ATTACHMENT 1

CATAWBA UNIT 2
DIESEL GENERATOR 2B #7 MAIN BEARING FAILURE REPORT
LOW POWER LICENSE CONDITION NO. 13, ATTACHMENT 1, ITEM 9

Prepared by

Duke Power Company

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1.0 Introduction

This report describes the results of inspections and evaluations performed on the Catawba 2B diesel engine as a result of two bearing failures on this engine. The 2B engine is a Transamerica Delaval (TDI) 16 cylinder engine, type DSRV-16.

The 2B engine was placed in service in July 1985. The engine was used to support testing of the unit prior to fuel loading until September 1985. In September 1985 the engine was shutdown to perform the Design Review and Quality Revalidation Inspections as part of the TDI Owners Group program. At the time of shutdown the engine had approximately 183 hours of operation. The engine was disassembled, inspected and reassembled during the period of September and November 1985.

Prior to putting the engine back into service it was subjected to a break-in run. On November 20, 1985, during this break-in run, the engine tripped on high bearing temperature. There were approximately 187 total hours of operation on the engine at this. Subsequent examination of the engine showed that the trip resulted from a high temperature on the #7 main bearing. Removal of this bearing showed that the upper shell had undergone severe wiping. The babbit material on the lower shell had been removed to the nickel diffusion barrier. In addition, the lower shell had fractured into three pieces. Inspections and flushes were then performed and the engine reassembled. On December 5, 1985, the engine was started and run for about 90 seconds at which time it again tripped due to a high No. 7 main bearing temperature. A review of the second bearing failure indicated that the generator end of the lower bearing shell was wiped down to the nickel diffusion barrier and the generator end half exhibited moderate wiping. Some interference between the locating keys and the lower shell bearing key cutouts was noted. Further a partial through-thickness crack had initiated in the lower bearing. The remainder of this report provides documentation of the actions which were taken to determine the cause of the bearing failures.

2.0 Conclusions

This section summarizes the conclusions based on work accomplished in correcting the #7 main bearing failures on Catawba's 2B diesel engine. The basis for these conclusions can be found in the body of the report.

- Based on the Duke Power Company Metallurgy Laboratory Report, the Failure Analysis Associates Report and observations of the bearing shells, it is concluded that a major contributor to both failures was damage to the bearings by large diameter particulate material carried into the bearings by the lube oil.

- Minor misinstallation resulting in very slight misalignment may have played a minor part in the first failure.

- Significant misinstallation/misalignment may have contributed to the second failure resulting in a much shorter failure time.

- The material which caused the scoring appeared to be iron shot from previous blast cleaning operations.

- Since iron shot was too large to pass through the lube oil strainer or filter there are two possible sources of this contamination in the engine.
  - Residual from shot blasting of engine during manufacture.
  - Residual from shot blasting of significant portions of the lube piping and the lube oil sump during plant construction.

- Lube oil system flushes conducted during construction were not adequate to remove the iron shot due to high flush oil viscosity and low flow rates.

- High velocity/low viscosity lube oil system flushes conducted after the two failures were effective in removing all foreign material.

- Extensive measurement showed that the engines were dimensionally in specification.

- The corrective program carried out by Duke Power Company was successful in correcting the bearing problem and returning the engine to service.

3.0 Discussion

The purpose of this section is to describe the tasks which were accomplished to determine the cause of the #7 main bearing failure on engine 2B. These tasks included: failure analysis of the bearings; detailed inspections and measurements of the engine; lube oil flushes; history of work accomplished on the engine; and final acceptance testing of the engine.

3.1 Catawba 2B Emergency Diesel Generator Bearing Failure Reports

This section summarizes the metallurgical failure analysis reports on the failed Catawba 2B emergency diesel generator main bearings prepared by the Duke Power Company Metallurgy Lab (Met. Lab.) and by Failure Analysis Associates (FaAA). These two reports are included as Appendix I and II.

3.1.1 Met. Lab Report:

The Met. Lab. examined the failed bearing shells from the first and second Catawba 2B diesel bearing failures and several other bearing shells that were removed from the 2B diesel after the second failure. In addition, the Met. Lab. examined granular material removed from the 2B diesel oil strainers and iron shot used for shot blasting operations at Catawba.

Analysis of the various samples of granular material and particles embedded in scored bearing shells indicated that the particles responsible for scoring the bearings were iron shot (approximately .01 to .02 in. diameter) from shot blasting operations. The pattern of scoring on the bearings indicates that the particles were carried into the bearing by the lube oil.

Tensile tests on samples from an unused bearing indicate that the mechanical properties of the material are normal for the alloy. Porosity was observed on metallographic sections and on fracture surfaces. However, it was determined that the observed porosity is normal for the bearing shell alloy.

Possible fatigue striations were observed on the fracture surfaces from the first failed bearing. This indicates that the observed cracks in the first failure grew over some period of time prior to the final failure for the bearing. Cracks in the second failed bearing were judged to have resulted from over stressing during the failure event.

The report concludes that the most likely cause of the bearing failures is the damage caused by the iron shot particles. It is postulated that this led to a breakdown of hydrodynamic lubrication. The cracking observed is concluded to be the result of the contamination, not an initial cause of failure.

3.1.2 FaAA Report:

FaAA examined the failed bearing shells from both the first and second 2B diesel main bearing failures. Examinations included metallographic and chemical analysis, and macro and micro fractography.

On the basis of an examination of the fracture surfaces from the fractured lower shell from the first failure, FaAA concludes that the fracture started at the end of the bearing shell near the cutouts for the keys. This conclusion is primarily based on the fact that the portion of the fracture surface at this location is contaminated by soot from the lube oil thus indicating that it was in contact with the oil for an extended period. Furthermore, this portion of the fracture surface is contaminated with babbit which indicates that the fracture existed prior to wiping of the bearing. The older portion of the fracture surface was judged to be a fatigue fracture.

Metallographic and chemical analysis of the bearing shell material showed that the material was typical of all B852. The report further notes that the bearing was severely scored by particles larger in diameter than the babbit thickness.

From an examination of the markings on the OD of the first bearing, FaAA concludes that the shell was not in uniform contact with its seat.

The report concludes that the time of operation (180 hrs.) on the first bearing prior to its failure indicates that misalignment was not the primary cause of the failure. It is, therefore, concluded that the primary cause of the failure was damage from particulate contamination that embedded in the bearing. Minor misalignment is mentioned as a possible contributing cause of the failure.

The report notes that the keys which hold the bearing shell during installation had left contact marks on the shells from the second failure. These witness marks are cited as evidence of misinstallation.

FaAA concludes that the second failure is a case of "infant mortality" resulting from misinstallation.

3.1.3 Conclusions:

It is concluded that a major contributor to both failures was damage to the bearings by large diameter particulate materials carried into the bearings by the lube oil.

Misinstallation was indicated as a minor contributor in the first failure and major contributor in the second failure. It is felt that contamination of the lube oil also played a major role in the second failure. This is based on the fact that significant scoring of the #7 bearing occurred despite the short time of operation prior to failure. In addition it should be noted that the #7 main bearing failed twice in succession. Since many of the bearings were removed and replaced after the first failure, any of the bearings could have been misinstalled. The fact that both the 1st and 2nd failures were essentially identical with respect to the wiping and cracking also supports the major contribution of lube oil contamination. Two successive failures on the #7 main bearing may indicate that it is more sensitive to damage from contamination than the other main bearings. It is concluded that even if significant misinstallation occurred prior to the second failure it resulted only in a shorter time to failure. The primary contributor was the scoring by large particles.

3.2 Details of Inspections Accomplished After Bearing Failures

Prior to the first main bearing failure, the 2B engine had undergone a quality revalidation inspection after about 180 hours of operation. While the #7 main bearing was not pulled during the quality revalidation inspection, results of inspections on #4, #6 and #8 main bearings were satisfactory (no scoring) and these bearings were reinstalled in the engine. Further, inspections of all connecting rod bearings were satisfactory with no scoring evident.

After the bearing failures a series of inspections and measurements were accomplished to aid in determining the cause of the failures and the overall condition of the 2B engine. This section will discuss the extent of the inspections made after the first and second bearing failures as well as measurements taken.

3.2.1 Inspections Made After First Bearing Failure

After the first bearing failure main bearings and journals #3, #5, #6, #7, #8, #9 and #10 were inspected. The crank journals, connecting rods and pistons and associated components on #6, #7 and #8 left and right were inspected. The inspections conducted included, visual, penetrant and dimensional testing.

Results of the inspections as well as parts replaced as a result of the inspections are as follows:

3.2.1.1 Main Bearings and Journals

Number	Shells Replaced	Condition
3	Yes	Damaged during rotation of shaft for web deflection checks. Journal in good condition.
5	Yes	Light scoring, journal polished.
6	Yes	Light scoring, journal polished.
7	Yes	Lower half broken in 3 pieces. Babbit removed. Nickel flashing was basically still intact. Journal had some babbit transfer. Journal polished.
8	Yes	Minor scratches on shell. Journal in good condition.
9	No	Light scoring. Minor scoring on journal. Journal polished.
10	No	Both bearing and journal in new condition.

3.2.1.2 Piston and Con-Rod Assemblies

Con-Rod No.	Dis-assembled	Shells Replaced	Condition
6L	Yes	No	Good condition. No damage on piston, liners, wrist pins, bearing shells or other con-rod parts.
6R	Yes	Yes	Slight scoring on bearing shells.
7L	Yes	Yes	Good condition. No damage on piston, liners, wrist pins, bearing shells or other con-rod parts. Replaced con-rod top shell.
7R	Yes	Yes	Slight scoring on shell and crank-pin journal. Polished

Con-Rod No.	Dis-assembled	Shells Replaced	Condition
			journal. Piston assembly in good condition. Replaced con-rod bottom shell.
8L	No	No	Piston and con-rod assembly in good condition.
8R	No	Yes	Slight scoring on lower half bottom shell only.

3.2.1.3 Other Work Accomplished

- Drained engine sump and sump tank to inspect for debris resulting from failure. No significant debris was found.
- Changed lube oil and pre-lube filters. Inspected for debris resulting from failure. None was found.
- Inspected all crank shaft oil plugs. All plugs were in place.
- Flushed crankshaft oil passages in 6, 7, 8 journals.
- Cold web-deflection and thrust checks were accomplished.

3.2.1.4 Discussion:

The above inspections showed minor scoring on a number of main bearings/journals and rod bearings/journals. This scoring was thought to be either related to the #7 main bearing failure or normal wear for an engine with 187 hours of operation. The limited inspections of the lube oil sump, tank piping and oil passages did not reveal any gross contamination.

Following this failure, contamination damage was principally confined to the #7 main bearing. At this point efforts were being directed at cleaning debris from the bearing failure rather than looking into gross contamination of the system. The cause of this failure was thought to be related to minor misinstallation of the bearing shells.

3.2.2 Inspections Made After Second Bearing Failure

After the second bearing failure all main journals were inspected. Further crank journals and connecting rods on #1, #6, #7 and #8 left and right were inspected.

Results of the inspections as well as parts replaced are summarized as follows:

3.2.2.1 Main Bearings:

Number	Shells Replaced	Condition
1	Yes	Moderate scoring. (Moderate is defined as relatively few score marks, but marks are deep).
2	Yes	Moderate Scoring.
3	Yes	Moderate scoring.
4	Yes	Moderate scoring.
5	Yes	Moderate scoring.
6	Yes	Moderate to heavy scoring.
7	Yes	Bearing was severely scored and wiped with crack in the lower shell. Journal had babbit on it.
8	Yes	Moderate to heavy scoring.
9	Yes	Moderate scoring of bearing.
10	Yes	Moderate scoring of bearing.

