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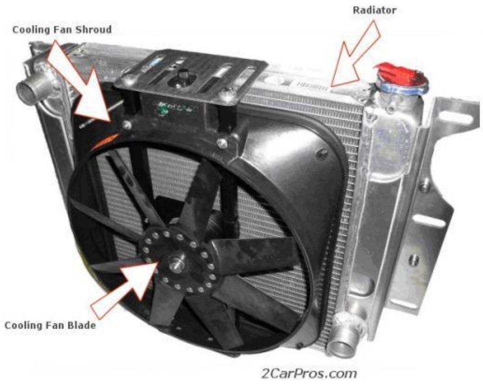
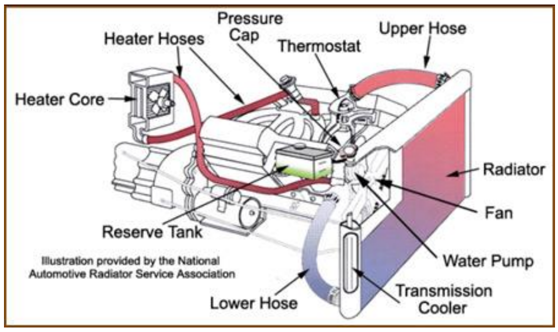
Failure Analysis of A Bus Radiator Core due to Deficient Soldering and Fatigue





Key Words: Radiator, Leakage, Soldering, Fatigue

Material: Brass

Introduction

Two radiator cores were submitted for failure analysis. The cores had been taken out from diesel engines which reported a leakage at the radiator head gasket and leaking again 6 to 8 months after replacement of an updated gasket by manufacturer. The manufacturer conducted second gasket replacement campaign and indicated that they re-soldered the tube-header joints on all the radiator cores that were retrofitted. However leakage was reported at the tube-header joint after several months service. Meanwhile, near 50% radiator from this fleet reported the same situation. In this case, visual examination, non-deductive test, chemical analysis, mechanical test and metallographic examination were performed on the submitted radiator cores to look for the root cause of failures.

Visual Examination

One of the Radiator cores was marked as 'leaking', and one is not. In figure 1-4, examination of the radiator cores shows cracks various sizes were observed at the baffle joints, solder around tubes on both cores. The "leaking' core showed a higher concentration of cracks at the periphery tubes on one of the plates.

Figure 1: Cracked baffles

Figure 2: Crack along the edge of the cover plate of leaking radiator

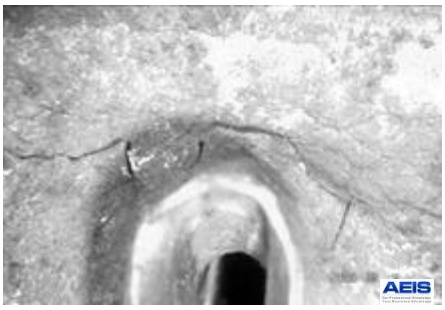


Figure 3: Cracks in the solder at header plate surface in leaking radiator

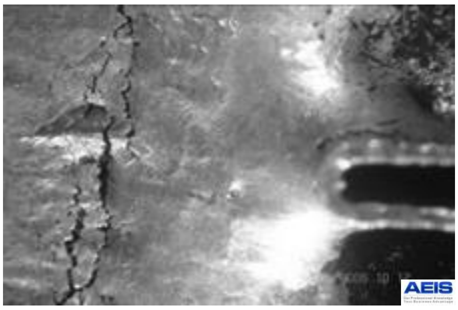


Figure 4: Cracks in the solder at header plate surface in the leaking radiator

Several suspect specimens were cut for examination of the cross section to determine the leak path. Figure 5 shows the void between the cover plate and the header plate with a continuation crack to the outside of the core. Figure 6 is collage of photographs that illustrate such an area that forms a void which eventually may form the leak path.

Figure 5: The void between the cover plate and the header plate

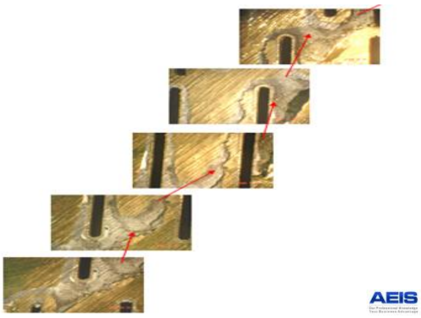


Figure 6: A collage of macroscopic photographs showing formation of a potential leak path

Non-Deductive Test

Dye Penetrate Testing of suspect area confirmed the presence of cracks, Figure 7.

