

REPAIR PROCEDURE OF BOILER FLUE PIPES PROCEDURA SANACIJE DIMNIH CEVI KOTLA

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Keywords

- boiler flue pipes
- repair procedure
- damage mechanism
- P235GHTC1 steel

Abstract

Due to exploitation conditions, pressure equipment is vulnerable to various damage mechanisms, including corrosion, fatigue, creep, etc. Therefore, it is of great importance to monitor and maintain such equipment regularly, in order to ensure its safe and reliable exploitation. In this paper, the focus is on repair welding activities for flue pipes in a steam boiler. In addition, research shown here also includes the techno-economical analysis of the repair procedure, outlining its numerous benefits in terms of structural integrity and sustainability.

INTRODUCTION

Damage of steam boilers represents one of key factors for their safety, reliability and life. During exploitation, steam boilers are subjected to high pressure and temperatures, cyclic loads and aggressive environments, which leads to various forms of material degradation over time.

Most common damage mechanisms involve corrosion, erosion, fatigue, creep and stress corrosion, whereas these damages are typically initiated in areas of stress concentration, such as welded joints, collectors and sharp transitions in geometry.

In the case that these degradation processes are not detected and repaired in time, they can lead to crack initiation, leakage and even catastrophic failure, with serious safety issues and economical consequences. Due to this, it is of crucial importance to use state-of-the-art non-destructive test methods, along with monitoring of work parameters and remaining life assessment. An integrated approach which combines experimental tests, numerical simulations and risk analysis allows the planning of maintenance activities to be performed in a timely manner, thus extending the work life of steam boilers under relevant exploitation conditions, while decreasing the need for repairs of such pressure vessels.

Corrosion represents one of the most common damage mechanisms and can occur on both the water and the gas side of boiler. This kind of damage often results in perforation of waterwall and/or economiser pipes. Thermal fatigue is another significant cause of damage that requires repairs,

Ključne reči

- dimne cevi kotla
- procedura sanacije
- mehanizmi oštećenja
- P235GHTC1 čelik

Izvod

Usled uslova eksploatacije, oprema pod pritiskom podložna je različitim mehanizmima oštećenja, uključujući koroziiju, zamor, puzanje i druge procese degradacije. Stoga je od izuzetnog značaja redovno praćenje, ispitivanje i održavanje takve opreme kako bi se obezbedila operativna bezbednost i pouzdanost. Ovaj rad se fokusira na reparaturno zavarivanje dimnih cevi u sistemu parnog kotla. Pored toga, rad obuhvata tehno-ekonomsku analizu predložene procedure sanacije, ističući njene prednosti u pogledu integriteta, produženja radnog veka, isplativosti i održivosti.

especially in the case of boilers that work in variable modes, including common start-stop cycles. Welded joints are particularly critical due to their heterogeneous microstructures and possible defects during manufacture, which additionally decreases their fatigue resistance. In the case of components subjected to elevated temperatures over long time periods, such as steam pre-heaters and collectors, creep is the dominant damage mechanism. This process leads to accumulation of residual stresses and crack initiation, and these cracks can result in eventual failure of the steam boiler. Erosion and corrosion induced damage also often occur at locations with high fluid velocities, due to a synergy between mechanical wear and chemical effects.

Repair of steam boilers more often than not involves the replacement of individual pipes, repair welding, local reconstruction of collectors, or the use of plugs. In certain cases, chemical cleaning is performed in order to remove deposits, and reoccurrence of damage is prevented by optimising work parameters of feed water treatment.

LITERATURE REVIEW

As mentioned in the paper by B. Ošljanac, one of the frequently encountered issues related to boiler corrosion (on the flame-flue side) involves deposits which occur due to precipitation of combustion products [1]. In a study by Ding [2], corrosion occurs on the outer side of an economiser pipe in a boiler. Results have shown that repeated failures are caused mainly by condensation of sulphur acid (corrosion at dew point temperature). Additionally, this paper considers

the mechanisms behind damage initiation and concrete technical measures are proposed for prevention of further issues related to corrosion. Local corrosion, such as pitting and erosion-corrosion degradation, is particularly dangerous, as it can lead to sudden penetration of boiler walls, as can be seen in a study by Sui /3/. In this case, leakage occurs at the connection between the pipe and pipe plate, and stress corrosion is determined to be the cause of failure.