Results of main bearing and journal inspections indicated that gross scoring due to debris was situated at #7 main bearing which had wiped. Bearing #6 and #8 while scored to the point where bearings should be replaced was not of the same magnitude as #7. All other bearings showed moderate scoring. These bearings would have continued to operate satisfactorily but were replaced for conservatism. All main bearing journals were polished to remove any babbit deposits or scores. The journals and base seating surfaces were also penetrant tested. This inspection showed all surfaces to be free from indications.

3.2.2.2 Piston and Con-Rod Assemblies

Con-Rod No.	Dis-assembled*	Shells Replaced	Condition
1L	No	No	Good condition. No scoring.
1R	No	No	Good condition. No scoring.
6L	Yes	Yes	Babbit flakes found within bearing. Replaced bottom shell.
7L	Yes	Yes	Babbit flakes found within link rod and link rod box. Replaced top shell.
7R	Yes	No	Babbit flakes found within link rod and line rod box. Replaced bottom shell.
8L	No	No	Good condition. No scoring.
8R	No	No	Good condition. No scoring.

* Disassembled refers to piston, wrist pin, etc.

3.2.2.3 Other Work Accomplished

- Connecting rod oil holes were T/V inspected for evidence of debris. No debris was found.
- Eddy current inspected main bearing journal oil holes per FaAA procedures on #6, #7 and #8. Results of inspections were satisfactory.
- Performed T/V inspection of left bank lube oil header, and #6, #7 and #8 main bearing oil holes in crankshaft to check for debris and blockage. No debris or blockage was found.
- Visually inspected lube oil jumpers from header to bearing cap on #6, #7 and #8 for sign of blockage. No blockage was

found. Hydrostatically tested #7 lube oil jumper. Hydrotest at 90 psi showed no leaks.

- Inspected lube oil hole in bearing caps on main bearings #6, #7 and #8 for signs of blockage. No blockage found.

- Solvent flushed and then oil flushed #6, #7 and #8 main journal and #6 and #7 rod journals. No debris found at #6 main journal. On #7 main journal fine debris and flakes recovered. No debris found on #8 main journal.

- Removed left bank lube oil strainer and inspected. Strainer was gritty on upstream side and clean on down stream side.

- Removed right bank lube oil strainer. Strainer was full of metal grit and grinding debris. All available documentation indicated that this strainer had not been inservice since turnover of the engine.

- Removed keep warm lube oil strainer. Strainer contained aluminum flakes.

- Inspected left bank lube oil strainer check valve. The valve was correctly installed, free to move and had no blockage.

- Cylinders #6 and #7, right and left subcovers were disassembled to determine if there was any lube oil contamination of the rocker arms. No contamination was found.

3.2.2.4 Conclusions:

Based on the supplemental inspections performed above and inspections of the main journals (3.2.2.1) it was evident that the lube oil system was contaminated with iron shot. The contamination had caused major scoring of the #7 main bearing, moderate to heavy scoring on the #6 and #8 main bearing, and moderate scoring on other main bearings. No significant scoring was noted on the rod bearings or link rod bushings. This was due to the size of the contaminant particles. The rod bearings receive oil from adjacent main bearings. The main bearings acted as an effective filter removing all of the large contaminant particles. The inspection of the upper portions of the engine (i.e., subcover area) showed the particles were too heavy to be lifted into these areas under normal oil flow. On this basis, work was initiated to determine how the oil became contaminated and flushing procedures developed to rid the lube oil system of this contamination.

3.2.3 Measurements Taken After Second Bearing Failure

Extensive measurements were taken after the second bearing failure to determine whether dimensional errors could have contributed to the #7 main bearing failures. These measurements were directed at:

- Determining if the crankshaft was running true in the bearing journal.
- Verifying proper clearance between crankshaft and bearing.
- Verifying proper diameter of the #7 main journal.
- Web deflections to determine whether the crankshaft was properly aligned with the base and bearing cap.
- Verifying bearing cap alignment with the base.
- Key-way measurements to check for interference of the alignment keys with the main bearing.
- Checks of the base to determine that it was structurally sound, was adequately mounted and flat (i.e., was not twisted).
- Measurements of bearings and bearing crush to determine any abnormalities with journal or cap and base.

The measurements were taken under the supervision of the TDI factory representative on site and the results of the measurements were reviewed with personnel at the TDI factory. A summary of the measurement inspection results appears below.

3.2.3.1	Crankshaft	Results
	• Dial indicator check of runout between #6, 7 and 8 journal base. This was accomplished by placing the indicator on the base and rotating	Satisfactory per TDI.

Crankshaft	Results
the shaft.	
• Diameter of #7 journal	13.000" which is satisfactory.
• Clearance between #7, journal and:	
base	uniform
cap	uniform

(This was accomplished with snap gauges with the cap torqued and untorqued. Checks made indicate that journal is not cocked in the bearing cap and that the base is not twisted with respect to the journal.)

• Web deflections	Cold web deflections are within spec.

3.2.3.2

Bearing Cap	Results
• Checked to see if bearing caps had been swapped.	Caps are stamped and are properly located.
• Axial gap between cap and base mating surface with no bearing installed. (U = Untorqued, T = Torqued).	U - .001" inside right. 0 on left. T - 0" both sides. Satisfactory.
• #7 cap pinch at base mating surface (untorqued).	.0015 pinch on a side.*

*(TDI concludes this is normal for an unloaded cap.)

• #7 cap pinch at base mating surface (torqued.)	Cap moves out under torque to eliminate pinch noted above. Satisfactory. Snap gaging of shaft shows uniform gap around perimeter.
• With #7 cap installed, key to base vertical clearance.	.020" Clearance. Satisfactory.
• Interference of #7 keys with lower main bearing.	Blue check indicated no interference between key and lower bearing.

	Bearing Cap	Results
	• Inspect dowels and caps to determine that dowel is not bottoming out in cap.	Satisfactory.
3.2.3.3	Base	Results
	• Visually inspected lower bearing seating surface with TV.	No signs of protrusions or over heating.
	• Visually inspected base internals and web to base corners for signs of cracks (#6, #7, #8).	No signs of cracking.
	• Verify that base is not twisted.	Transit measurements of base indicated that it was properly installed.
	• Ring foundation bolts to check if they are tight.	All foundation bolts had a uniform sound indicating proper installation.
	• Used .0015" feeler gauge to check for soft foot between grouting plate and engine base.	No gap between grouting plate and engine base.
	• Turned shaft and installed snap gage to check base and cap bearing surface uniformity. Determine uniformity in three planes, 1/2" from front, 1/2" from back and about 1/8" aft of oil groove. Measured at 5 locations on base and 5 locations on cap diametrically opposite. Cap was torqued during measurements.	No protrusions of base or cap bearing surface.
3.2.2.4	Bearings	Results
	• Dimensionally inspect new bearings.	Bearing thickness .618/.619 throughout per specification
	• Determine bearing protrusion above base on	TDI indicates readings are

#7 for bearing crush. satisfactory.

3.2.2.5 Conclusions:

Results of all of the above measurements indicated to TDI and Duke Power Company that the engine was built to specification in the as-assembled condition. The measurements did not identify any problems which could have contributed to the two bearing failures experienced.

3.3 Lube Oil Flush After Second Bearing Failure

After the second #7 main bearing failure shot blasting material was found embedded in the surface of the bearing shells. Inspection of the right bank strainer showed significant amounts of shot blast material. It was concluded that this contamination played a significant part in the two failures. On this basis, the flushing procedures used during the construction phase were modified to provide high flow flushes with reduced viscosity oil. During normal operation the engine lube oil pump produces flows on the order of 500 gpm. A flushing pump was therefore selected that produced minimum flows of 900 gpm. A 5 micron filter rated at 1250 gpm was used. The flushing medium selected was SAE 5W base stock oil as opposed to the SAE 40W flushing oil used previously. The cleanness criteria established were:

- No more than 0.5% by volume of pentane insolubles per ASTM D4055.
- Particles per 100 ml should be below SAE Hydraulic Systems Class 2 which is:

Particle Size (micron)	Particles
5-10	9700
10-25	2680
25-50	380
50-100	56
100+	5

Three types of flushes were conducted on the lube oil system:

- Flush #1 - The flush pump took suction on the sump tank and bypassed the engine driven lube oil pump and lube oil heat exchanger. The oil flushed piping downstream of the heat exchanger, the lube oil filters and strainers and their connected piping. The lube oil heat exchanger tube bundle was pulled and the heat exchanger was cleaned.

- Flush #2 - The 4" lube oil headers inside the engine block and the bed plate were connected to the piping circuit identified in flush #1. This entire system was flushed.

- Flush #3 - The lube oil keepwarm system was flushed.

3.3.1 Conclusions:

All of these flushes were continued until the above criteria was met. Based on this criteria and amount the lube oil system flushed it is concluded that no further contaminant is present in the engine. Samples taken during the flush and the clean up of the sump tank after the flush contained iron beads. The size of these beads and the bead material was the same as that found embedded in the #7 main bearing. The size of shot was such that it could not have passed either the lube oil strainers or filters. On this basis it was concluded that the engine lube system was contaminated with the shot during manufacture or during the site construction phase. While it is not documented it is possible that the lube oil strainers and filters were by passed or out of service at some time, allowing the contaminant material into the engine.

3.4 History of Work Done on Engine 2B

Construction work orders were reviewed to determine whether any work done on the 2B engine could have contributed to the main bearing failures. The results of this review which are pertinent to the failure are summarized below:

- In February 1980, the engine and generator were installed, leveled, foundation bolts torqued and initial web deflections of the crankshaft taken.

- In August 1982, flooding of the sump tank pit occurred to a level approximately 4 feet above the bottom. This necessitated reconditioning the prelube oil pump in the sump pit.

- In May 1984, flooding of the 2B engine room occurred and water entered the sump tank. Inspection after the flooding of the lube oil piping and the sump tank showed rust and scale.

- In June 1984, lube oil piping was removed for shot blast cleaning and wire brushing. The sump tank was also shot blasted.

- Lube oil piping was reinstalled after cleaning during the period of September through December 1984.

- Flushing of the lube oil system was accomplished between the latter part of February and early May 1985. Flushing was accomplished at the TDI recommended value of 300 gpm with SAE 40W diesel lube oil.

- To eliminate interference between the idler gear bracket and #1 main bearing stud grinding was performed on the bracket. It was decided to determine whether the crankshaft and bearings had been contaminated due to this grinding. In May 1985, #1 main, #1 connecting rod and #2 main were removed and inspected. Grit was found in #1 main and connecting rod journals but none in #2 main. Based on these inspections it was concluded that the contamination had been limited to the #1 main bearing.

3.4.1 Conclusions:

From the above review it is concluded that the most probable source of the particulate material found in the bearings was shot blast cleaning of lube oil piping and the sump tank after the May 1984 flooding. Further, the flushes done with the TDI recommended flow rate of 300 gpm with diesel lube oil during the construction period did not remove this contamination from the lube oil piping.

3.5 Verification Tests of #7 Main Bearing After

In a meeting held with the NRC on December 30, 1985, at Catawba the extent of the inspection program after the first and second #7 main bearing failures was reviewed. Pending satisfactory results of remaining inspections and additional lube oil flushes it was agreed that the following test program should be implemented on the #7 main bearing after a new bearing was installed.

