Reparation, inspection and damage analysis of steam boiler

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1. Introduction

Boilers are welded structures commonly used in a huge array of industry branches, and with that in mind regular maintenance and reparation are of crucial significance, and good reparation timing and valid reparing technology is needed to keep in mind, because there is a constant risk of failure. Almost 20% of all failures in facilities are due to boiler failure. Not so common problem in all boilers is the wave furnace tube failure and that can lead to their outage. There are several known failure mechanisms, ranging from high temperature to others associated with corrosion factors [1-4].

Boilers and furnace tube should be within regulations for parent materials used for manufacturing, welded joint quality and exploitation safety. This is the primary reason why they are controlled during, before and after welding process, along with regular inspections during exploitation. Inspection of welded joints involves the application of non-destructive test methods such as ultrasound, magnets, x-rays, penetrant methods, acoustic emission, etc. [5, 6].

2. Boiler damage analysis

In this particular case, subject was steam boiler "Đuro Đaković S 1200", manufactured as a three-pass steam boiler, using oil fuel and the upper smoke gas exhaust via chimney. Fuel burns in a wave-shaped furnace tube type "FOX", which is built into the cylindrical shell. The dimensions of the wave furnace tube are Ø1450/Ø1300mm. The distance between the first and the last wave is 18x200=3600 mm. Dimensions are shown in manufacturer technical documentation. Steam boiler consists of furnace tube, cylindrical shell. and a front and rare tube plate, which make up the water space wherein evaporation takes place. Hot gases are going through the wave furnace tube to the reversal chamber, where they are diverted to smoke tubes of the second pass, and are then directed into third pass tubes via smoke canal in the back part of the boiler. Second pass tubes dimensions are Ø70x3, 2x4081 mm – 99 pieces, whereas the third pass tubes (a total of 94) have the following dimensions – 70x3, 2x4100 mm. Second and third pass tubes are welded to the front and rear tube plate of the cylindrical shell. The boiler is working under overpressure, and necessary pass is provided by a fresh air ventilator. The boiler is equipped with a device that protects against elevated pressure: a safety valve, which is most important safety measure [7, 8].

3. Definition and selection of welding technology

Leakage was observed in boiler (fabric number 5473) wave furnace tube (Fig. 1). It was noticed by maintenance staff and the other pipe layer was disassembled to find the exact place where leakage occurred. It happened at the burner pipe, nearest to the boiler, some 100 mm from back side of boiler and some 30 mm from burner pipe axis. Crack vas longitudinal and its propagation was across the whole thickness of burner pipe (Fig. 2), and by it was concluded by the Notified body that

