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Failure Analysis of Boiler Tubes

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Boiler pipes have important uses in steam and power generating plants. These pipes work with long life in hot thermal conditions. Damages that may occur in pipes cause serious losses such as cost loss and plant downtime. In this study, microstructure analysis was done for possible damages in boiler pipes operating under hot conditions.

Keywords: Boiler Tubes, Microstructure, Failure Analysis, High Temperature, Degenerated Pearlite

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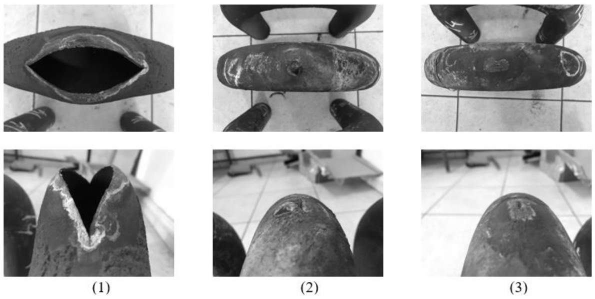
1. Introduction

Inspection of some damaged steel pipes which were worked under hot conditions. Chemical analysis, microstructure and scanning electron microscopy investigation of these steel materials were carried out to see the mechanism of damage. The boiler pipe samples selected for examination as having SA-213 standard. ***Table 1*** lists the chemical composition ranges of this standard. These materials, which serve as superheater pipes, have a working life of 200 thousand hours and are suitable for operating temperatures of 550 °C.

Table 1. Chemical Analysis

Quality	C	Mn	Si	S	P	Cr	Mo
SA-213 T2 Standart	0,10-0,20	0,30-0,61	0,10-0,30	0,025	0,025	0,50-0,81	0,44-0,65

Damaged boiler pipes are classified as different regions and according to degree of damage. In the following pictures, you can see the sample boiler pipe which has worked and damaged at different points. (***Picture 1)***



Picture 1 *– Macro photos of damaged pipe regions (1) pipe that has been exposed to prolonged overheating and then torn as a result of severe overheating, (2) and (3) thermal oxidation and beginning to tear*

In sample 1, the type of cleavage, defined as "fish mouth", was observed in the convex portion of the damaged pipes, approximately 200 mm long in the longitudinal direction. Spots like yellow-white color were observed in the rupture region from edge to the ends. A significant decrease in wall thickness was noted on the torn surfaces.

In sample 2, there was an swelling in the bending region of the pipe and a crack of approximately 20 mm in length in the longitudinal direction. In addition, there are white-yellow spots from the crack to the outside.

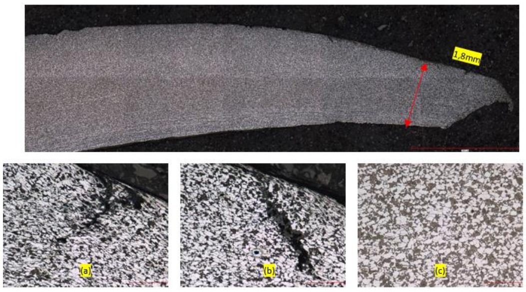
In the sample 3, swelling and cracking were also determined in the twist zone.

2. Micro and SEM / EDS Investigation:

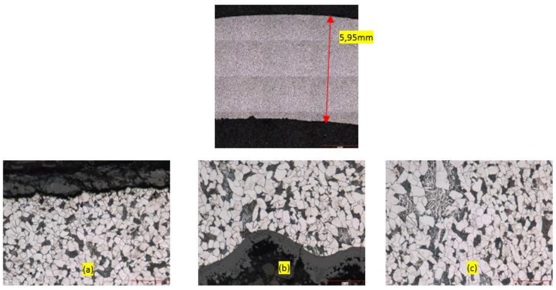
Pipe Sample Number 1

In the area close to the rupture point, crevations forming determined from the outer surface to inner. It was found that the wall thickness decreased to 1,8 mm near the tearing surface. ***(Picture 2).***

Iron oxide compounds in the cracks were determined by SEM EDS analysis. Intergranular gap formation was also noted. In the region of the opposite wall of the damaged surface, the cavities in the inner wall and the formation of the scaling layer caused by thermal oxidation covering them were observed. The wall thickness measured 5,95 mm. ***(Picture 3)***



Picture 2* - *Microstructure photos of tearing area (a) and (b) crack formation and deformed grain orientation on the surface, (c) microstructure of the defect free zone.

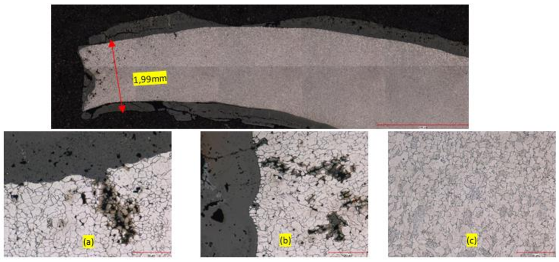


Picture 3 - *Cross-sectional view of the opposite region of the tear (a) and (b) oxide layers on the inner and outer surface of the pipe section. (c) Matrix ferrite, perlite microstructure and degenarated perlite*

