An AEIS Case Study

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Case Study: Failure Analysis of Diesel Engine Cylinder Liners

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Introduction

Three used cylinder liners identified by numbers 277, 1016 and 1076 were submitted for failure analysis. The liners were pitted on the outside surface. Liner 277 had a crack under the flange, additionally. An unused liner was also submitted for reference. The following mileage information was provided

Liner Number	*Mileage*
277	***156,829***
1016	***23,273***
1076	***189,000***

Additional information was provided from sections of manufacturer's manual. The cylinder liners are replaceable wet type, made from hardened alloy cast iron, and are slip fit in the cylinder block. The coolant in the block water jacket surrounds the liner and cools it directly. A cooling channel is also cut into the liner immediately below the flange. Coolant flow through this channel and around the rest of the liner controls critical ring and liner temperature for long cylinder life.

Key Words

Engine, Diesel, Cylinder, Failure Analysis,

Circumstances Leading to Failure

Cavitation.

Visual Examination of General Feature

Cylinder Number 277 showed pitting and erosion on the outside surface. No pitting was observed below the seal region. The metal loss was defined to distinct patches suggesting a perpetual flow pattern over a finite length of time. Cavitation was also observed in isolated regions in the cooling channel. Approximately 1/16 inch deep grooving immediately below the flange was observed. Attack was also observed on the lower face of the flange. A crack on the other side of the wall i.e. on the internal surface was apparent. The crack covered approximately half the circumference and had an opening approximately 1/32 of an inch in its widest spot; in the middle. Some scoring was observed in a band approximately 1/8 inch at the upper edge of the crack. A slight difference in surface level was felt by touch. The crevice seal, though slightly compressed, was found to be intact. The surface underneath was clean and free of any damage. Both the sealing O-rings were found to be intact and without any noticeable damage. The surface underneath was clean and free of any damage.

Figure 1: Cylinder liners in as received condition

Cylinder liner Number 1016 had similar cavitation patches though deeper than cylinder liner number 277. The metal damage below the flange was observed in this cylinder liner too. The loss appeared to be similar in depth though on a lesser cumulative linear dimension. The crevice seal was found to be intact. The surface underneath was clean and free of any damage. Both the bearing shells were found to be intact and without any noticeable damage. The surface underneath was clean and free of any damage

Cylinder liner Number 10076 was found to be generally free of cavitation, both on the general outside surface as well as under the flange. A small patch with a cumulative area of about one and a half square inch was found on the upper half of the liner. The cooling channel had some golden colored patches which appeared to be remains of an adhesive. Rectangular marks suggesting that the surface was covered by some strip was observed. The flange had a straw coloration apparently from an oxide film. The crevice seal was chipped at the upper edge. The damage did not spread across the width. The surface underneath was clean and free of any damage. Both the bearing shells were found to be intact and without any noticeable damage. The surface underneath was clean and free of any damage on cylinder liner 1076. The radius under the flange was recessed into the corner, Figure 2 unlike the new liner, Figure 3.

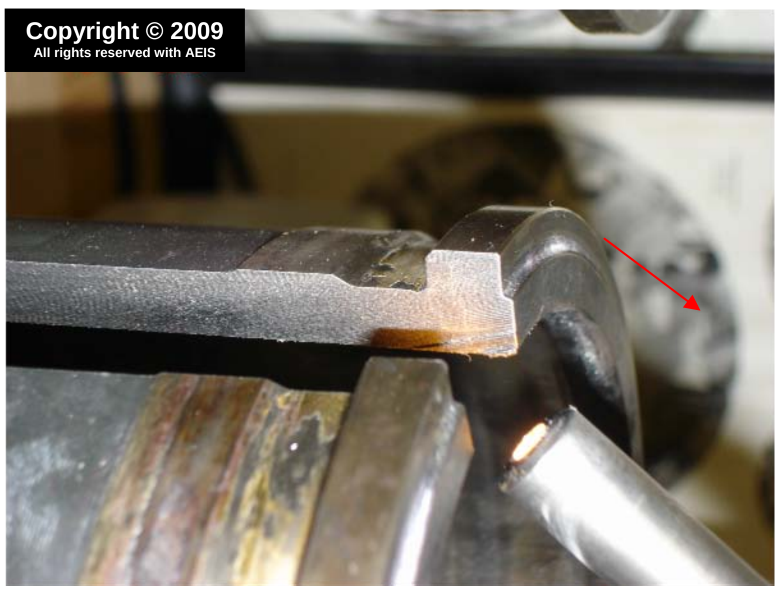

Figure 2: Profile of flange radius in cylinder liner 1076

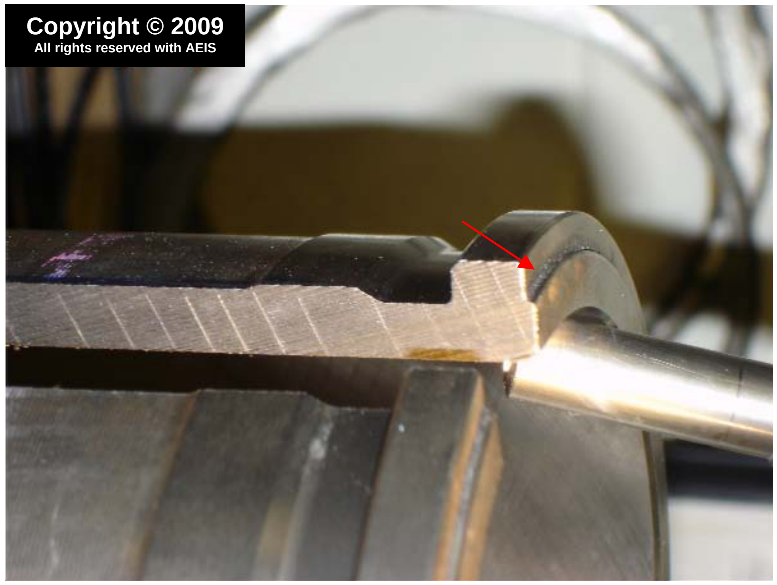

Figure 3: Profile of flange radius in new cylinder liner

Figure 4: Cavitation patches on cylinder liner 1016

Figure 5: Close up of cavitation damage under the flange on cylinder liner 1016

Figure 6: Outside surface of cylinder liner 1076 generally free of cavitations.