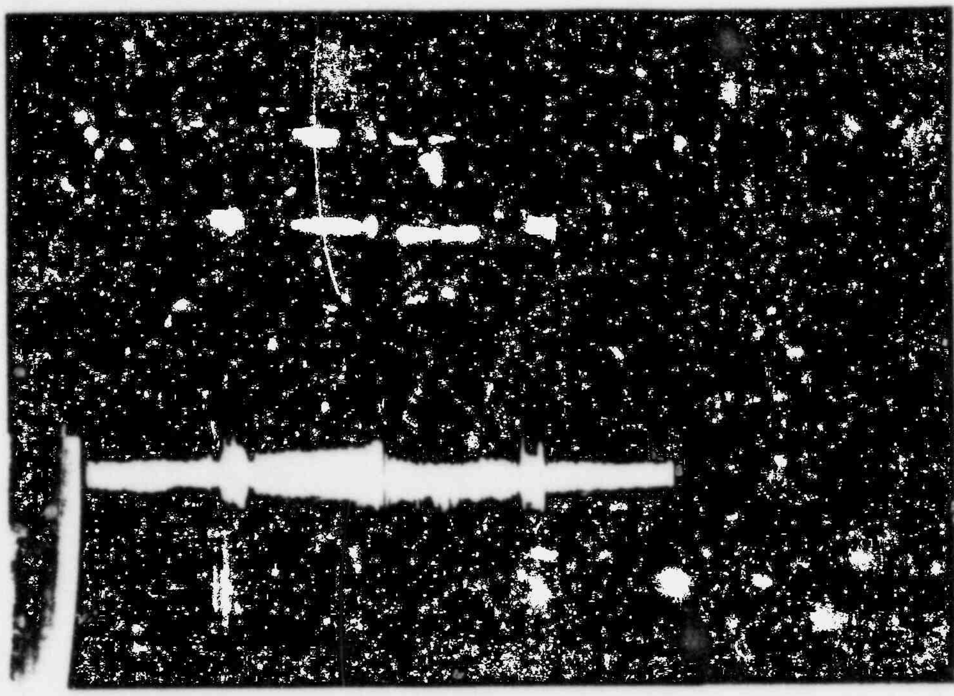
- At one hour into the break-in run, the #7 main bearing should be rolled out, visually inspected for signs of scoring or babbit wear and photographed.
- After approximately 15 hours of operation the #7 main bearing was visually inspected in place.
- After approximately 100 hours of operation, the #7 main bearing should again be rolled out visually inspected and photographed.
- Pending satisfactory results of these three inspections, the engine could be placed into service.

On January 18, 1986, the 2B engine was restarted to undergo break-in runs. Results of inspections of the #7 main bearing in accordance with the test program are as follows:

- Photographs of the #7 main bearing after removal from the engine at 1 hour are shown in figure 1. As can be seen from the photographs, there is no evidence of scoring or babbit wear. Further, the seat surfaces and key areas of the bearing show no wear. However, the lower bearing had an oil seal with the base such that the ends of the bearing were damaged in attempting to pry the bearing out. Hence, this lower bearing was not reinstalled.
- Photographs of the #7 main bearing after removal from the engine at approximately 130 hours of operation are also shown in figure 2. At the time of this inspection the engine had approximately 110 hours of operation with loads greater than 5500 kw. As can be seen from the photographs, no evidence of scoring or babbit removal can be detected. Further, seating surfaces and key areas show no disruption or wear. Both the upper and lower bearing were reinstalled in the engine.

3.5.1 <u>Conclusions:</u>

The above inspections showed no evidence of lube oil contamination. In addition, since the bearing operated properly for 130 hours at a significant load, the installation was correct. On this basis, it was concluded that the particulate contamination which was the major contributor to the two failures has been eliminated and the engine was returned to service.



Front →

Upper Half   Lower Half

Fig. 1: CNS 2B diesel engine #7 main bearing after 1 hour verification run.

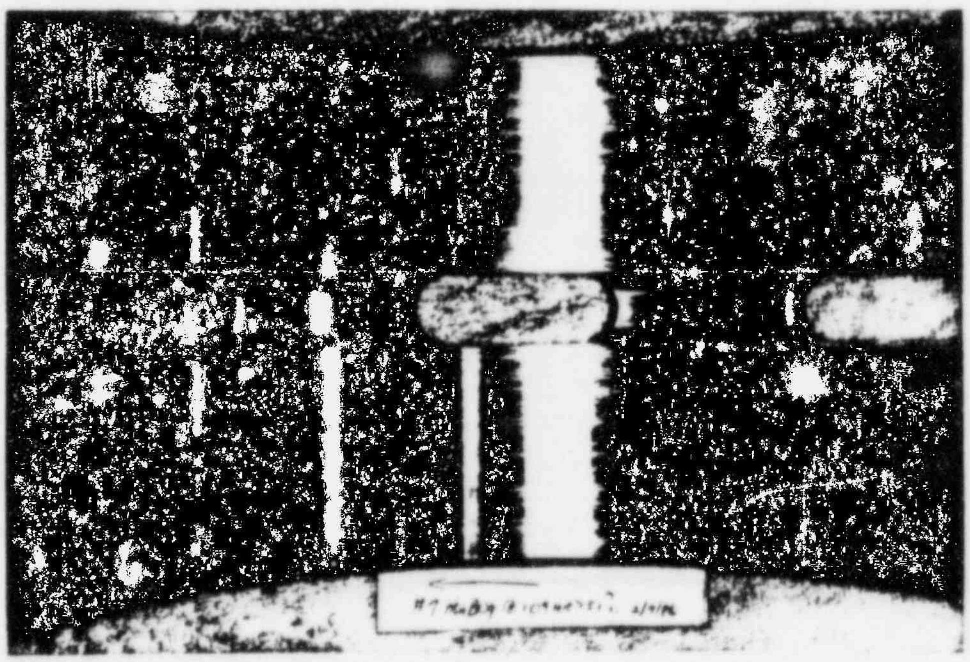


Fig. 2: CNS 2B diesel engine #7 main bearing lower half after 130 hour verification run.

April 14, 1986

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Memo to: C. W. Hendrix
Nuclear Production Department

Subject: Catawba 2B Emergency Diesel Generator
Aluminum Cast Bearing Shells
Metallurgy Samples Nos. 306, 318, 319

Bearing shells from the Catawba 2B emergency diesel generator were examined at the Metallurgy Lab to determine the nature of scoring and cracking of the cast aluminum material. Iron shot associated with sandblasting operations were found embedded in the Pb babbitt material of the bearings, indicating the cause of scoring. Fracture of the bearing shells is attributed to fatigue initiated cracking and is considered secondary due to the particulate contamination of the lubricating oil. Non-uniform loading is also indicated in the #7 second failure bearing.

The following bearings were received for evaluation at the Metallurgy Lab.

Metallurgy Sample No. 306
#7 upper and lower bearing, 1st failure

Metallurgy Sample No. 318
2nd failure bearings
#7 upper and lower
#2 main
#6 upper
#3 upper
#4 lower

In addition to bearing shells, granular material taken from the 2B diesel oil strainers was sent to the Metallurgy Lab for analysis (Metallurgy Sample No. 319). The material was characterized by SEM and EDS to be Fe particles generally 10-20 mils in diameter with some particles approximately 5-30 mils in diameter. The material was identified as sandblasting iron shot. A visual comparison between the oil strainer particles and used iron shot from CNS is shown in Figures 25, 26, and 27.

Scored bearings were examined using a low power magnification light microscope, SEM and EDS (Figures 27-30). Numerous particles, identified to be Fe rich and resembling the sandblasting Fe shot, were found embedded in the Pb babbitt and especially at the end of the deep score marks. In most cases, the Fe particles had penetrated completely into the underlying aluminum material. The particles were most numerous in the vicinity of the oil holes and annular groove, suggesting the source of origin being the lubricating oil.

The #7 upper and lower bearings from both failures were more heavily abraded than the others resulting in almost complete removal of the babbitt. Extensive embedding of Fe particles was found in the upper #7 bearing, first failure. Particles were not evident in the lower bearing, but traces of Fe were observed. The #7 second failure contained more general deposition of Fe particles with the particles themselves being heavily abraded. In the #7 second failure, certain areas of babbitt remained intact while others were completely removed, suggesting the bearing was non-uniformly loaded. The possible cause for such a condition is not known.

The #3 upper bearing contained no Fe particles or deep score marks. Normal polishing of the babbitt was evident. The bearing was considered to be in good, operating condition.

Tensile specimens were taken from an unused bearing and tested. The yield strength was 25,000 psi with an ultimate strength of 27,500 psi. The cross section reduction of area was 2.5% with 2.9% elongation. The fractures were brittle with little deformation which is consistent with the properties of this alloy.

Cracking occurred in the #7 bearings from both failures. The #7 lower bearing, 1st failure was extensively cracked along the annular groove and across the bearing surface (Figs. 1-5). The #7 lower bearing, 2nd failure was also circumferentially cracked (Figs. 6-8). Circumferential cracking of the keyslot was observed in both #7 lower failures and in the #7 upper first failure. Coining of the keyslots by the keys was observed in the #7 upper and lower bearing, 1st and 2nd failure, the #6 upper and #4 lower bearing. Coining of the keyslots does not appear correlate with cracking of the keyslots.

The bearing fracture faces appeared similar to those of the tensile specimens, consistent with the brittle nature of the material. SEM, fractographic evaluation revealed porosity to exist across the fracture surface. Many pores were interconnecting, but not atypical of those found in cast aluminum materials. The porosity observed on the failed bearing fracture faces was also consistent with that on the fracture faces of tensile specimens from an unused bearing.

Possible fatigue striations were discovered adjacent to some surface pores. The interior regions of the fracture faces generally appeared to be cleavage type brittle fracture. Micrographs of a circumferential crack show the crack tip to be wandering between voids, inclusions, and additional phases, suggesting the material has an inherent susceptibility to fatigue cracking. The microstructure of the material, pores, inclusions, et al, under normal operating conditions, is not considered to be detrimental to the life of the bearings.

In conclusion, scoring of the bearings is due to Fe particles trapped between the journal and the bearing shell. The source of the Fe particles is considered to be contaminated lubricating oil. Fracture of the bearing shells is possibly due to fatigue originated cracking. The source of the fatigue type loading is unclear, but is possibly the result of the breakdown of hydrodynamic lubrication due to the presence of Fe shot in association with the load characteristics of the bearing. The porosity of the aluminum cast bearing shell would make the material susceptible to fatigue initiated damage.

If such is the case, the cracking can be considered secondary and should be resolved by correcting the contaminated lubricating oil situation.

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Figure 1 - Fractured #7 lower bearing from 1st failure. Fracture is believed to have initiated at left side, in the annular groove. Ma-451.

