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Rocco O. D'Ascenzo
Counsel

December 6, 2007

Public Utilities Commission
Docketing Division
180 East Broad Street, 13th Floor
Columbus, Ohio 43215-3793

Re: Case No 07-723-EL-UNC

Dear Docketing:

Attached, please find an original and 10 copies of the Supplemental Testimony of Charles Whitlock and Direct Testimony of Michael L. Hofmann in the above referenced matter. Please file the same and return two time-stamped copies. Copies of the documents and attachments were served upon all Parties of record. Thank you.

Sincerely,

Rocco D'Ascenzo, Counsel
Duke Energy Ohio
2500 Atrium II, 139 East Fourth Street
P. O. Box 960
Cincinnati, Ohio 45201-0960

DE-Ohio Exhibit____

BEFORE

THE PUBLIC UTILITIES COMMISSION OF OHIO

In the Matter of the Commission's Review and Adjustment of the Fuel and Purchased Power and the System Reliability Tracker Components of Duke Energy Ohio, Inc., and Related Matters.	))))))	Case No. 07-723-EL-UNC

DIRECT TESTIMONY OF

MICHAEL L. HOFMANN

ON BEHALF OF

DUKE ENERGY OHIO, INC.

December 6, 2007

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I. INTRODUCTION

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Michael L. Hofmann, and my business address is 139 East Fourth Street, Cincinnati, Ohio 45202.

Q. BY WHOM ARE YOU EMPLOYED AND IN WHAT CAPACITY?

A. I am employed by Duke Energy Shared Services as General Manager, Generation Services.

Q. PLEASE DESCRIBE YOUR EDUCATIONAL AND PROFESSIONAL BACKGROUND.

A. I received a B.S. in Chemistry from the University of Cincinnati. In addition, during the past twenty-seven years, I have attended many seminars, workshops and forums on subject matter ranging from generation related activities to transmission system operation as well as other utility related topics. I began my career at Miami Fort Station in 1979. In 1982, I was promoted to Station Chemist. I worked at Miami Fort Station until January 1992 in various functions, which included Boiler Maintenance Liaison, Maintenance Outage Coordinator, Turbine Maintenance Liaison, Turbine Outage Coordinator, Capital Project Manager, as well as Station Chemist.

In 1992, I joined the Electric Production staff office as Performance Engineer. In that role, I was responsible for heat rate and other associated performance related activity for The Cincinnati Gas & Electric Company ("CG&E"), now known as Duke Energy Ohio, Inc., ("DE-Ohio" or "Company"). In 1994, I joined the Electric Systems Operations group as an Operations

Engineer. My responsibilities in this group dealt primarily with the relationship of the Cinergy generation system to the Cinergy transmission system, the projected pricing of generation on a monthly basis, as well as cost analysis studies involving generation activities. In 1997, my function was transferred to the Energy Commodities Business Unit in Power Services. Later, in 1997, I was promoted to Manager, Operations Services where I supervised employees responsible for the commitment, control and economic dispatch of Cinergy generation. In addition, I supervised the employees who performed after-the-fact billing cost analysis and was responsible for generating unit outage coordination, among other duties. In January 2001, I was promoted to General Manager of Power Services. In this role, I managed services necessary to support Cinergy's generation operations including: responsibility for long-term maintenance outage scheduling, planning and scheduling of station and contractor resources during maintenance outages, NO_x compliance, measures development and support, station chemistry and chemical management, generating station performance monitoring and management, generating station condition based maintenance, work management practices, management of generating station by product disposal, generating station financial management and business planning, as well as responsibility for management of the CD/CCD joint owner partnership. In April 2006, I became General Manager, Generation Services

Q. PLEASE DESCRIBE YOUR RESPONSIBILITIES AS GENERAL MANAGER, GENERATION SERVICES.

A. I am responsible for managing services that support Duke Energy Ohio's generation operations including: responsibility for long-term maintenance outage scheduling, fleet measures development and support, generating station financial management and business planning, management of long-term service contracts with OEM, as well as responsibility for CD/CCD joint owner issues.

Q. HAVE YOU PREVIOUSLY TESTIFIED BEFORE THIS COMMISSION?

A. No. However I have testified on behalf of Cinergy Corporation and its affiliated operating company Public Service Indiana ("PSI"), now known as Duke Energy Indiana, Inc. ("DE-Indiana").

II. PURPOSE OF TESTIMONY

Q. WHAT IS THE PURPOSE OF YOUR TESTIMONY IN THIS PROCEEDING?

A. The purpose of my testimony is to respond to certain recommendations made by Liberty Consulting ("Auditor") contained in its *Final Report Management/ Performance Audit and Financial Audit Duke Energy Ohio Case No. 07-EL-UNC* ("Audit Report"). Specifically, I address the Auditor's recommendations contained on pages ES-7 and ES-8 with respect to Chapter 3, Supply Management, and Chapter 5, Plant Operations.

III. DISCUSSION OF AUDITOR RECOMMENDATIONS

Q. WHAT IS THE AUDITOR'S RECOMMENDATION REGARDING SUPPLY MANAGEMENT?

A. The Auditor recommends that DE-Ohio institute a security program to protect the integrity of coal samples from the time samples are bagged and ready for shipment until the samples arrive at the laboratory. Based upon this recommendation, DE-Ohio will investigate the need for additional security measures related to the shipment of coal samples to outside laboratories for analysis.

Q. WHAT ARE THE AUDITOR'S RECOMMENDATIONS REGARDING PLANT OPERATIONS?

A. The Auditor makes five recommendations regarding Plant Operations. Specifically, the Auditor recommends that replacement power costs associated with the Zimmer Station "unplanned extended" outage in the spring of 2007 be excluded from DE-Ohio's Fuel and Economy Purchased Power Rider ("Rider FPP") recovery. The Auditor also recommends that the Company address what the Auditor perceives as safety, cleanliness and employee morale issues at the Company's Beckjord Station. The Auditor also makes recommendations regarding the Company's capital and O&M budget for Beckjord, the need to conduct a staffing review at coal plants, and the need to perform an economic analysis to determine the level of spare parts and ability to share parts among generating stations.

Q. PLEASE EXPLAIN AND DESCRIBE THE ZIMMER STATION OUTAGE DISCUSSED IN THE AUDIT REPORT.

A. Zimmer Station had a planned six-week maintenance outage that began on April 13, 2007 and was scheduled for completion on May 27, 2007. The scope of the planned outage included boiler and turbine inspections, scrubber maintenance, significant boiler tube replacement, and other boiler and balance of plant maintenance. During the inspection, damage was found in the low-pressure turbines. Due to the limited availability of replacement turbine components, the outage was extended until June 11, 2007, to allow for the replacement of two rows of turbine blades on each of the two low-pressure turbines.

Q. PLEASE EXPLAIN LIBERTY'S RECOMMENDATION TO EXCLUDE THE PURCHASE POWER COSTS DURING THE ZIMMER OUTAGE.

A. The Auditor concluded through discussions with DE-Ohio that steam parameters and water chemistry were different for a coal plant and a nuclear plant and that those differences in conjunction with the nuclear grade metallurgy employed on the turbine had caused the observed blade damage. In addition, the Auditor believes that the two-week extension of the outage at Zimmer could have been avoided had "an examination of the effects of differing steam conditions between nuclear and coal operations"[1] been undertaken earlier. DE-Ohio understands that the Auditor recommends that replacement power costs be excluded from Rider FPP because DE-Ohio did not examine the effects of differing steam conditions earlier.

Q. DO YOU AGREE WITH THIS RECOMMENDATION?

A. No. DE-Ohio believes that 100% of the replacement power cost associated with the Zimmer outage should be included in the Rider FPP calculation. DE-Ohio acknowledges there is a known difference between the nuclear cycle steam conditions and the fossil cycle chemistry. However, contrary to the Auditor's assertion, an examination of the existing turbine materials was, in fact, performed

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[1] *In re DE-Ohio's Application to Adjust its Rider FPP and SRT,* Case No. 07-723-EL-UNC, (*Final Report Management/Performance Audit, Duke Energy Ohio,* Page V-14) (Filed November 1, 2007).

during the conversion from nuclear to fossil service nearly two decades ago. The turbine materials were determined by the Original Equipment Manufacturer (OEM), the Architectural Engineer (AE), the General Contractor (American Electric Power), and all the joint owners, to be acceptable for fossil service. This configuration has operated extremely reliably with minimal maintenance expense for more than 16 years. In addition, the reuse of this turbine was a central feature of the conversion from a nuclear unit to one that burns coal. In evaluating different designs for the conversion, the joint owners used three criteria: (1) maximizing the utilization of existing Zimmer facilities from the nuclear design; (2) utilization of a proven engineering design; and (3) achieving an acceptable heat rate. The design ultimately selected was performed by American Electric Power Service Company (AEPSC), who was also chosen as the conversion project manager. If this turbine was not utilized, additional tens of millions of dollars and likely additional time for construction would have been required before placing this unit in service.

The selection of the AEPSC 1300 MW design resulted from an analysis performed in 1984 by EBASCO Services who examined six alternative design concepts for the nuclear to coal conversion. This study established the conceptual design basis for many of the systems including the turbine configuration and the modification of the existing turbines. AEPSC had successfully managed the construction of six 1300 MW units prior to the Zimmer conversion. The turbine configuration employed in Zimmer, although modified from the configuration used at the other 1300 MW units, was fully vetted. Even the Staff of the

Commission examined the conversion process and reported its findings in its "Zimmer Conversion Project Staff Reconnaissance Report" dated July 1990. Specifically, the Staff found the "management of AEPSC's engineering and design for Zimmer coal conversion project to be effective and efficient."[2]

The Auditor's recommendation amounts to a hindsight prudence review of a conversion that occurred nearly two decades ago, and which was performed under the view of the Public Utilities Commission of Ohio ("Commission").

Q. PLEASE EXPLAIN THE FAILURE OF THE TURBINE BLADES THAT RESULTED IN THE EXTENDED ZIMMER OUTAGE.

A. Following the failure of the turbine blades, the Company had two metallurgical studies performed to determine the cause of the blade failure. These studies were requested by DE-Ohio and were provided to the Company. The first study was performed internally by Duke Energy's Metallurgical Laboratory. A true and accurate copy of this study is attached as to my testimony as MLH-1. The second analysis was performed by Siemens Power Generation, Inc. A true and accurate copy of the study is included as Attachment MLH-2. I received the two reports, and I have reviewed them. Based upon these two reports and upon my training, education, and nearly 28 years of experience, the failure of the turbine blades was determined to be high-cycle fatigue cracking initiated by several contributing factors, including pitting corrosion and Stress Corrosion Cracking (SCC) and improper welding techniques. Pitting corrosion creates small shallow holes on the surface of the blade where fatigue cracks can later initiate. SCC is caused by the

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[2] In re CG&E's Application for an Increase in Rates, *Case No 91-410-EL-AIR*, (Staff Exhibit 24A, Zimmer Conversion Project, Staff Reconnaissance Report, July 1990 at 115) (Filed January 28, 1992).

combination of tensile stress and a corrosive environment, and was observed to have occurred in some of the aforementioned pits. Fatigue cracks developed at some of these SCC cracks. DE-Ohio believes that the steam condition inducing pitting corrosion may be one of the contributing factors to the blade damage, but it is not the only contributing factor of the failures. As detailed in Attachment MLH-2, two of the additional modes of failure determined in post-mortem analysis are the stress riser at the base of the notch for the Stellite strip and the lack of penetration at the weld root in the under shroud welds on the turbine blade.

Q. WAS THERE ANY INDICATION THAT THERE WAS A PROBLEM OR POTENTIAL PROBLEM WITH THE DIFFERENCE IN STEAM CONDITIONS BETWEEN COAL AND NUCLEAR GENERATION?

A. No. DE-Ohio had no indication that an examination of differing steam conditions between nuclear and coal operations should have been undertaken far earlier. As I discussed previously, the use of the existing turbine was a significant factor, if not the determining factor, in deciding to go forward with the conversion from nuclear to coal generation in the mid 1980's and was analyzed before the decision was made to go forward with the conversion. As indicated in the two reports, the cause of the blade failure was not primarily due to differences in steam conditions between nuclear and fossil generation.

Q. DID THE OPERATIONAL PERFORMANCE OF THE ZIMMER STATION GIVE ANY INDICATION THAT A PROBLEM EXISTED?

A. No. DE-Ohio is vigilant in the maintenance and operation of all its generating stations including the Zimmer Station, as evidenced by Zimmer's continued efficiency and reliability. DE-Ohio performs routine inspections of the L-0 blades during unit outages. These inspections gave no indication that a corrosion problem existed. The L-0 blades are typically associated with higher maintenance due to operating in a more severe, wet condition and accordingly more susceptible to corrosion. Exposure to stress damage was mitigated over time by continuous vibration monitoring as well as periodic balancing efforts that kept the turbines operating in acceptable operating ranges. Failed turbine blades have specific signs and symptoms, including but not limited to, increased vibration and heat rate degradation. None of the telltale signs of failed blades were apparent.

As indicated in the Auditor's own report, the Zimmer station was one of DE-Ohio's most reliable in terms of availability. Further, the Auditor's report identified the Zimmer station as being one of the most efficient units in the generating fleet, and provided historical data indicating that the unit efficiency during the past three years has actually improved relative to 2004 performance. The Zimmer Station did not have any of the problems typically associated with blade failure.

Q. WERE CONSUMERS HARMED IN ANY WAY DUE TO THE EXTENDED OUTAGE IN APRIL 2007 THAT INCLUDED THE TURBINE OVERHAUL?

A. No. Ignoring, for a moment, all other factors determined to have contributed to the Zimmer blade failure, fatigue has a dubious incubation period. It is not possible to predict, with any degree of accuracy, if or when a crack will initiate. Metallurgical evaluation suggests that L-2 blade failures on the Zimmer Turbine occurred within the last two years. Even if the corrosion, which initiated the cracking, had been discovered earlier, the result would have been the same. A total six-week outage would have been required to address the damaged turbine blades, regardless of timing of discovery, in order to inspect and make necessary repairs.

DE-Ohio's standard maintenance is to schedule an annual one-week outage and a biannual four-week outage for Zimmer. To inspect or repair the low-pressure Turbine, a minimum six-week outage is required. Had Zimmer elected to utilize a six-week outage to open and inspect the low-pressure Turbine sooner and found the damage, two different courses of actions could have been taken, but the outcome would be the same. The first option would require a subsequent planned six-week outage for blade replacement. The second option would require an additional and immediate two-weeks of outage time (in addition to the scheduled six-week inspection outage) to replace the damaged blades immediately. Each of these two options would result in purchase power costs for the same incremental two-week outage period.

Either outcome results in a comparable incremental outage time for replacement and repair of the turbine versus the events, which occurred on the back end of the 2007 spring outage.

DE-Ohio believes that even if a more conservative approach was used to determine overhaul frequencies in the range of 7-9 years ago, indications of turbine failures would not have been not present. Had the Company suspected the existence of fatigue cracking, customers would have likely experienced either more frequent outages or longer scheduled outages to allow the time to open up the turbine and inspect thereby incurring incremental purchased power costs.

While this two-week outage extension into June 2007 was forced due to the unknown condition of the turbine, the bottom line is that it eliminated the need for an additional two-week outage extension to inspect, plan and execute the turbine overhaul in a more typical manner. Consequently, DE-Ohio native load customers were not harmed. Customers now have a refurbished turbine to serve their generation needs, at no capital costs to them. Neither Rider FPP, nor any other portion of DE-Ohio's MBSSO pricing mechanism, includes recovery for any such capital expenditures or repairs related to generation plant as existed prior to electric restructuring. Further DE-Ohio's rate structure does not include any return of or on new investment in generation plant.

Q. WHAT IS DE-OHIO'S RESPONSE TO THE AUDITOR'S RECOMMENDATION THAT THE COMPANY SHOULD ESTABLISH HIGH EXPECTATIONS FOR SAFETY CONSCIOUSNESS, CLEANLINESS, AND EMPLOYEE ATTITUDE AT THE BECKJORD STATION?

A. The Company agrees with this recommendation. In fact, DE-Ohio has already taken steps to address this recommendation at all of its generation facilities, not just Beckjord. Several months ago, DE-Ohio retained a consultant to help identify ways to address the very items mentioned in the recommendation. In addition, the Beckjord Station has embarked on a full site cleanup effort to be completed before the end of 2007.

Q. PLEASE EXPLAIN THE AUDITOR'S RECOMMENDATION THAT DE-OHIO PERFORM AN ECONOMIC ANALYSIS TO DETERMINE THE INVENTORY LEVEL OF SPARE PARTS, ABILITY TO SHARE PARTS AND USE OF ONLINE MAINTENANCE AND REDUNDANT EQUIPMENT AMONG GENERATING STATIONS.

A. The Auditor recommends that DE-Ohio perform an economic analysis to determine the level of spare parts carried, the ability to share parts, and the use of on-line maintenance and redundant equipment at its generating stations. DE-Ohio understands that the Auditor believes that additional spare parts inventories, inventory sharing, on-line maintenance and redundant equipment can reduce outage length and as a result, Rider FPP costs to consumers may decrease.

Q. DOES DE-OHIO AGREE WITH THIS PREMISE AND RECOMMENDATION?

A. In part. DE-Ohio does not believe that an economic analysis is necessary to determine the level of spare parts carried in inventories because the current processes are more than sufficient and already satisfy this recommendation. First, DE-Ohio already has mechanisms in place to share parts and inventory among its own generating stations. DE-Ohio, through parts storage at its generating facilities has the ability to make readily available spare parts far greater than most other utilities. Second, Duke Energy Corporation has become an industry leader in warehousing because of the wide breadth of operated generating units in its portfolio of greater than 46,000 megawatts that allows a potential to share parts among its many generating facilities in both North and South America. The Duke Energy warehouse supply inventory is connected electronically across the Duke Energy footprint, providing DE-Ohio the benefit of leveraging storage capability and the ability transfer parts and supplies to and from all of its locations. However, various codes of conduct within the states, and on the Federal level create restrictions on transactions between jurisdictions, including among Duke Energy Corporation's utility operating companies. While an accessible and sharable inventory on an enterprise-wide basis could create some additional efficiency in terms of operating costs and reduced lead times for acquisition of emergency critical equipment, there are multiple levels of regulatory hurdles across the jurisdictions, which are outside the control of DE-Ohio.

That being said, DE-Ohio is currently exploring this alternative. To enhance the ability to expedite access and minimize the cost of spare parts and supplies, and to maintain best in class performance, the Duke Energy's warehouse organization has initiated work with the benchmarking group, Scott Madden Associates to develop benchmarks to broaden our capabilities in this area. DE-Ohio expects that comparable information to other utilities will be available by the end of First Quarter 2008.

DE-Ohio's policy is that critical spare parts are available where appropriate and economically justified to ensure uninterrupted generation and, in fact, has spare/redundant equipment in place and available throughout its fleet. DE-Ohio does evaluate the installation/replacement/maintenance of redundant critical equipment on a routine basis to insure service capability. Like all projects, they are evaluated on economic merit. If the economic benefit justifies installation of redundant equipment then the project is funded and executed.

