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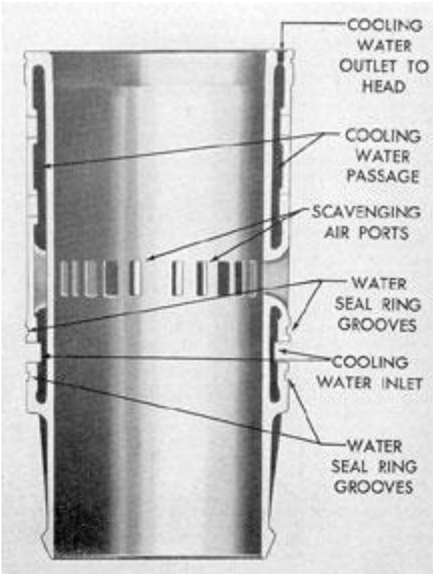
Failure Analysis Case Study

Failure Analysis of Diesel Engine Cylinder Liners due to Cavitation Damage



Key words: Engine cylinder liner, Pitting, Crack, Cavitation damage

Material: harden alloy cast iron

Introduction

Three used cylinder liners identified by numbers 277, 1016 and 1076 and an unused liner were submitted for failure analysis. This three liners were found pitted outside after service of 156,829/23,273/189,000 mileages. By the manufacturer 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. Visual examination, Non-destructive test, chemical, mechanical and metallographic analyses was performed on the submitted liners to look for root cause of the failure.

Visual examination

Cylinder Number 277 in Fig 1&2 showed pitting and erosion on the outside surface. 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. Some scoring was observed in a band approximately 1/8 inch at the upper edge of the crack.

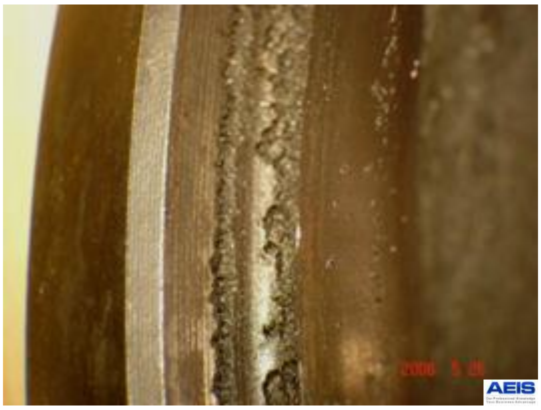


Figure 1: Cavitations immediately under the flange

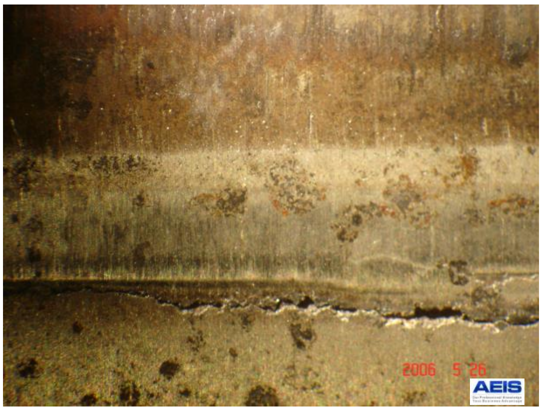


Figure 2: The crack and the scored band on the inside surface

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. Cylinder liner Number 1076 in Fig 3 was found to be generally free of cavities, 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.

