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Initial Evaluation of Microstructure and Mechanical Properties of SA213 T22 Superheater Tube in a Bituminous Coal-Fired Power Plant

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ABSTRACT

A comprehensive understanding of microstructural and mechanical property changes is essential for assessing superheater tube conditions. This article presents the initial monitoring of microstructural and mechanical property change of SA213 T22 utilized in a coal-fired boiler. The monitoring involves visual examination, chemical composition test, micrographic investigation, tensile and hardness test. Results show that exposure to the elevated temperature and ash deposition promotes oxidizing environment, subsequently leading to thermal oxidation and decarburization.The combination of both degradation results in the decreased strength and harness as well as the increased elongation in the SA213 T22 steel tube exposed to the superheat condition for three years. Regular inspections are recommended to ensure the availability of the tubes. Additionally, metallurgical replica testing is advised for the microstructural evaluation of the superheater tube.

Keywords: SA-213 Grade T22; Superheater tube; Microstructure; Mechanical Properties

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Introduction

In bituminous coal-fired power plants, boilers function as an essential pressure vessel, producing steam for steam turbine to generate electricity. Before being transferred to the steam turbine, the steam is heated in superheater tubes at an elevated temperature to turn steam into superheated steam whose temperature can be in a range of 400-500 °C with the working pressure of 10 to 100 bar [1]. This working condition is considered as one of extreme environments where combination of high temperature, operating stress and operating time can damage superheat tube [2]. Hence, the materials of the superheater tubes have toendure such severe working conditions without the significant change in microstructural and mechanical properties for the required operating period.

SA 213 T22 is a low alloy steel containing chromium (Cr) and molybdenum (Mo) [3]. It is known that the addition of Cr increases oxidation resistance and Mo addition also improves creep resistance [4]. Thus, this steel is a commonly used material for superheater tubes. Its performance is better than the ordinary carbon steel, particularly high temperature oxidation and creep resistance. However, after being exposed to the severe working environment in the superheat zone for a prolonged operating period, this steel can undergo microstructural degradation and loss in their properties, potentially leading to the premature failure of tubes [3-4]. Microstructural degradation, i.e. spheroidization and graphitization, and high temperature oxidation are often responsible for the failure of tubes, as reported by a number of articles. Ghosh et al [5] reported that graphitization occurred in the superheater tube. Simultaneously, oxidation took place at the exterior of the tube. Both degenerations certainly shorten the tube's life span. Peeratatsuwan [6] investigated the steel used in the boiler and found the onset of the spheroidization in the ferrite matrix of the boiler steel tube, resulting in the considerable decrease of the mechanical properties of the tube. Dehnavi et al [7] report the microstructural change due to overheating resulted in the premature failure of the superheater tube. Obviously, the consequence of the microstructural degradation in the superheater tube is enormous. To prevent the failure, the annual inspection to investigate the boiler tube condition is normally conducted. Visual inspection and thickness evaluation are often performed to examine the aged tubes. Such evaluations can provide quick suggestions for maintenance works. Nevertheless, the degradation in the microstructures and mechanical properties can continuously occur. Thus, the monitoring of such degradation is obviously important for maintaining the reliability of the boiler, particularly during the initial stage of operation.

This study investigated the initial degradation of an SA 213 T22 superheater tube after 26,280 hours (3 years) of operation under working conditions in a bituminous coal-fired power boiler. The microstructural and mechanical properties of the aged tube were analyzed in comparison to those of a new tube to gain a better understanding of microstructural and mechanical alterations occurring in the early stages of thermal degradation. Besides, the mechanisms of the initial degradation of the aged SA 213 T22 tube were examined.

Materials and methods

The material used in this study is SA-213 T22 superheat tube used in the bituminous coal-fired power boiler for 3 year. The diameter of this aged tube was 38 mm with a thickness of 5 mm. The interesting parameters of this tube are given in Table 1

Table 1 Significant parameters of the initially aged tube

Parameters	Range of values
Outside diameter and thickness	38 mm and 5 mm
Operating pressure	58.8barg
External temperature	700-800 °C
Internal temperature	450-550 °C