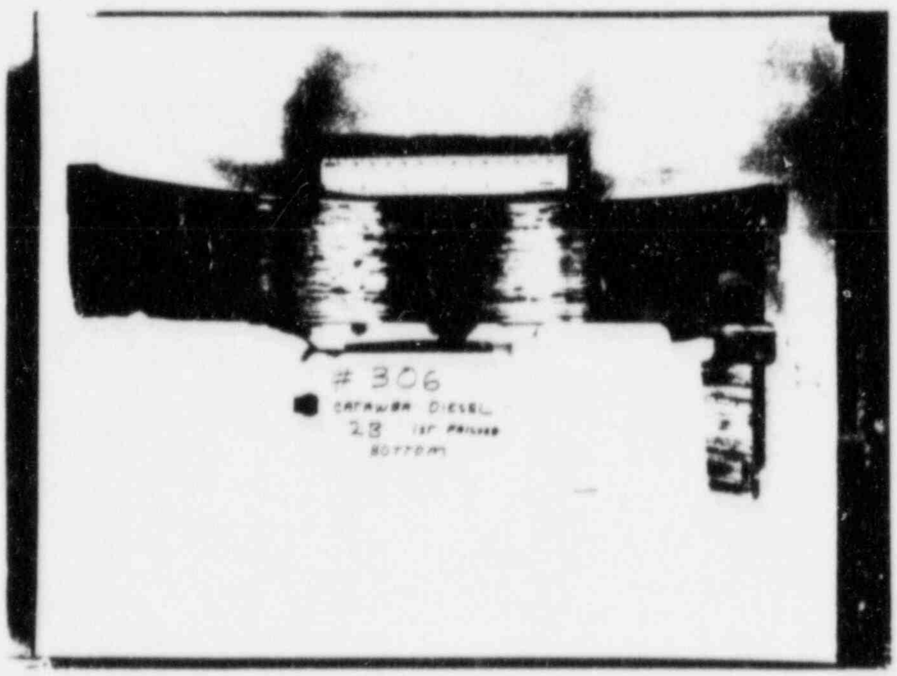


Figure 2 - Top view of #7 lower bearing first failure. Note fracture of the keyslot, which is not considered the primary fracture, secondary cracks in the webbing parallel to the primary fracture, and the change of direction of the fracture at right. Ma-453.

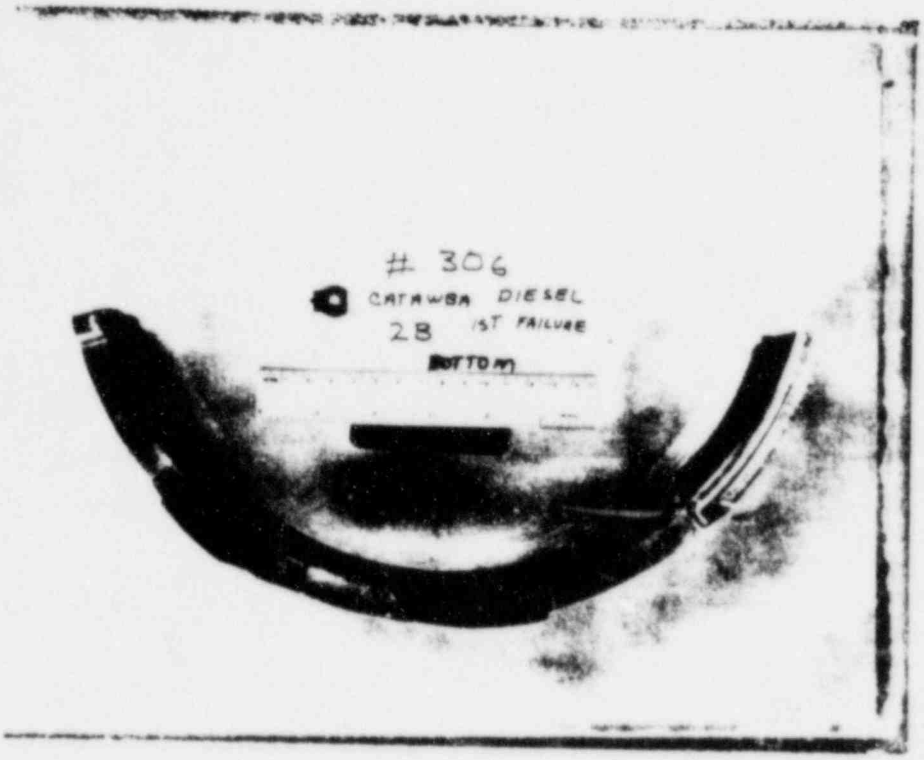


Figure 3 - Remaining portion of #7 lower bearing, first failure. Fracture face on right web was removed for examination by FaAA. Ma-450.

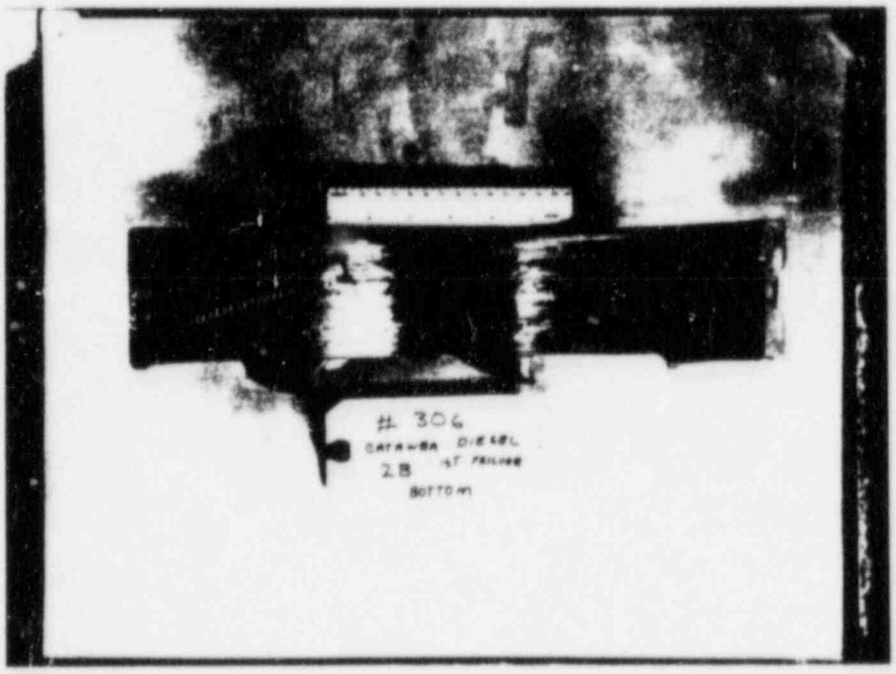


Figure 4 - Top view of above bearing. Babbitt overlay is completely worn away and aluminum surface is heavily abraded. Crack changed directions and fractured perpendicular to annular groove. Ma-452.

Figure 5 - Fracture at keyslot of #7 lower bearing. Separate piece at right broke completely free at the time of the first failure. Ma-454.

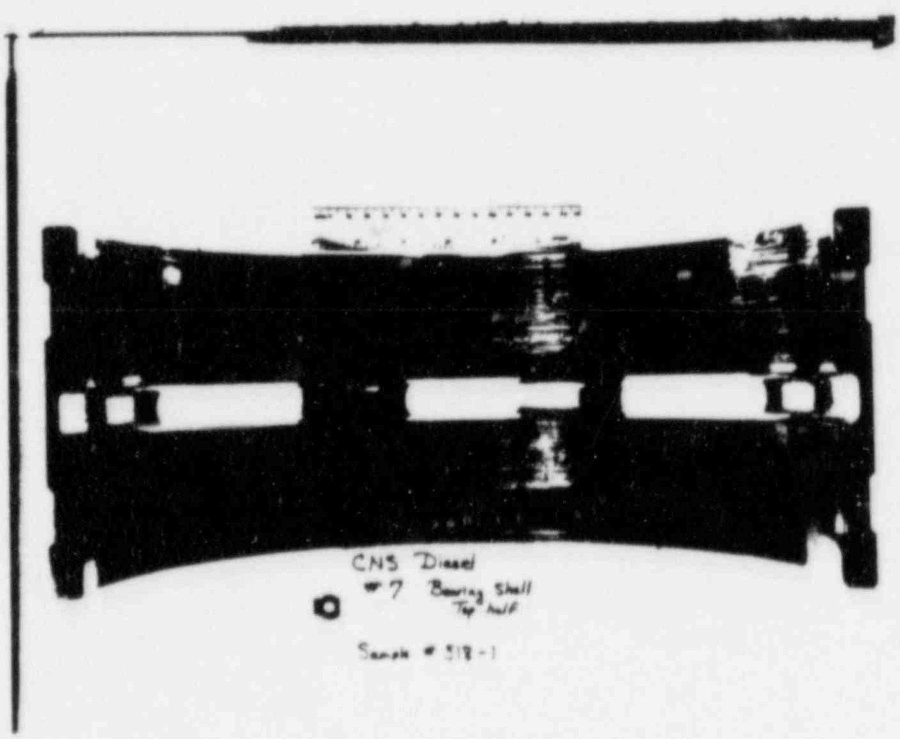
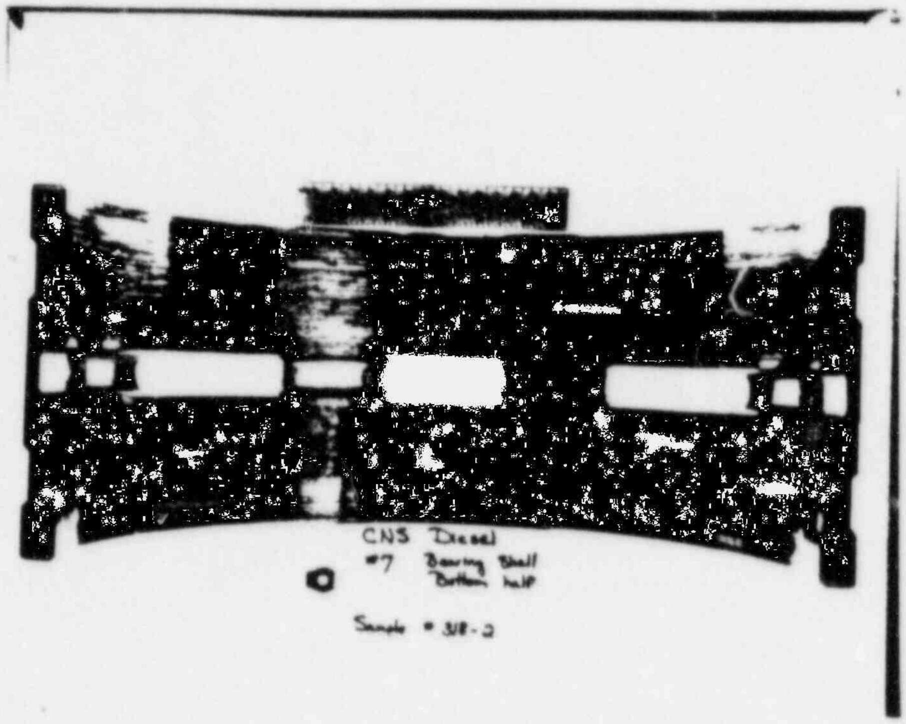


Figure 6 - Lower #7 bearing, 2nd failure. Upper portion of bearing is heavily abraded while Pb based babbitt is still intact at outer edge of lower portion, suggesting non-uniform loading. Ma-444.



Lower #7 bearing, 2nd failure, exhibiting non-uniform wear previously mentioned. Crack can be seen at lower right corner of annular groove. Ma-446.