Thermal-induced damage occurs as a consequence of irregular heating, local overheating or when boilers operate outside of their design parameters. This type of damage is manifested in the form of deformations, bulges and cracks. Extended exploitation at elevated temperatures can result in creep, especially in the case of pipelines and boiler drums. /4, 5/.

Since welded joints represent the most critical points in structures, they are often the locations where fatigue, micro- and macro-cracks occur due to stress concentration. Aranđelović et al. /6-9/ had conducted extensive studies about the effect of multiple defects in welded joints on structural integrity. Since boilers are subjected to variable pressure and temperatures when their operation starts and ends, the integrity of their welded joints is of great importance. Inadequate welding and/or heat treatment additionally increases the risk of such damages.

Apart from the above, mechanical damages are also present, caused by vibrations, impacts, inadequate supports and errors during assembly. Stone and mud deposits on the inner side of the pipe decrease its heat transfer, increase the temperature and indirectly contribute to other types of damage as boiler tubes used in power plants and manufacturing industries are prone to failure due to the harsh environment in which they operate, /10, 11/.

Repairs of equipment in general, as well as in the case of pressure equipment, such as steam boilers, represent an important means of maintaining safe and reliable functioning of this equipment during its work life. Regular repairs of observed damages prevent them from further expanding, thus decreasing the risk of catastrophic failures and unplanned downtime. In this way, the risk of serious material and safety-related consequences is also reduced, /12-16/.

A well-performed repair results in increased work life of boilers, while maintaining design work parameters, in accordance with relevant technical regulations. Due to this, repairs represent an inseparable part of maintenance systems and safety management of steam boilers. This is of great importance for assessing the remaining work life of the steam boiler, which in turn can result in fewer downtimes and significant savings in both time and resources, /17-19/.

This specific case involves the replacement of flue pipes for the second and third draft (a total of 8 pipes, one for each draft group) on a block steam boiler. Damage is caused by combustion product depositing and results in leakage during a cold water pressure test. Figure 1 shows the position of flue pipes that are replaced.

Repair procedure includes the deinstallation, delivery and installation of aforementioned boiler pipes. These elements are made of pipes with dimensions of $\text{Ø}63.5 \times 3.6 \times 4150$ mm and $\text{Ø}51 \times 3.6 \times 4800$ mm, made of material of P235GHTC1

grade, as per standard SRPS EN 10216-2:2020. Work parameters of the boiler are given in Table 1.

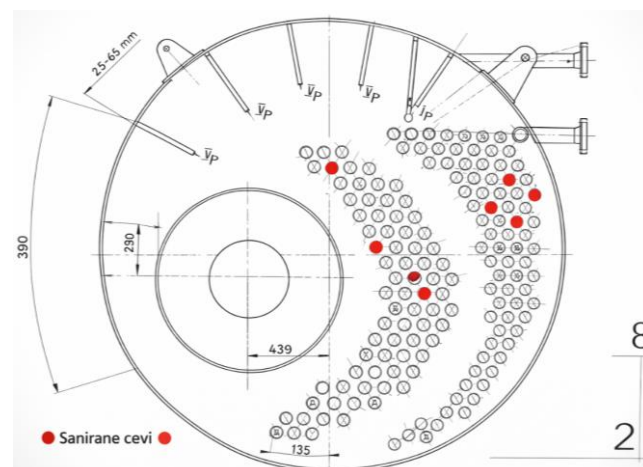


Figure 1. Position of repaired pipes of the second and third draft of a steam boiler.

Table 1. Work parameters for the repaired steam boiler.

Name	Steam boiler/ Oro 65
Year of manufacture	1979
Maximum work pressure	6 bar
Test pressure	9 bar
Heat surface area of the boiler	165 m ²

TECHNICAL DESCRIPTION OF REPAIR ACTIVITIES

Preparations included deinstallation of burner canals and securing of the burner and other elements on the front side of the boiler, along with the installation of scaffolds where necessary. All pipes which are delivered are required to have certificates. Pipes had dimensions of $\text{Ø}63.5 \times 3.6 \times 4150$ mm and $\text{Ø}51 \times 3.6 \times 4800$ mm. Contractors are required to provide adequate welding technology qualification reports (WPQR), along with certified welders and filler material.