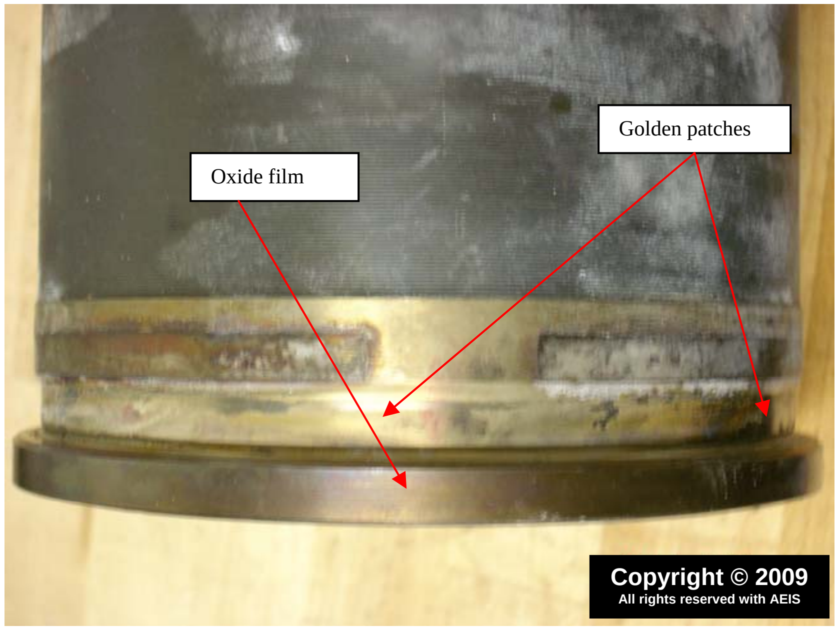

Figure 7: Close up of cooling channel area of cylinder liner 1076

Macroscopic Examination

The cracked area on the cylinder liner number 277 was examined under low powered optical microscope. The observations made in the visual examination were confirmed. Figure xx and Figure XX shows the cavitation loss under the flange. The crack surfaced along a circumferential mark approximately 3/16 inches from the upper surface of the flange. The outside opening coincided with the eroded corner of the flange. The crack on the cross section at one end was observed to be having a profile of an arc with an approximately ¼ inch radius. The difference in surface level across the crack is obvious in figure.

Radiography

The cracked cylinder liner 277 was radiographed with double wall technique. The crack could not be defined in the radiograph though the image of the pentrameters confirmed that the sensitivity and density were satisfactory. This is attributed to the curved profile of the crack as observed on a cross section of the liner wall . No other crack on the liner was detected. The radiography report is appended.

Liquid Penetrant Test

The inside surface of the liners was cleaned and examined by LPT technique. No crack was observed in cylinder Liners 1016 and 1076. The crack in the liner 277 covered approximately 50 percent circumference. No other surface defect was observed on the inside of any cylinder liner.

Scanning Electron Microscopy

The fracture surface was examined under a scanning microscope. Cavitation pits were observed on the fracture surface.