As a matter of routine process, DE-Ohio always looks at performing on-line maintenance before taking an outage on a generating plant unit. Outages and subsequent startups are costly from an operations and maintenance standpoint. DE-Ohio's policy is to avoid unit shutdowns wherever possible. There are times however, that safety and environmental concerns, or even the difficulty of a repair that necessitates a decision to perform maintenance work with the unit out of service.

In summary, DE-Ohio believes that its operating costs cannot be reduced significantly through an economic study around increasing spare parts, inventory sharing, or using on-line maintenance/redundant equipment, and that the current systems in place have already created any efficiencies that could result.

Q. PLEASE RESPOND TO THE AUDITOR'S RECOMMENDATIONS REGARDING CAPITAL AND O&M BUDGETS AT BECKJORD STATION AND STAFFING LEVELS AT DE-OHIO'S COAL PLANTS.

A. With respect to the recommendation regarding 2008 capital and O&M budgets at Beckjord, DE-Ohio does not have any plans to decrease the current 2008 O&M Beckjord budget at this time. Additionally, DE-Ohio will act promptly and prudently to address any maintenance issues if they occur.

Regarding the staffing level recommendation, DE-Ohio agrees with this recommendation. A staffing level review will be initiated to insure not only that optimum staffing levels exist, but also that there is an appropriate mix of disciplines to insure maximum performance.

IV. CONCLUSION

Q. DOES THIS CONCLUDE YOUR DIRECT TESTIMONY?

A. Yes.

Duke Energy®

Nuclear Generation
Materials Engineering & Lab Services

May 14, 2007

Memorandum to: David Warren, Turbine SMEs, Duke Energy Corporation
C.T. Alley Jr., Nuclear Generation, Duke Energy Corporation

Subject: Evaluation of Failed Turbine Blades from Zimmer Station
Metallurgy File #3791

Introduction

A total of four failed low pressure turbine blades were received in the Metallurgy Laboratory for evaluation of failure mode. Two from LPA L-2 were fractured and one from LPB L-2 was severely cracked. The fourth from LPA L-3 had cracks in the peened end of the tenon and a crack in the shroud (cover band). Information received with the blades included the following:

The L-2 governor end blade failures on LP1 (or LPA) failed approximately 4-3/4" to 5-1/2" from the tip of the blade. Two blades from this row were submitted for laboratory evaluation. The L-2 generator end blade failures on L-2 (or LPB) failed approximately 1" from the tip. One failed blade from this location was submitted for laboratory evaluation. Both rows had been undershroud welded. All failed blades are reported to be type 403 stainless steel. Both LPs had fairly heavy deposits on the L-2 blades. The failed blades were in service for 16 years and some of the failures may have occurred as long as two years ago. At the time the blades were removed for examination, visual examination had confirmed twelve failed L-2 blades on the governor end of LP1 And seven failed L-2 blades on the generator end of LP2.

Visual Examination

The most striking characteristic of the three L-2 blades was the adherent brown deposit on the convex side of each. The deposit lay over the blades in a pattern that suggests condensation ran from the root end of the blade outward toward the tip depositing material and producing erosion-corrosion grooves oriented along the radial axis of each blade (Figures 1, 2 and 3). The blade that was not completely fractured shown in Figures 3 and 4 had a complex crack pattern that did not appear to be particularly related to the direction of the stresses that would be expected to occur during operation. Figure 4 also serves to illustrate the typical surface condition of all three blades. Each had thin discontinuous black deposits also oriented in a radial deposition pattern on the concave side of the blade. Figure 5 shows the multi-directional looping crack pattern extending through the thickness of the blade.

The portion of the fracture faces near the leading edge of the two broken blades shown in Figure 6 have the macroscopic characteristics of fatigue. Some portions of each face is relatively deposit free suggesting that the final fracture probably occurred recently. Further toward the trailing edge, the fracture surface is much rougher (stepped) and has more deposit which suggests corrosion rather than fatigue.

The results of macroscopic examination indicate both corrosion and mechanical fatigue were associated with the failures of the blades from LPA L-2. The complex crack pattern on the LPB blade does not rule out mechanical fatigue but suggests corrosion as the predominant mechanism.

Figure 7 illustrates the as-received condition of the L-3 blade. The face of the crack in the shroud of this blade was covered with a tenacious brown deposit similar to that seen on the convex surface of the other blades. No secondary or branch cracking was observed either on the shroud or on the tenon. The shroud and tenon were cut to separate the parts for further examination. The crevice between the two parts was tightly packed with debris. A strong solvent smell emanating from the area of the deposits was noted. Later conversations with the turbine SME suggested this odor might come from the penetrating oil used when the blade was removed from the rotor. SiliKroil was suggested as one of the possible solvents used. The crack in the tenon was longer on the flank of the tenon than on the peened end which suggests it initiated in the crevice and propagated toward the outer surface.

Scanning Electron Microscopy (SEM)
Adherent deposits obscured much of the fracture faces of the L-2 blades but the cleaner areas had evidence of fatigue propagation of the fractures (Figures 8, 9 and 10). Other than the heavy deposits in the region of the trailing edge, no indications of intergranular or transgranular corrosion were found.

The entire surface of L-3 blade shroud crack was covered with the adherent brown deposit that could not be successfully removed without damaging the underlying fracture features. No useful SEM information was obtained. A part of the crack in the tenon was opened and examined by SEM. The features near the end of the crack were more consistent with corrosion than with fatigue (Figure 11). The deposits analyzed by EDS are discussed below.

Metallography
Sections through the blade from LPB and one of the blades from LPA were prepared for microscopic examination by grinding and polishing. The first crack examined (Figure 12) was from LPB and ran in a direction consistent with through thickness loading. It is mixed intergranular and transgranular consistent with a corrosion driven crack. Figure 13 shows a pit on the convex surface of one of the LPA blades. It has a network of stress corrosion cracks growing from the bottom of the pit. The convex surface illustrated in Figure 14 shows that metallic copper is associated with many of the pits. The metallographic results indicate corrosion pitting on the surface of the L-2 blades was widespread and that copper is associated with most of the pits. Not all pits have stress corrosion cracks emanating from the bottom of the pit but many do.

A section through the crack in the tenon of the L-3 blade revealed a crack on a plane parallel to the tenon axis that turned 90 degrees as it approached the peened head of the tenon (Figure 15). There were numerous small secondary cracks at right angles to the main crack (cracking on planes normal to the tenon axis). These cracks were multi-branched and filled with corrosion deposit (Figure 16).

Deposit Characterization
As noted above, the L-2 blades had an adherent brown deposit on the convex surface. Some of the material was scraped from the surface and examined by energy dispersive spectroscopy (EDS) to determine if any specific corrosive species could be detected (Figures 17 and 18). The bulk of the deposit consists of a silicon compound. No elements were detected that might commonly be associated with silicon as a silicate, therefore, it appears that the bulk of the deposit is silica. Several other elements such as copper, aluminum and nickel were also detected in the deposit. Nickel and aluminum were not uniformly dispersed among the particles examined but copper appeared in almost every spectrum. No chlorides or sulfur compounds were detected in any of the deposits. One analysis by Nalco (below) confirmed the presence of these elements.

Silicon as (SiO_2) 68 %
Iron as (Fe_2O_3) 22 %
Chromium as (Cr_2O_3) 1 %
Copper as (CuO) 1 %
Nickel as (NiO) 1 %
Total From XRF: 93 %
The results for the XRF analysis were normalized to Loss at 925° C
Thus, XRF + L925 = 100%

Deposits scraped from the blade in the Metallurgy Laboratory found detectable quantities of calcium, chromium, copper, magnesium, nickel, phosphorus, potassium and sodium. These elements were present in quantities much less than the detectable limits for the EDS. This analysis is consistent with the Nalco analysis and with the EDS analysis.

EDS analysis of the deposits from the crevice between the tenon and shroud on the L-3 blade contained essentially the same chemical elements as the surface deposits on the L-2 blades except chlorine and sulfur compounds were detected (Figure 19). These two elements may have been present from service but are more likely the result of contamination with penetrating oil noted during macroscopic examination.

A small quantity of black magnetic deposit was also seen under the shroud (Figure 20). The angular appearance of the fragments and EDS analysis indicate these are magnetite deposits.

Base Material Characterization

The base material was reported to be type 403; however, hardness and quantitative chemical analysis indicate the blade material is 17-4PH or similar precipitation hardening material. The microstructure evaluated during metallography is tempered martensite as expected for a turbine blade. Hardness of all blades is Rockwell C 30 to 34 (see tables below). The characteristics are consistent with hardened 17-4PH stainless steel sometimes used for turbine blades. The specified hardness is not known.

Table 1 Rockwell C Hardness

LPA #115	LPA #58	LPB #150	L-3 Row
30	32	33	34
33	33	32	33
31	34	31	34
31	33	31	33

Table 2 Chemical Analysis (wt%)

(1)	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Nb	Ta
L2-3	0.04	0.31	0.013	0.015	0.71	4.30	16.53	0.06	3.13	0.46	0.03
LPA-L2-2	0.04	0.31	0.016	0.015	0.73	4.39	16.44	0.07	3.10	0.49	0.02
LPA-L2-1	0.04	0.29	0.015	0.015	0.71	4.11	16.98	0.06	3.15	0.46	0.02
LPA-L3	0.06	0.34	0.010	0.006	0.62	4.21	15.75	0.19	3.07	0.49	0.01

(1) LP-3—Blade no. 58 from LP A
L2-2—Blade no. 115 from LP A
L2-1—Blade no. 150 from LP B
LPA-L3—Unidentified blade from L-3 row of low pressure turbine A

Discussion and Conclusions

The data indicate that both corrosion and mechanical fatigue are participating in the blade failures. The pitting corrosion and stress corrosion cracking appear to be more severe on the half of the blade toward the trailing edge. The most common corrosive species, chlorides and sulfur compounds were not detected in the deposits but these are generally very soluble and may have been reduced to undetectable levels by condensate leaching of the surface. The association of the copper with pits suggests that plating of this element from solution may have been the primary driving force for pitting. The dissolution of the blade alloy and diffusion of anions due to charge balance considerations within the pits would then create the acidic conditions conducive to stress corrosion cracking at the bottom of the pit.

In summary, it appears that the most likely failure scenario is pitting and stress corrosion cracking initiated first and then fatigue drove crack extension from these small stress concentrations.

The presence of copper suggests that copper components such as condenser tubes elsewhere in the boiler are experiencing significant corrosion. High copper contents in the feedwater could be contributing to problems elsewhere including in the waterwalls of the boiler. Silica and alumina found in the deposits are likely carry over in the feedwater. The magnetite deposits may suggest significant exfoliation is occurring in the superheater and reheater sections of the boiler.

If the Metallurgy Lab can be of further assistance, please call us at (704)875-5275.

C.R. Frye

C. R. Frye, P.E.
Senior Engineer
Materials, Metallurgy & Piping

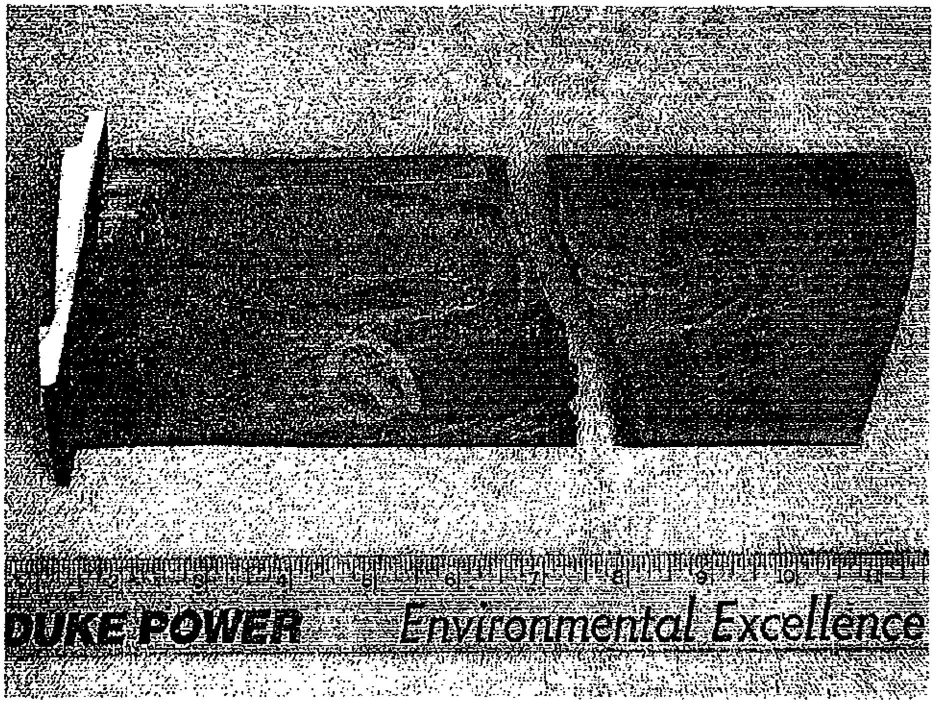

Figure: 1 LPA blade 115, number 4 in group. Macro 01

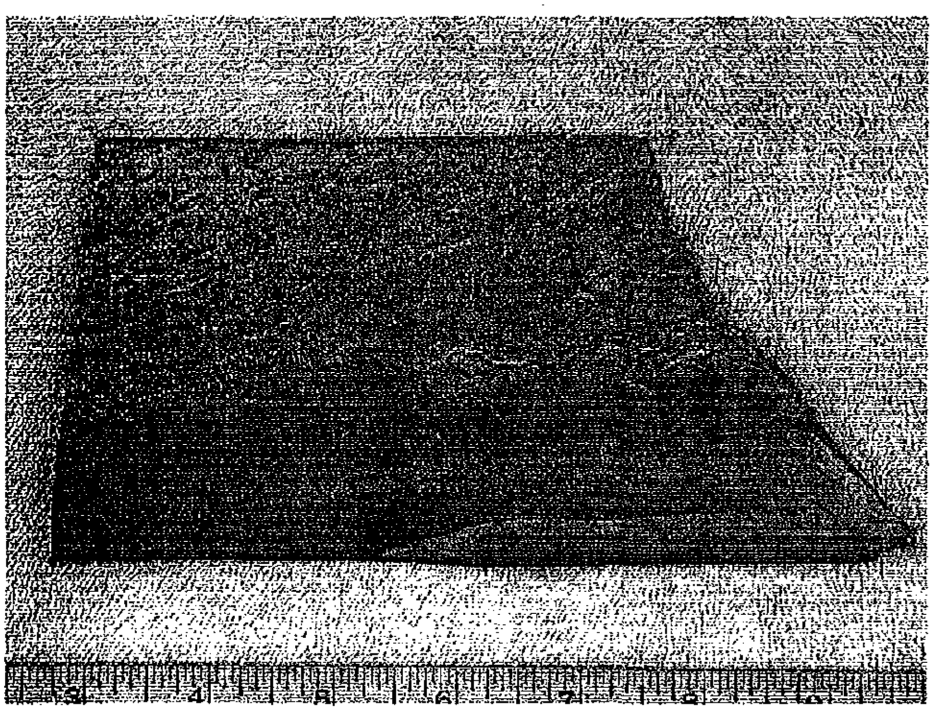

Figure: 2 LPA blade 58, start of group. Macro-06

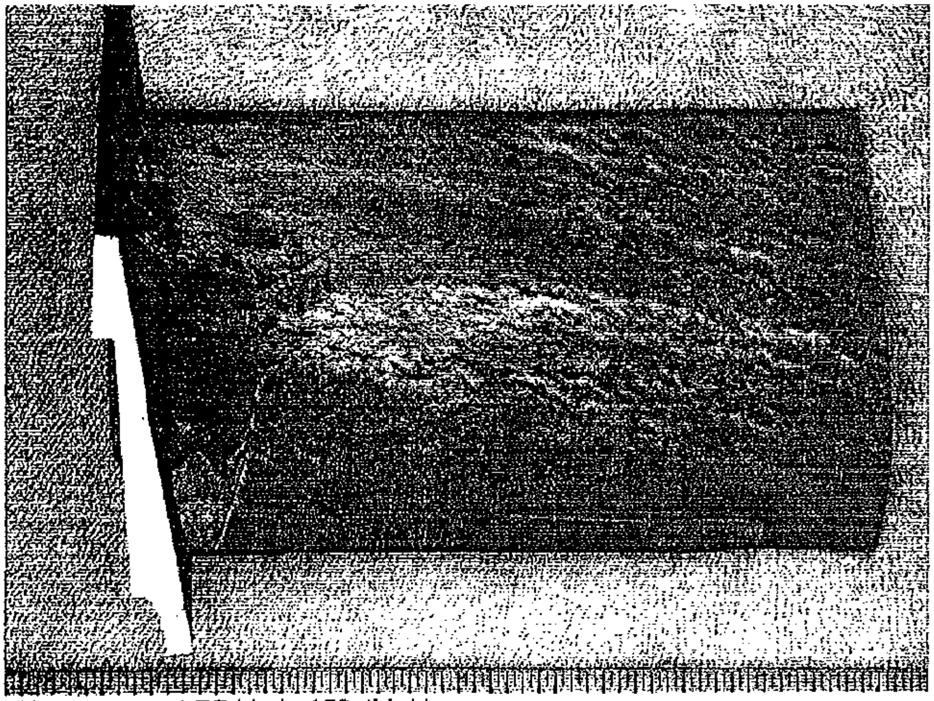

Figure: 3 LPB blade 150, third in group. Macro-04

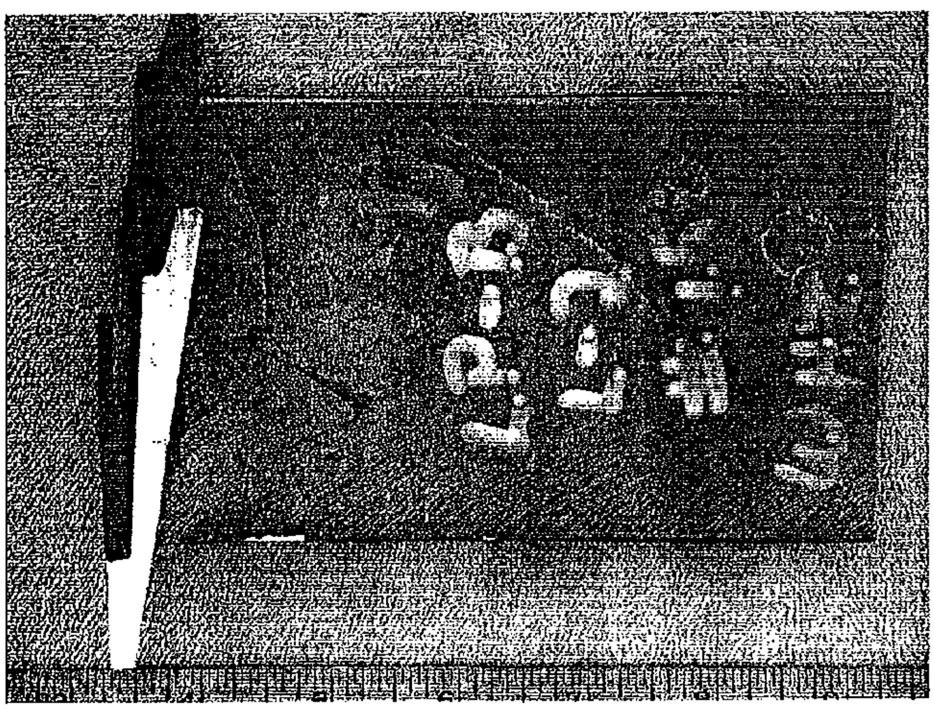

Figure: 4 LPB blade 150, third in group. Enlarged View of cracks looking on concave side (opposite side of Figure 3) Macro-05