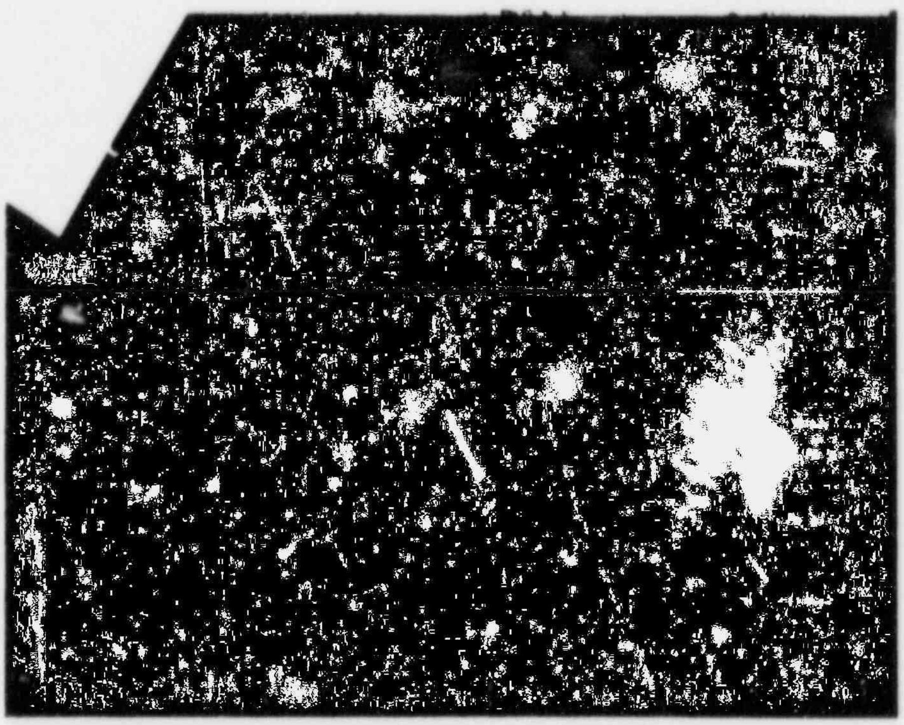


Figure 8 - Crack in lower right corner of annular groove of lower #7 bearing, 2nd failure. Crack propagated into thick section of bearing and is turning back toward oil hole. Second crack can be seen radiating from end of oil hole. Ma-448.

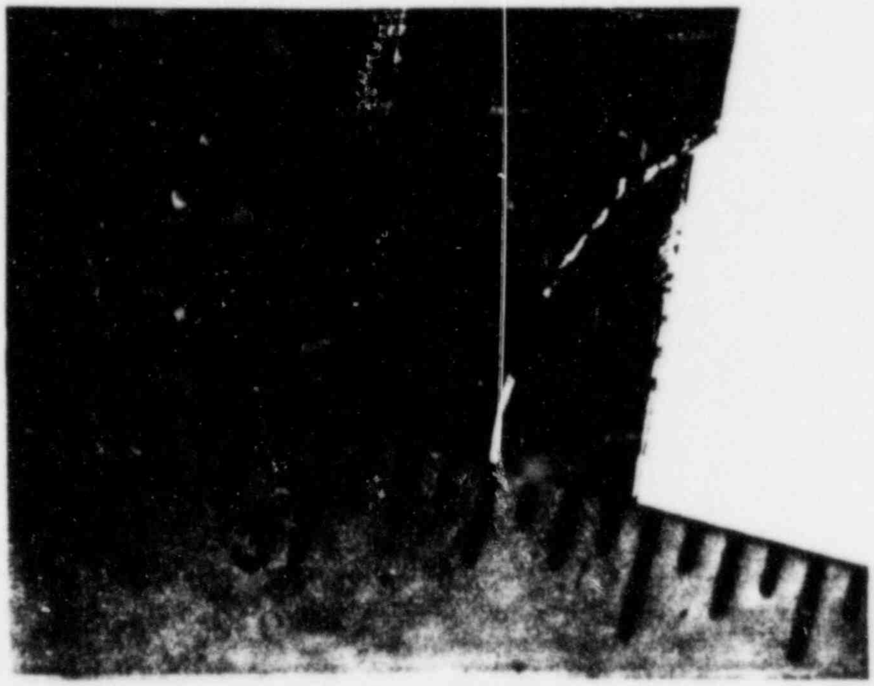


Figure 9 - Crack at keyslot of #7 upper bearing, 1st failure is typical of keyslots which cracked. Ma-461.

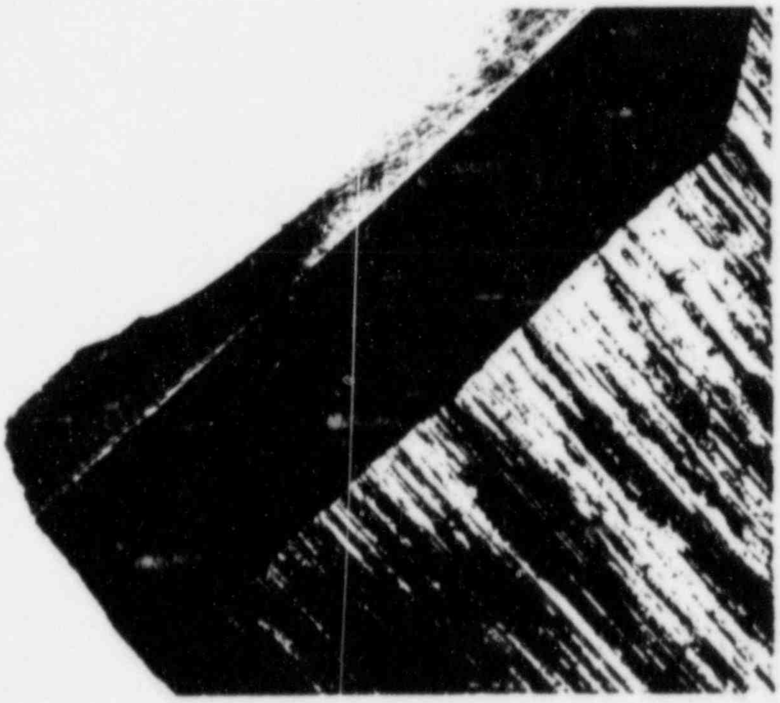


Figure 10 - Front view of crack shown above. Ma-462.

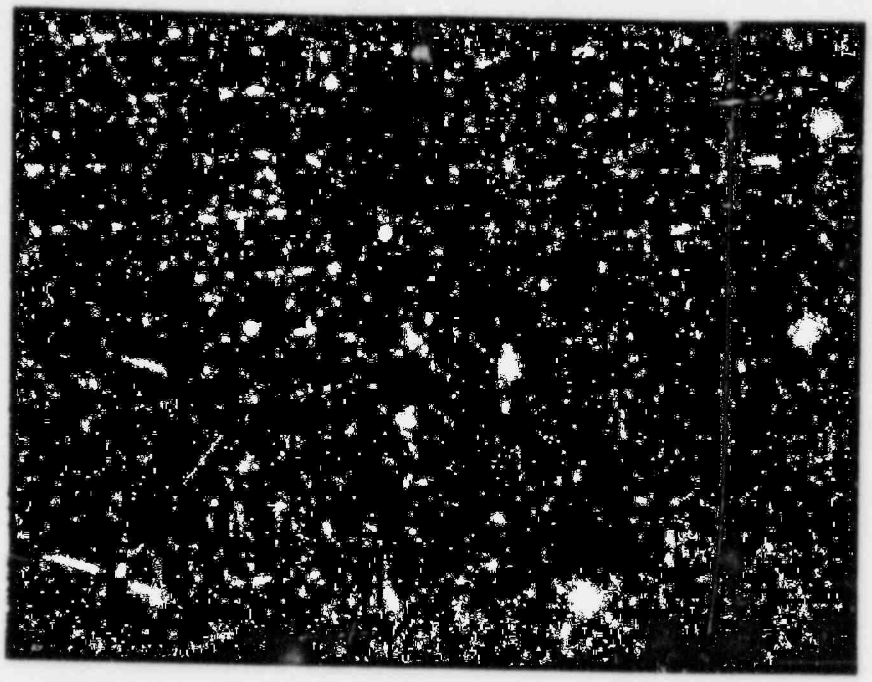


Figure 11 - Close-up of crack in keyslot of #7 upper bearing, 2nd failure. (10x) Ma-457.

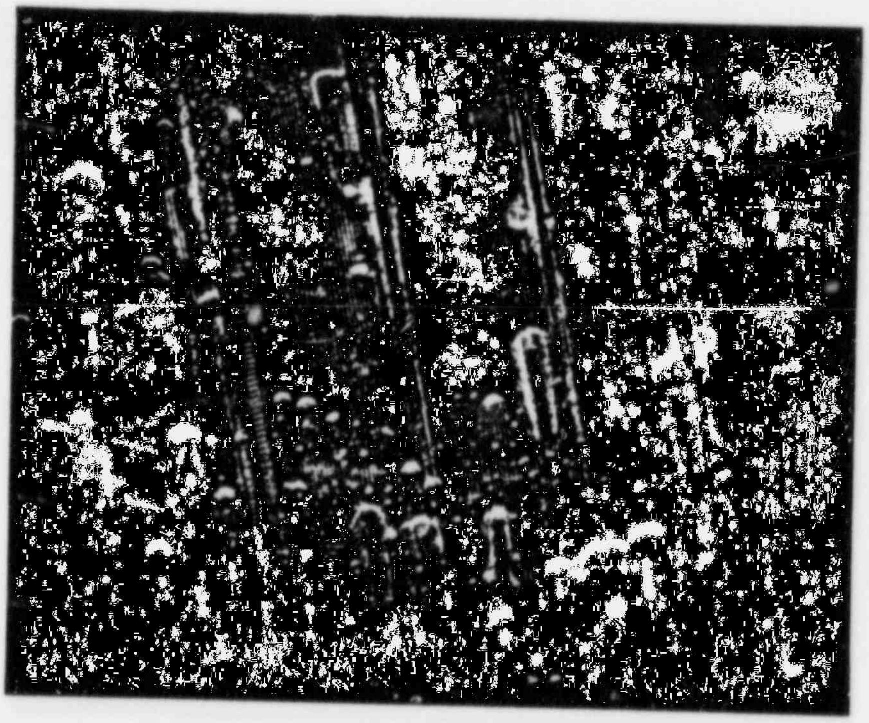


Figure 12 - Spherical particles embedded in Pb babbitt of #4 lower bearing, 2nd failure. Particles are located at the end of score marks as well as other places, and are typical of those found on other bearings. (10x) Ma-456.

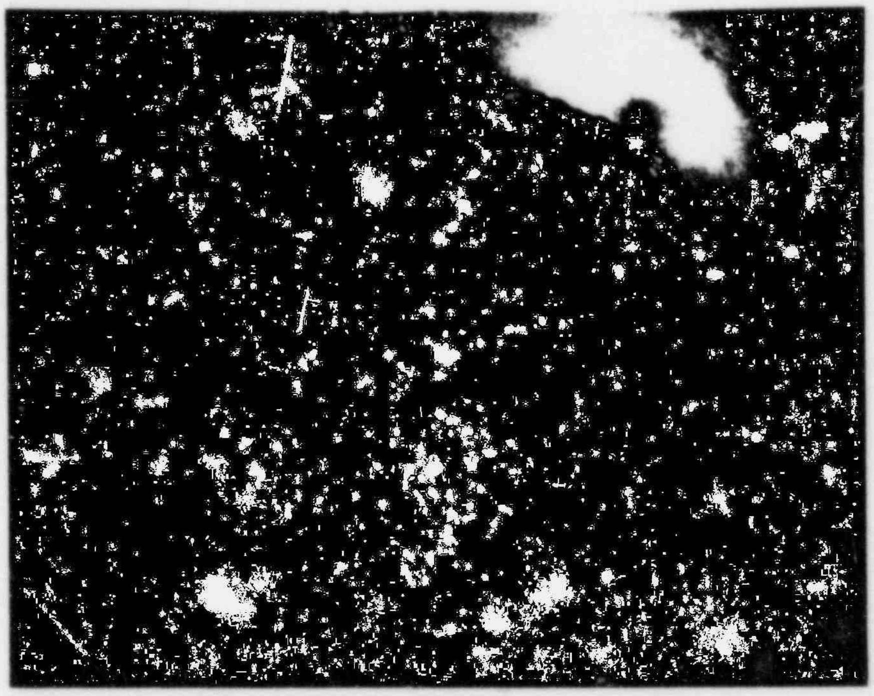


Figure 13 - Fracture face of tensile specimen cut from unused bearing shell. Fracture is basically brittle in nature with little deformation having taken place. (10x) Ma-459.