Figure 8: Crack in Cylinder liner 277

Figure 9: Cavitations immediately under the flange

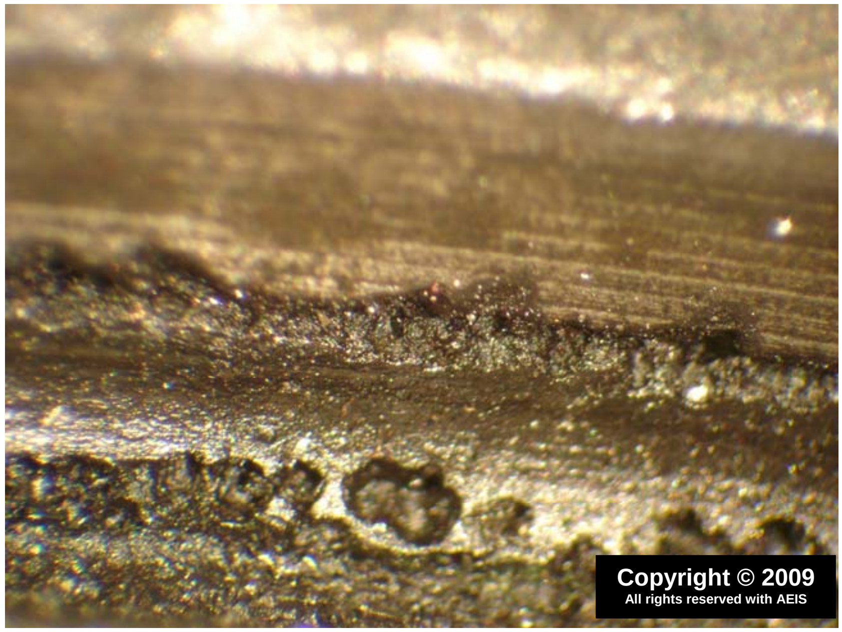

Figure 10: Close up of the cavitations immediately under the flange

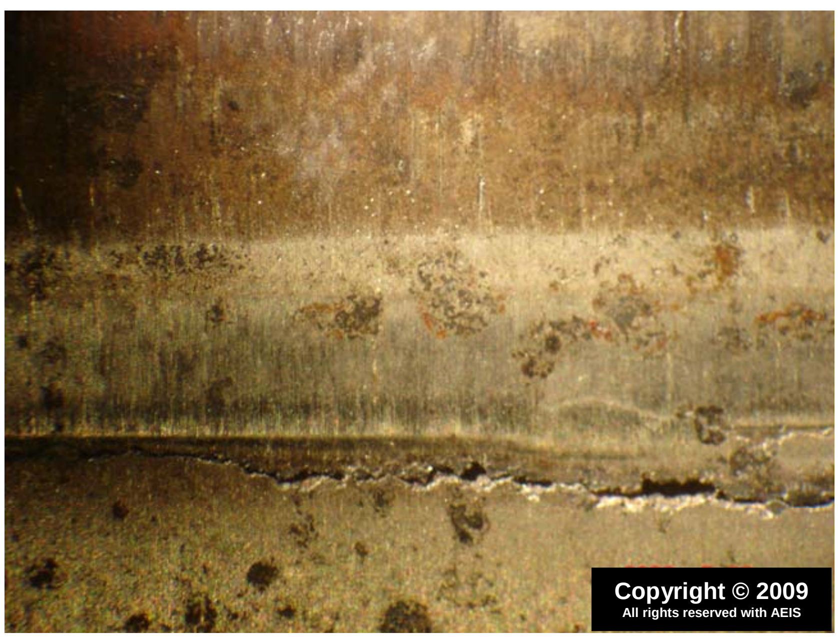

Figure 11: The crack and the scored band on the inside surface

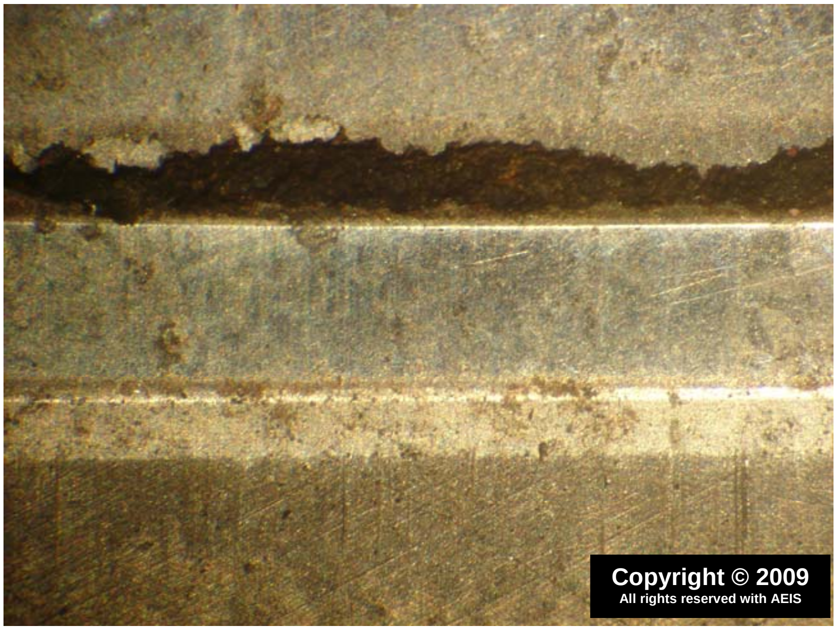

Figure 12: Damage on the inside surface in the middle of the crack length..

Mechanical Properties

Hardness was measured on the inside surface on longitudinal strips cut from each cylinder on Brinell scale using 3000 Kg load. The locations were chosen in the fired zone. Following values were obtained.

Liner Number	**Location**	**Value (HB)**	**Average**
New	Top	269	
	Middle	277	
	Bottom	286	277
277	Top	387	
	Middle	387	
	Bottom	375	383
1016	Top	293	
	Middle	302	
	Bottom	293	296
1076	Top	402	
	Middle	402	
	Bottom	387	397

It can be observed that the new liner and the liner 1016 have a similar hardness whereas liner 277 and has a hardness close to 1076. Tensile test on specimens extracted from Liner 277 revealed a tensile value of.

Chemical Analysis

Element Percent / Liner number	New	277	1016	1076
Carbon	3.05	3.57	3.09	3.50
Manganese	0.32	0.66	0.35	0.65
Phosphorus	0.061	0.067	0.054	0.064
Sulphur	0.045	0.132	0.059	0.156
Silicon	2.52	2.66	2.54	2.69
Chromium	0.05	0.3	0.07	0.31
Nickel	1.15	0.08	1.30	0.11
Molybdenum	1.14	0.05	1.66	0.04
Copper	0.23	0.64	0.21	0.61

It can be observed that the new liner and the liner 1016 have a similar chemical composition especially regarding the alloying elements where as liners 277 and 1076 bear a resemblance.

Microscopic Examination

Specimens were prepared from the cross section of each cylinder liner for microscopic examination. Two locations were selected from each liner, one in the middle of the fired zone and one near the flange. Additional cross section specimens were prepared from the failed cylinder. Figures underneath show that the graphite distribution in the new and the liner 1016 is similar where as liner 277 and 1076 show similarity. The matrix was found to be heat treated though under different parameters. Microstructure showed that crack propagation in Liner 277 was along the graphite flakes. Microstructure also showed stress concentration points at bottom of pits.

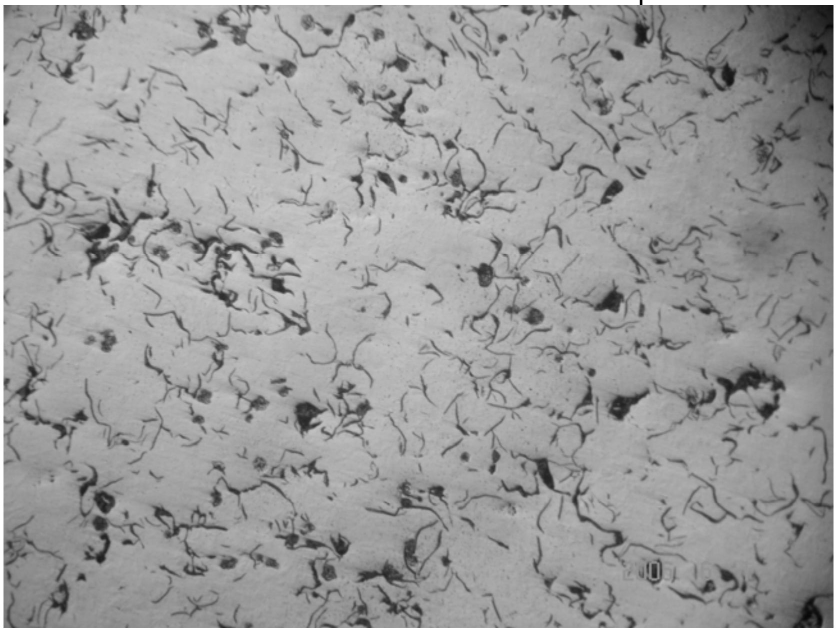

Figure 13: New Liner microstructure in the middle of the fire length in as polished condition. Magnification 100X

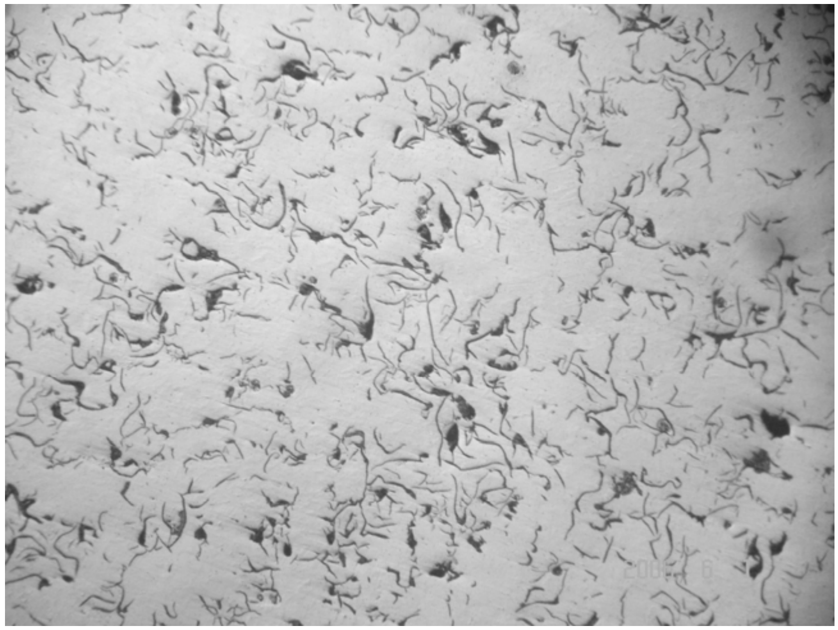

Figure 14: New Liner microstructure near the flange in as polished condition 100X Magnification