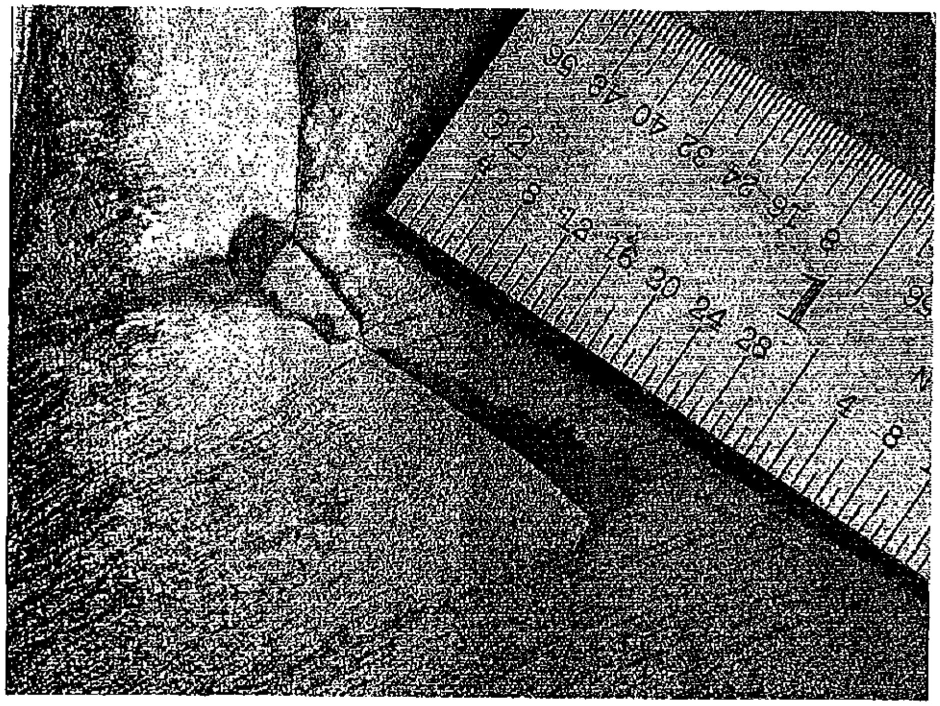

Figure: 5 LPB blade 150, third in group. Enlarged View of cracks looking on concave side (opposite side of Figure 3) Macro-08

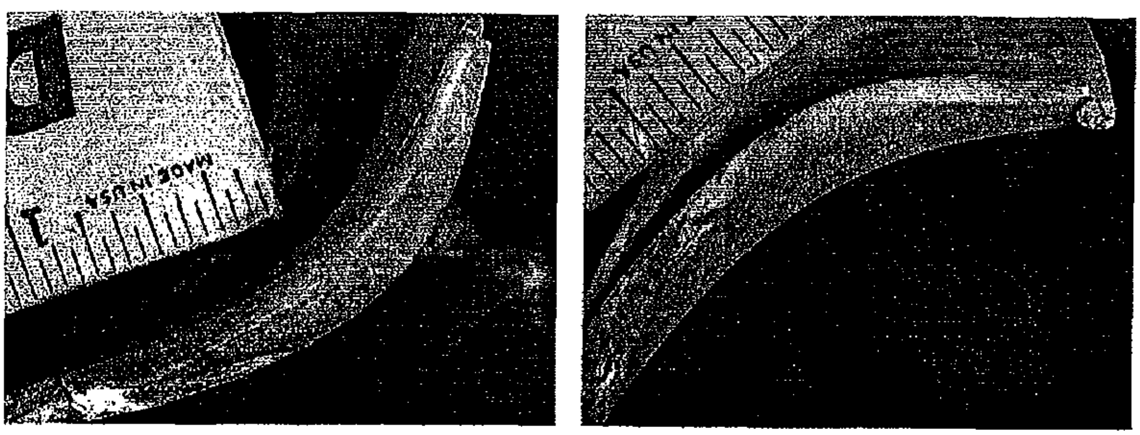

Figure: 6 Fracture surfaces from LPA-115 (left) and LPA-58 blades that were broken as received in laboratory. Macro-12 Macro-14

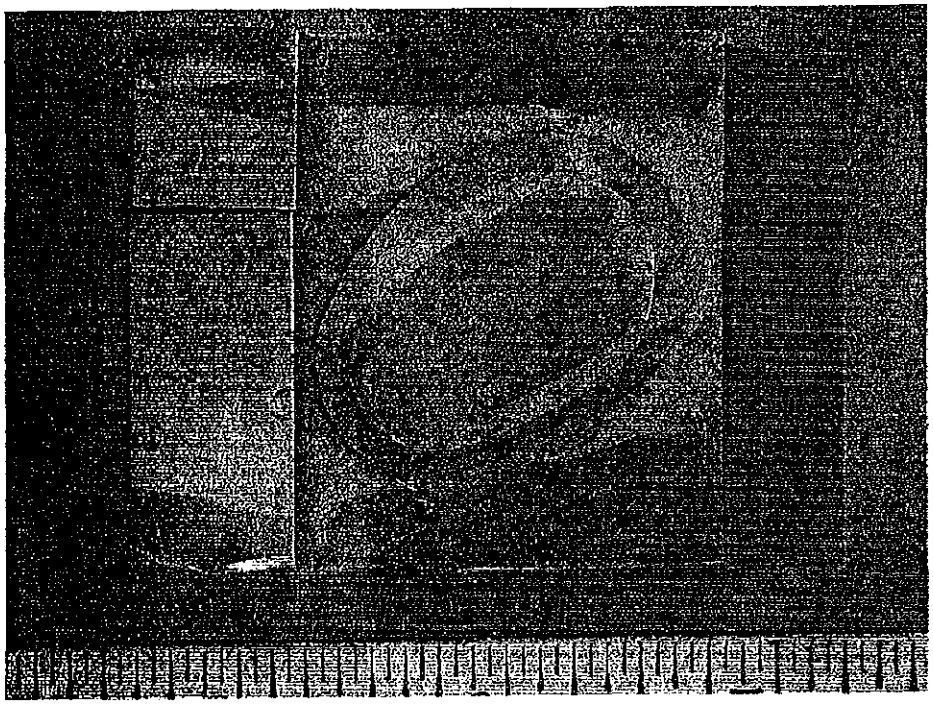

Figure: 7 .L-3 blade as-received. Note crack in shroud aligned with crack in tenon. Macro-16

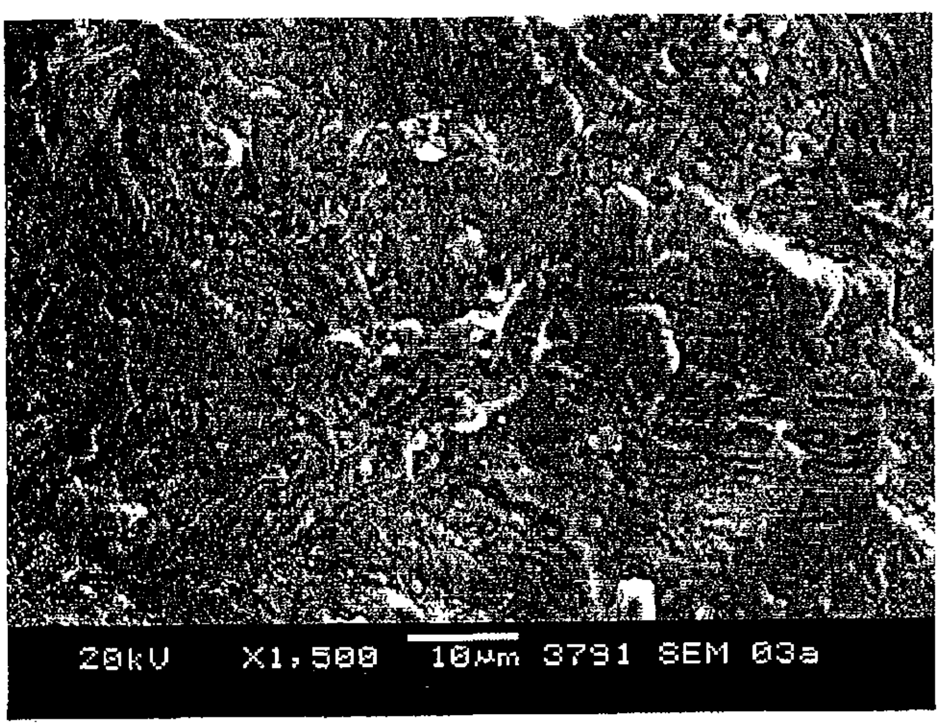

Figure: 8 SEM micrograph of fracture face near leading edge of blade from LPA. Features are characteristic of striated fatigue. SEM-3a SEI

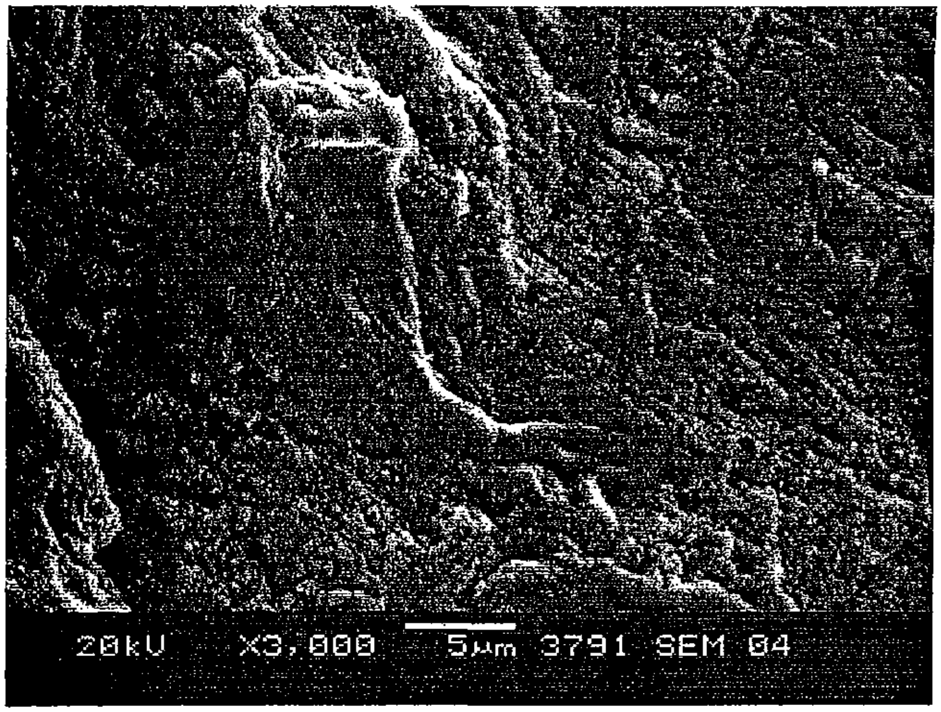

Figure: 9 SEM micrograph of fracture face near trailing edge of blade from LPA. Features are characteristic of striated fatigue. SEM-04 SEI

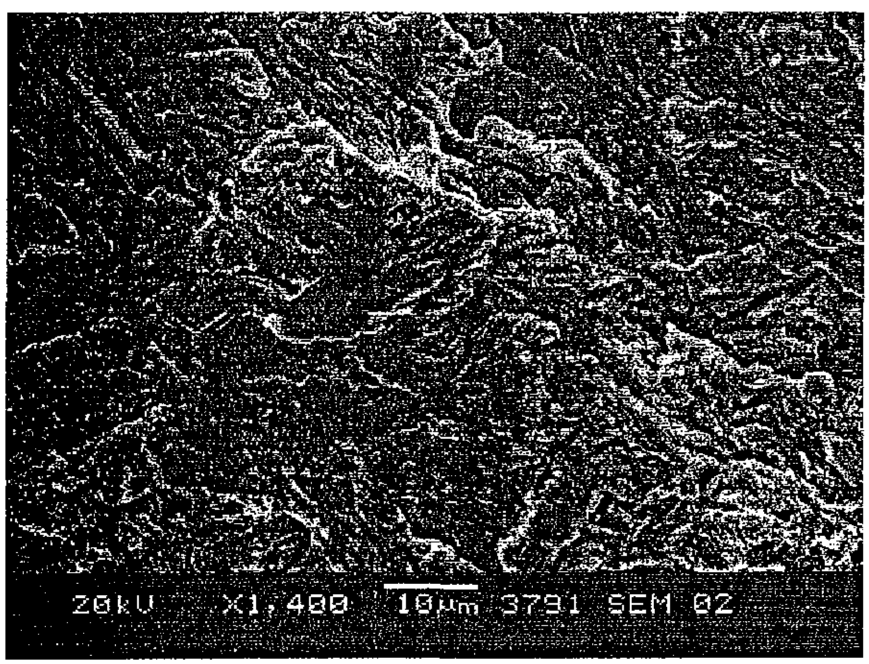

Figure: 10 SEM micrograph of opened crack near leading edge of blade from LPB. Features are characteristic of striated fatigue. SEM-02 SEI

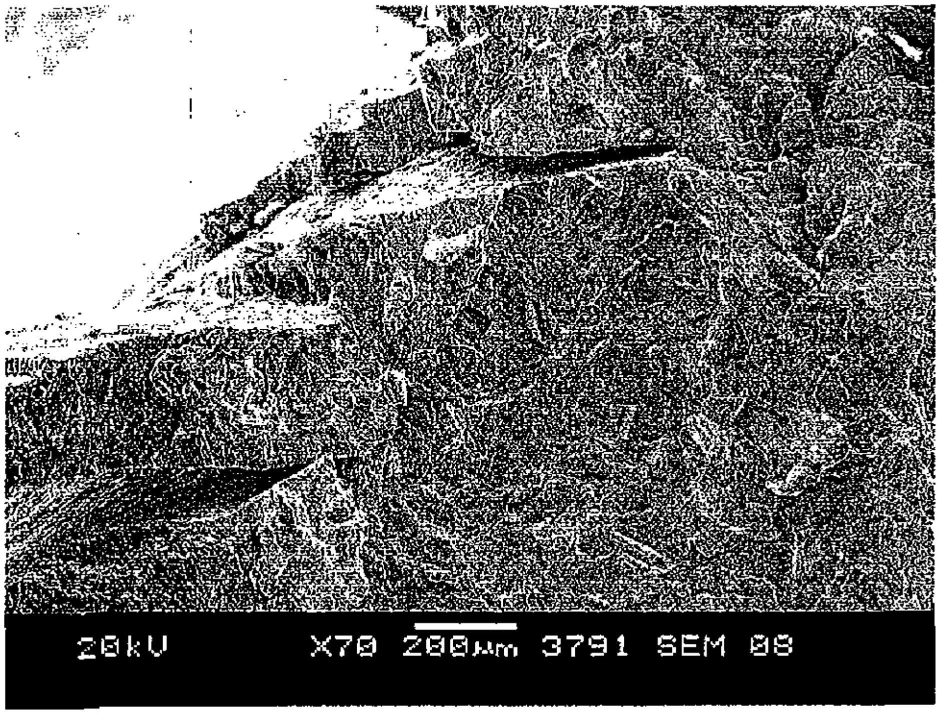

Figure: 11 Fracture produced in lab by opening crack in tenon. Note secondary cracking at top edge of picture

SEM-08
SEI

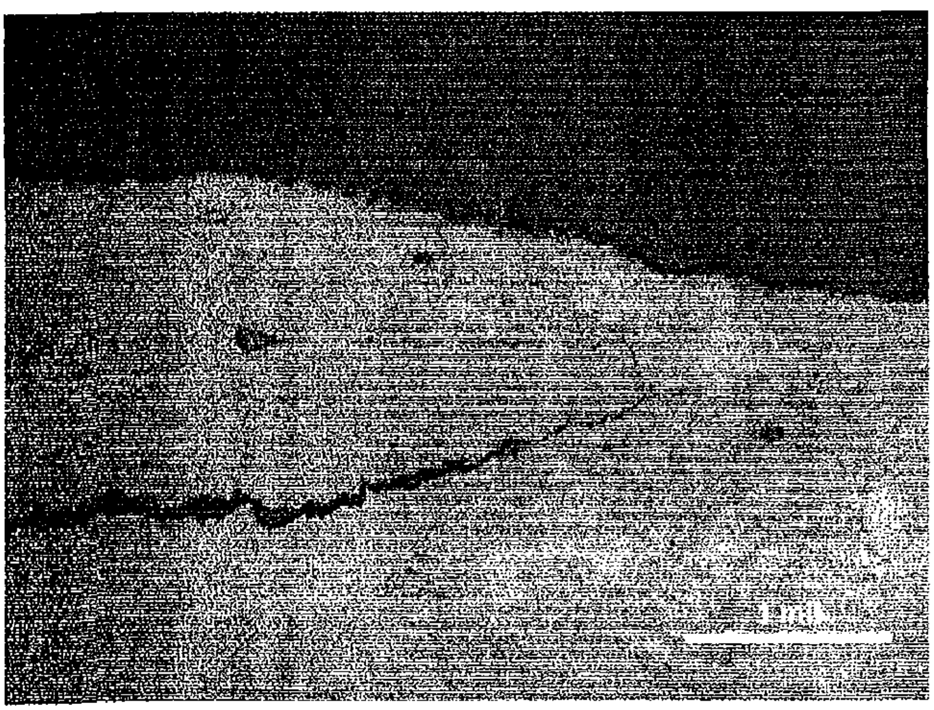

Figure: 12 Transverse cross section through crack in LPB blade (axis of blade runs into paper). Cracking is mixed transgranular and intergranular.