To monitor the microstructural degeneration of the used steel boiler tube, visual examination, chemical analysis, micrographic investigation using optical microscopy, scanning electron microscope equipped with energy dispersive x-ray spectrometer (SEM-EDS) were employed. Tensile test and hardness test were also conducted to measure the mechanical property alternation. The new steel tube was observed as a reference material in this monitoring. The exterior of the tube was visually checked, and chemical analysis was then conducted using spectrometer (model ARL-3460) by specifying to ASME SA213 T22 [8]. Samples for microstructural monitoring were produced at the interior, the mid-wall, and the exterior of both tubes. Hardness and tensile test was conducted to evaluate the alternation of mechanical properties. The hardness measurement was on the basis of NACE TM 0498-98 [9]. The hardness test was performed using a 0.5 kg load with 15 seconds dwell time at both cross-section area and the exterior of the tubes with three points per quadrant at 0°, 90°, 180° and 270°, as exhibited in Fig.1(a). The tensile test was performed based upon the standard JIS Z2241 [10]. The positions where tensile test samples were produced are at 0°, 90°, 180° and 270° in the circumference of the cross-sectional area of the tube as illustrated in Fig.1(b).

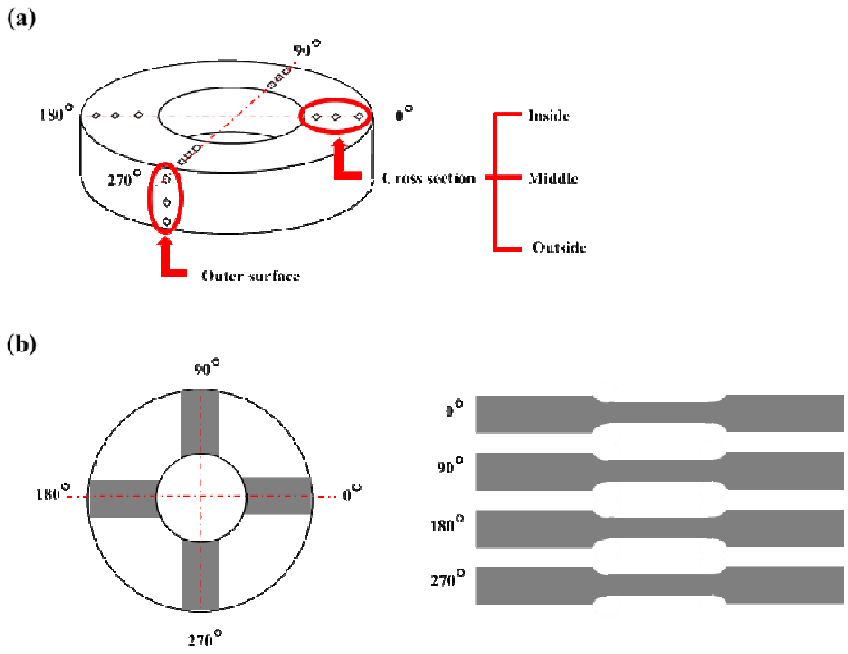

Figure 1 (a) Positions of the hardness measurement; (b) Locations of the tensile specimen production.

Results

Visual examination and chemical composition study

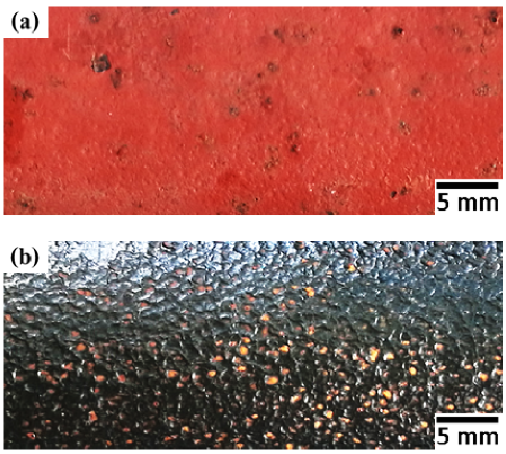

Figure 2 Exterior surface (a) unused tube; (b) used tube.

Visual inspection was performed to observe if the dimension of diameter or cracks would occur in the used steel tube. It was found that the diameter dimension showed no diameter dimension changes and no cracks taking place on the interior of the tube. The exterior conditions were then visually inspected and subsequently considered with that of the unused tube. It is clear that the exterior of the unused tube was smoother as compared to that of the used tube. Normally, during the operating period, the superheat tube experienced an elevated temperature atmosphere in the superheat zone of the boiler, which would be up to 500 °C. In addition, the burning of the bituminous coal can generate fly ash, which potentially results in ash deposition [3-4]. Both can cause the oxidizing environment, leading to the formation of oxide layer on the exterior of the used tube [5-6]. Nevertheless, this oxide layer was loose and discontinuous, leading to the disintegration into flakes and scales [4-5]. Thus, the rough surface of the outer can be attributed to the scale disintegration of the oxide formed in this severe environment [5-6]. The chemical composition of both tubes was analyzed and shown in Table 2. Besides, the chemical composition of SA213 T22 in the standard values is also given.