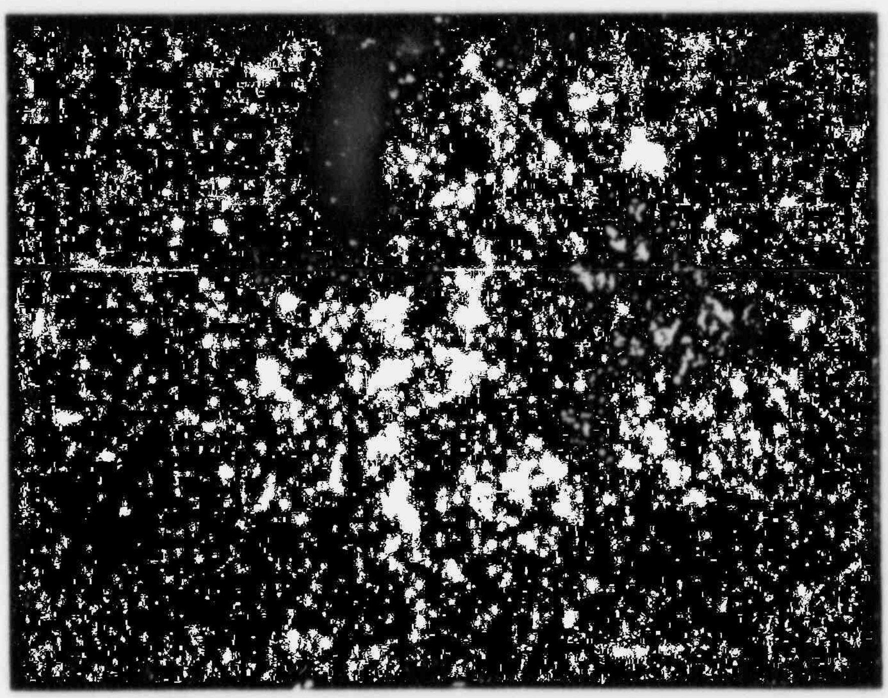


Figure 14 - Fracture surface of crack in #7 lower bearing, 1st failure. Fracture closely resembles that of the tensile specimen shown above. (10x) Ma-460.

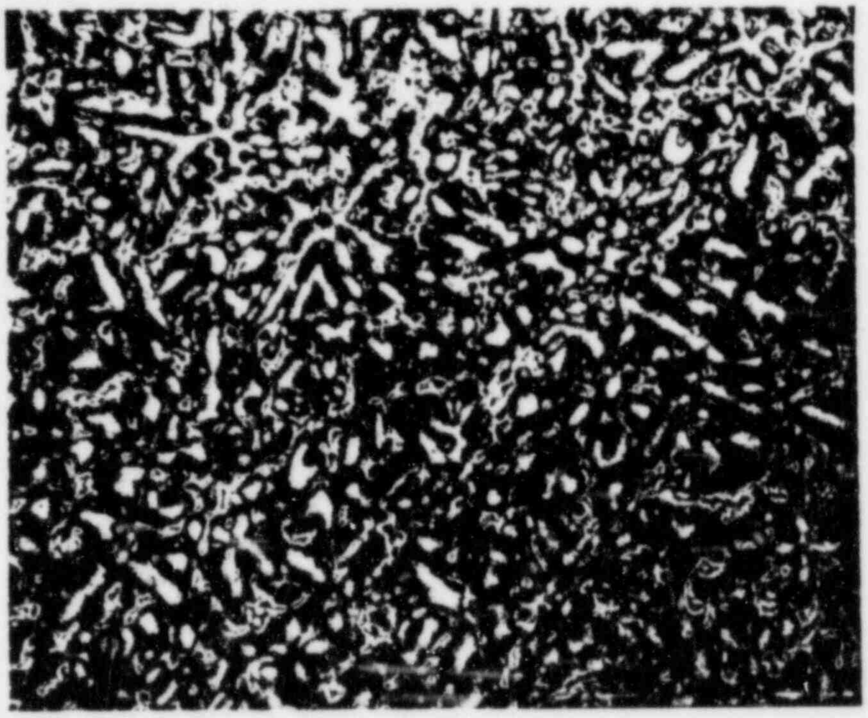


Figure 15 - Microstructure of bearing material. The material is reported to be B850 aluminum alloy. (100x) Mi-685.

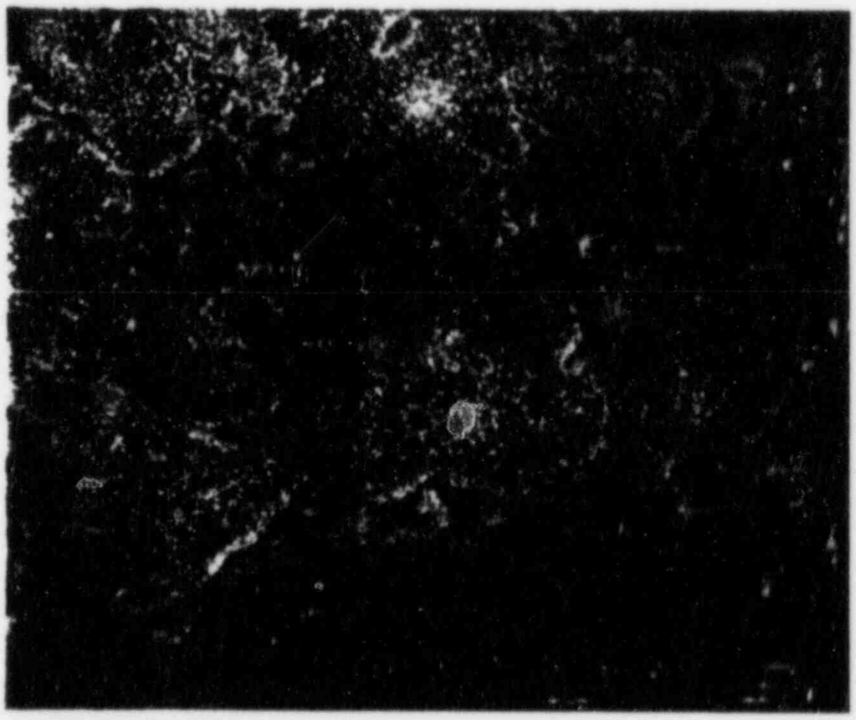


Figure 16 - Higher magnification micrograph of cast bearing alloy. Rounded structures are likely Sn particles. Other phases are probably Al-Cu, Ni-Al compositions. Dark areas out of focus are voids. (500x) MI-686.

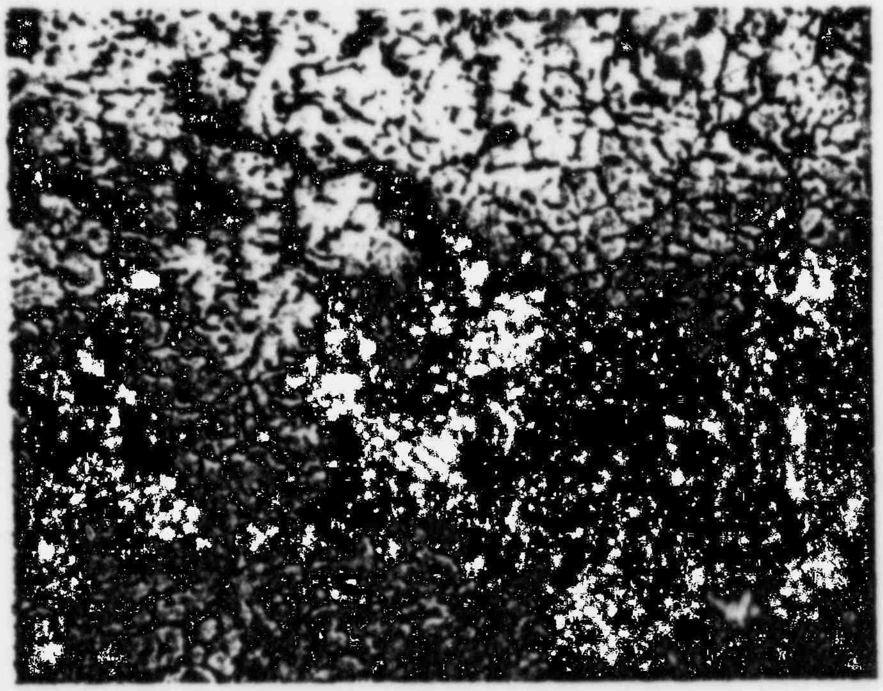


Figure 17 - Cross section of crack in 2nd failure of #7 lower bearing. Crack is following an intergranular path between voids and inclusions. (50x) Mi-687.

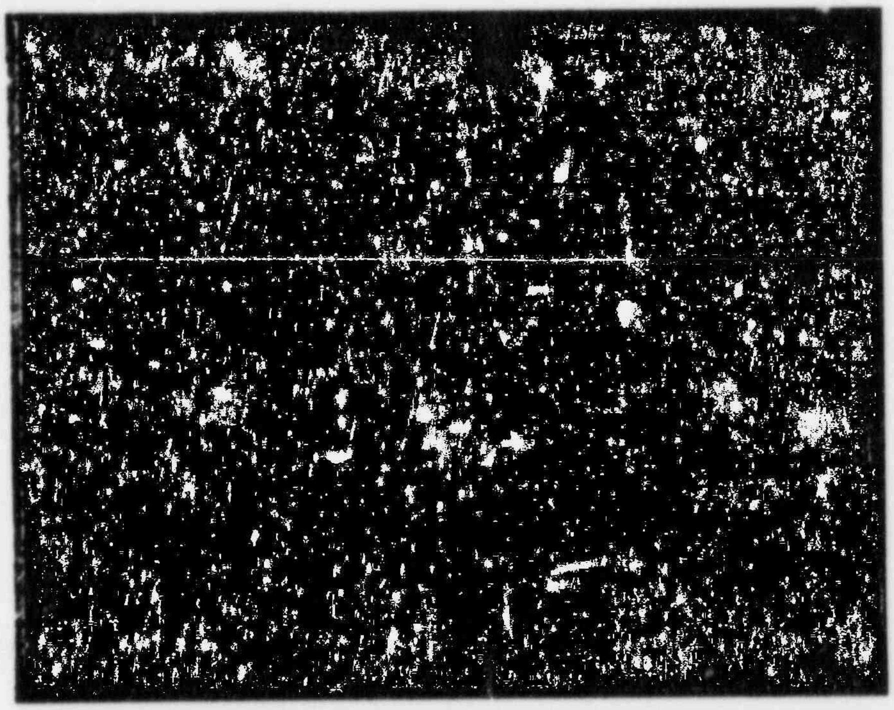


Figure 18 - Crack tip of crack shown above. Crack tip is at lower right within the conglomeration of voids and second and third phase particles. (1000x) Mi-689.