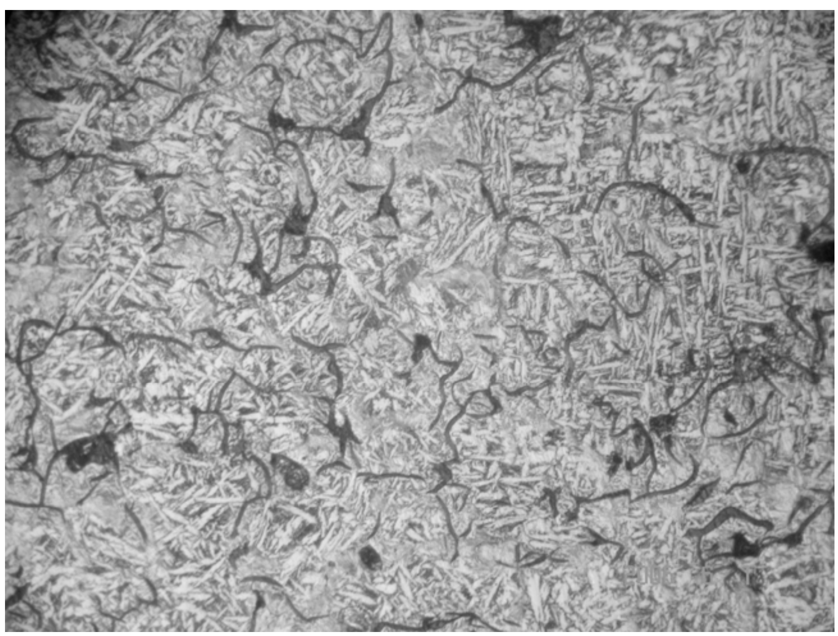

Figure 15: Microscopic structure of matrix the new liner. 250X Magnification

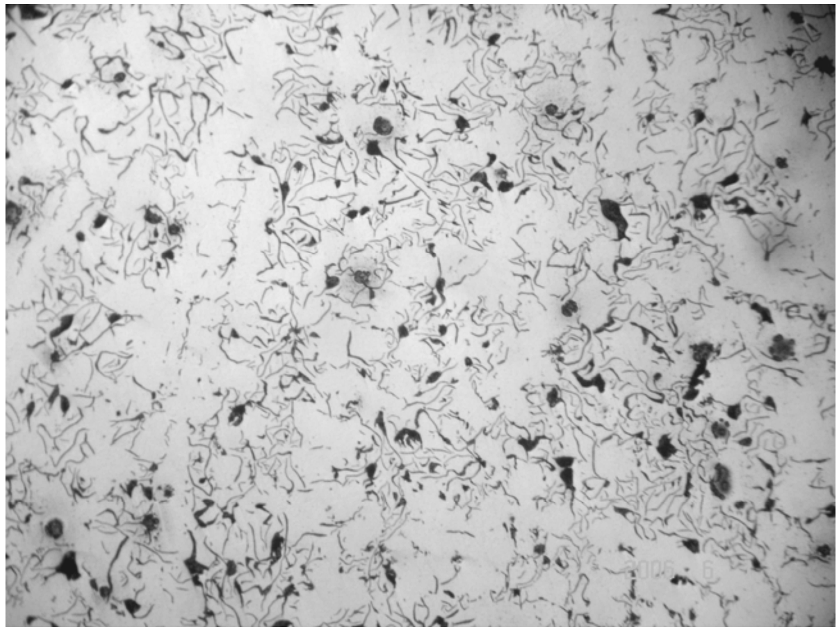

Figure 16: Liner 277 microstructure in the middle of the fire zone in a polished condition.
100X Magnification

Figure 17: Liner 277 microstructure near the flange in as polished condition.
100X Magnification