From Table 2, the chemical composition of both tubes is agreeable to that of the standard composition range of SA213 T22. However, the significant reduction in carbon content in the used tube in comparison to that in the new tube is obvious. The reduction in carbon content may imply the degradation of the microstructure and properties of the used steel tube after initial exposure to the superheat atmosphere of the coal fired vessel.

Table 2 Chemical compositions examined by spectrometer and standard values

Tube	Element (wt.%)						
	C	Mn	P	S	Si	Cr	Mo
Unused tube	0.147	0.523	0.011	0.009	0.231	2.033	0.984
Used tube	0.090	0.379	0.016	0.011	0.188	1.941	0.996
Standard	0.05-0.15	0.03-0.60	0.025	0.025	0.5 (Max)	1.90-2.60	0.87-1.13

Microstructure examination

Samples of the used and unused steel tubes were prepared for microstructure examination. Fig.3 shows the micrograph of both tubes. It is obvious that both tubes consist of ferrite (white area) and nodular pearlitic (dark area), as indicated by arrows in

Fig.3. Besides, no microstructural changes in shapes or sizes of pearlite were observed from the used tube.

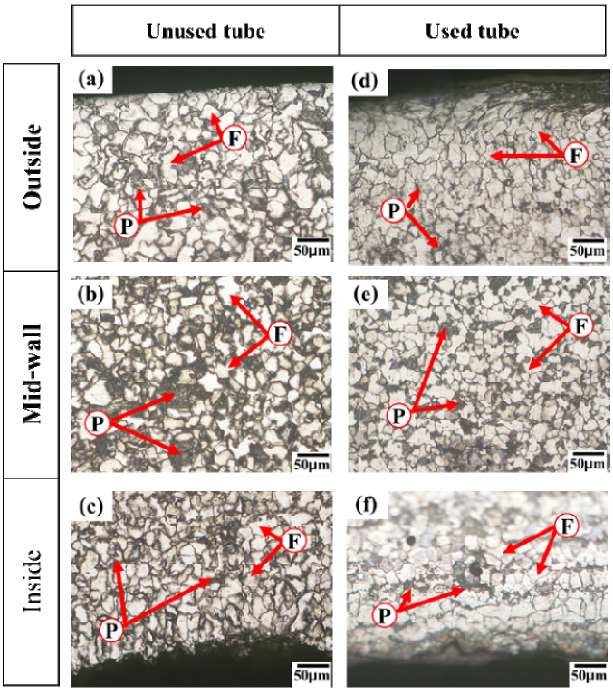

Figure 3 Optical micrographs of outer, mid-wall, and inner of the unused tube (a-c) and used tube (d-f).

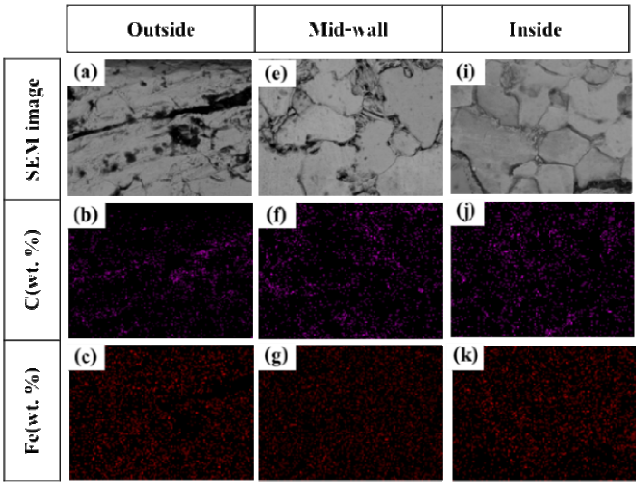

Figure 4 SEM micrograph and EDS examination of used steel tube (50X) of the exterior, mid-wall, and interior of the used tube: SEM image (a, e, and i); carbon distribution (b, f, and j); ferrous distribution (c, g, and k). The carbon (C) distribution is shown in purple and the ferrous (Fe) distribution in red, respectively

Fig. 4(a), (e) and (i) show SEM micrographs obtained from the exterior, mid-wall, and interior of the used steel tube from. From these micrographs, it was found that the pearlite morphology did not present any significant changes. No pearlite disintegration was found in the initial exposure in the superheat environment. Carbon and ferrous distribution at the outer, mid-wall, and inner of the utilized steel tube are given in Figs. 4(b) and (c), Figs. 4(f) and (g), and Figs. 4(j) and (k), respectively. Obviously, ferrous was uniformly distributed all over the matrix of the whole monitored regions and the carbon dispersion means the presence of carbon accumulation in pearlite.