Micro-01a
Villela's etch

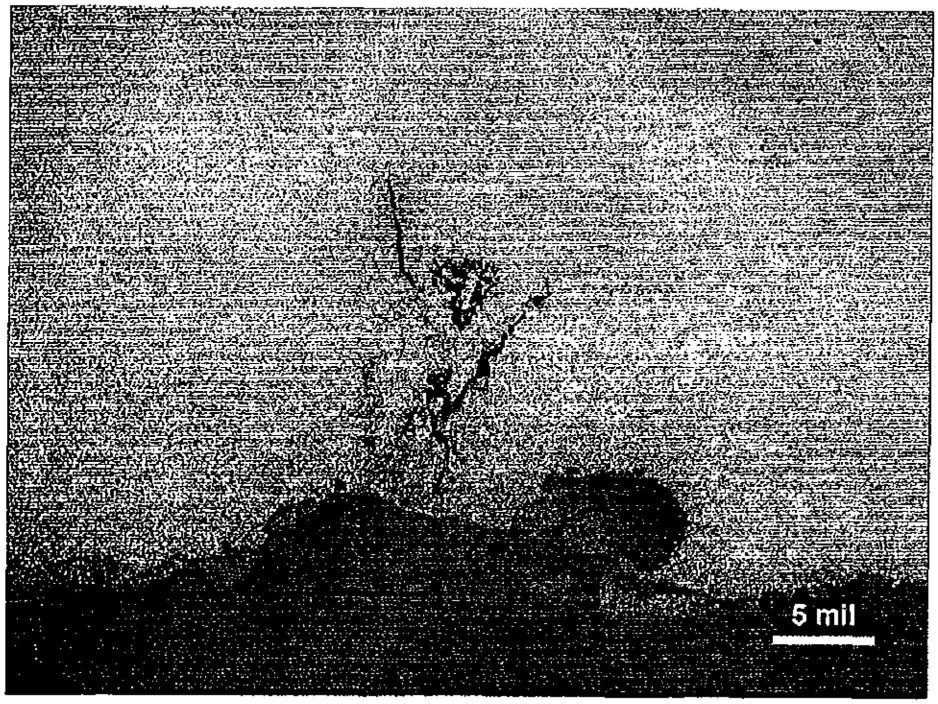

Figure: 13 Stress corrosion cracking at base of a pit on convex surface.

Micro-03
Villela's etch

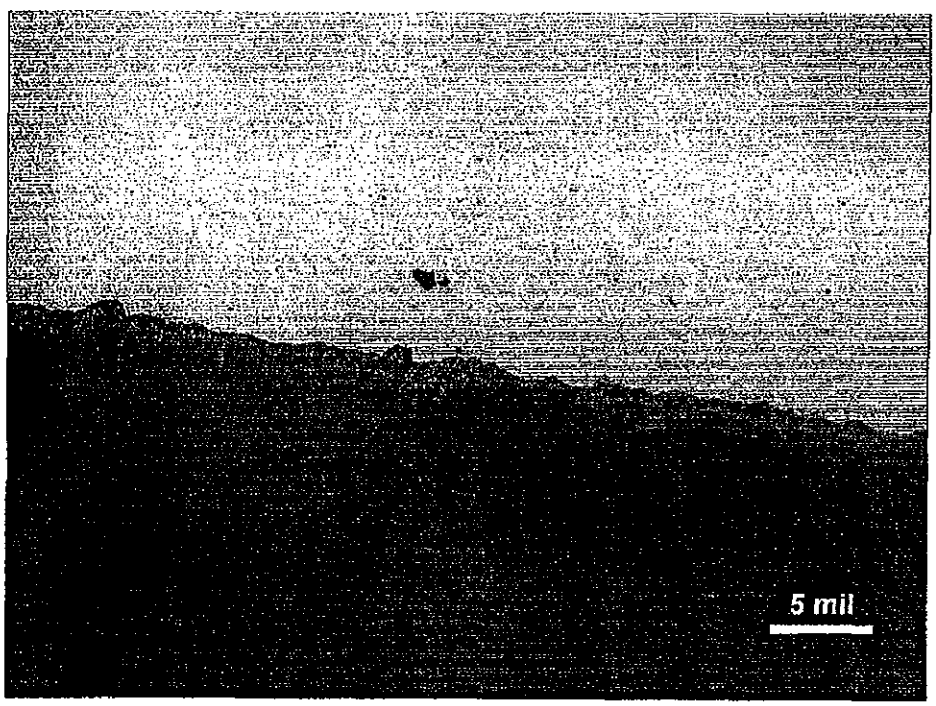

Figure: 14 Cross section through typical deposit on convex face. Note copper association with pits.

Micro-04
Unetched

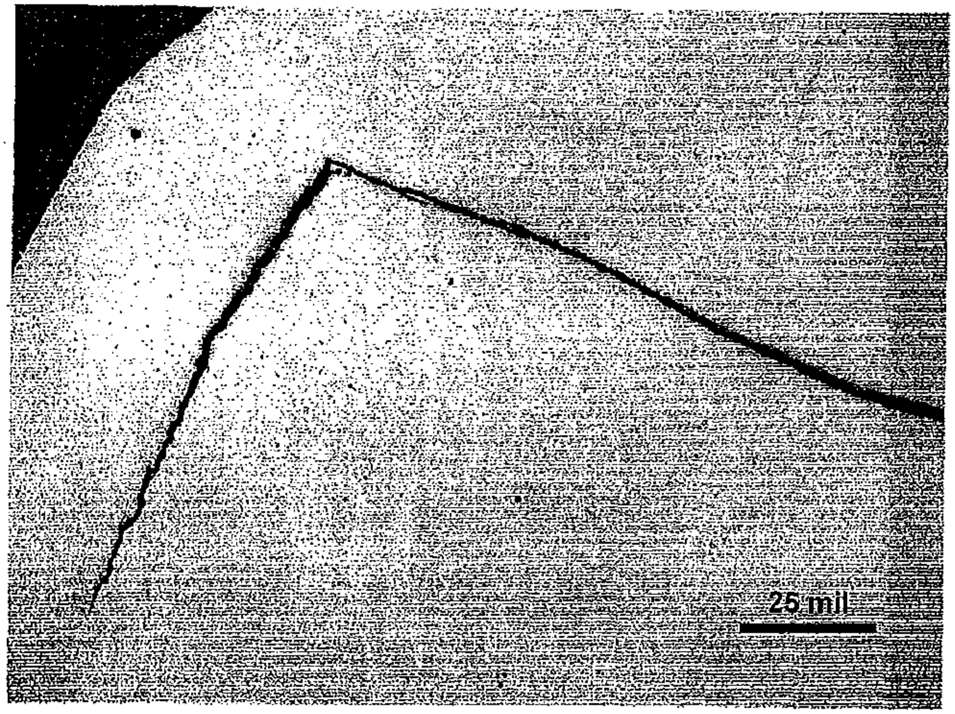

Figure: 15 Section through crack in tenon. Axis of tenon is parallel to crack. Peened head is at upper left.

Micro-09
Unetched

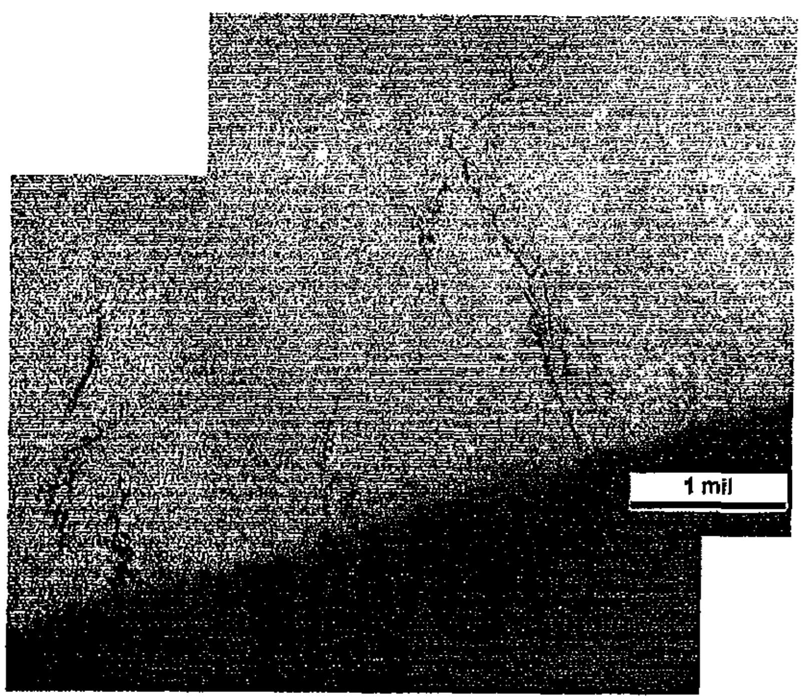

Figure: 16 Secondary cracking along main crack in tenon. Edge at bottom of photo is surface of main crack parallel to tenon axis.

Micro-14
Villela's etch

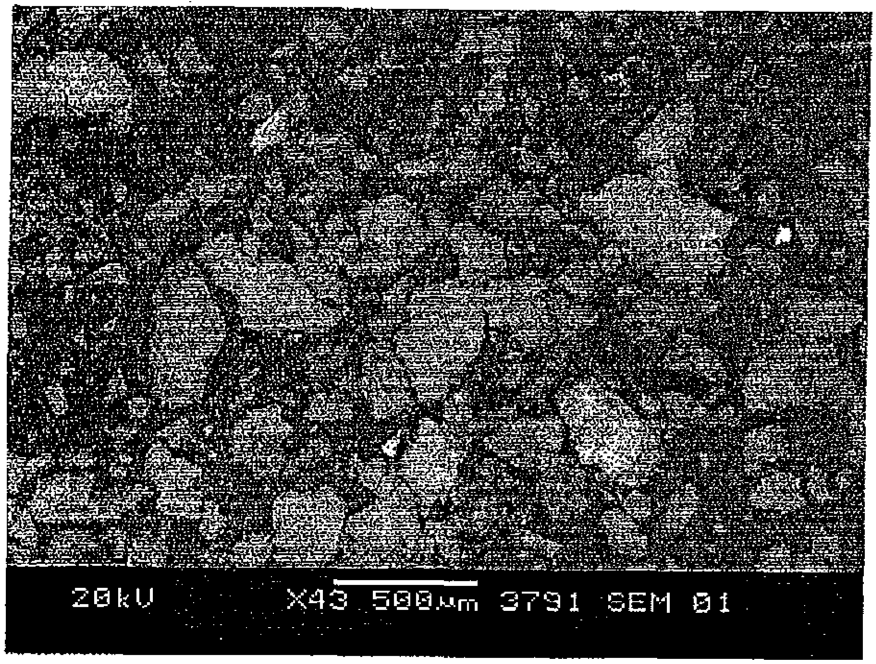

Figure: 17 Deposit particles scraped from the surface of one of the LPA L-2 blades. Lighter areas indicate the presence of heaver elements such a copper, iron, chromium and nickel.

SEM-01
BEI

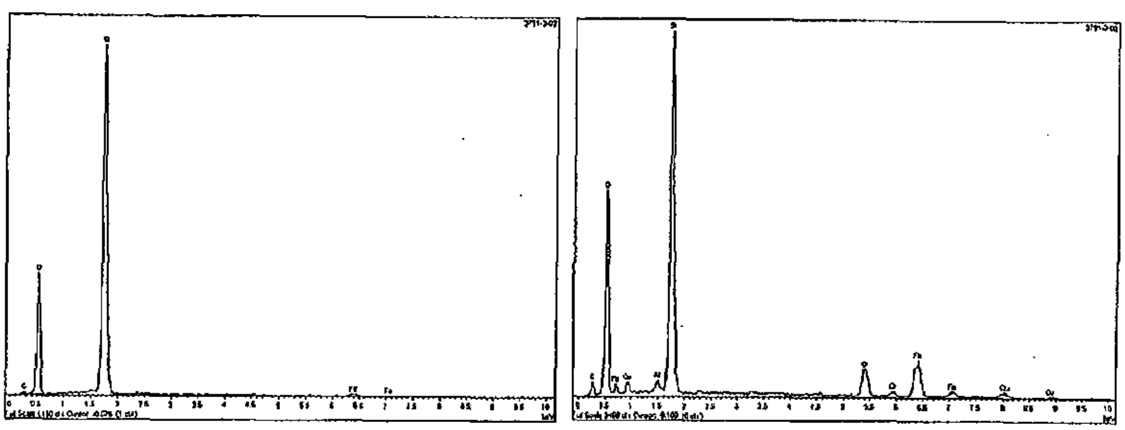

Figure: 18 EDS spectra of particles at left and bottom of Figure 13. Composition variation is typical from particle to particle.

3791-3-02
3791-3-03

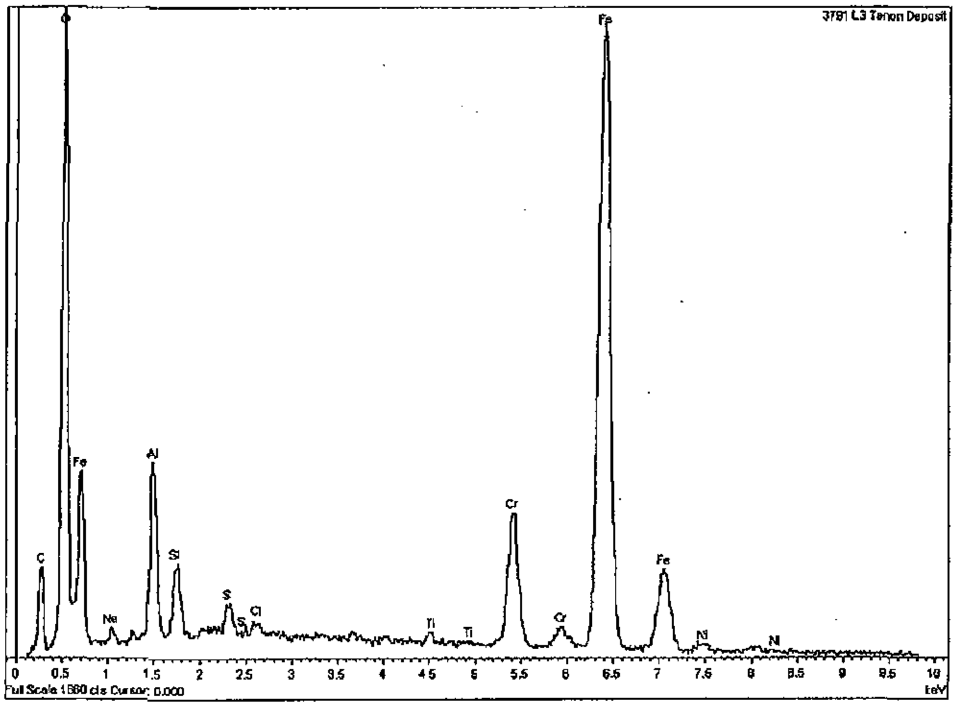

Figure: 19 EDS spectrum of material in L-3 tenon crevice. 3791-L3

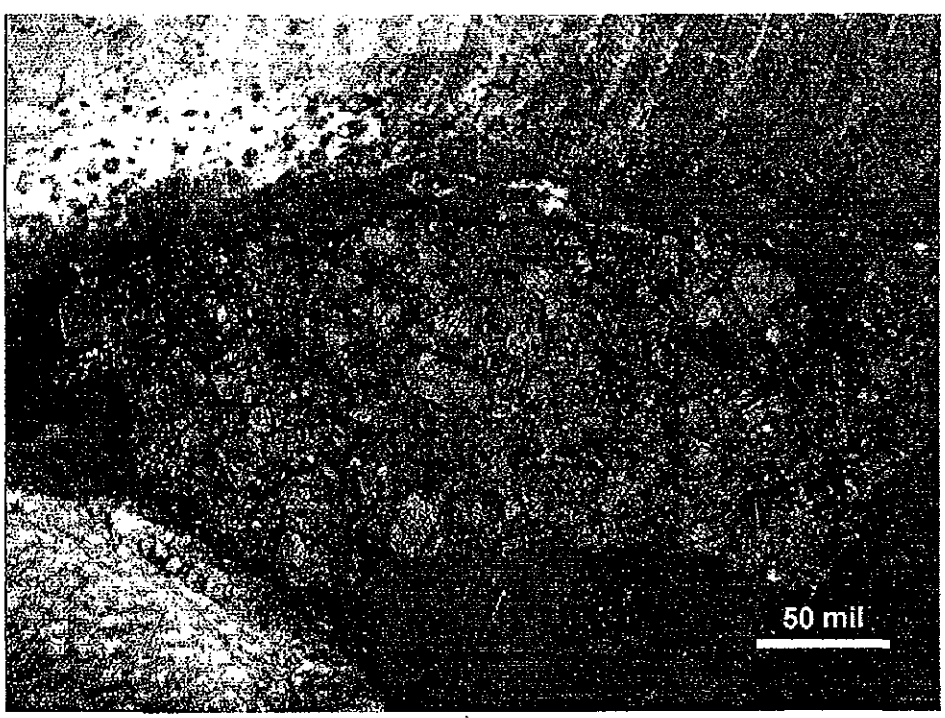

Figure: 20 Angular magnetic deposits under shroud. Stereo-03

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Siemens Power Generation, Inc.

TGME 07-107

To: Todd Anderson.

From: Ravi Angal

Date: July 30, 2007

Subject: L-2R fractured blades evaluation and L-3R blade root fracture evaluation from Duke Energy Ohio, Inc. Zimmer (ST) Unit 1

Siemens Confidential

INTRODUCTION

LP-A L-2R fractured blades #49 and #175 and LP-B L-2R fractured blades #103 and #141 from Duke Energy Ohio, Inc. Zimmer Station (ST) Unit 1 were submitted to Siemens Materials Engineering for metallurgical evaluation of the fracture. The LP-A L-3R #4 blade was also submitted for metallurgical evaluation of the fracture in the blade root. This was the first complete disassembly and inspection performed on these LPs since they went into operation in 1991.

CONCLUSIONS

1. The fracture surface of the blades LP-A L-2R #49 and #175 and LP-B L-2R #103 and #141 was obliterated due to exposure to oxidizing atmosphere for a long period. No interesting fracture features were found. No clear origin of the crack was found. Microstructure of the cross section of the fracture surface indicates that the crack propagated in a transgranular fashion, typical of high cycle fatigue.
2. The hardness and chemistry of the blades LP-A L-2R #49 and #175 and LP-B L-2R #103 and #141 meets the specification requirements of Siemens material specification. The microstructure of the core of the blades consists of tempered martensite and delta ferrite. The percentage of delta ferrite is approximately 15% (5% maximum per internal specification) in the core of the blade LP-B L-2R #14. Pitting was found below the reddish brown deposits of blade LP-B L-2R #103. Delta ferrite phase greater than 5% did not contribute into the fracture of the blades as fracture also occurred in blades having less than 5% as per the specification.
3. The chemical and X-Ray Diffraction analysis of reddish brown deposit on the blades LP-A L-2R #49 and #175 and LP-B L-2R #103 and #141 revealed up to 71% amorphous SiO_2 and

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24% Fe_2O_3. The chemical and XRD analysis of black deposit revealed iron oxides of hematite and magnetite.

4. The fracture surface of the LP-A L-3 #4 blade showed a number of secondary crack origins and these cracks propagated in a transgranular fashion. The beach / arrest marks were found to be consistent with a fatigue fracture. Primary crack originated at the trailing edge and propagated towards the leading edge. Pitting was found in the blade root grooves and around the fracture surface.
5. The chemical analysis of the weld filler metal of the undershroud welds of blades LP-A L-2R #175 and LP-B L-2R #141 was typical 17-4PH stainless steel.
6. The lack of penetration at the weld root was found in both the undershroud welds of LP-A L-2R #175 and LP-B L-2R #141 blades. Shrinkage porosity was found in the weld bead of LP-B L-2R #141 blade. Hydrogen cracking due to low preheat temperature was found in the weld bead of LP-B L-2R #141 blade.