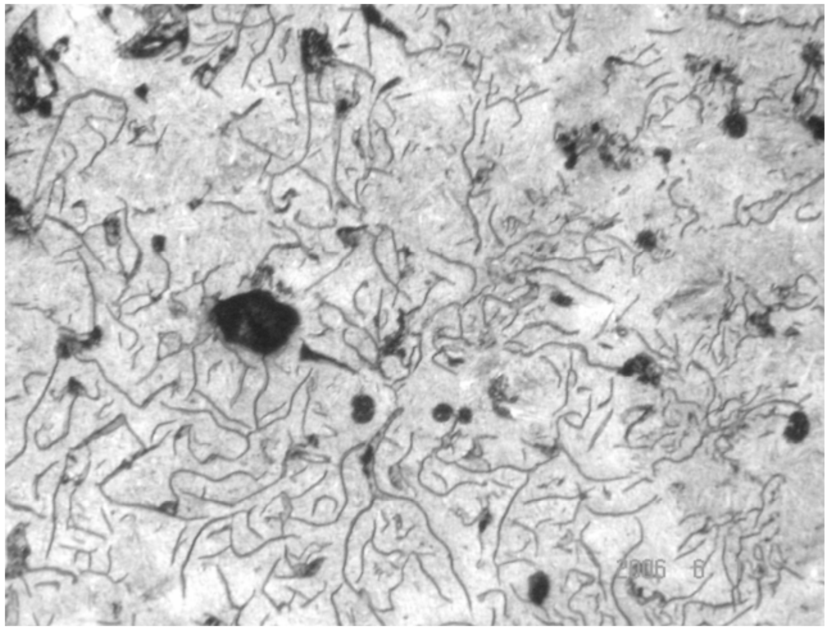

Figure 18: Microscopic structure of matrix the liner 277. 250X Magnification

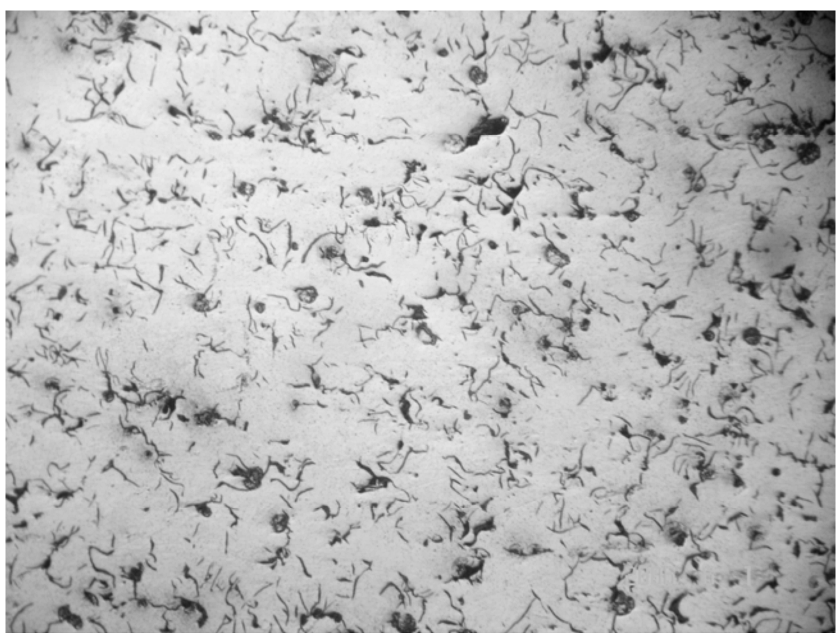

Figure 19: Liner 1016 Microstructure in the middle of the fire length in as polished condition. 100X Magnification

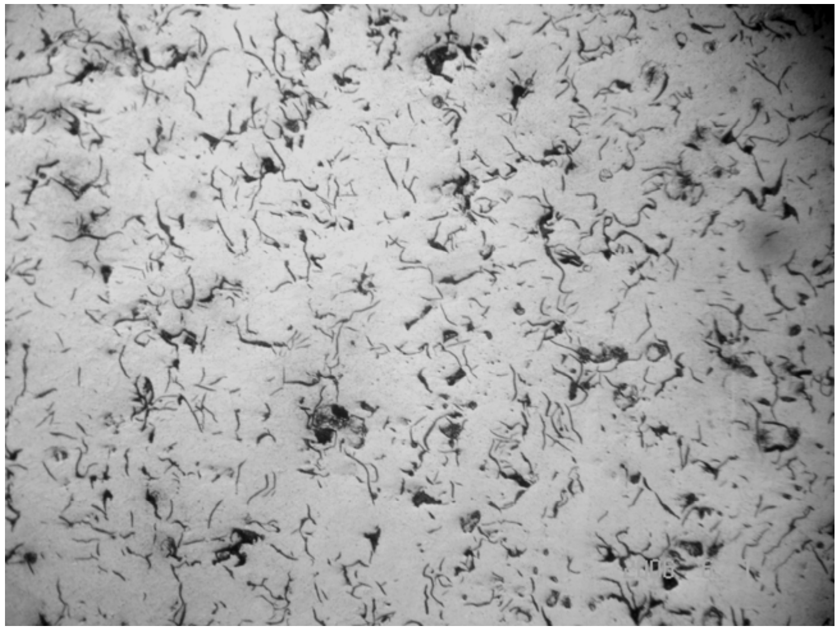

Figure 20: Liner 1016 Microstructure near the flange in as polished condition. 100X Magnification

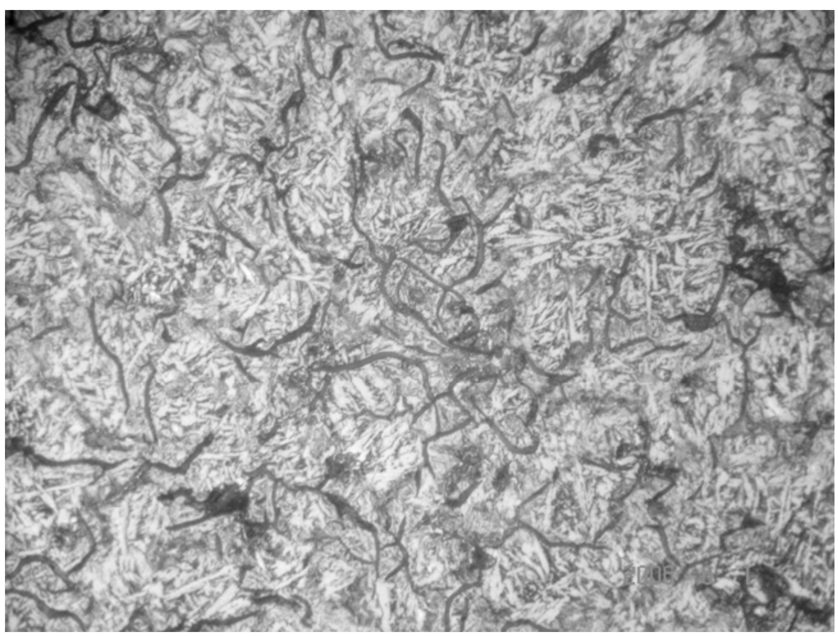

Figure 21: Microscopic structure of matrix the liner 1016. 250X Magnification

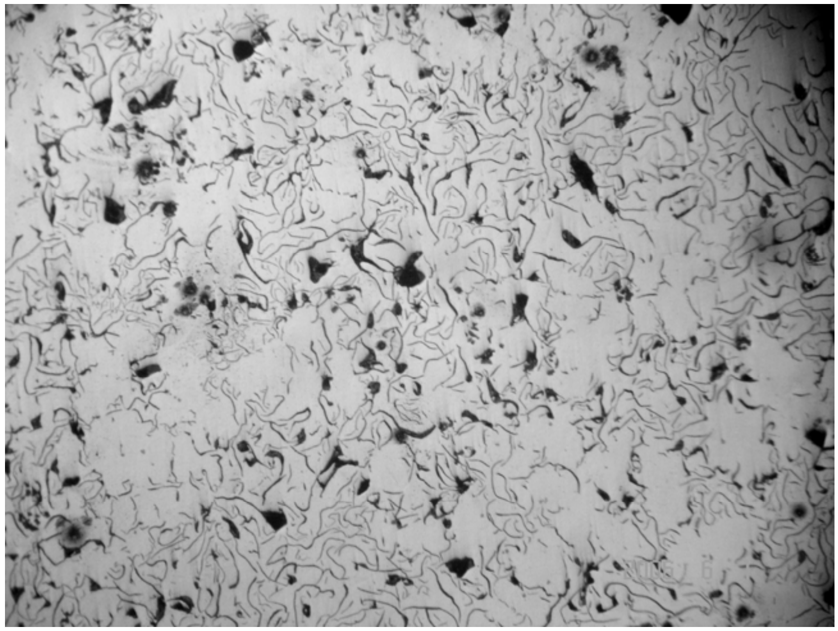

Figure 22: Liner 1076 Microstructure in the middle of the fire length in as polished condition. 100X Magnification