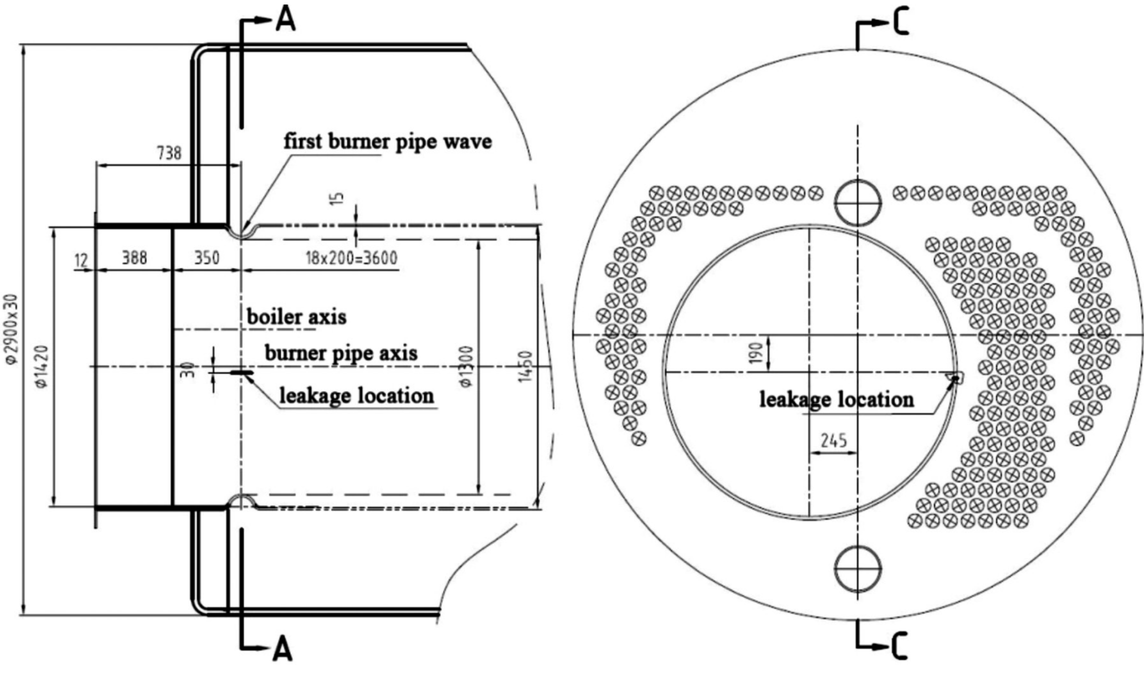

Figure 1. Schematic of boiler wave burner pipe and leakage location.

reparation was needed, by welding without changing the base material. Welding process was done in accordance with adequate welding technology and that will be explained latter in more detail. Before reparation, visual inspection was done in scope of 100%. Also penetrate testing was done to find beginning and end of crack propagation.

Groove preparation was performed for the purpose of cracks repairing by grinding and the groove making until it is clean and smooth, with sloped sides and a root fillet of R = 8 mm. Welding procedure qualification was done for TIG welding for the root pass and manual electric arc welding for filler passes, but in cite is decided to do only MAW technique for both root and filler both respectively. Visual control and penetrant testing was also performed, once the grooves were prepared. Preparation was done in accordance with the welding technology which will be shown in detail in the following sections. During the repair, after the root pass was welded, visual dimension control of it was performed. Following the root pass inspection, welding was continued in accordance with the welding technology specifications. After the welded joint was completed, it was ground and then inspected using visual and testing with a scope of 100%, upon a successfully performed control, the boiler was tested using cold water pressure in the presence of the Notified body, with a test pressure of 16.9 bar.

Figure 2. Cracks across the whole thickness of wave furnace tube.

4. Groove Preparation

Due to the lack of ultrasound control for the purpose of determining crack depth, the real state was only possible to detect after they were removed. Gradual removal of cracks during the forming of the groove, it was concluded they are spread along the whole length of the flame pipe. Based on the type of detected cracks, the groove was prepared for welding according to Figure 3. Prior to this, every free end of the crack was bored using 5 and 8 mm drills. Groove preparation should be done using grinding tools with controlled heat input (boring should be done with interruptions to prevent material overheating). Prepared groove surface was ground until it was smooth and clean with sloped sides and root fillet with R = 8 mm.

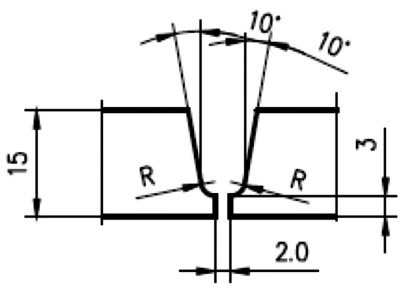

Figure 3. Preparation of grooves for welding.

Prepared grooves were controlled using visual and penetrant testing with a scope of 100% This control included a wider zone around the prepared grooves. These grooves fulfilled the acceptability requirements, since the inspection determined that the existing cracks were completely removed.

5. Welding Technology

Welding technology defines the procedure for repairing of a crack in the flame pipe of a boiler pipe with the following parameters:

- allowed pressure of 13 bar
- test pressure of 16.9 bar
- steam temperature of 195°C

Wave flame pipe was made of 17Mn4 steel (Tables 1 and 2), with a thickness of S = 15 mm. Repairing of the crack should be undertaken after the welding technology qualification in accordance with SRPS EN ISO15614-1:2017 [9], SRPS EN 12953-4:2018 [10]. Welded joint quality must meet the requirement defined in SRPS EN ISO 5817 [11, 12], welded joint quality level C.

Table 1. Chemical composition of 17Mn4 material (%).