Deinstallation requires the removal of front chamber cover and rear manhole cover, along with the removal of secondary air fans and channels. All flue pipes on the front and back lids are also deinstalled using a machine for mechanical removal of welded joints. The next step was to remove residual stresses by grinding, and preparation for penetrant tests. After PT is completed, the damages are removed and repair welding is performed.

Installation activities involve preparation of pipes by cleaning and machining (up to 50-100 mm from pipe edges), ensuring there are no notches or scratches in these areas. Inner pipe surfaces are also cleaned. After preparation, pipes are positioned inside the boiler and welded in accordance with the provided welding technology, followed by visual and penetrant testing of filled welds of new flue pipes on both front and rear ends. The final part of the installation stage involves the installation of blind flanges for the purpose of performing a hydrotest, with a test pressure of 9 bar and duration of 30 min.

The final stage of repair activities includes the removal of all blind flanges and reconnection of pipe connectors, secondary air fan and the reinstallation of secondary air channels and front and rear chamber covers.

MATERIALS AND WELDING TECHNOLOGY

Parent and filler material

Parent materials used for the pipes are:

- P235GH TC1 for Ø63.5×3.6×6000 pipes and
- P355GH for plates with dimensions of 20×16000×6000.

P235GH TC1 is a non-alloyed low-carbon structural steel used for pressure equipment. This material is characterised by good mechanical properties and weldability and is suitable for both cold and hot forming. It is most commonly used in manufacturing of pressure vessels, boilers, pipelines and other parts of thermal and process equipment. TC1 designation refers to controlled delivery conditions, which in turn means it is related to conducted tests and the supervision of material properties and their compliance to relevant standards. In this way, reliability of the material during exploitation is ensured. P235GH is typically used at moderate work

temperatures and pressures, which require stable mechanical properties and long work life.

P355GH is a non-alloyed low-carbon structural steel used, also used for pressure equipment. Compared to the previous one, it has higher demands in terms of strength. In addition to its improved mechanical properties, it has all of the above advantages of P235GH (weldability, suitability for hot and cold forming) and is used for similar purposes in energy and processing industry. Thanks to its increased yield stress, the P355GH steel is well-suited for working at higher pressure and moderate to elevated temperature, as such structures require increased load-bearing capacity and reliability during long-term exploitation.

The material is delivered in accordance with relevant standards, after all necessary testing is performed, ensuring stable and safe exploitation. Mechanical properties and chemical composition of these materials are given in Tables 2-5.

Table 2. Chemical composition of P235GH TC1 and P355GH.

Steel	C [%]	Si [%]	Mn [%]	P [%]	S [%]	Al [%]	N [%]	Cu [%]	Cr [%]	Ni [%]	Mo [%]
P235GH TC1	≤ 0.16	≤ 0.35	0.40–1.20	≤ 0.025	≤ 0.015	≥ 0.020	≤ 0.012	≤ 0.30	≤ 0.30	≤ 0.30	≤ 0.08
P355GH	≤ 0.20	≤ 0.55	0.40–1.60	≤ 0.025	≤ 0.015	≥ 0.020	≤ 0.012	≤ 0.30	≤ 0.30	≤ 0.30	≤ 0.08

Table 3. Mechanical properties of P235GH TC1 and P355GH.

Steel	Re [MPa]	Rm [MPa]	A [%] (Elongation)	KV [J] (Impact toughness, 20 °C)
P235GH TC1	235	360-510	≥ 20	≥ 27
P355GH	355	470-630	≥ 20	≥ 27

SUPER B filler material (ELLIKN, Greece) is used as filler material. It is a coated electrode used for manual arc welding of non- and low-alloyed steels, and is characterised by a stable arc, good weld forming and the ease of slag removal, which makes them applicable to a wide range of welding activities.

SUPER B electrodes are usually used for welding general purpose steels, including pressure vessel and pipeline steels, which require high quality welds with good mechanical properties. The chemical composition and mechanical properties of this material are given in Tables 4 and 5.

