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Selection and analysis of material for boiler pipes in a steam plant

Vukić Lazić[a], Dušan Arsić[a,*], Ružica R. Nikolić[a,b], Dragan Rakić[a], Srbislav Aleksandrović[a], Milan Djordjević[a], Branislav Hadzima[b]

[a] *Faculty of Engineering University of Kragujevac, Sestre Janjić 6, 34000 Kragujevac, Serbia*
[b] *Research Center, University of Žilina, Univerzitna 8215/1, Žilina 010 26, Slovakia.*

Abstract

The problems of a material selection for making the boiler pipes in a responsible steam plant and the technology for their welding are considered in this paper. The boiler is screened, complex, radiating energetic plant, with the natural water circulation in the hanging steel structure. Based on the legal regulations, the mandatory periodic reparation of the most important components is performed. This is why the check of mechanical properties, for the used and new materials for eventual replacement and building-in was done, as well as the check of the prescribed reparation procedures. The components that were in exploitation were checked, since their properties change with time. Checking consisted of testing the tensile material properties at room and elevated temperatures, measurements of hardness and analysis of materials' microstructures. Besides the experimental tests, the numerical modeling and analysis of the workload of the fluid transporting pipes was conducted. In that way it was established which material is optimal for manufacturing the boiler pipes.

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Keywords: Screened steam boiler; low-carbon structural steel; seamless pipes; mechanical properties; welding.

1. Introduction

Metal materials are generally used for manufacturing the boiler components, mainly the carbon and alloyed steels. The largest number of subassemblies and assemblies of the boiler are made by various welding procedures. The manufactured parts are exposed to influence of time, what could cause degradation of some of material characteristics, so their reliability must be checked [1, 2]. According to the place of mounting, components are divided into those exposed to water or steam pressure and to high temperatures. In addition, certain components are subjected to various kinds of external loadings and chemical influences, what has additional negative effect on integrity of the structure. It is not infrequent that materials can have flaws like cracks or non-metallic inclusions, due to what the exploitation characteristics of the structure are significantly reduced [3].

Results of theoretical, experimental and numerical investigations, whose objectives were to verify various properties of the most loaded components (both existing ones and the newly made), at room and elevated temperatures, are presented in this paper. In addition, the technology of pipes joining by gas welding was checked, since the considered boiler pipes are joined by welding.

Similar boiler installations were subject of research of numerous authors. Milović et al. [4] presented estimate of integrity of the pressure vessels made of the low-alloyed steel. The integrity estimate was done by experimental measurements of the *J*-integral at the working temperature of – 40 °C. Then they performed the numerical simulation whose results were in agreement

* Corresponding author. Tel.:+381-64-276-39-81.
E-mail address: dusan.arsic@fink.rs

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Nomenclature

R_m – Tensile strength
$R_{p0.2}$ – Yield stress
$R_{p0.2min}$ – Minimal yield stress
A_5 – Elongation
BM – Base metal
HAZ – Heat affected zone
WM – Weld metal
E – Elasticity modulus
ν – Poisson's ratio
α – Linear thermal expansion coefficient
$\sigma_{M100000}$ – Permanent time strength
l_0 – Specimen measurement length
a – Wall thickness
b – Sample width

with experimental ones. Jovičić et al. in [5] have shown that the reservoir for storage of liquids is prone to appearance of cracks in the welded joints. The subject of the research was to point to possibilities for revitalization of the damaged plants by eliminating the flaws and re-welding. In welded structures the flaws can frequently appear during the manufacturing process, what was shown by Balać et al. in [6]. They performed the numerical investigation of behavior of a pressure vessel, to whose shell two connectors were welded. In that way, the critical point on the structure for appearance of the fatigue crack was successfully determined by application of the Finite Element Method. The similar procedure was applied by Žmindak et al. in [7] for numerical analysis of the radial crack and the crack on the Y-joint on the pipe for fluid transport. Katavic et al. [8] have presented an analysis of damages on the boiler's pipes as well as procedures for elimination or reparation of those damages. The problem that they noticed appears at the back screen of the boiler's combustion chamber of a boiler, in the area attacked by the burner's flame. An evaluation of the quality of a reservoir after reparation of cracks was presented in Bakić et al. [9], what testifies about importance of the structural operation safety after revitalization. The authors were in fact dealing with criteria, which are defined by the corresponding ISO and EN standards that the repaired plant should satisfy. Dimić et al. [10] have analyzed influence of flaws in the welded joint on integrity of pipes subjected to internal pressure. They first identified the flaws – the lack of penetration – by the ultrasound testing and then examined their influence on the structure's reliability by the FEM modeling. It was concluded that the present flaw does not decisively influence the reliability of a structure; however, the fracture could result from the crack that appeared at the outside of the pipe. The similar pipes were investigated by Rakin et al. in [11] where, also both by measurement and numerical analysis, was established that the existing crack is not immanently dangerous, but here further propagation above the critical value, could lead to fracture. Szubka et al. [12] have also analyzed potential causes of the steam line failure. The failure was predicted by the probability sampling method. The certain parts of the plant were subjected to estimate of the residual life by this method and it turned out that this way of the structure's integrity estimate was quite reliable. Applying the similar procedure, Pilch et al. [13, 14] have shown that corrosion could be a cause of damages, besides other causes already cited here. They monitored the influence of corrosion on reduction of the pipe wall's thickness and created a model, which should help in estimates of the pipe's residual life. Kalaba et al. in [15] have shown that the failure could be predicted, besides by experimental and numerical methods, also by the statistical methods and mathematical models. They were monitoring the downtimes during an 11 year period and then established a mathematical-statistical model, which could serve as a basis for monitoring other plants, as well. Unlike the previous researchers, Bassi et al. [16] and Bošnjak et al. [17] have dealt with analysis of materials for manufacturing the mentioned installations, related to carrying capacity of certain devices, material degradation and analysis of initiation and growth of cracks, as well as their influence of the structural reliability, can be successfully solved. Besides analysis of failures due to flaws like cracks, one always has to keep in mind material characteristics at room and elevated temperatures [18-20]. As potential causes of failures of the similar plants, one can also consider material brittleness developed with exploitation time and pipes' corrosion, what was investigated by Novotny et al. [21]. But when cracks occur there are some possibilities and concepts of pipes repairing analyzed by Mician et al. [22].

All those detailed and expensive investigations were aimed at increasing the working life, reliability and safety of this very responsible installation.

2. Description of the screened steam boiler

All experimental, theoretical and numerical investigations were performed on the screened boiler TE-523, thus it is necessary first to explain the function of the boiler installation and conditions in which certain components are operating.

The boiler is a steam vent device with natural water circulation; it is a hanging structure, thus the total load is transferred to the boiler foundation via the columns of the steel structure. The combustion chamber of the boiler is densely screened so the good burning of coal is enabled even at the lower boiler loads. The combustion chamber circuit is designed with the unheated