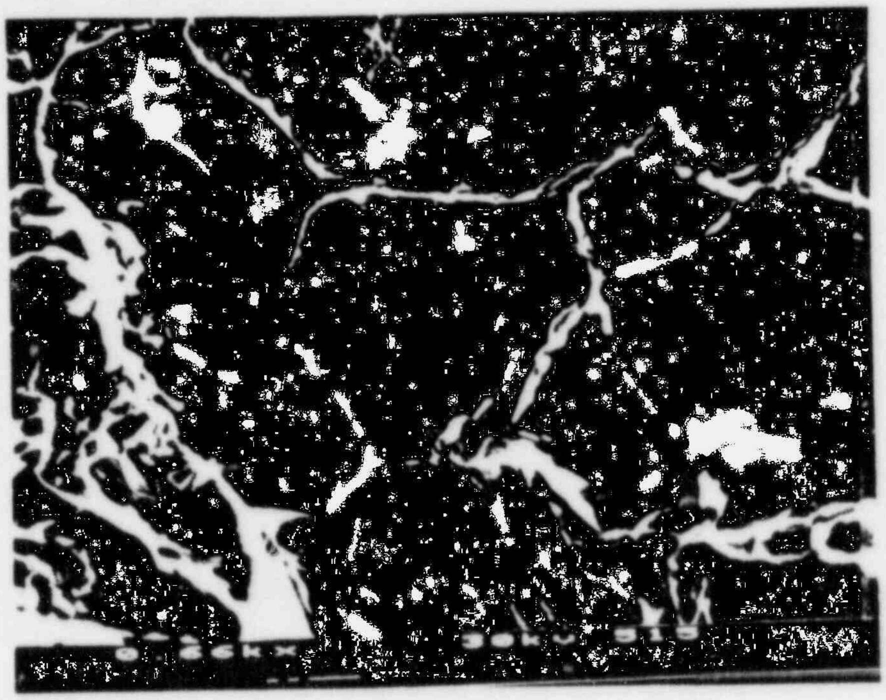


Figure 19 - Intergranular appearance of fracture of tensile specimen. (660x) S-345.

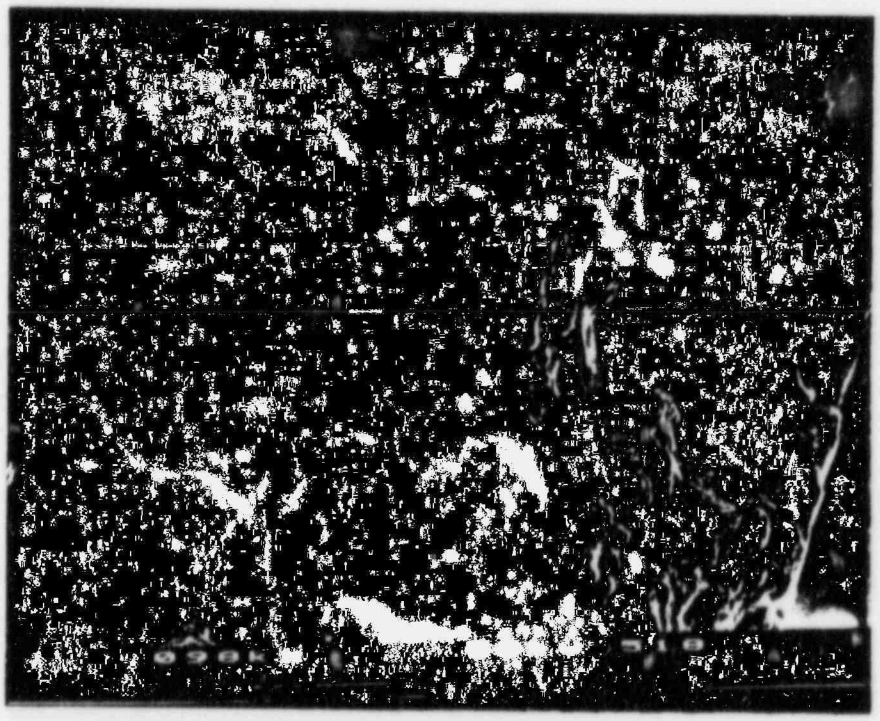


Figure 20 - SEM photo showing area of interconnecting voids on fracture face. Outer edge of bearing can be seen at bottom right of photograph. (98x) S-349.

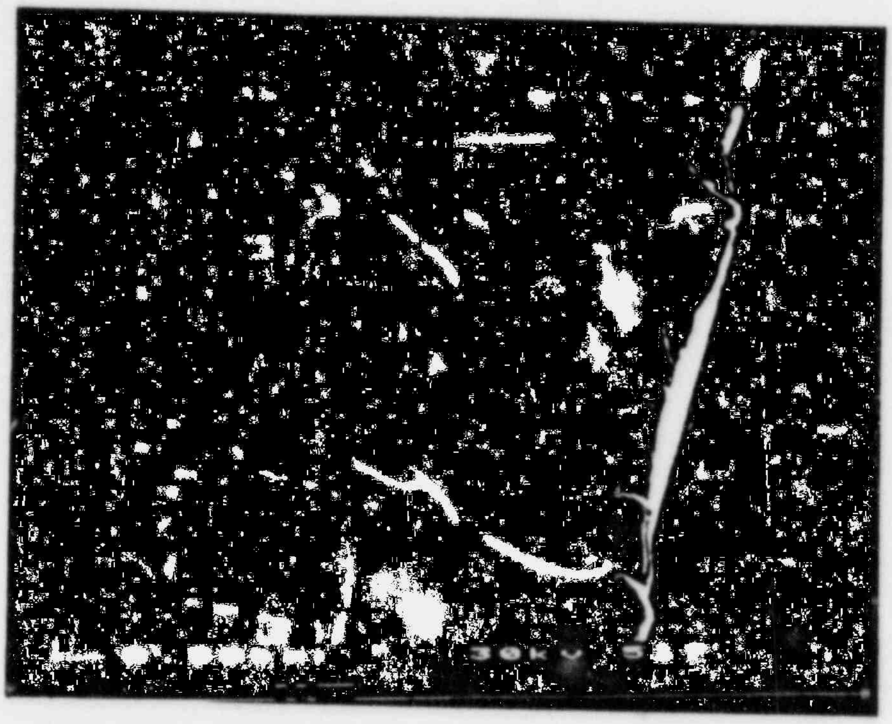


Figure 21 - Additional voids at surface of bearing casting. Voids are numerous and are found throughout the fracture surface. (500x) S-347.

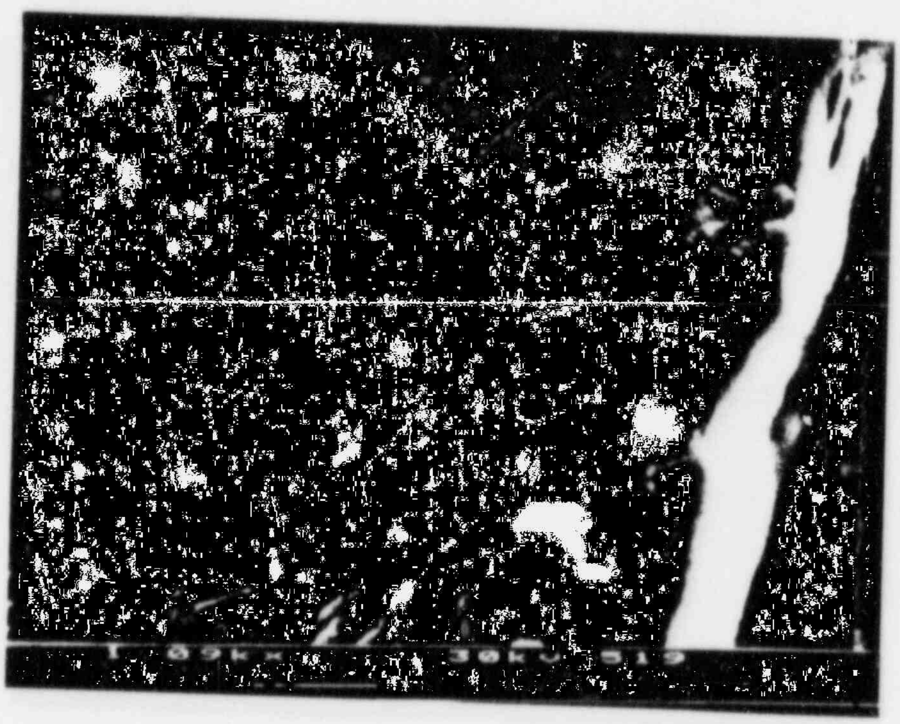


Figure 22 - Apparent fatigue striations can be seen in immediate center of photograph. This area is located just above void shown in Fig. 21 (1090x) S-350.

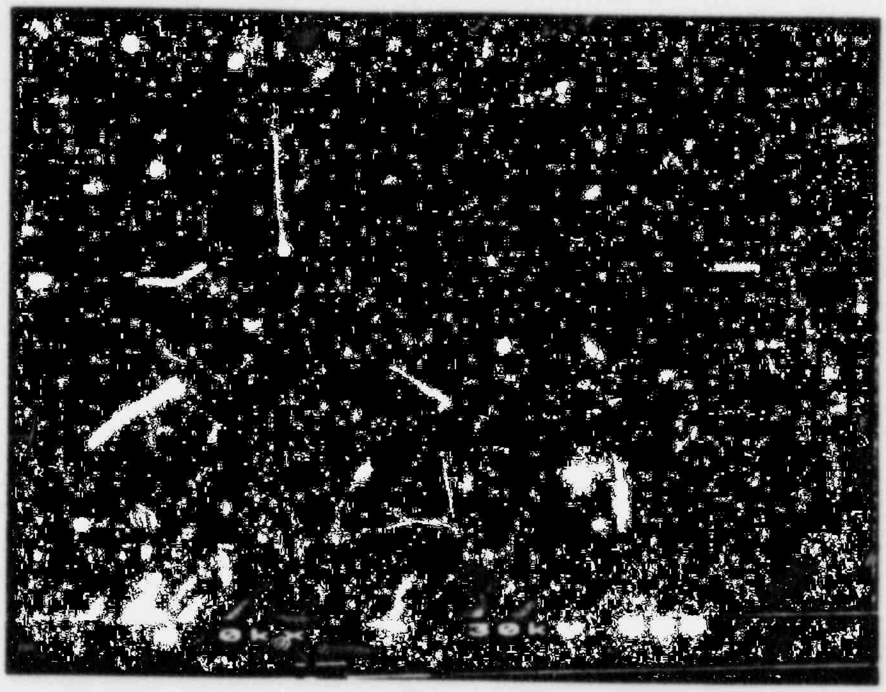


Figure 23 - Artifacts appear to be fatigue striations. Outer edge of fracture is at left. Location is inner surface of #7 lower bearing. (4000x) S-348.