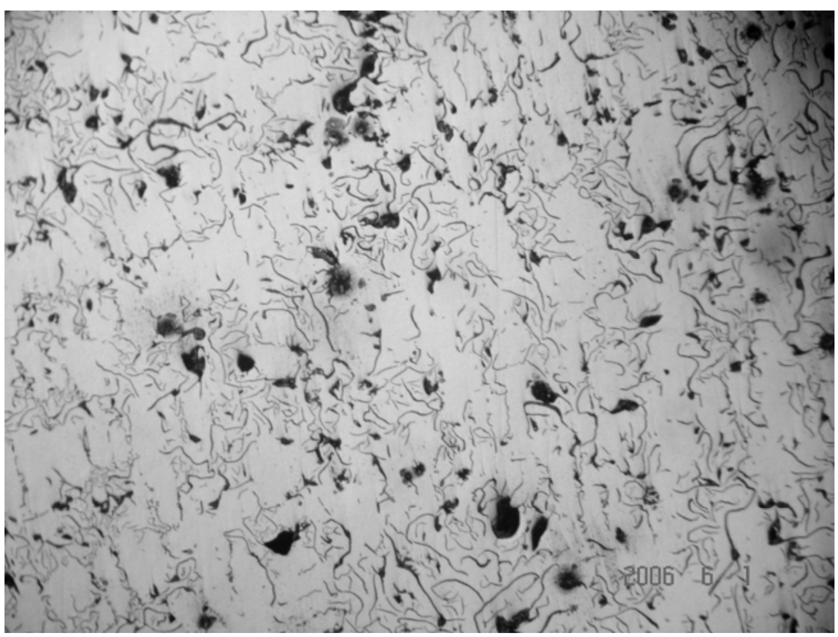

Figure 23: Liner 1076 Microstructure near the flange in as polished condition 100X Magnification

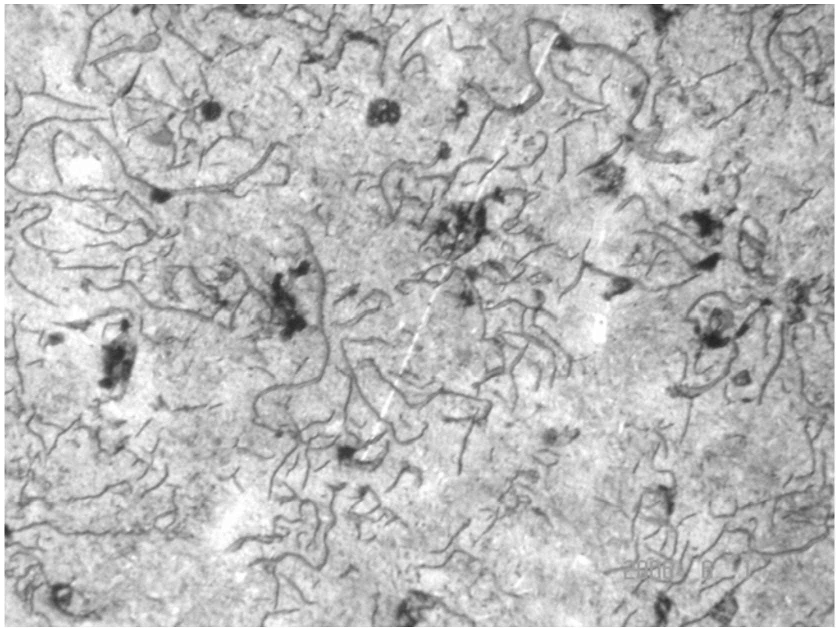

Figure 24: Microscopic structure of matrix the liner 1076. 250X Magnification

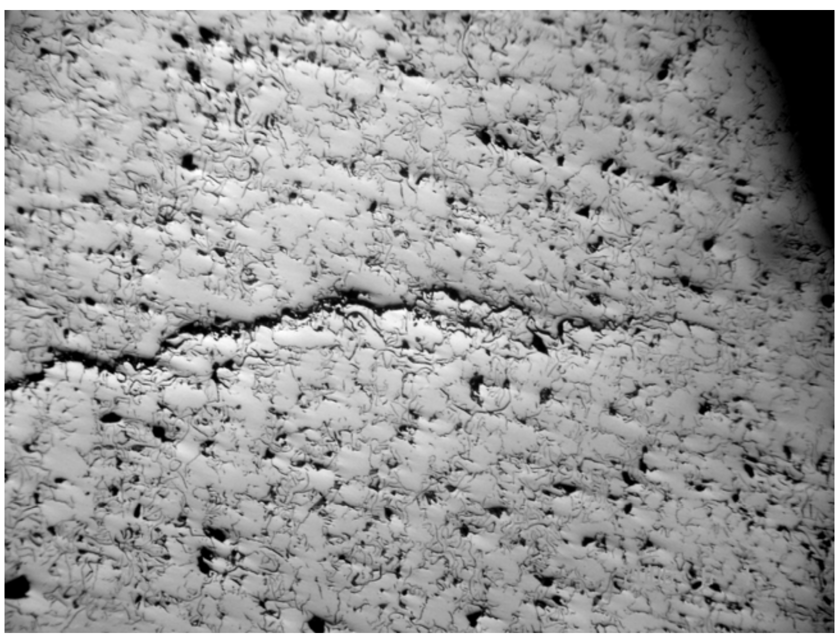

Figure 25: Crack propagation profile in liner 277 100X Magnification

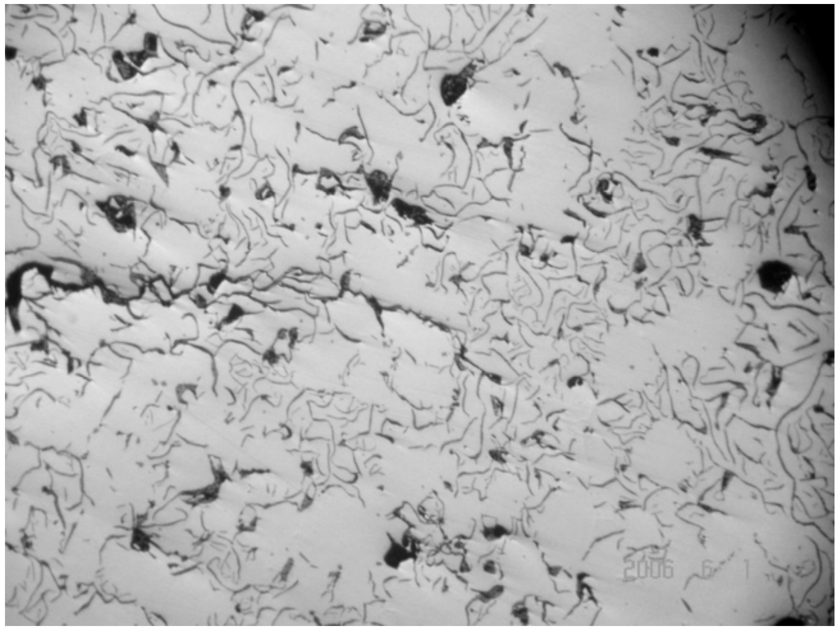

Figure 26: The crack propagation in liner 277 along the graphite flakes. 150X Magnification

