Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 13 (2018) 2249–2254

Structural Integrity Procedia

www.elsevier.com/locate/procedia

ECF22 - Loading and Environmental effects on Structural Integrity

Influence of temperature and exploitation time on hardness and micro-structure of a welded joint in a reactor mantle

Ivica Čamagić[a,]*, Simon Sedmak[b], Zijah Burzić[c], Aleksandar Sedmak[d]

[a]*Faculty of Technical Sciences, 7 Kneza Miloša Street, K. Mitrovica*
[b]*Innovation Centre of the Faculty of Mechanical Engineering, 16 Kraljice Marije Street*
[c]*Military Technical Institute, 1 Ratka Resanovića Street, Belgrade*
[d]*Faculty of Mechanical Engineering, University of Belgrade*

Abstract

This paper presents the analysis of the influence of temperature and exploitation time on the cross-sectional hardness and micro-structure changes of characteristic zones of a welded joint made of low-alloyed Cr-Mo steel A-387 Gr. B. Exploited parent metal is a part of a reactor mantle which was working for over 40 years and is in the damage repair stage, i.e. part of its mantle is being replaced with new material. Cross-sectional hardness of a butt-welded joint was measured and macroscopic investigation of the welded joint and microstructural analysis of the parent material, weld metal and the heat affected zone were performed. The comparison of parameters obtained for characteristic zones of a welded joint provides a way to meausre the justifiability of the selected welding technology.

Peer-review under responsibility of the ECF22 organizers.

Keywords: Crack, low-alloyed steels, welded joint, hardness, micro-structural properties

1. Introduction

Long-time exploitation period of a pressure vessel - reactor (over 40 years) caused certain damage to the reactor mantle. The occurrence of this damage demanded a thorough inspection of the reactor structure itself, along with repairing of damaged parts. Reactor repairs included replacing of a part of the reactor mantle with new material. The pressure vessel considered here was made low-alloyed Cr-Mo steel A-387 Gr. B in accordance with ASTM standard with (0,8-

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: ivica.camagic@pr.ac.rs

2452-3216 © 2018 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the ECF22 organizers.
10.1016/j.prostr.2018.12.132

1,15)% Cr and (0,45-0,6)% Mo. For designed work parameters (p = 35 bar and t = 537 °C), the material is in the area where it is prone to decarbonization of the surface in contact with hydrogen. As a consequence of surface decarbonization, material strength may be reduced. The reactor represents a vertical pressure vessel with a cylindrical mantle. Deep lids were welded on the top and bottom sides of the mantle, of the same quality as the mantle itself. Inside the reactor, the most important process in the motor gasoline production stage takes place, and it involves platforming in order to change the structure of hydrocarbon compounds and thus achieve a higher octane rating. Tests performed involved determining of hardness, macroscopic examination and microstructural analysis of all welded joint components [1].

2. Materials

Exploited PM was steel A-387 Gr. B with thickness of 102 mm, whereas the new PM is also made of steel A-387 Gr. B and thickness of 102 mm. Chemical composition and mechanical properties of the exploited and new PM according to the atest documentation are given in tables 1 and 2.

Table 1. Chemical composition of exploited and new PM specimens

Specimen designation	% mas.							
	C	Si	Mn	P	S	Cr	Mo	Cu
E	0.15	0.31	0.56	0.007	0.006	0.89	0.47	0.027
N	0.13	0.23	0.46	0.009	0.006	0.85	0.51	0.035

Table 2. Mechanical properties of exploited and new PM specimens

Specimen deisgnation	Yield stress, $R_{p0,2}$, MPa	Tensile strength, R_m, MPa	Elongation, A, %	Impact energy, J
E	320	450	34.0	155
N	325	495	35.0	165

Welding of steel sheets made of exploited and new PM was performed in two stages, according to the requirements given in the welding procedure provided by a welding specialist, and these stages include:

- Root weld by E procedure, using a coated LINCOLN S1 19G electrode (AWS: E8018-B2), and
- Filling by arc welding under powder protection (EPP), where wire denoted as LINCOLN LNS 150 and powder denoted as LINCOLN P230 were used as additional materials.

Chemical composition of the coated electrode LINCOLN S1 19G, and the wire LINCOLN LNS 150 according to the atest documentation is given in tab. 3, whereas their mechanical properties, also according to the atest documentation, are given in tab. 4.

Table 3. Chemical composition of additional welding materials

Filler material	% mas.						
	C	Si	Mn	P	S	Cr	Mo
LINCOLN Sl 19G	0.07	0.31	0.62	0.009	0.010	1.17	0.54
LINCOLN LNS 150	0.10	0.14	0.71	0.010	0.010	1.12	0.48

Table 4. Mechanical properties of additional materials

Filler material	Yield stress, $R_{p0,2}$, MPa	Tensile strength, R_m, MPa	Elongation, A, %	Impact energy, J na 20°C
LINCOLN Sl 19G	515	610	20	> 60
LINCOLN LNS 150	495	605	21	> 80

Butt welded joint was made with a U-weld. The shape of the groove for welding preparation was chosen based on sheet thickness, in accordance with appropriate standards SRPS EN ISO 9692-1:2012, [2], and SRPS EN ISO 9692-2:2008, [3].