Table 4. Chemical composition of SUPER B.

Size (mm)	C	Mn	Si	P	S
Ø2.50	0.08	1.15	0.49	0.011	0.009
Ø2.50	0.08	1.17	0.50	0.012	0.010
Ø2.50	0.08	1.19	0.51	0.009	0.008

Table 5. Mechanical properties of SUPER B (EN DIN class).

Yield [N/mm ²]	Tensile [N/mm ²]	Elongation [%]	Temp [°C]	Impact Energy [J]
> 460	530-680	> 22	-40	> 47

Welding technology

Manual arc welding with coated electrode is used. The geometry and dimensions of the weld groove are shown in Fig. 2. Grooves are made in accordance with relevant standards, while ensuring that they are clean and that no defects are present and that welding is performed by certified welders (according to standard EN 9606-1).

Welding is performed in two passes, Fig. 2. Weld root is performed in the way that fulfils all acceptance criteria according to standard SRPS 12953, including the use of adequate NDT methods, e.g., penetrant testing in the case

that visual inspection of the weld indicates presence of potential cracks.

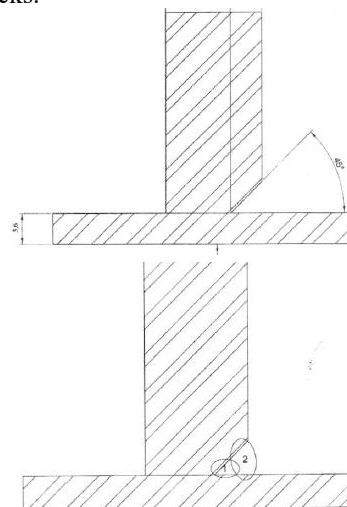


Figure 2. Weld groove geometry and welding sequence.

Interpass temperature is monitored during the welding, based on the value calculated and specified by the Welding Procedure Specification (WPS). In this case, weld passes are done in segments of 300-400 mm, with at least two welders. In order to avoid residual stresses during welding, each new weld is displaced by 20-30 mm, after the previous weld end is ground. Grinding is also performed in the cases of excess weld metal in the previous pass, along with any other visible defects, which are removed as well.

Repair welding is performed using the same filler material which is used during regular welding, with a particular focus on the quality of the root pass and good transition between the repaired and the remaining 'healthy' weld.

In the case that the repaired elements are deformed by the heat input during welding, they are restored to their original geometry by heating up to 650-850 °C and straightening. It is important to avoid temperatures high enough to cause overheating and/or melting of the welded element surface, as this could lead to significant changes in the micro-structure.

Due to the chemical composition and thickness of the used material, there is no need for heat treatment of welded joints. The scope of NDT, according to SRPS EN 12953-5 is as follows:

- 100 % visual control (before, during and after welding),
- 100 % penetrant testing of lid and flue pipe welds.

Figure 3 shows the welded joints after successful repair welding, and Fig. 4 shows the same after penetrant testing is performed, indicating no defects in the welded joints.



Figure 3. Front and back side of the boiler after repairs.



Figure 4. Welded joints of flue pipes after PT techno-economical analysis of repair of flue pipes in steam boiler Oro 65.

Scope of work included the replacement of 8 flue pipes, with dimensions of $\text{Ø}63.5 \times 3.6 \times 4150$ mm (second draft) and $\text{Ø}51 \times 3.6 \times 4800$ mm (third draft), made of P235GH TC1 steel. Work parameters of the boiler are as follows:

- work pressure - 6 bar,
- test pressure - 9 bar,
- heated surface - 165 m²,
- year of manufacture: 1979 (47 years old).

Damages, in the form of local corrosion and leakage are caused by depositing of combustion products.

The cost of all materials, components and repair activities is shown in Table 6 below, and the results of, and benefits of performed repair activities are shown in Table 7.

The final results of the techno-economical analysis of repairs performed on steam boiler Oro 65 are shown below, in relation to potential losses due to downtime, and include the total amount of gas that could be saved, investment return period, and total expected savings, among other things, Table

8. This analysis is based on the following estimates and assumptions:

- cost of production losses per day of downtime → 100.000 RSD/day,
- average annual downtime without repairs (estimated) → 4-10 days/year,
- fuel price per season (estimated) → 2.500.000-4.000.000 RSD,
- expected saving of gas after repairs → 3 % → 75.000-120.000 RSD/year.