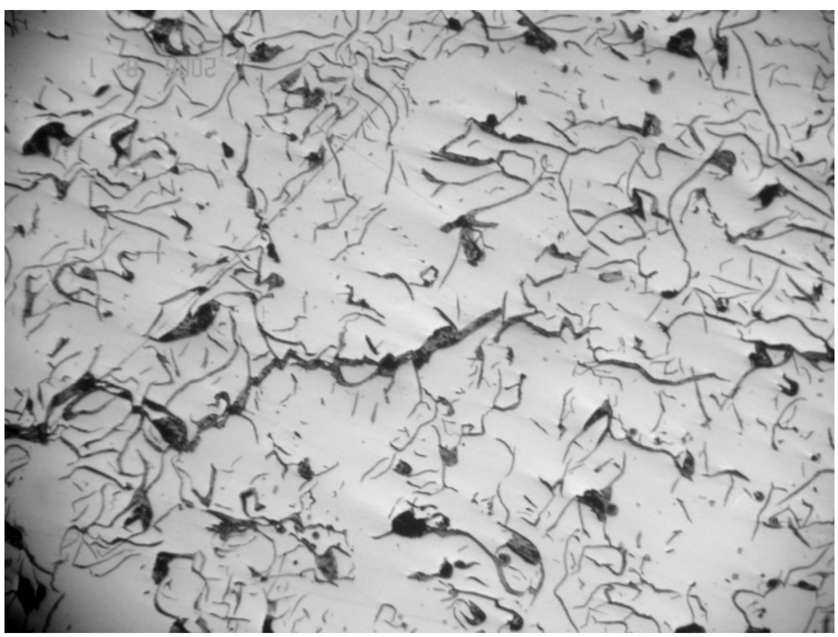

Figure 27: The crack propagation in liner 277 along the graphite flakes. 200X   Magnification

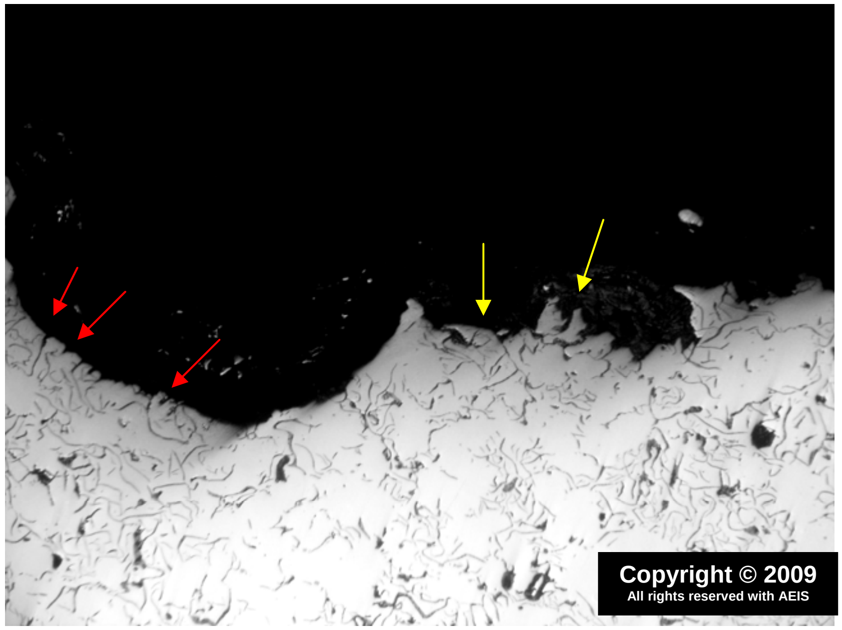

Figure 28: Stress points and attrition at the bottom of the cavitation pit. 100X Magnification