DETAILS OF EVALUATION:

The LP-A L-2R fractured blades #49 and #175 and LP-B L-2R fractured blades #103 and #141 in the as received condition are shown in Figures 1 – 8. All the blades were covered with a reddish brown deposit on the convex side. The fracture surface of the blades was covered by oxide deposits.

Deposit from all the blades were collected and analyzed for chemical composition, compound identification and corrosive ionic elements using inductively coupled plasma – optical emission spectroscopy (ICP-OES), X-Ray Diffraction and Ion Chromatography. No corrosive elements were found in the deposit sample. The results of the analysis of deposit indicated presence of amorphous SiO_2 and iron oxides (hematite and magnetite). Refer to chemical analysis report attached as Appendix 1. The chemical composition of the L-2R blades meets the Siemens material specification. Refer to the chemical analysis report attached as Appendix 2.

After ultrasonic cleaning to remove the oxide deposits, the macro fractography of the L-2R blades was done to find the origin of the primary crack and direction of crack propagation. The macro fractographs are shown in Figures 10-13. The fracture surface of the L-2R blades comprises of a smooth flat surface starting from the leading edge and merging into the overload fracture area towards the trailing edge. The fracture surface of L-2R blades was obliterated and no interesting fracture features were found. The exact origin of the crack could not be confirmed. The

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Scanning Electron Microscope (SEM) evaluation of the fracture surface did not reveal any useful information as the surface was badly oxidized.

A cross section normal to the flat fracture surface was metallographically prepared for evaluation under the optical microscope. The micrographs are shown in the Figures 14-17. From the micrographs it seems like the crack in L-2R blades propagated in a transgranular fashion consistent with the fatigue mode, most likely high cycle fatigue. The microstructure at the fracture surface of L-2R blades consists of uniform tempered martensite.

Metallographic samples and hardness measurements were taken from the core of L-2R blades. The micrographs are shown in Figures 18-21. The microstructure of the L-2R blades #49, #175 and #103 consists of tempered martensite and delta ferrite (<5%). The microstructure of L-2R blade #141 consists of tempered martensite and delta ferrite, the delta ferrite content is greater than 5% (~15%). The measured hardness values for L-2R blades are shown in Table 1. The hardness of the L-2R blades meets the Siemens materials specification requirements (262-321 BHN).

The as received pictures of the L-3R #4 cracked blade are shown in the Figure 9. The fracture surface was covered with oxide deposits. After ultrasonic cleaning to remove the oxide deposits, the macro fractography of the LP-A L-3R #4 blade was done to find the origin of the primary crack and direction of the crack propagation. The macro fractograph is shown in Figures 23 & 24. Numerous secondary crack origins were found. Secondary cracks propagated in a transcrystalline mode as shown by the black arrows. Beach / arrest marks were found consistent with fatigue fracture. Primary crack originated at the trailing edge and propagated towards leading edge consistent with fatigue fracture. Pits due to corrosion were found around the fracture surface. The SEM fractography of the fracture surface revealed beach marks in the secondary crack consistent with fatigue fracture (Figures 23 & 24). The microstructure (Figure 22) of L-3R blade consists of tempered martensite and delta ferrite greater than 5% (~10%). The measured hardness values for L-3R blade are shown in Table 1. The hardness of the L-3R blade meets the specification requirements of Siemens material specification (262-321 BHN). The chemical analysis of the blade also meets the specification requirements. Refer to the attached Appendix 2.

A cross section of the undershroud weld of LP-A L2-R #175 and LP-B L2-R #141 was mounted for optical microscope evaluation. Refer to Figures 24 and 25. Lack of penetration at weld root was found in both the blades. Shrinkage porosity and crack originating at the interface of the heat affected zone and fusion zone was found in the weld bead of the LP-B L2-R #141. The crack is consistent with "hydrogen cracking" that can be attributed to low preheat

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temperatures. Semi - quantitative elemental chemical analysis via X-ray energy dispersive spectroscope (EDS) was performed on the undershroud weld beads of both blades. The chemical analysis of weld filler material was typical of grade 17-4PH stainless steel.

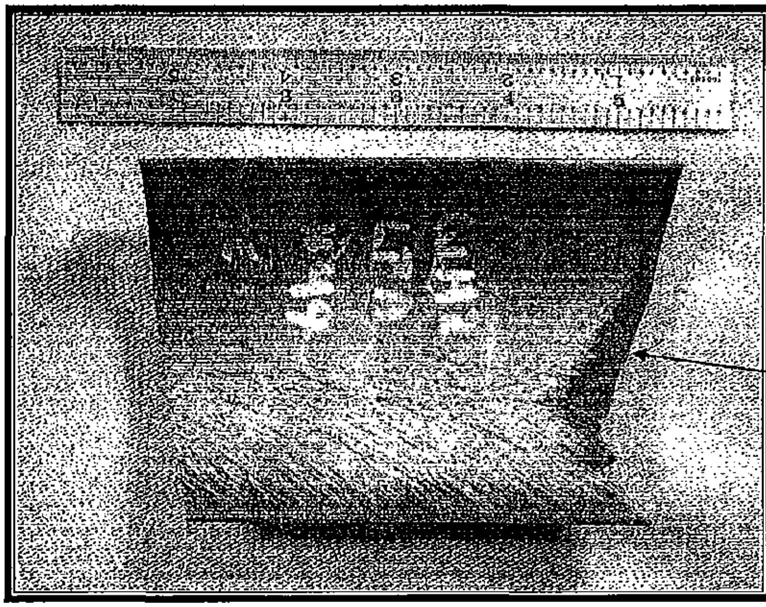

Figure 1: As received LP-A L-2 #49 blade concave side.

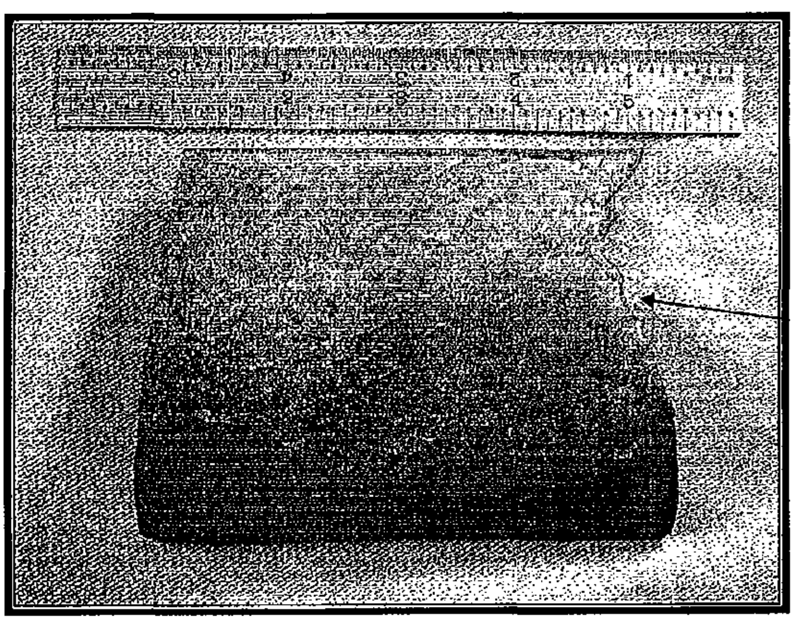

Figure 2: As received LP-A L-2 #49 blade convex side. Reddish brown deposit is seen on the convex side.

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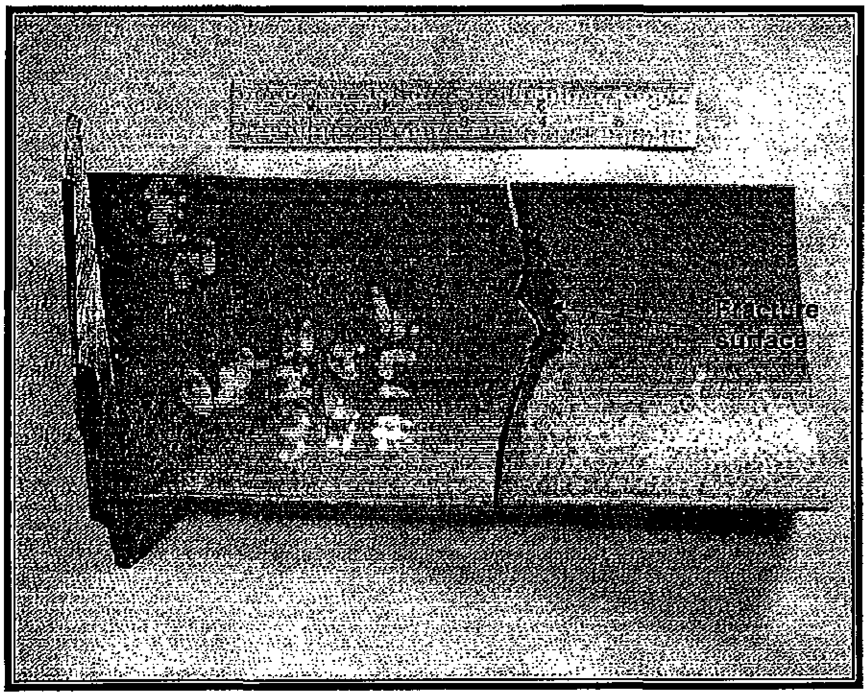

Figure 3: As received LP-A L-2 #175 blade concave side

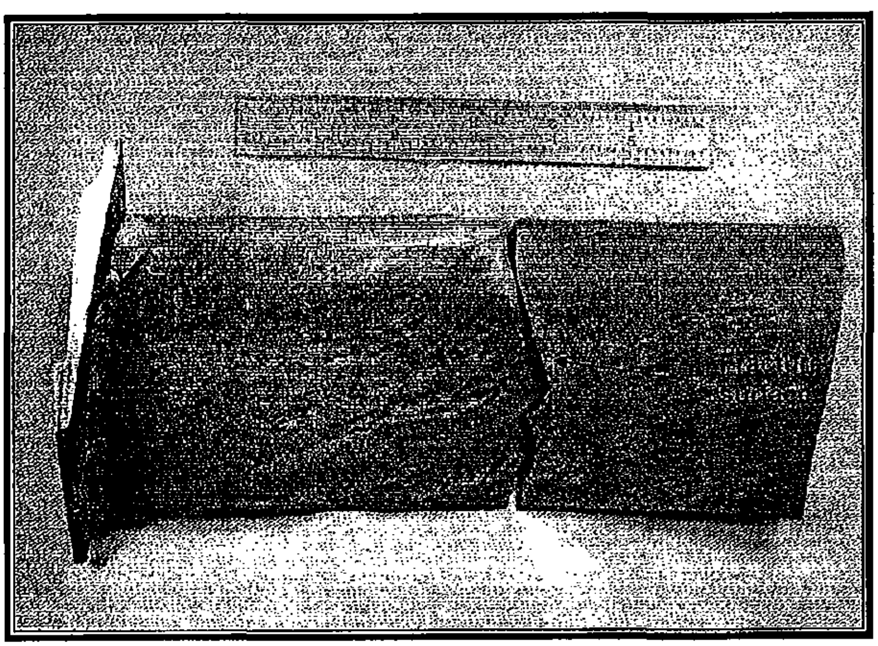

Figure 4: As received LP-A L-2 #175 blade convex side. Reddish brown deposit is seen on the convex side.

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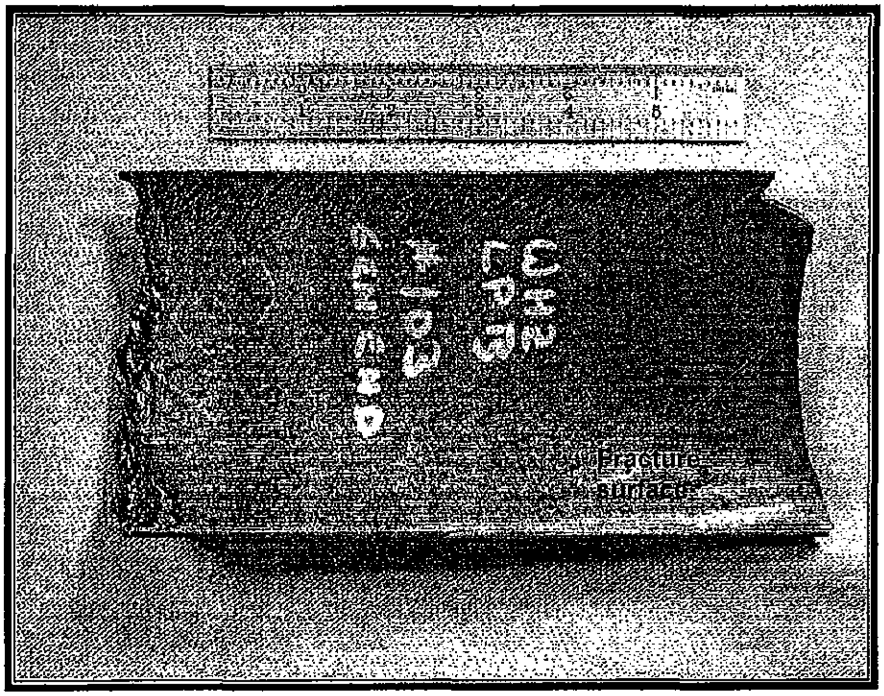

Figure 5: As received LP-B L-2 #103 blade concave side

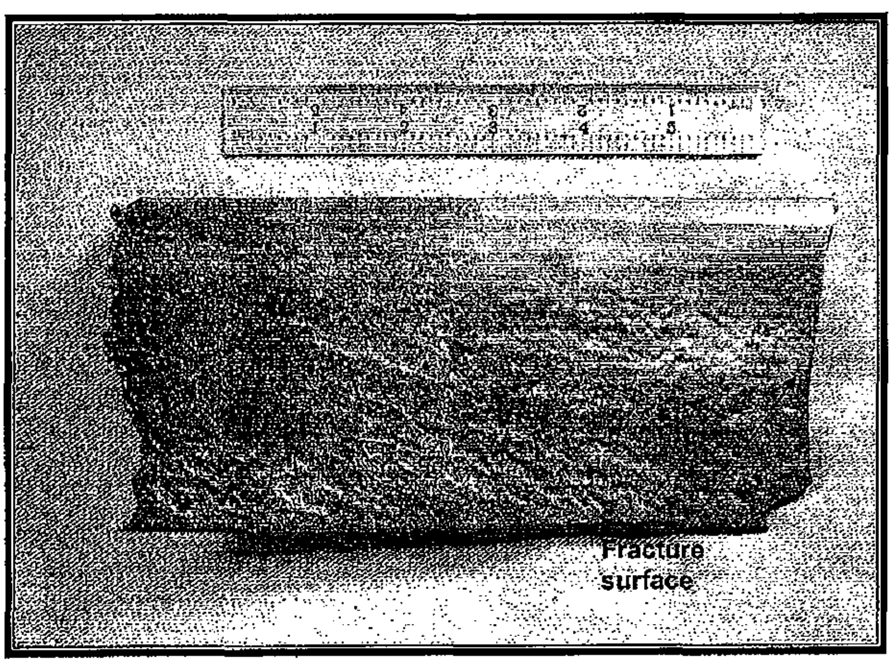

Figure 6: As received LP-B L-2 #103 blade convex side. Reddish brown deposit is seen on the convex side.

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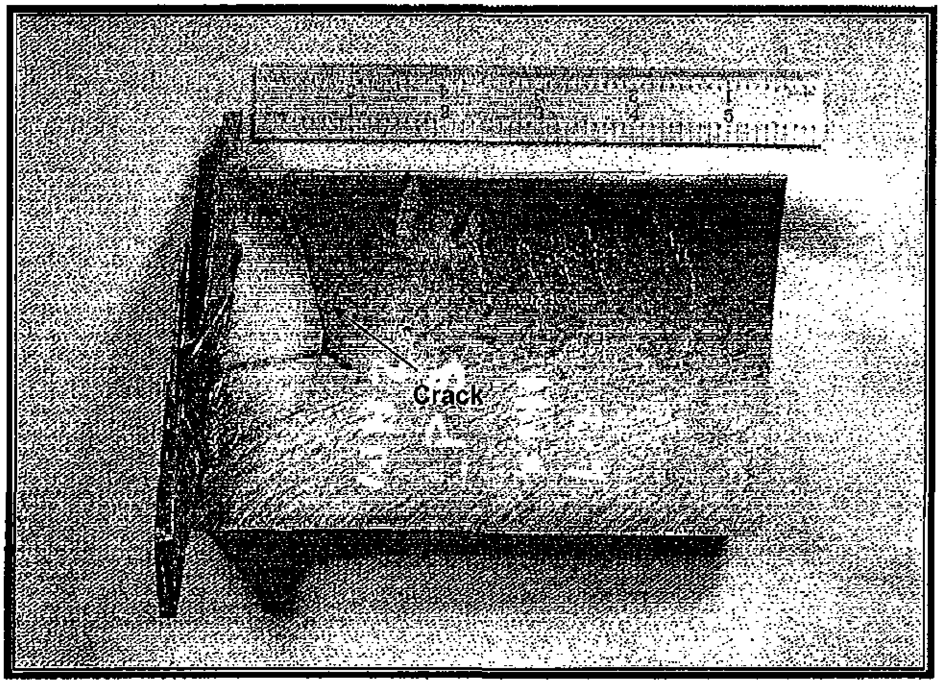

Figure 7: As received LP-B L-2 #141 blade concave side

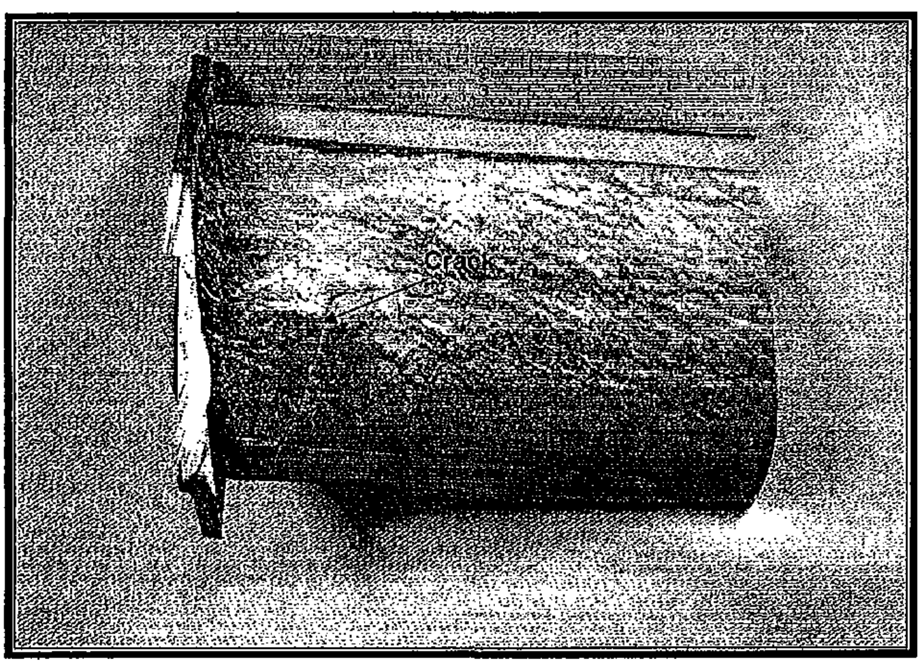

Figure 8: As received LP-B L-2 #141 blade convex side. Reddish brown deposit is seen on the convex side.