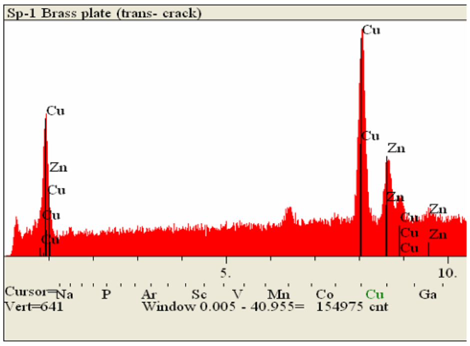
Figure7: Cracks in the header plate to tube joint of leaking radiator

Mechanical Test

The two submitted cores were hydrostatically tested at 30 psig. The core marked "leaking" started sweating at the soldered joints near the top plate after approximately 20 psig. The exact location of the leak could not be pinpointed. The other core withstood a pressure of 30 psig without showing signs of leakage even after holding this pressure for three hours.

Chemical Analysis

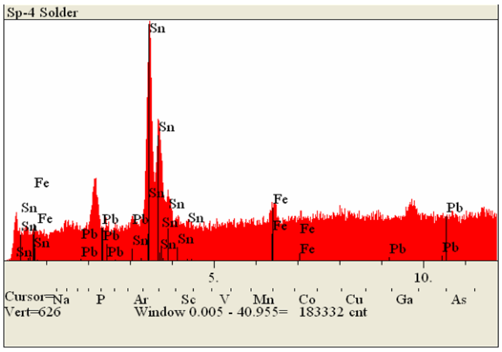
Energy dispersive x-ray spectroscopy (EDS) performed on the two plate cross sections showed that the plates are 70/30 Brass Figures 8. The solder, rich in Tin, showed a variation in chemical composition at spots. Some spectra are shown in Figures 9.



Elt.	Line	Conc	Units	
Cu	Ka	70.769	wt.%	
Zn	Ka	29.231	wt.%	
		100.000	wt.%	Total

kV 20.0
Elapsed Livetime 100.0

Figure 8: Chemical analysis of radiator core plate



Elt.	Line	Conc	Units	
Fe	Ka	5.470	wt.%	
Sn	La	70.562	wt.%	
Pb	La	23.968	wt.%	
		100.000	wt.%	Total

kV 20.0
Elapsed Livetime 100.0

Figure 9: Chemical analysis of cracked solder

Microscopic Examination

A typical crack in the solder was forced open to study the fracture surface under Scanning

Electron Microscopy(SEM). The fracture face showed inter-granular nature of cracks. Fatigue striations were observed in regions that were comparatively flatter, Figure 10， 11

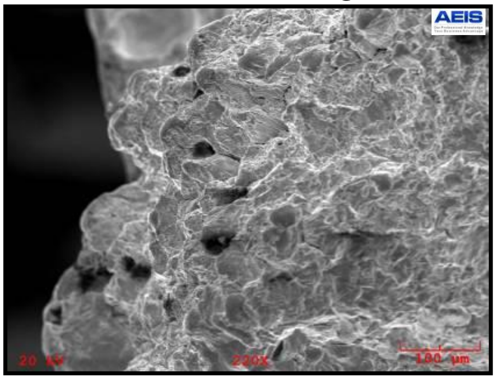


Figure 10: Crack that was forced opened at 220X Magnification

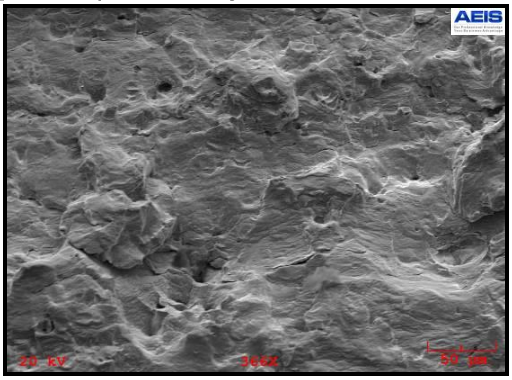


Figure 11: Fracture face of solder showing fatigue striations at 366 X Magnification

Similar cracks were observed on both the radiator header plates.

Discussion

From the above observations it is clear that the leakage had taken place through the cracks and voids in the solder. It is also clear that the soldering did not join the metal surfaces and voids were present. The solder composition is far from homogenous where significant percentage of lead was detected. There is a possibility that more than one solder composition was used to fabricate the radiator assembly. Some diffusion from adjacent species can take place. Overall, the filler material is unlikely to have uniform solidifying characteristics, such as the pasty temperature range, wetting properties and spread.

If the cores were hydro-tested satisfactorily after manufacture it would be evident that there was no leak to start with. All the same the weaknesses, such as observed during the investigation, provided sufficient sensitive spots (stress raisers) where the combined action of residual stresses, hydraulic, thermal and cyclic stresses produced by vibrations in service were sufficient for generation and propagation of fatigue cracks observed in figure 10. The effect was most severe at the corner and the edges of the cover plate due to the geometry of the base components.

Similar cracks were observed on the header plate solder of the second radiator core too though no leaks were observed during the hydrostatic test. No further investigation on this core was considered necessary.

Conclusion

From the above observations and discussion it is concluded that the radiator core leakage took place through the solder layers above the cover plate. The cracks originated from deficiencies in the solder and propagated under cyclic service stresses till a definite leak path was established.