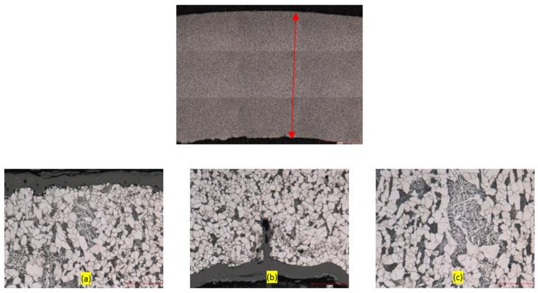
Pipe Sample Number 2

In the sample, the wall thickness was decreased to 1,99 mm in the area close to the crack. (Picture 4). İncreasing of intergranular gap formation was observed in the regions close to the rupture point. There is supportive literature data that cavities can occur as a result of uneven sliding of grains in the structure under high temperature and stress conditions, also known as creep.

In the SEM examination of the sample taken from the opposite wall of the cleaved region, a pit with a depth of approximately 90 µm was observed and scale layer was observed. ***(Picture 5)***
Information of scaling with the thermal oxidation available in the literature.



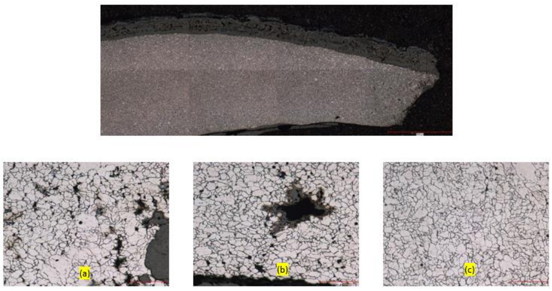
Picture 4* - *Microstructure photos of tearing area (a) and (b) intergranular corrosion starting from the outer surface in the pipe section. (c) Ferrite and carbide structures of the area



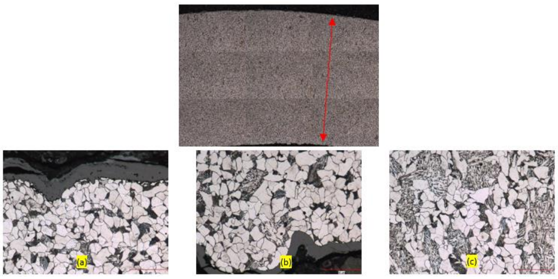
Picture 5* - *Cross-sectional views of the opposite region of the tear (a) ferrite, perlite and degenerated perlite structures of the outer pipe surface; (b) Thermal oxidation and pitting corrosion on the inner surface of the pipe.

Pipe Sample Number 3

In the examination of the damaged surface section, ferritic grain structure was observed and scaling was observed in the inner and outer walls and in the intergranular spaces ***(Picture 6).*** In the section taken from the opposite wall, the ferritic-perlitic structure was seen. The pit formation and scales were identified on the outer and inner surface ***(Picture 7).***



Picture 6 *– Microstructure of the teared surface (a) and (b) Intergranular corrosion and intergranular space formation in the pipe section. (c) Ferrite and carbide structures*



Picture 7 - *Cross-sectional images of the opposite region of the tear*
(a) Thermal oxidation, ferrite, perlite and degenerated perlite structures of pipe outer surface (b) thermal oxidation at the inner surface of the pipe. (c) Ferrite, perlite microstructure and degenerated perlite

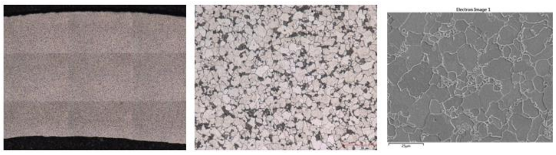
4. Results and discussion

Fish mouth openings can occur when the pipes work over the safe temperature range. Pipe swelling characterized by excessive scale formation in the inner wall and typical signs of oxidation and corrosion. In the microstructure, findings such as cavity formation, grain boundary separation and intergranular cracks obtained.

According to microscope-based examination and analysis recommendations are listed below;

- The inside of the pipe has a ferritic and pearlitic microstructure, while the outer surface transformed into a ferritic structure beacuse of the high thermal working conditions.
- Decomposition of the perlite phase formation thought to occur by the effect of temperature and thermal stress.
- The fact that the damages are not the same in the 3 samples shows that the positions can affect the level of damage severity.
- It is thought that the stopping and starting frequency of the facilities may also be effective in the occurrence of damage.

The unused pipe sample did not show any structural signs that could lead to damage. ***(Picture 8)***



Picture 8 – *Section view, SEM image*
General microstructure appearance, ferrite and perlite structures

References

[1] ASM Handbook Vol.11 "Failure Analysis and Prevention"; "Creep and Stress Rupture Failures"; s.1538

[2] The Nalco Guide to Boiler Failure Analysis; "Long Term Overheating"; s.32

[3] ASM Handbook Vol.11 "Failure Analysis and Prevention"; "Failures of Boilers and Related Equipment"; David N. French

[4] ASME BVPC IIA-2017, s.289

[5] ailure Investigation of Boiler Tubes;"Materials for Boiler Tubes"; Paresh HARIBHAKTI et.al.;s.101

[6] The Nalco Guide to Boiler Failure Analysis; "Long Term Overheating"; s.33