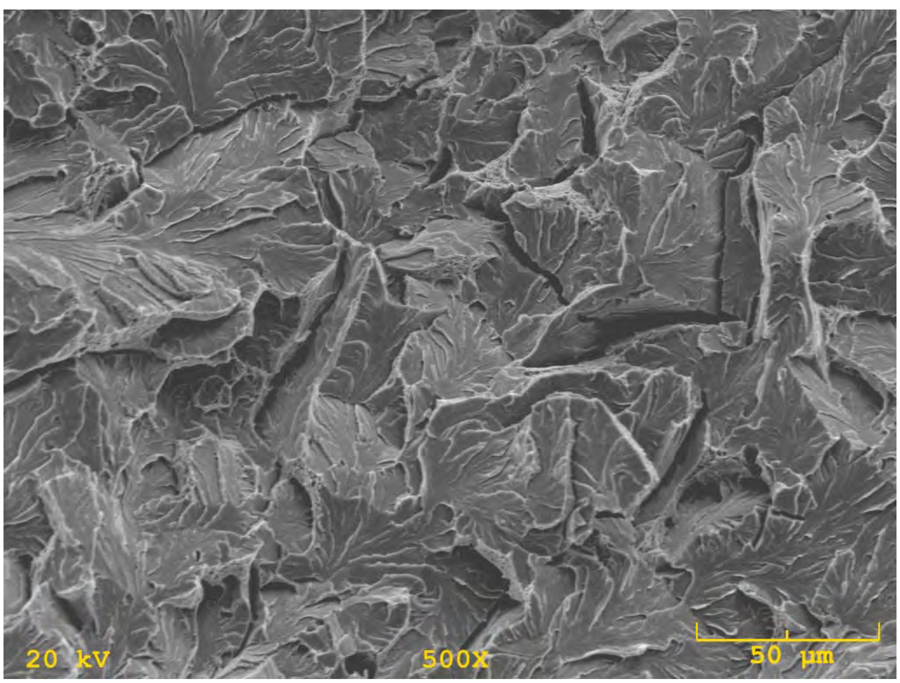

Fig 8