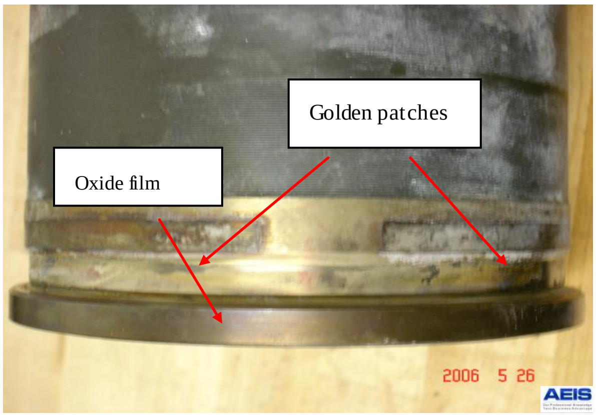


Figure 3: Close up of cooling channel area of cylinder liner 1076

Non-destructive Test

The inside surface of the liners was cleaned and examined by Liquid Penetrant Test technique. No crack was observed in cylinder Liners 1016 and 1076. The crack in the liner 277 covered approximately 50 percent circumference, showed in Fig 4.

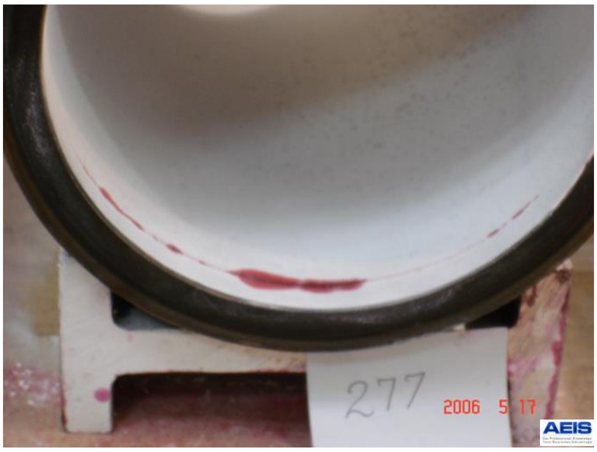


Figure 4: Crack in Cylinder liner 277

Chemical Analysis

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

Element Percent / Liner number	New	277	1016	1076
Carbon	3.05	3.57	3.09	3.5
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	1.3	0.11
Molybdenum	1.14	0.05	1.66	0.04
Copper	0.23	0.64	0.21	0.61

Mechanical Test

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

Liner Number	Location	Value (HB)	Average
1016	Top	293	
	Middle	302	
	Bottom	293	296
1076	Top	402	
	Middle	402	
	Bottom	387	397

Microscopic examination

Specimens were prepared from the cross section of each cylinder liner for optic microscopy and SEM. 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.

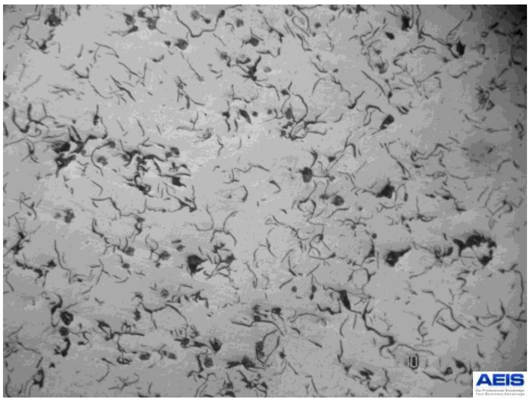


Figure 5: New Liner microstructure in the middle of the fire length in as polished condition. Magnification 100X

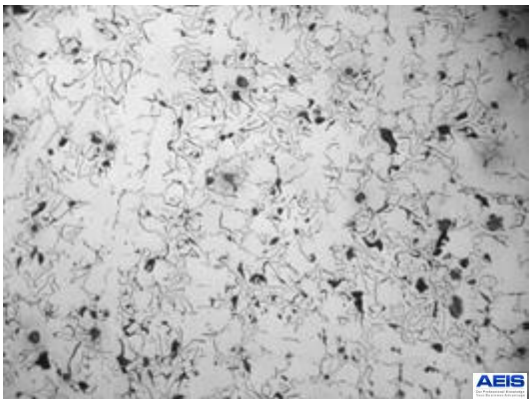


Figure 6: Liner 277 microstructure in the middle of the fire zone in as polished condition. 100X Magnification