Element	C_{max}	Si_{max}	Mn	Cr_{max}	P_{max}	S_{max}
Percentage	0.08-0.20	0.40	0.90-1.50	0.30	0.025	0.015

Table 2. Mechanical properties of 17Mn4.

Yield stress R_{eH} (N/mm^2) min	Tensile strength R_m (N/mm^2)	Elongation A (%)	Impact toughness A_v (J) on 0°C min
min 250	460 - 580	22/22	40

By taking into account the following factors like chemical composition of steel, material thickness, welding conditions (during installation), heat loss (welded joint geometry), heat input (arc energy) etc., it was concluded that there is no need to preheat the base material.

Based on the type of repair performed, and the possibilities for surface preparation, the welding location and required repair quality, the manual arc welding using a coated electrode (MAW) was used for welding procedure. Chemical and mechanical compositions of filler material for used coated electrode is given in Tables 3 and 4.

Table 3. Chemical composition of weld metal (%).

Element	C	Si	Mn	Mo
Percentage	0.1	0.5	0.8	0.5

Table 4. Mechanical properties of weld metal.

Yield stress R_{eH} (N/mm^2)	Tensile strength R_m (N/mm^2)	Elongation A (%)	Impact toughness A_v (J) on -20°C min
>450	530-630	>22	>47

EVB Mo wire [13] was dried prior to its use at 250°C for a total of 4 hours and 15 minutes, and was then placed in a quiver with a temperature of 100°C until it was used. It is recommended to dry as many wire as can be used during a single day, and to re-dry the unused ones.

Due to the lack of ultrasound control for the purpose of determining crack depth, the real state was only before welding, it was necessary to provide proper working conditions. Taking into account the cramped space in which the repairs were performed, and that the welder(s) had to have access to the weld, necessary auxiliary and protective equipment was provided. Welding activities were performed at an ambient temperature of +50°C. Surfaces that would be welded were cleaned by removing any impurities (oil, rust, etc.) using a steel brush, in the area up to 100 mm from both sides of the welded joint. Welding was performed using MAW procedure, with a basic electrode, using the prescribed parameters.

Welders are qualified and possesses a certificate about their competence in accordance with the relevant requirements given by SRPS EN ISO 9606-1 [14].

Before the laying of the second weld pass, slag was cleaned using a “welder’s hammer” and steel brush, along with visual inspection. No defects were detected using this method. Upon reaching the end of the weld, or when the electrode is consumed, welding must be stopped. Before restarting the arc, slag needs to be removed using the welder’s hammer and steel brush. Two weld passes must be joined in a way that ensures a continued joint. There longitudinal overlap is 15 mm. Welding interruption was performed by moving the arc backward during manual arc welding with the basic electrode. Filler material parameters and dimensions are given in Table 5.

Welding layers were laid out from the center to the groove ends. Root weld was done in two passes, using the electrode dragging technique. The second pass should be done immediately after the first one, using the same technique (cooling of the previous layer was not allowed). Root weld height was 6-8 mm. Electrode that was used was EVB Mo (E Mo B 42), with a diameter of 2.5 mm. All requirements given by the welding technology were met. Filler material parameters are shown in the table 5 as well.

Weld root was done in two passes, using the electrode tip dragging technique. Root weld height should be 6-8 mm. Groove slopes, including the edge zones, should be welded during the first pass, with multiple layers, along the whole surface, using a 2.5 mm electrode. Every subsequent layer should be laid out so that it overlaps with the previous one up to one third of its width. This ensures the annealing of the base material. Overlapping must be within the range 1-3 mm. Final layer is completely covered, hence stress annealing of all previous layers was fully achieved in this case (Figure 4).

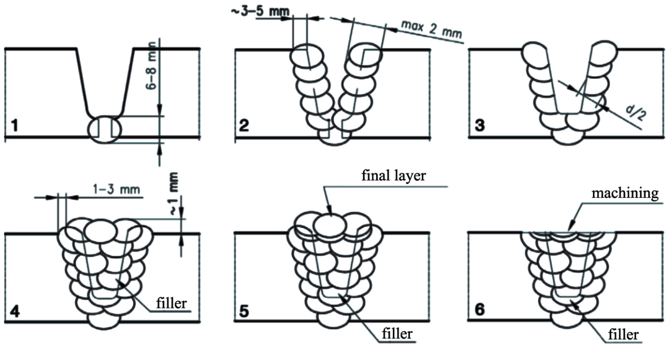

Figure 4. Exact way how welding procedures where done.