Mechanical property investigation

Fig. 5 shows tensile test results of new and used tubes. Evidently, tensile strength and yield strength values of the used steel tube were lower in contrast to those from the unused tube. However, the used tube exhibited higher elongation values as compared to those of the unused tube.

The hardness test results of unused and used tubes are shown in Fig. 6. It was obvious that the hardness values of the used tube were smaller than those of the new tube. Normally, strength of material can be indicated by both yield and tensile strength, whereas ductility can be specified by elongation [6-7,11]. In this monitoring, the used tube showed the lower values in tensile and yield strength in all measured positions.

Technically, during the operating period, the used tube experienced the high temperature environment (500 °C or above 500 °C) [12,13]. In addition, ash deposition can occur due to the combustion of bituminous coal. In this condition, oxidizing environment can occur, resulting in the scale disintegration of the oxide layers formed in the used tube, known as "Thermal oxidation" [13-15]. In addition to this degradation, the chemical composition in Table 1 shows the decreased carbon content in the used steel tube. Normally, the decreased carbon content in steel probably means the decarburization, resulting in the significant reduction in the strength and hardness of materials. Furthermore, decarburization requires carbon diffusion [13,16]. This can cause the formation of the decarburized zone, which facilitates the phase transformations [14]. The recovery process or grain growth process may occur and would result in increased ductility, but lower strength. Thus, decarburization and high temperature oxidation were responsible for the decreased strength and hardness and increased elongation of the used steel tube in the superheat zone.