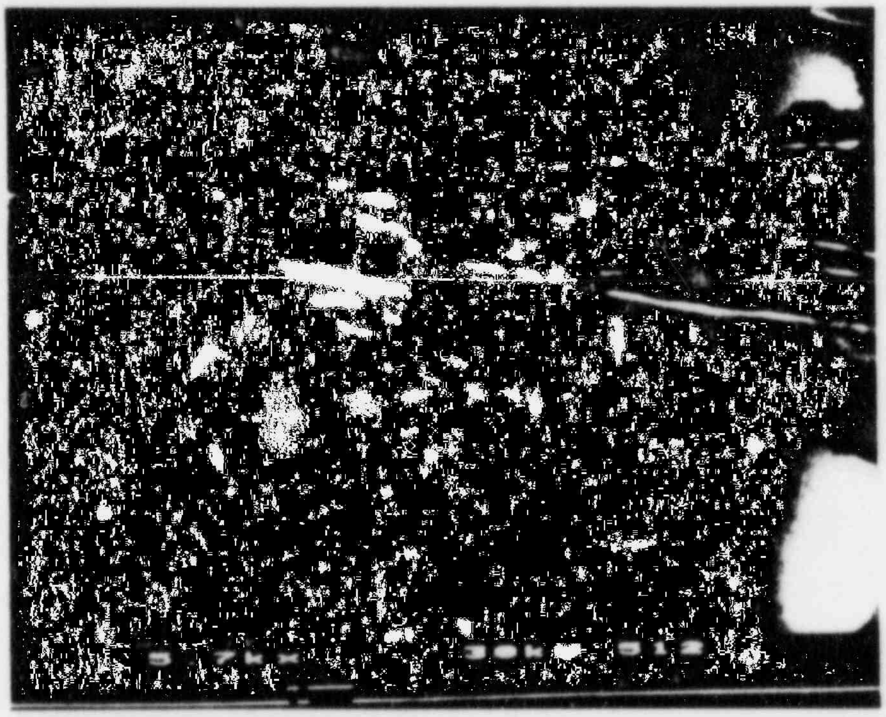


Figure 24 - Fatigue striations? Photograph is from edge of fracture at inner surface of the first failure of the #7 lower bearing. (5700x) S-343.

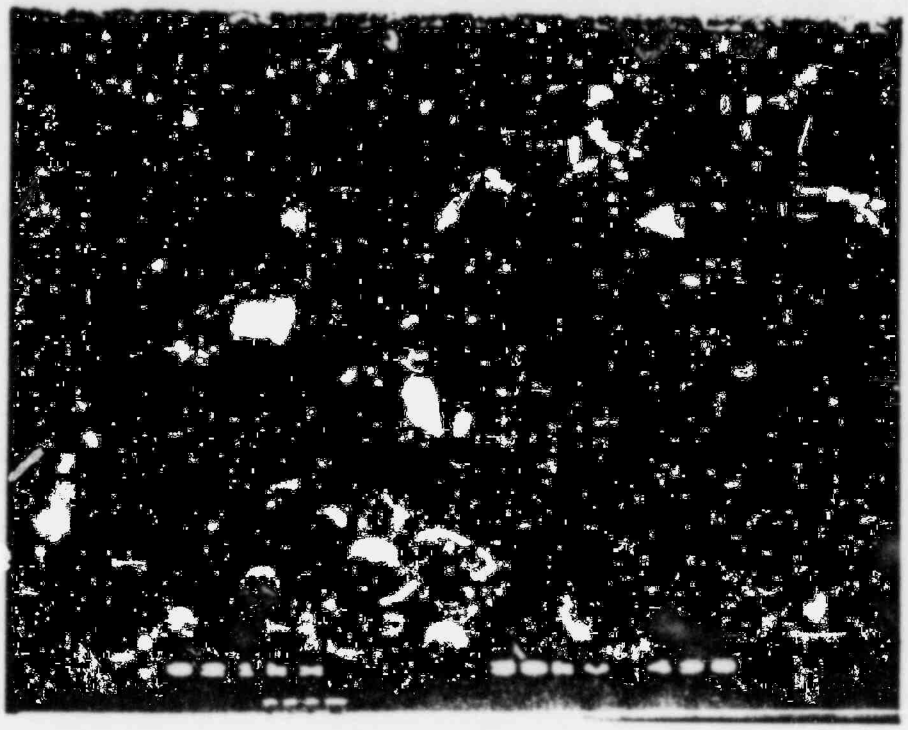


Figure 25 - Particles removed from 2B diesel oil strainers. White particles are of high silicon content (sand). (21x) S-320.

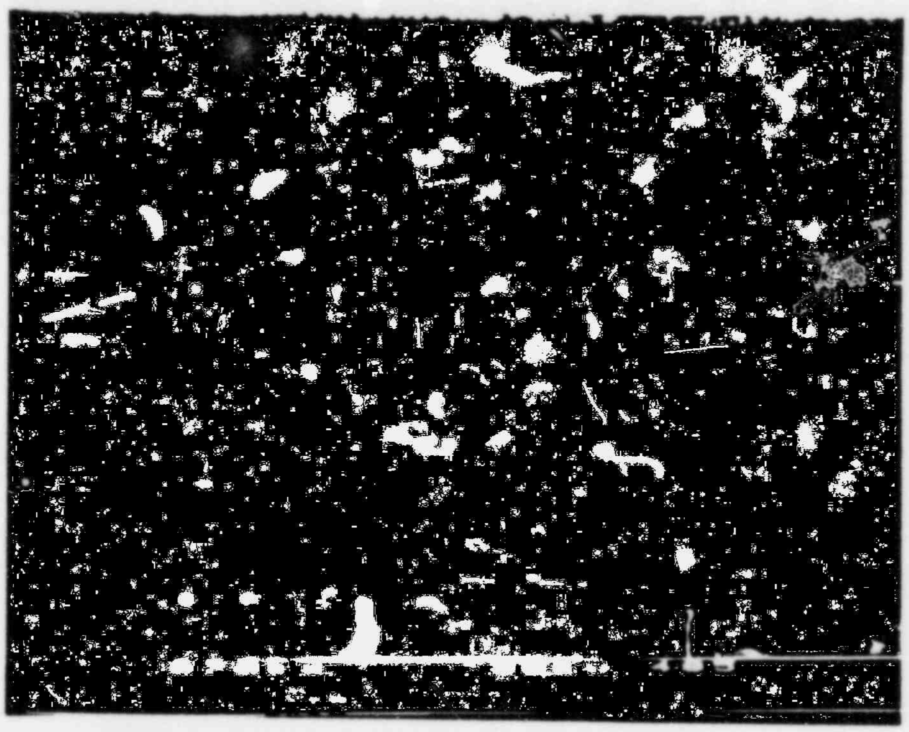


Figure 26 - Iron shot used for sandblasting applications. Material is from CNS maintenance shops. Material is used and particles range from 5-30 mil in size. (20x) S-315.

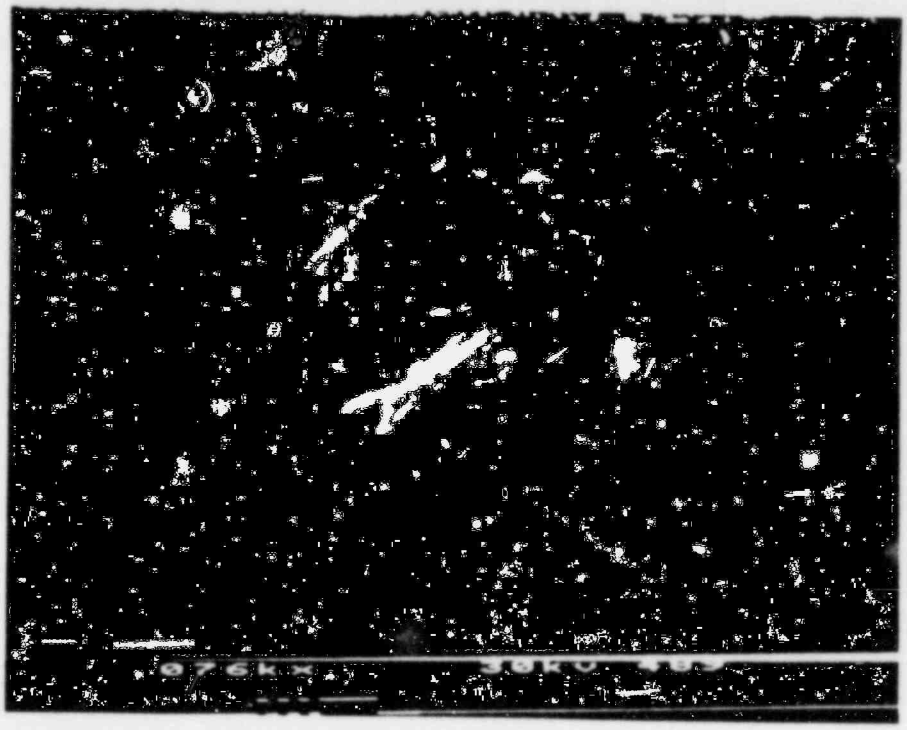


Figure 27 - Close-up of particles from 2B diesel oil strainer. Particles were identified by EDS to be Fe and are considered to be iron shot for sandblasting. (76x) S-318.

Figure 28 - Iron particles embedded in Pb babbitt. Scoring penetrated into Al cast material. Identification was by EDS.

Figure 29 - Fe particle embeddea in Pb babbitt. Particles are considered to be sandblast shot. (53x) S-321.

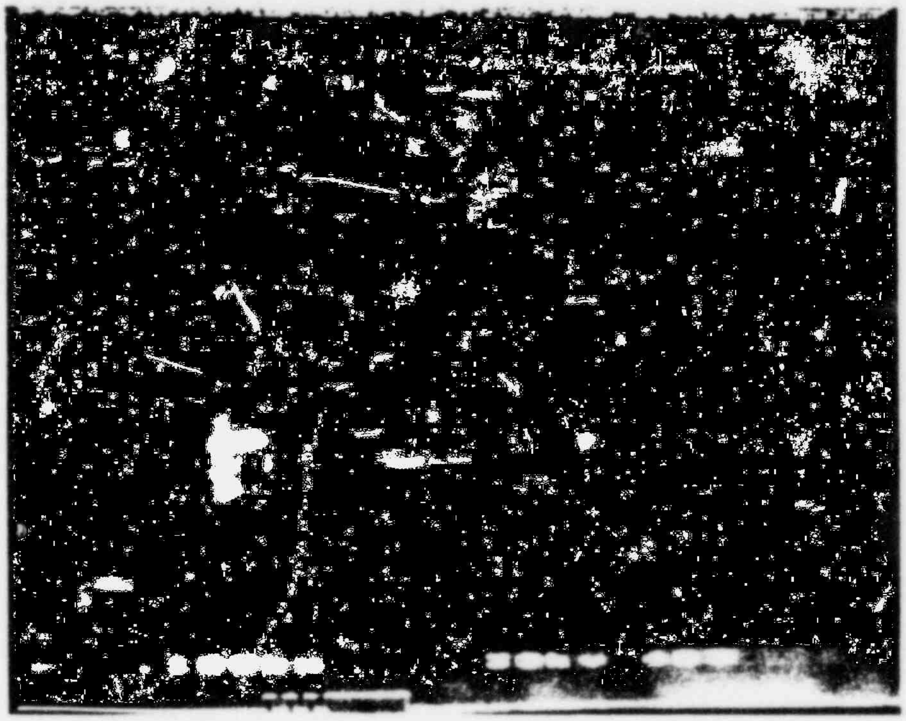


Figure 30 - Close-up of above Fe particle. White particles are sand. (105x) S-321.