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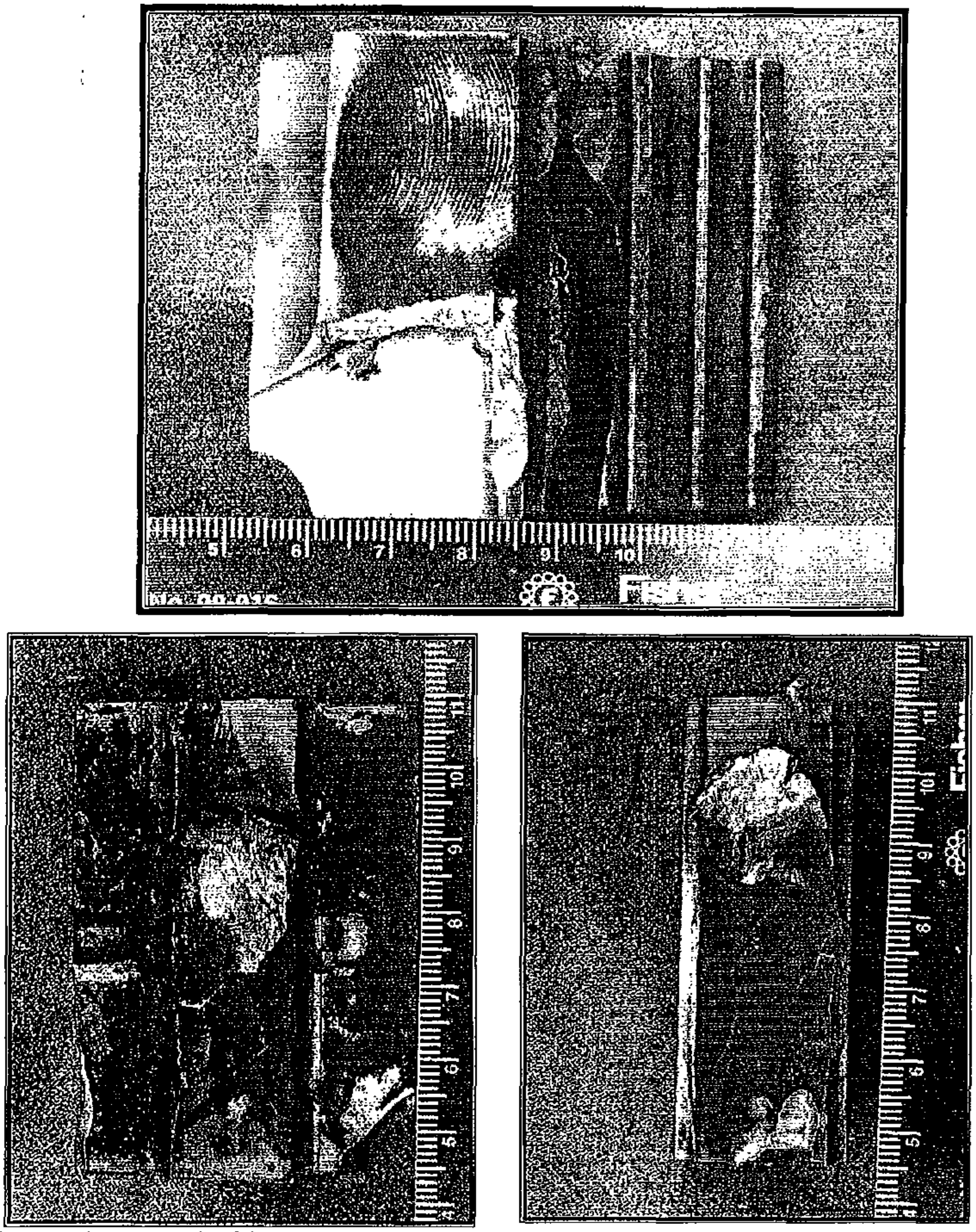

Figure 9: As received LP-A L-3 #4 blade cracked in the root. Fracture surface is covered by reddish brown oxide deposits.

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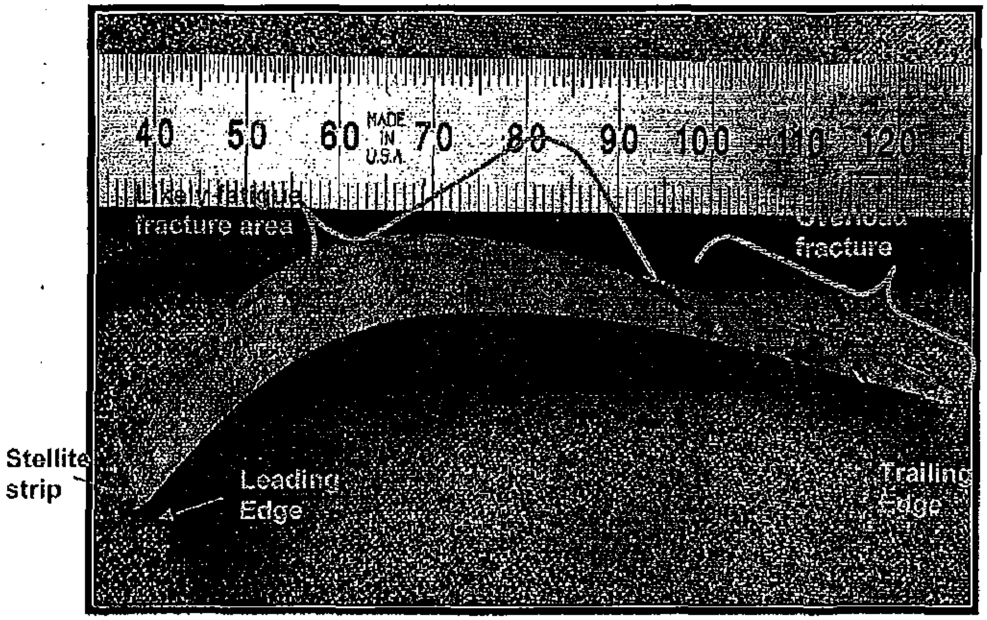

Figure 10: Macro photograph of fracture surface of LP-A L-2 #49 blade. Fracture surface was cleaned to remove thick oxide deposit. Flat fracture surface can be seen from the leading edge continuing into a fracture surface due to overload towards the trailing edge.

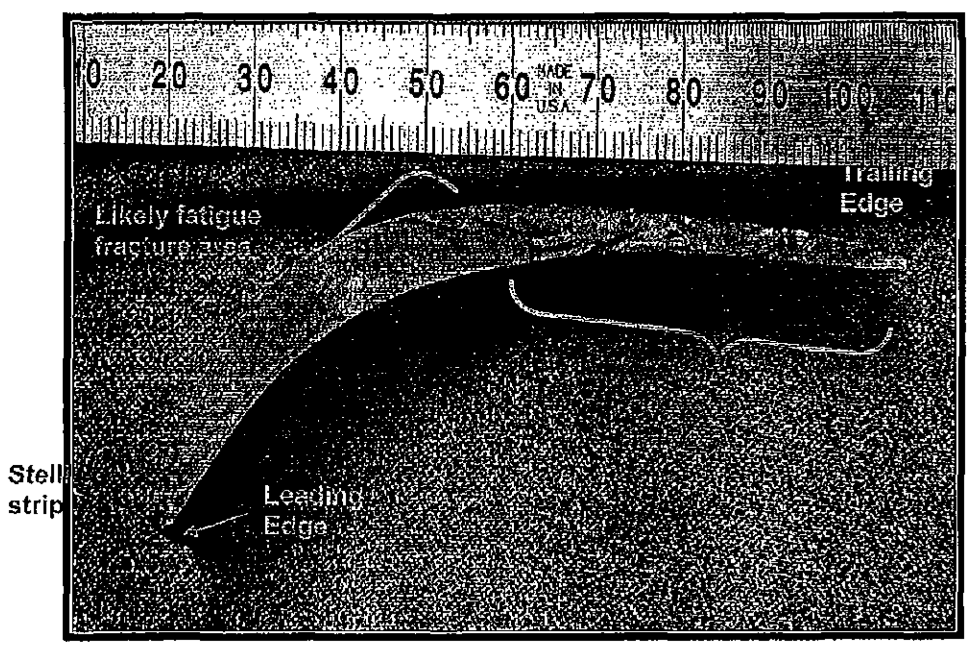

Figure 11: Macro photograph of fracture surface of LP-A L-2 #175 blade. Fracture surface was cleaned to *remove thick oxide deposit. Flat fracture surface can be seen from the leading edge continuing into a fracture* surface due to overload towards the trailing edge

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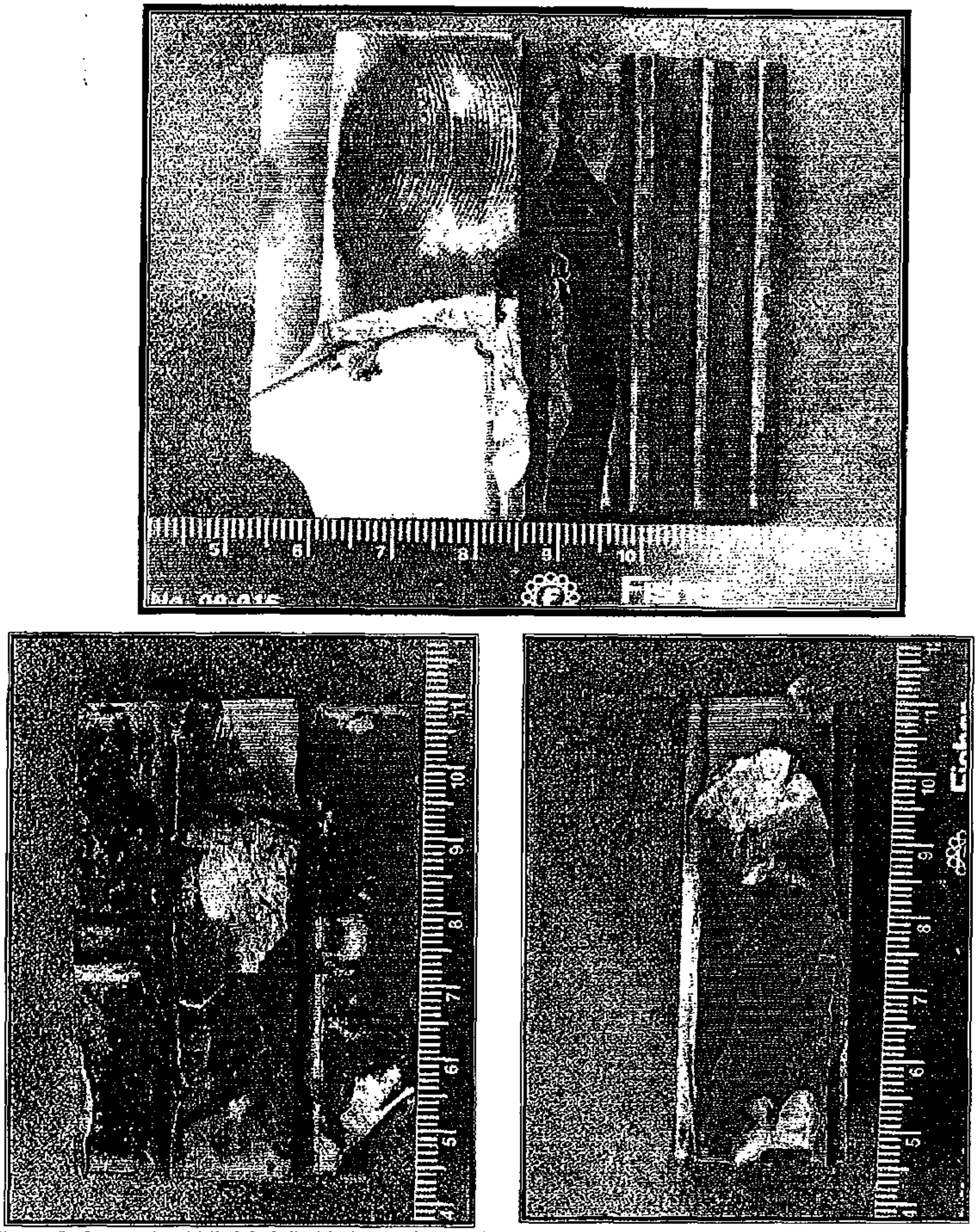

Figure 9: As received LP-A L-3 #4 blade cracked in the root. Fracture surface is covered by reddish brown oxide deposits.

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Stellite strip

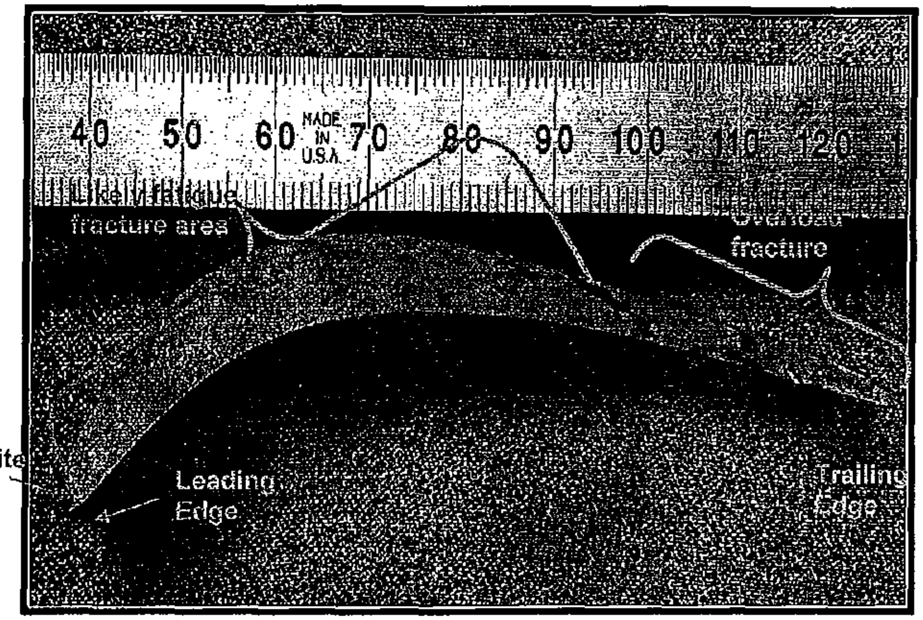

Figure 10: Macro photograph of fracture surface of LP-A L-2 #49 blade. Fracture surface was cleaned to remove thick oxide deposit. Flat fracture surface can be seen from the leading edge continuing into a fracture surface due to overload towards the trailing edge.

Stell strip

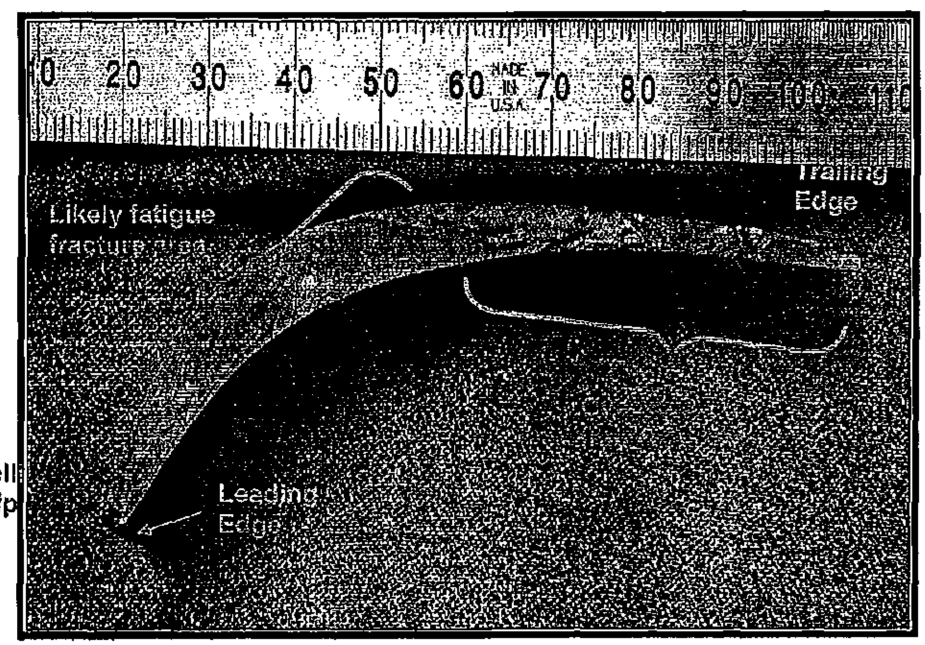

Figure 11: Macro photograph of fracture surface of LP-A L-2 #175 blade. Fracture surface was cleaned to remove thick oxide deposit. Flat fracture surface can be seen from the leading edge continuing into a fracture surface due to overload towards the trailing edge

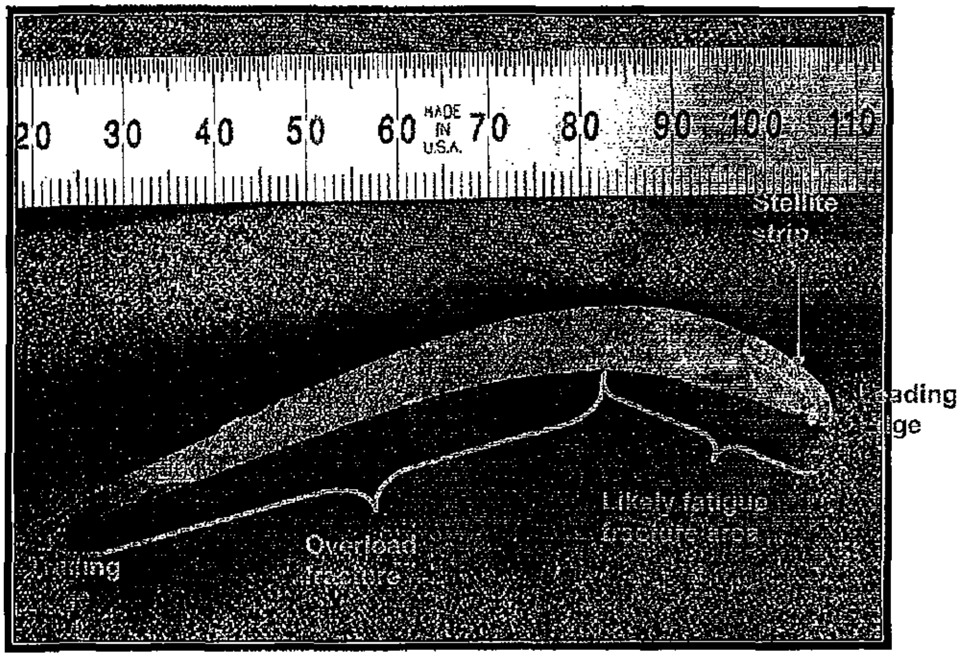

Figure 12: Macro photograph of fracture surface of LP-B L-2 #103 blade. Fracture surface was cleaned to remove thick oxide deposit. Flat fracture surface can be seen from the leading edge continuing into a fracture surface due to overload towards the trailing edge.