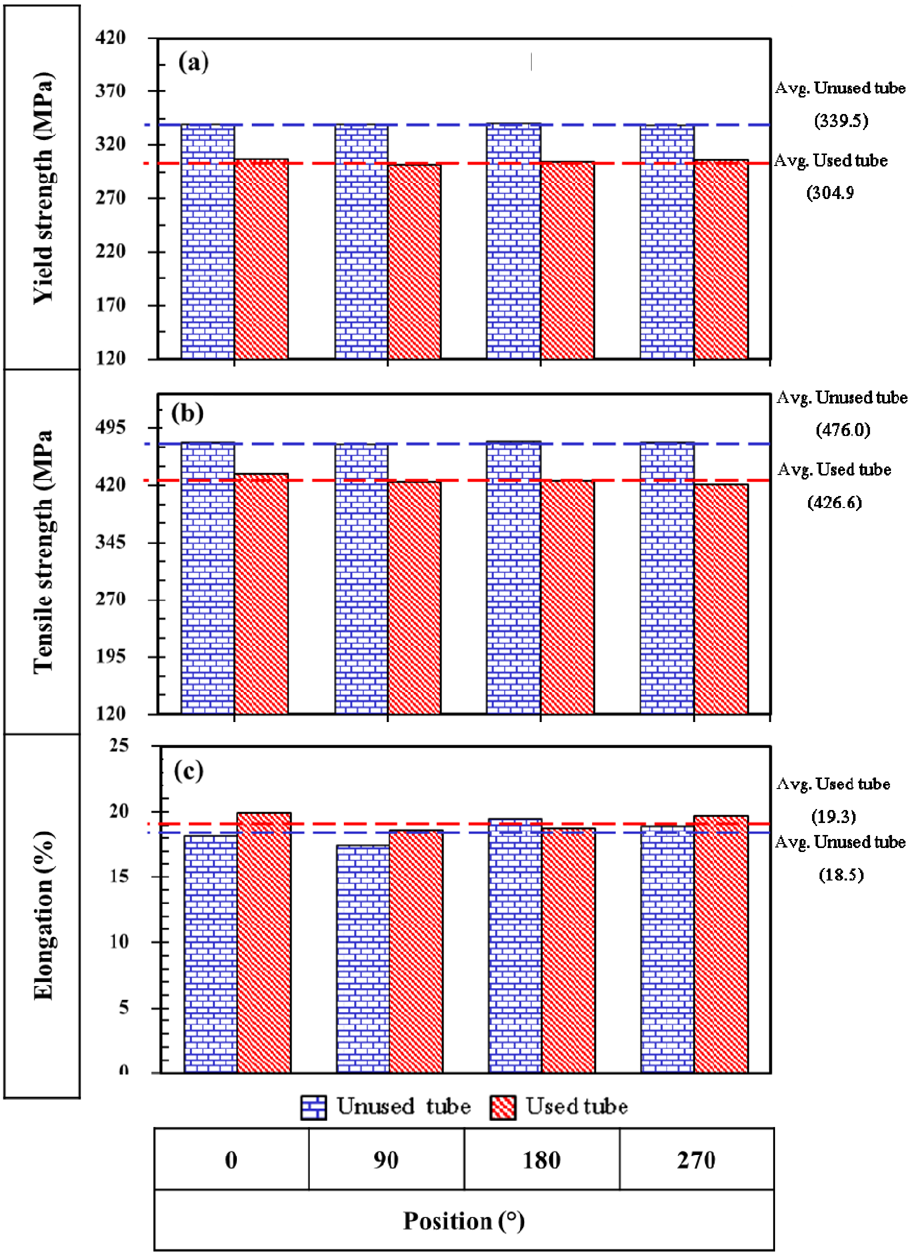

Figure 5 Tensile test results of unused and used tube (a) Yield strength, (b) Tensile strength; (c) Elongation.

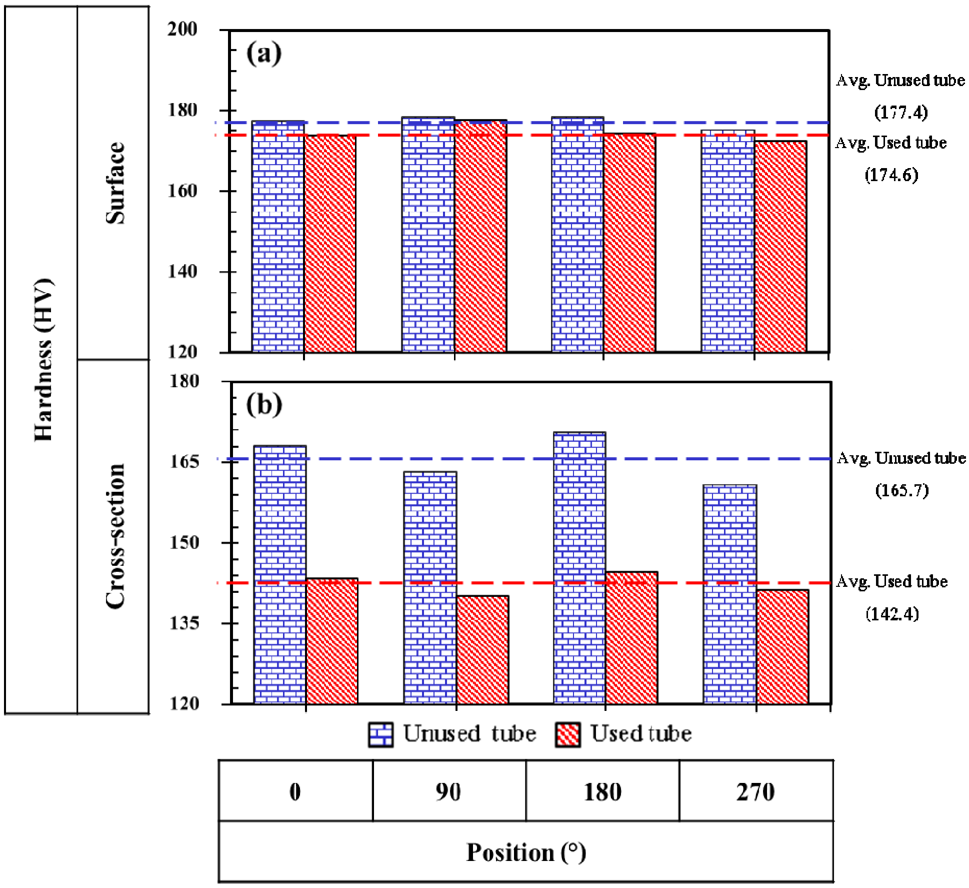

Figure 6 The hardness test results of unused and used tube (a) surface; (b) Cross-section.

Conclusion

The initial monitoring of Microstructure and Mechanical Properties Evaluation of SA213 T22 used as Superheat Tube in water tube boiler of a bituminous coal-fired power plant was already conducted. The results show that the outer surface of the tube was degraded by the thermal conditions in the superheat environment of the coal-fired boiler. The carbon content reduction in the steel tube indicated decarburization, resulting in decreased strength and hardness and increased elongation. Thus, the main degradations of this SA213 T22 steel tube were dominated by thermal oxidation and decarburization. The strength, hardness and elongation of the steel tube were found not to be considerably changed. However, regular inspection and monitoring should be carried out to ensure the optimal performance of the superheater tubes.Furthermore, replica testing is advised for monitoring microstructural degradation, which may adversely affect the performance of this coal-fired power plant.

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