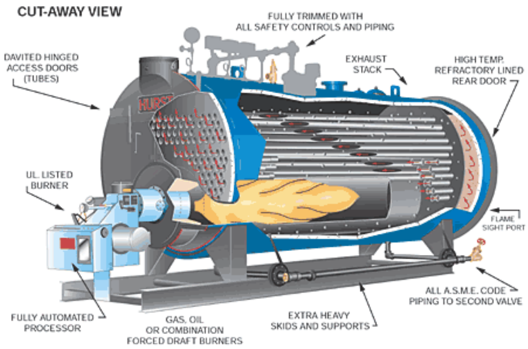
Failure Analysis of a Boiler due to Thermal Stresses



Key Words: Boiler, Leakage, Thermal stress

Material: Gray cast iron

Introduction

An eleven section Boiler was found to be leaking after two years of service. Two out of 11 sections from the failed boiler were submitted for determining the cause of failure. The sections were delivered in pieces to the laboratory for failure analysis. The common environmentally cause of boiling tube failures includes overheating, corrosion, erosion, mechanical fatigue and caustic attack. By taking possible environmental causes into consideration, visual examination, chemical, mechanical and metallographic analyses was performed on the submitted boiler sections to look for root cause of the failure.

Visual examination

In figure 1. Examination of the fractured edges of the pieces showed that there was only one piece, arrow, in Figure 1, that had cracked during service. This section will be referred to as Section A and the other section as Section B in failure analysis.

The inside surface (waterside) as noted through the broken ends, had deposits up to a thickness of about 1/8 inch as shown in Figure 2. No evidence found to indicate corrosion pitting or appreciable thinning.

The fracture surface was brittle, typical of grey cast iron. Close examination of the nine inch delivery port elastomer sealing rings showed that these rings had failed on both the sections during service.

Figure 1: Assembly of broken segments of the Boiler Sections

Figure 2: Deposits on the inside surface (waterside) of the fractured segment

Chemical anlysis

A chemical analysis conducted on the two boiler sections yielded the following composition

Table 1 Chemical composition of Section A and Section B

	Section A	Section B	Typical Grey Cast Iron
Carbon	2.97	3.03	2.5 / 4.0
Manganese	0.6	0.57	0.2 / 1.0
Phosphorus	0.068	0.068	0.002 / 1.0
Sulphur	0.05	0.068	0.02 / 0.025
Silicon	2.16	2.28	1.0 / 3.0

The chemical analysis confirms that the material of the sections is cast iron as specified by manufacturer. Carbon% and Sulfur% conformed to the requirement of chemical composition of ASTM A278 for Gray Iron Castings for Pressure-Containing Parts for Temperatures Up to 350° C.

Mechanical Test

Tensile test specimens were taken from a non heat transfer location near the nine inch delivery port on each of the two boiler sections.

Table 2 Mechanical test result of Section A and Section B

	Section A	Section B
Tensile strength	8,600 psi	10, 500 psi
Hardness tests （Brinnel scale load of 3000 Kgs）	BHN 126/126	BHN 143/143

A tensile strength of about 20,000 psi would be typically expected with the chemical compositions by ASTM A 278. The results obtained on test specimens removed from the farthest end (non heat transfer area) were practically half the value. Hardness values at the two locations were found similar that the both the locations have been softened to similar levels.

Microscopic Examination

Cross-section of fracture edge and non heat transfer location of Section A were metallographically prepared for examination. Figures 3 showed corrosion attack in general and around the graphite flakes on the water side up to depth about 0.020 inch.

The bulk of the microstructure at the core was graphite flakes in a matrix of pearlite with some ferrite as shown in Figure 4. Transformation products of pearlite to ferrite at various stages could be seen between the surface scale and the core structure. No martensite was observed at all.

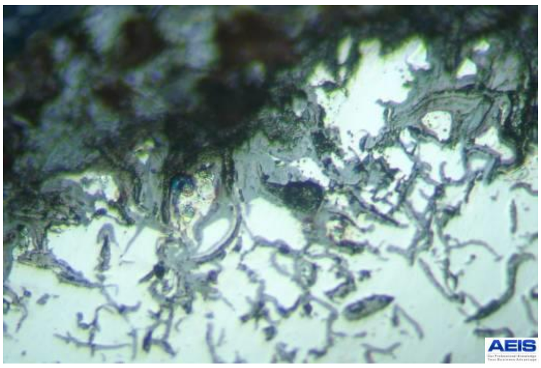


Figure 3 Corrosive Attack on Water Side Surface 375X Magnification

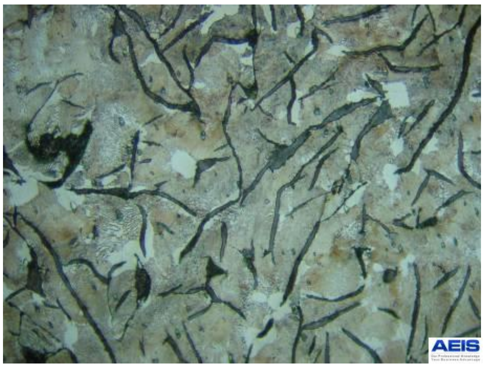


Figure 4 Section Core Microstructure 375X Magnification

Discussion

The failed segment of Section A, marked with an arrow in Figure 1, had cracked at both the edges. Both the cracks are in the parallel indicates that the stresses and localized material defects responsible for the cracking. The flame path runs along the surface of the crown in a plane normal to the cracks suggesting that the stresses could be the result of the differential temperatre between the crown area and the restraining baffles at the back on the water side, showed in figure 5.

Figure 5 Restraining Baffles Behind Crown

Loss of strength is also a cumulative effect of heat cycles that the metal has gone through. It is evident that the boiler sections have seen temperatures high enough to have softened the metal.

Conclusions

The Composition of the cast iron sections are as specified by the manufacturer. The material composition conforms to the requirement of ASTM A 278 for Gray Iron Castings for Pressure Containing Parts for temperatures up to 350 C. The tensile strength at the time of failure was poor. Stresses generated by overheating crossed the threshold limit to cause the failure. Protective devices were unable to prevent such an overheating.