Table 6. Total cost of repair work, including materials and parts.

	Unit	Quantity	Price per units (RSD)	Total (RSD)	Notes/source of estimation
Pipe Ø63.5×3.6 mm	m	~16.6 m	4.800 – 6.200	80.000 – 103.000	~5.500 RSD/m on average
Pipe Ø51×3.6 mm	m	~19.2 m	4.200 – 5.500	80.000 – 106.000	~4.800 RSD/m on average
Total pipes				160.000 – 209.000	Attests
Filler material	lot	1		35.000 – 55.000	For 8 pipes + spares
Activity - deinstallation				80.000 – 140.000	Removal of welds and pipes, cleaning of the lid
Activity - preparation and welding				140.000 – 220.000	Expanding, welding of 16 joints, 100 % PT
Activity - installation and finishing				60.000 – 100.000	Fireclaying, installation of canals, fans...
Non-destructive testing (PT + visual)	100 % of welds	16 welds	2.500 – 4.000 per weld	40.000 – 65.000	Penetrants + cleaning
Pressure test - 9 bar	boiler	1		25.000 – 45.000	in the presence of a notified body
Miscellaneous costs (scaffold, transport, tool storage, cleaning...)	lot	1		40.000 – 80.000	Depends on the location
Total direct costs			580.000 – 914.000	650.000 – 820.000	
VAT 20 %				130.000 – 164.000	
Total price including VAT				780.000 – 984.000	820.000 – 920.000 RSD

Table 7. Technical effects and benefits of performed repair work.

Effect	Quantification of benefits
Extension of boiler's work life	8-15 years (in reality, 10-12 years with regular maintenance)
Prevention of catastrophic failure	High risk of pipe penetration → leakage, shutdown, insulation damage, potential disaster
Decrease in downtime	Unplanned downtime → 50.000-250.000 RSD/day (depending on activity)
Improved heat transfer efficiency	2-5 % less deposits in new pipes
Compliance with regulations	Requirements for work permit/extension of certification of the boiler
Reduced risk of corrosion in the future period	Significant decrease (new pipes + clean welds)

Table 8. Techno-economical analysis indicators.

Indicator	Value	Comment
Investment (with VAT)	~850.000 RSD	Mean estimated value
Investment return period (pay-back)	2,5 – 5 years	Depends on the downtime cost and fuel savings
Avoided downtime costs (1 year)	400.000 – 1.000.000 RSD	In the case of catastrophic failure or major leakage
Overall expected gain (10 years)	3.500.000 – 9.000.000 RSD	Saving on downtimes + fuel + avoided failures

CONCLUSIONS

Based on the performed repairs of flue pipes, it can be concluded that all required activities are performed in accordance with valid technical documentation, relevant standards and regulations. Repairs involve complete deinstallation of damaged flue pipes, as well as the installation of new flue pipes made of P235GH TC1, in accordance with an adequately defined welding procedure.

All welded joints are made by certified welders, in accordance with valid WPQR/WPS documentation, using SUPER B as filler material. After welding is completed, NDT methods, including 100 % VT and 100 % PT are per-

formed, and no defects are detected, thus confirming the proper choice of welding technology.

Hydrotest, performed after the repair welding activities, did not reveal leakage or any other issues with the repaired steam boiler, which further confirmed that the steam boiler is completely safe and fit for future exploitation.

It can also be concluded that the repair of 8 flue pipes on steam boiler Oro 65 is justified from the techno-economy standpoint. In the technical sense, the steam boiler is made fit for further exploitation, risk of failure is eliminated, and its work life extended. On the economic side, the investment of around 850,000 thousand RSD will pay itself back around 3-5 years, thanks to avoided downtimes and reduced fuel consumption, in addition to foregoing the far more expensive

replacement of the whole steam boiler (estimated to cost around 8-15 million RSD). The combined effect of reduced costs and downtimes, and increased life also represents an important improvement in terms of sustainability of such structures.

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