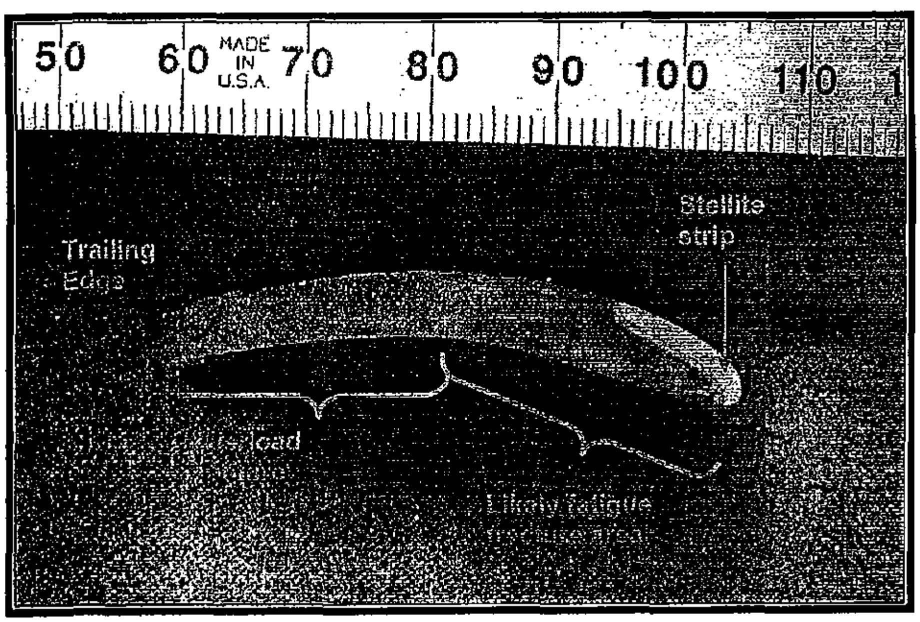

Figure 13: Macro photograph of fracture surface of LP-B L-2 #141 blade after opening the crack. Fracture surface was cleaned to remove thick oxide deposit. Flat fracture surface can be seen from the leading edge continuing into a fracture surface due to overload towards the trailing edge.

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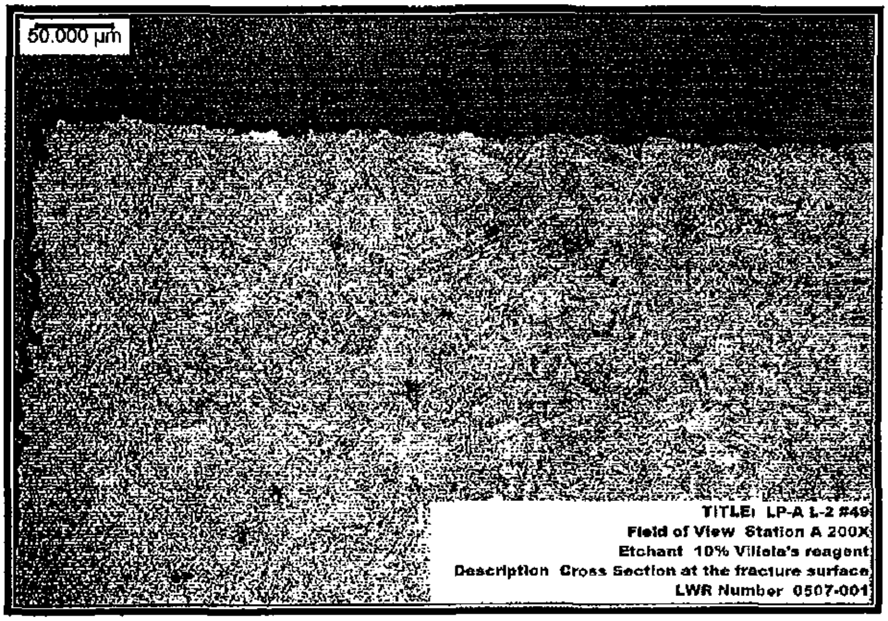

Figure 14: Photomicrograph of the cross section of the flat fracture surface of LP-A L-2 #49 blade. Microstructure indicates that the crack propagated in a transgranular fashion. The microstructure consists of tempered martensite.

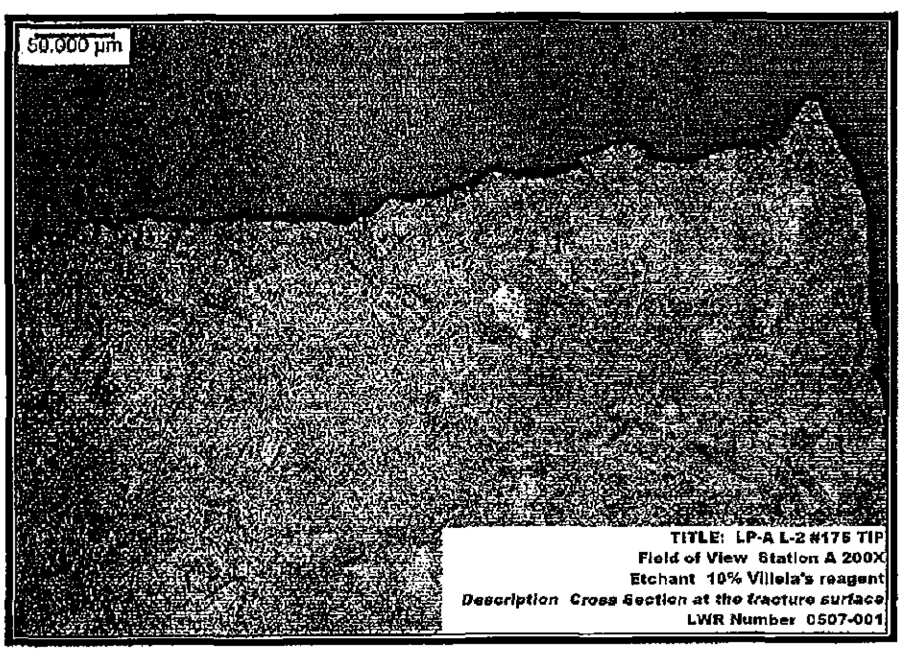

Figure 15: Photomicrograph of the cross section of the flat fracture surface of LP-A L-2 #175 blade. Microstructure indicates that the crack propagated in a transgranular fashion. The microstructure consists of tempered martensite.

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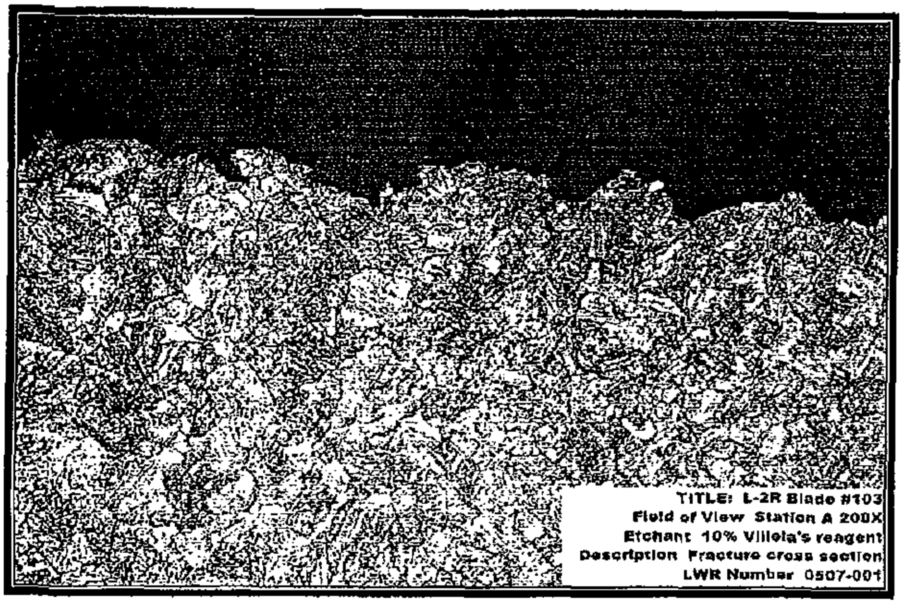

Figure 16: Photomicrograph of the cross section of the flat fracture surface of LP-B L-2 #103 blade. Microstructure indicates that the crack propagated in a transgranular fashion. The microstructure consists of tempered martensite.

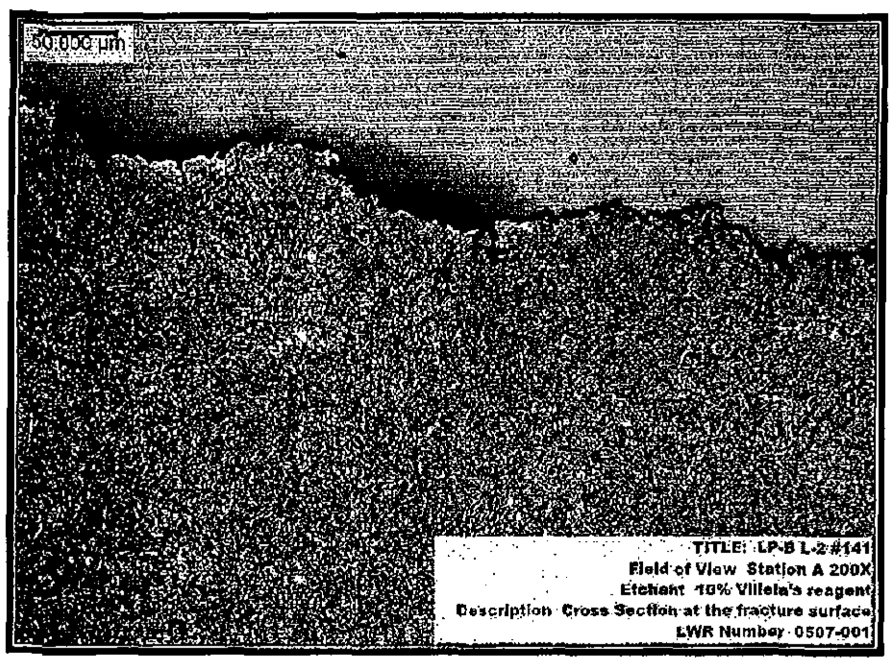

Figure 17: Photomicrograph of the cross section of the flat fracture surface of LP-B L-2 #141 blade. Microstructure indicates that the crack propagated in a transgranular fashion. The microstructure consists of tempered martensite and delta ferrite.

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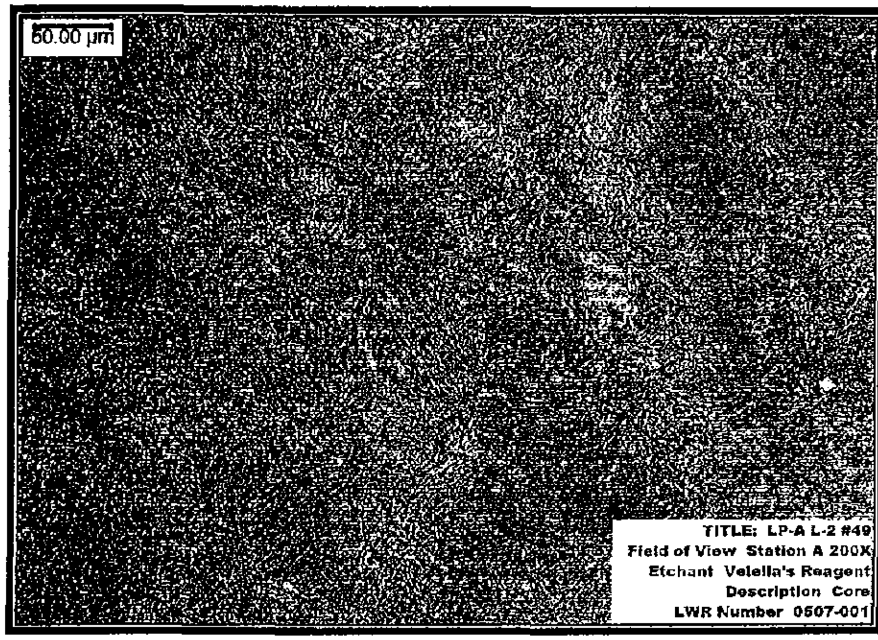

Figure 18: Photomicrograph of the core of LP-A L-2R #49 blade. The microstructure consists of tempered martensite and delta ferrite (<5%).

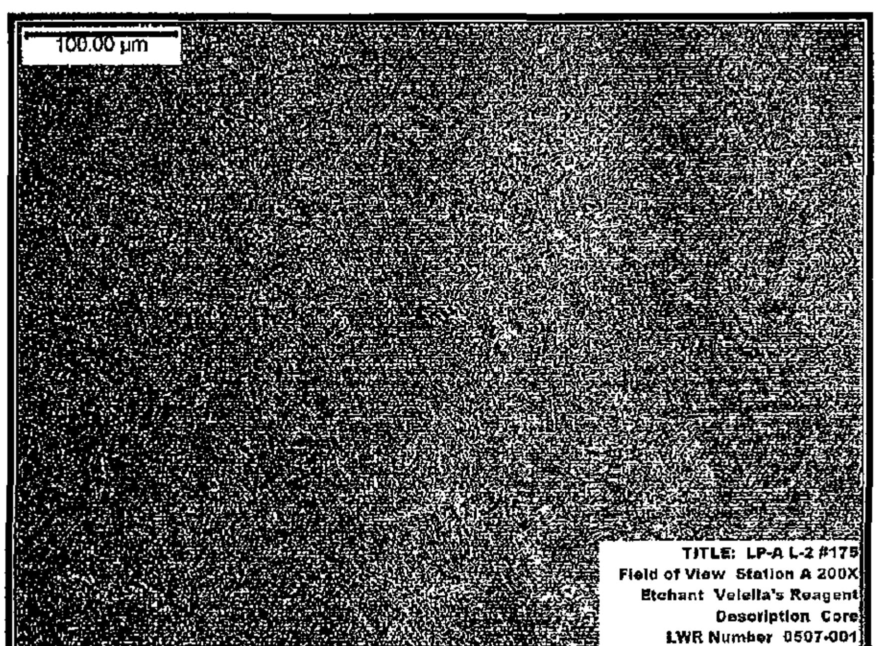

Figure 19: Photomicrograph of the core of LP-A L-2R #175 blade. The microstructure consists of tempered martensite and delta ferrite (<5%).

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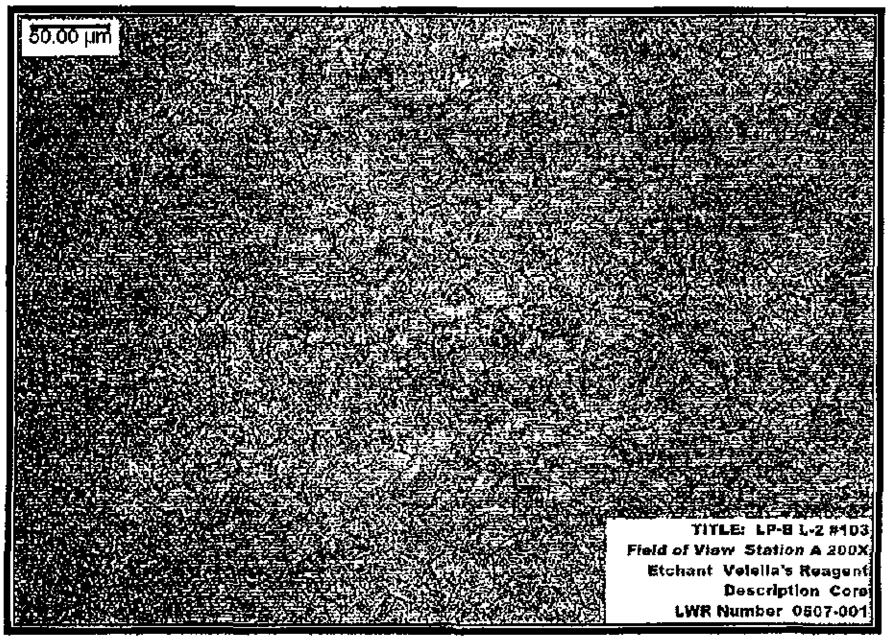

Figure 20: Photomicrograph of the core of LP-B L-2R #103 blade. The microstructure consists of tempered martensite and delta ferrite (<5%).

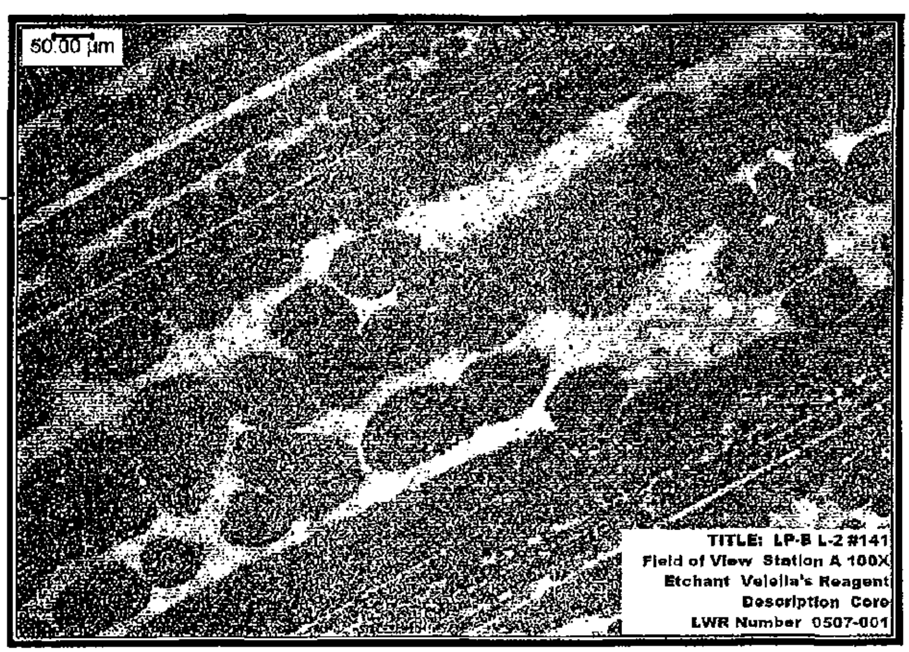

Figure 21: Photomicrograph of the core of LP-B L-2R #141 blade. The microstructure consists of tempered martensite and delta ferrite (~15%).