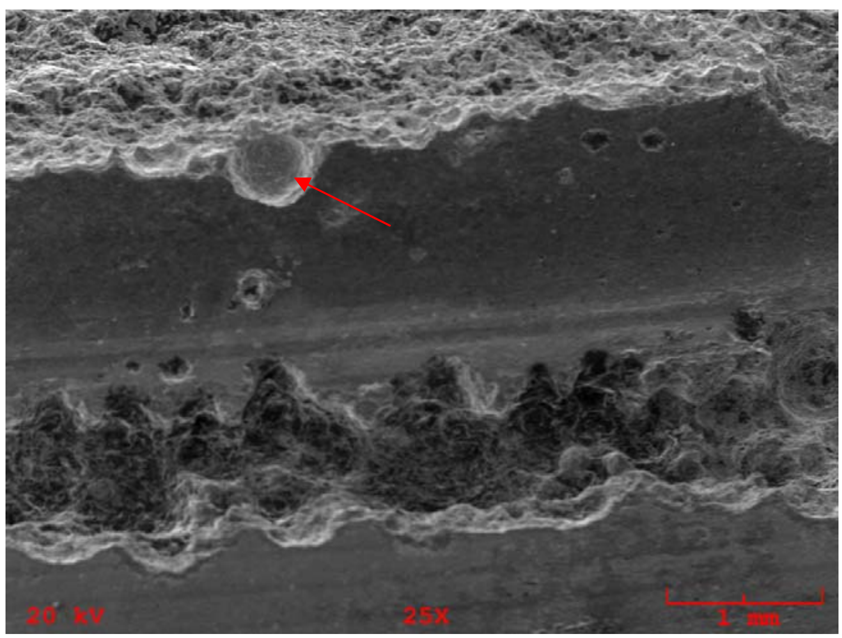

Figure 29: SEM photograph of fracture surface showing a pit profile

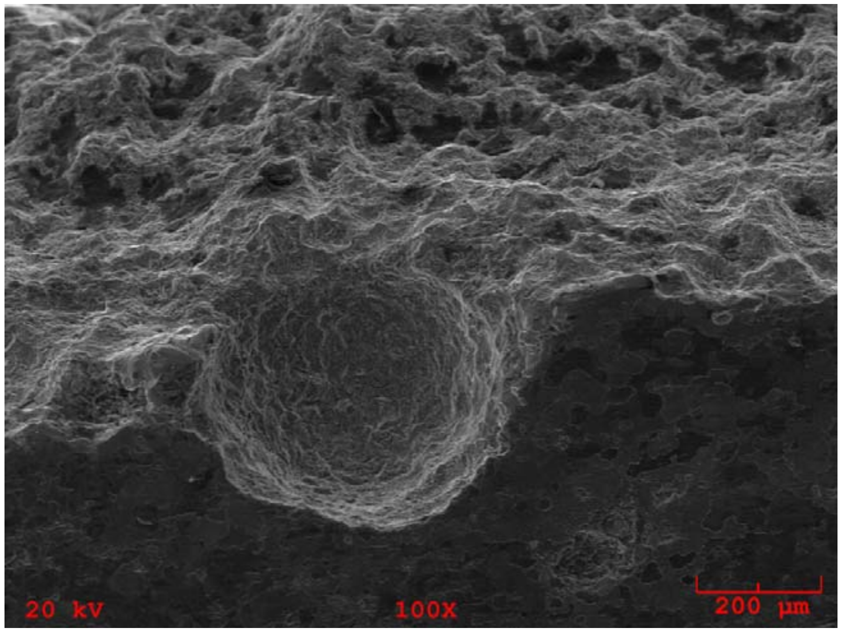

Figure 30: SEM photograph of close up of the pit

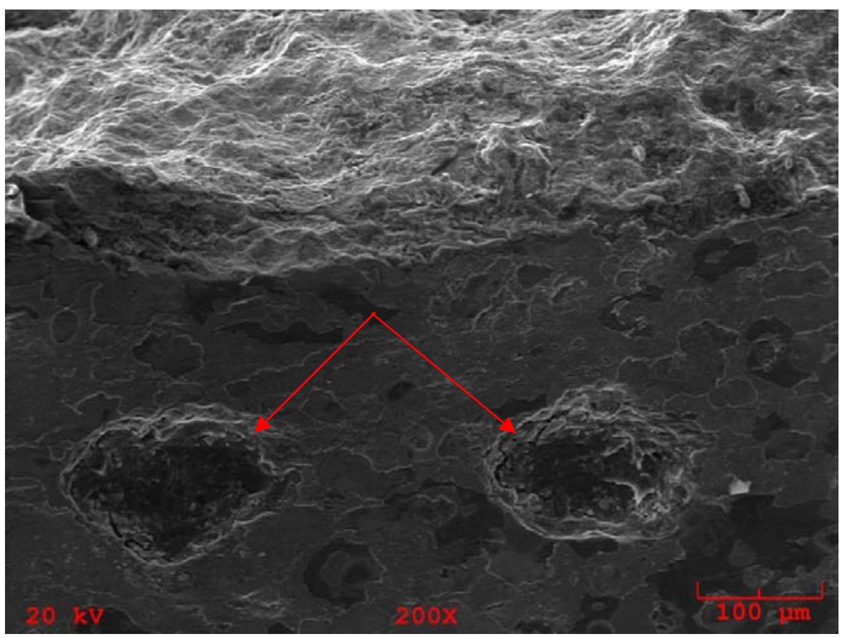

Figure 31: SEM photgraph of pits on the fracture surface

Discussion

As can be observed from the test results on the submitted cylinder liners are of two different varieties, chemical composition wise, hardness wise and microscopic structure wise. Liners 277 and 1076 form one group and 1016 and the new liner form the other group. Since technical specification are not known beyond the broad information that all the cylinder liners are supposed to be of alloyed grey cast iron in a heat treated condition, it is not possible to classify any one as substandard or otherwise. Performance wise cylinder liner 1076 has the least cavitation, even after 189,000 miles. At the same time liner 277 which has similar characteristics has appreciable cavitation. In the other group 1016 has additional molybdenum and nickel, would enhance strength with lesser residual stresses. However the principal elements that would promote corrosion resistance are chromium, silicon and copper. All the three elements are comparatively lesser in 1016 than the other group. Even if excessive cavitation in 1016 is excused for that, there is no plausible material reason why 277 would perform inferior to 1076. It is therefore logical to conclude that the main reason for excessive cavitation is aggressive environment rather than the material or its heat treatment condition. The quality of coolant and its circulation could be play a major role in observed cavitation.

Cavitation is caused by collapse of cavitation bubbles resulting in implosions damage to the passivating film on the metallic surface. Literature suggests that the pressures in excess of 10 KSI and temperatures more than 9000 degrees F are produced locally. Unless the passivation film is recreated immediately corrosion will take over. Supplemental additives in the coolants (SCA) provide a continuous protective coating on the metallic surface. Presence of cavitation suggests that coolant either inherently did not have adequate protective additives or required concentrations were not maintained. Lack of free flow in the circulation system could also shield some areas from protection.

It may be observed that the crack in liner is circumferential in morphology and does not cover the entire circumference. Such a crack can result from an axial force that is not uniformly distributed on the entire periphery or a weakness in material at the crack initiation point. Had an inherent weakness in the cylinder liner been of sufficient magnitude the liner would have failed before the recorded 156,829 miles. The force exerted by the firing stroke however could exert an unbalanced and increased pressure around the periphery because of randomly reduced cross section and the stress concentration occurring because of very small size of pits. The crack initiation was from such a grooved area. It is noteworthy that graphite flakes in cast iron are in fact tiny lamination in themselves and are a cause of stress concentration. Should an excessive force be exerted across its plane, it can open up along its surface. Microstructure shows the propagation of crack along such planes. Visual observations and macroscopic examination showed that cavitation was present on a well spread area on the upper half of the cylinder liner 277, including area on the under side of the flange. It had cut a groove into the lower corner of the flange. This suggests that the coolant had access to these surfaces including the surfaces governing the critical dimensions. This could misalign / cause a play in the liner. Such a condition could raise the stress to a damaging level.

Conclusion

From the above observations and discussion following conclusions can be reached.

Cylinder liners 277 and 1076 have a different material and heat treatment from the new and cylinder liner 1016

All the used liners suffered from cavitation damage. In our opinion the metallurgy of the liners did not have any significant bearing on the extent of damage. In absence of that, the cooling environment was the major single factor for causing pitting. It is also our opinion that cavitation under the flange was primarily responsible for cracking of cylinder liner 722.