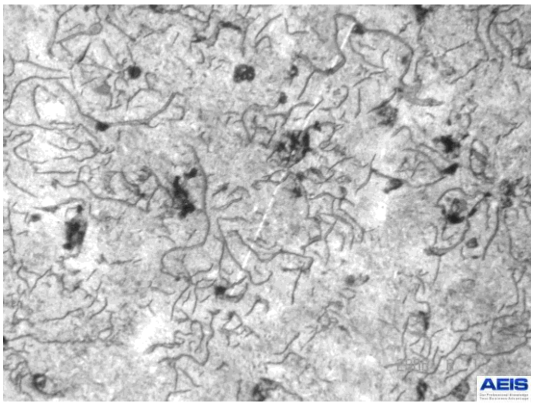


Figure 7: Microscopic structure of matrix the liner 1076. 250X Magnification

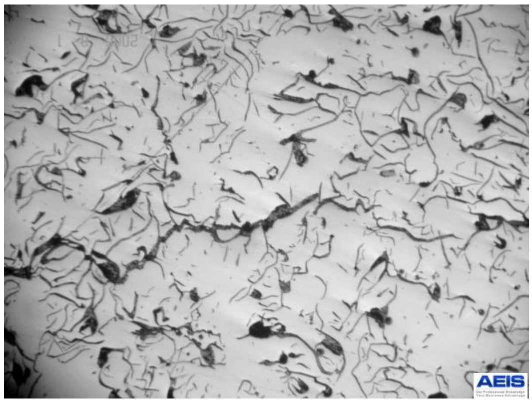


Figure 8: The crack propagation in liner 277 along the graphite flakes 200X Magnification

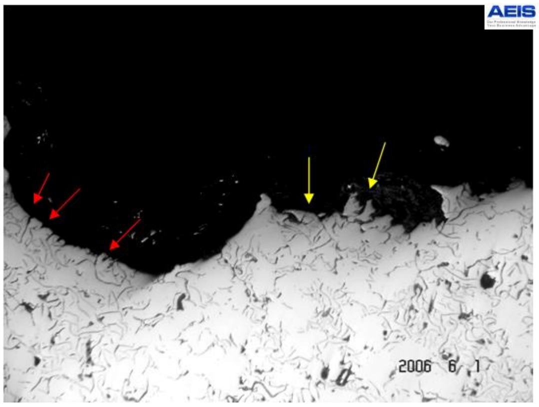


Figure 9: Stress points and attrition at the bottom of the cavitation pit 100xMagnification

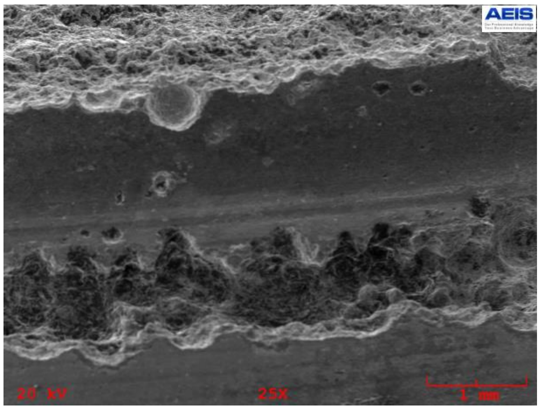


Figure 10: SEM photograph of fracture surface showing a pit profile

Microstructure showed 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. The crack propagation in Liner 277 was along the graphite flakes and stress concentration points at the bottom of the pits.

Discussion

From chemical composition wise, hardness wise and microscopic structure, Liners 277 and 1076 form one group and 1016 and the new liner form 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. The quality of coolant and its circulation could be play a major role in observed cavitation.

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.

Crack on cylinder 227 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. The force exerted by the firing stroke however could exert an unbalanced and increased pressure around the periphery and the stress concentration occurring. The crack initiation was from such a grooved area. Microstructure shows the propagation of crack along graphite flakes in cast iron which are in fact tiny lamination in themselves and are a cause of stress concentration.

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.