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Delta ferrite

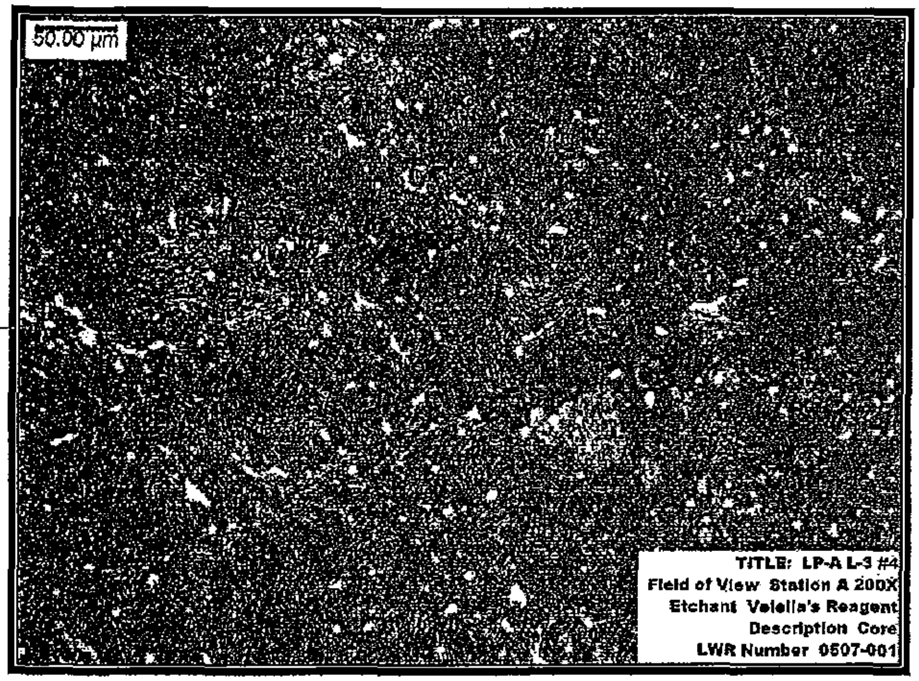

Figure 22: Photomicrograph of the core of LP-B L-2R #141 blade. Microstructure consists of tempered martensite and delta ferrite (~10%).

Sample No.	Measurement No	Hardness (HRC)	BHN (converted)
LP-A L-2 #49	1	30.3	309
	2	31.9	319
	3	32.3	319
LP-A L-2 #175	1	31.7	315
	2	32.1	319
	3	31.7	315
LP-B L-2 #103	1	30.5	305
	2	29.6	301
	3	29.6	301
LP-B L-2 #141	1	30.6	305
	2	30.9	309
	3	30.9	309
LP-A L-3 #4	1	30.3	309
	2	30.5	309
	3	31.2	311

Table 1: Measured hardness values of the L-2R blades and L-3R blade

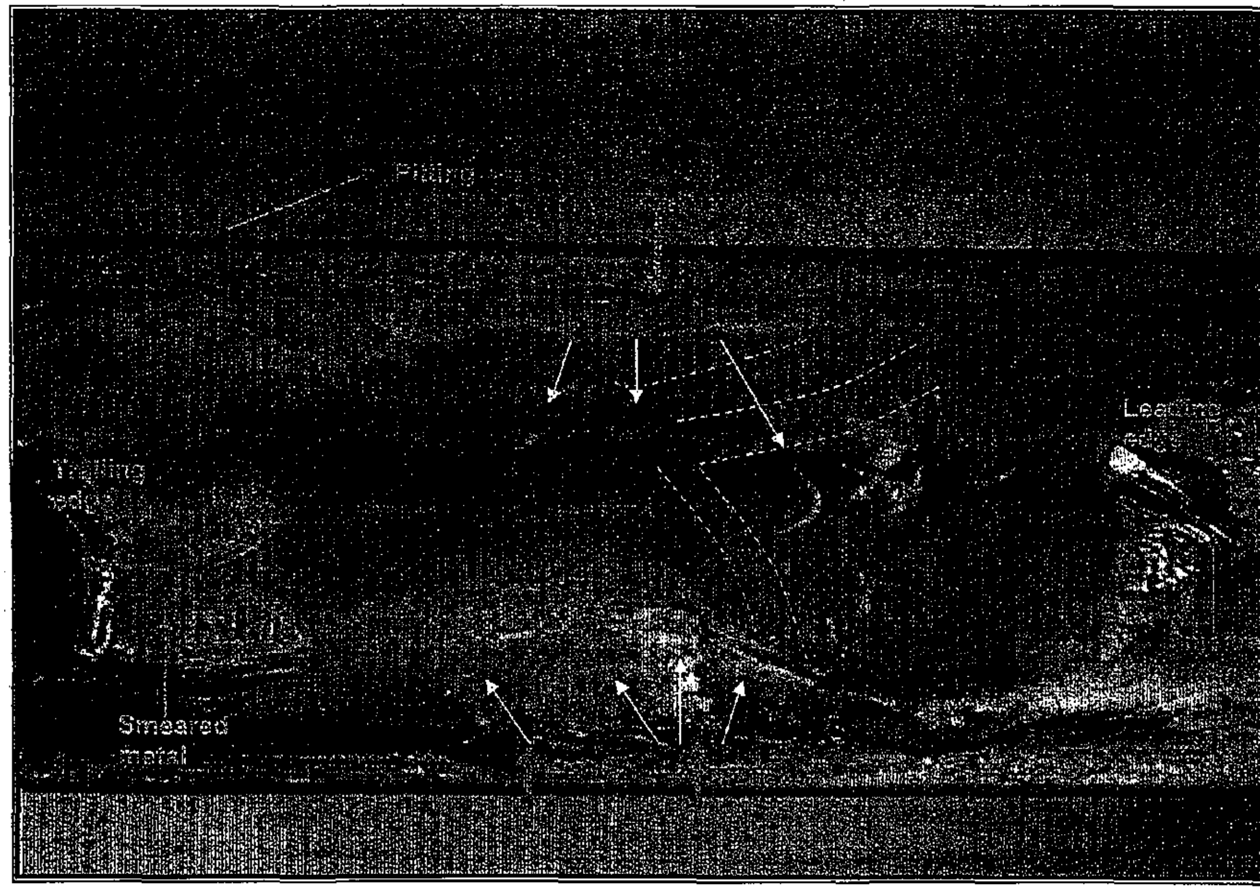

Figure 23: Macrograph of the lower half of the L-3 #4 blade root after cleaning. Numerous secondary crack origins (red arrows) were found. *Secondary cracks propagated in transcrystalline mode as shown by the yellow arrows. Beach / arrest marks (dashed red lines) can be seen* consistent with fatigue fracture. Primary crack propagates from the trailing edge to the leading edge as shown by the blue arrows.

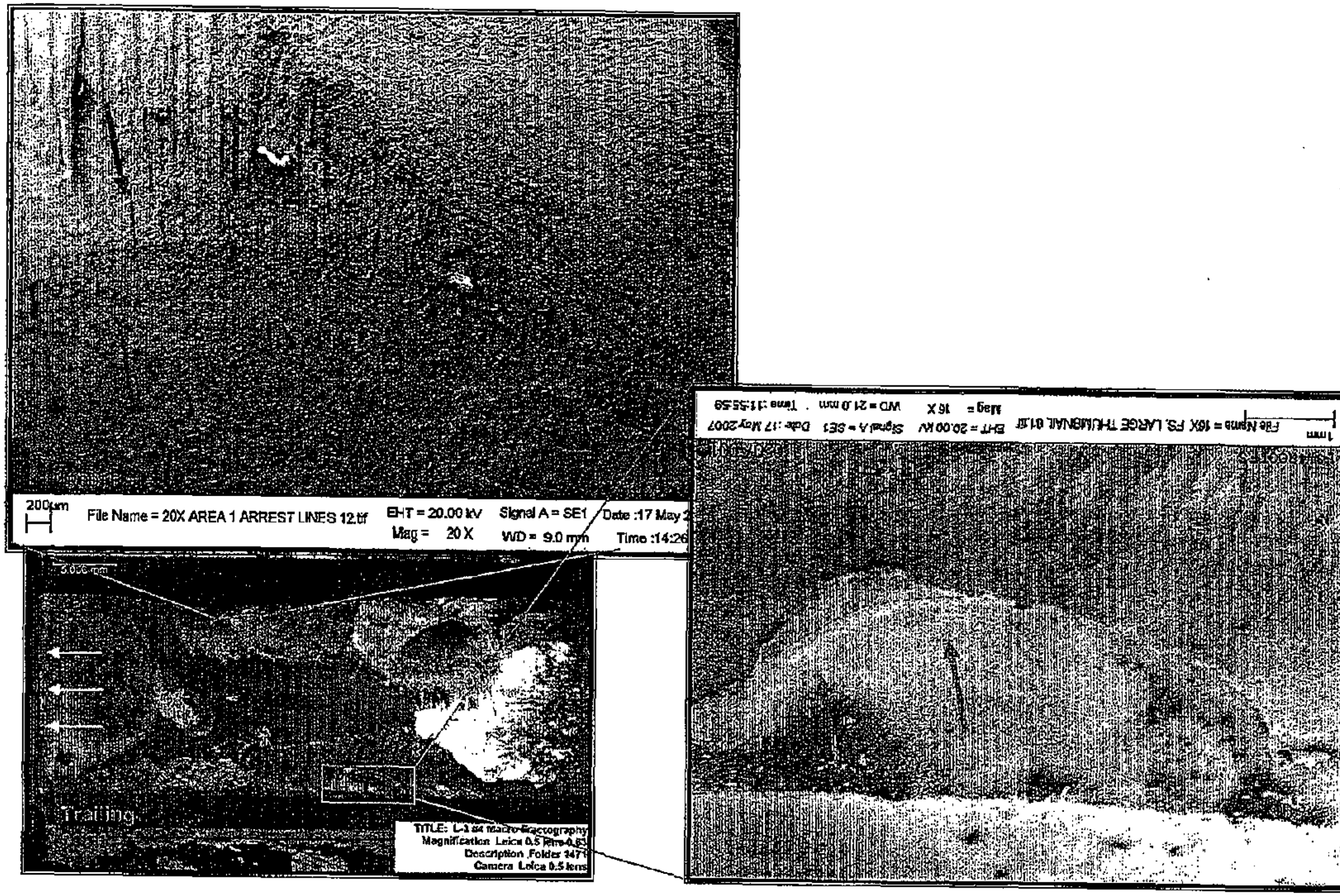

Figure 24: Macrograph of the upper half (tip side) of the L-3 #4 blade root after cleaning. SEM fractographs of the secondary cracks are shown taken at two different locations. Secondary cracks propagated in transcrystalline mode as shown by the red arrows. Beach / arrest marks (dashed red lines) can be seen consistent with fatigue fracture. Smooth thumb nail print area at the trailing edge indicates that primary crack originated at the at the trailing edge shown by yellow arrow and propagated towards leading edge as shown by blue arrow.

SIEMENS

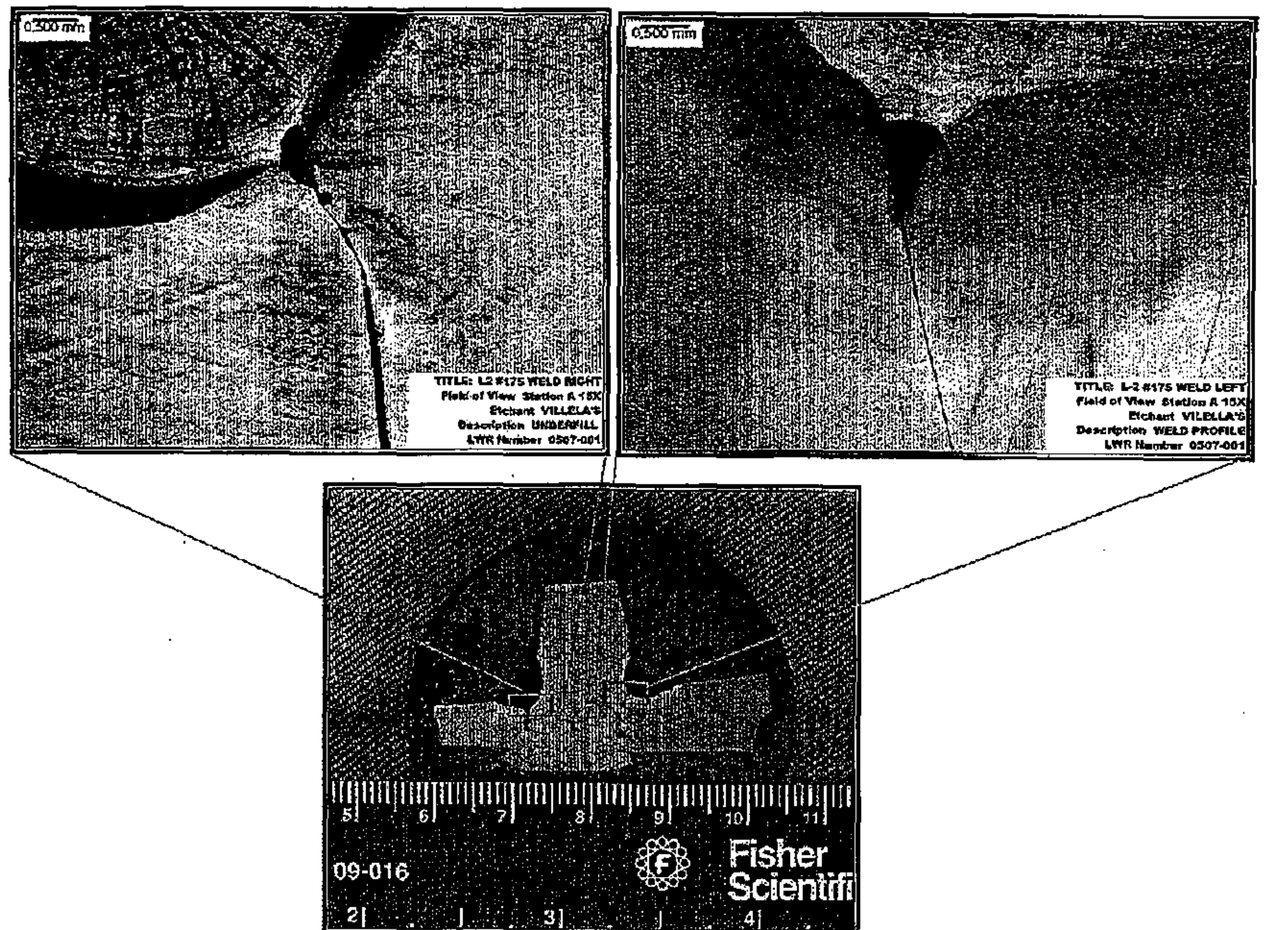

Figure 25: Micrographs of undershroud welding joint of LP-A L-2R #175 blade. Lack of penetration at the weld root was found on both sides of the blade.

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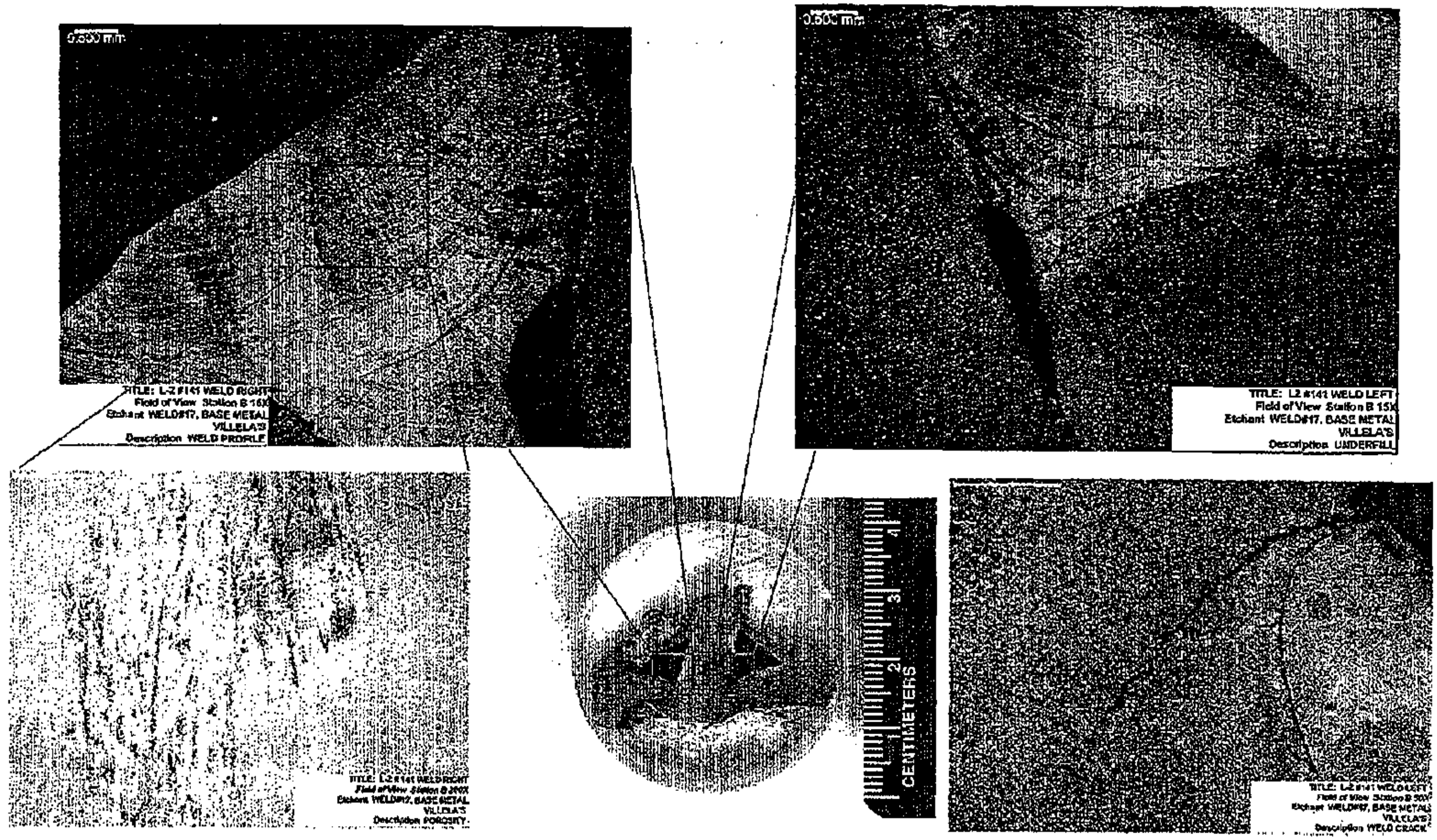

Figure 26: Micrographs of undershroud welding joint of LP-B L-2R #141 blade. Lack of penetration at the weld root was found on both sides of the blade. Shrinkage porosity was found in the left side weld and crack originating at the interface of fusion and heat affected zone was found in the right side weld. The crack propagated along the grain boundary.