6. Control and inspection

6.1. Visual and penetrate testing

Non-destructive methods (NDT), are vital for safety testing of any mechanical structure [15]. In this particular case visual ant penetrant testing was performed.

Visual testing of fusion welded joints was first inspection method used with a scope of 100%, it was done in accordance to SRPS EN ISO 17637 [16] standard. Also, SRPS EN ISO 17637, also visual testing was performed both before, during and after performed welding process. Surface illumination was standard 500lx.

Penetrant testing was also done in with scope 100% in accordance SRPS EN ISO 3452-1 [17], illumination was also standard 500lx. Penetrant was applied to the test component by spraying, and was afterwards removed and a developer was applied.

Acceptability criteria for defects in a welded (or surface welded) joint (part) according to standard SRPS EN ISO 5817, for the adopted welded joint quality level – C, and no defects were found.

6.2. Pressure testing (hydro test)

Next testing that was performed on wave furnace tube was pressure test (test fluid was water) with 16.9 bar (Fig. 5). Pressure was gradually raised (4 bar/minute) until pressure in pipe reached the work value of 13 bar, and that pressure was maintained for some 10 minutes and in next 15 minutes pressure was raised to test pressure of 16.9 bar. Test pressure was maintained for 30 minutes, and after that period of time, slowly started to drop for next 10 minutes to work pressure of 13 bar. In this moment, inspection was performed along with leakage test to see if there is leakage in the welded joint. During this

Table 5. Welding parameters for manual arc welding.

Welding layers	Welding procedure	Filler material		Current			Welding speed [mm/s]
		Electrode	Diameter (mm)	Amperage (A)	Voltage (V)	Polarity	
1-2	111	E Mo B 42	2,5	65-95	-	DC-RP (+)	-
n	111	E Mo B 42	2,5	65-95	-	DC-RP (+)	-

test, no defects were detected, as was case with surface testing. After testing was done, test fluid was released from tube over a time interval of 5 minutes.

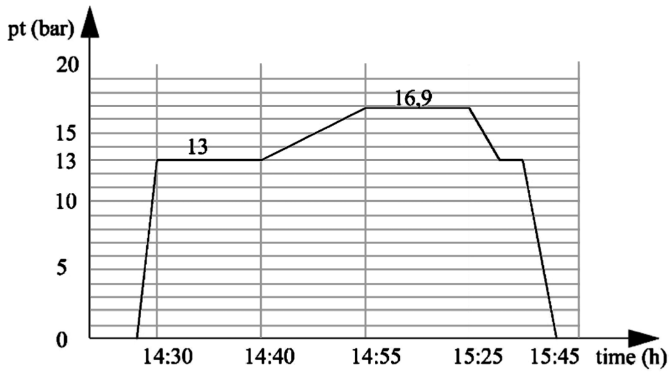

Figure 5. Plan of hydro-testing.

7. Discussion and conclusion

During welding, the following was checked, in adequate intervals: basic welding parameters (current, voltage etc.), cleaning and the shape of welds and passes in the weld metal, visual and inter-stage control of weld passes, welding order, regular use and handling of consumables, dimensional check.

Before the welding begins, the following needs to be checked usefulness and validity of welder competence certificates (according to SRPS EN ISO 9606-1), base material identity, filler material identity and preparation, welded joint preparation (shape, dimensions, etc.), work surface setup and cleaning, suitability of welding conditions etc.

It is assumed that failure happened in base material of a tube where defects occurred during material production or casting. The reasoning behind this conclusion was that usually this type of failure during exploitation is not that common in wave pipe burners.

Even though there was in this particular case a legitimate reason for exclusion of ultrasound testing, which it is highly recommended as one of the volumetric method of testing. Reason behind this statement is that volumetric method of testing provide the information about direction and longitude of crack inside the inspected material.

Last but not the least is saving of time and expanses, repairing (if possible) is much cheaper and quicker solution in comparison to the ordering of a new element. Repairing can be done in just few days, until ordering a new part can take month to arrive.

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