3. Hardness measuring

Hardness measuring of the butt-welded joint made of new and exploited PM was performed in accordance with standard EN 1043, [4]. Vickers method was used, with the applied load of 30 HV. Hardness was measured linearly along the New PM-New HAZ-WM-Exploited HAZ-Exploited PM, as shown schematically in figure 1.

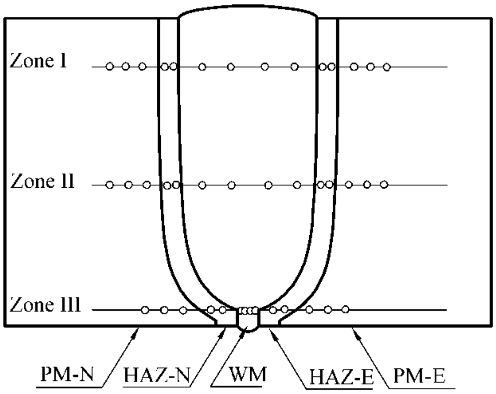


Figure 1. Hardness measuring scheme of a but-welded joint

By analyzing the obtained hardness values shown in Figure 2, it can be clearly seen that the highest hardness was measured in the WM. Moving from the WM through the HAZ and towards the PM, hardness gradually decreases.

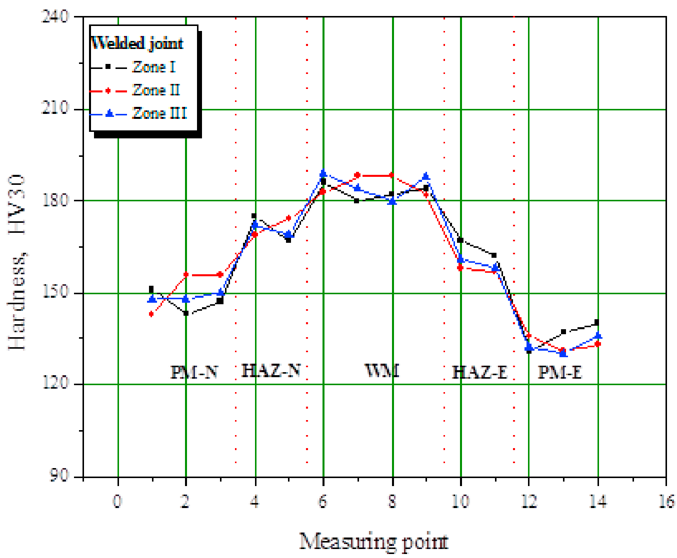


Figure 2. Graphical representation of hardness measuring results of a butt-welded joint with new and exploited PM

4. Macro and microstructural testing

For a successful application of A-387 Gr. B steel and it maximal creep resistance, guaranteed mechanical properties are requested at higher temperatures, as well as creep resistance at exploitation temperatures in a period that can be longer than 150000 hours. These properties are obtained with the proper thermal treatment, which should provide the structure consisting of ferrite and beinite. Very fine carbides, which start to sediment during this thermal treatment, segregate at grain border, as well as within the grain which can be seen under high magnification, [5, 6].

Carbide precipitation, which begins during thermal treatment for residual stress elimination, continues during exploitation at exploitation temperatures and pressures, [7]. Appearance of these brittle phases can be ascertain by metallographic analysis under high magnification. This testing was conducted in order to evaluate exploitation period of parent metal and welded joint components in respect of microstructural properties change. Macro recording of butt welded joint of new PM and exploited PM is given in fig. 3, [1].

After etching of butt welded joint it can be clearly differentiate:

- new and exploited parent metal,
- heat affected zone from the both sides
- weld metal with well-marked groove filling zone.

Both parent metals shows even structure, which consists of bright polygonal ferrite crystals and transformed areas that can be analysed under high magnification. These transformed areas represent dark surfaces of perlite that looks like a compact dark micro constituent. Microstructure of the PM that were in exploitation for over 40 years is shown in fig. 4, and microstructure of the new PM is shown in fig. 5, [1]. Difference is in a grain size. Newly installed parent metal has structure with a grain size 5 according to ASTM scale, while exploited material has structure with a grain size 3 according ASTM scale.

It is clear that at 100x magnification it is impossible to notice essential difference between used and new material, except in a grain size.

Microstructure in HAZ on exploited and new PM side is shown in fig 6 and fig. 7 respectively, [1]. It consists of ferrite, beinite and perlite. Beinite in HAZ forms as consequence of higher cooling rate of a part of the parent metal that was heated to the austenitizing temperature during welding. Beinite level declines increasing the distance from the joint line.

Figure 3. Welded joint macro recording

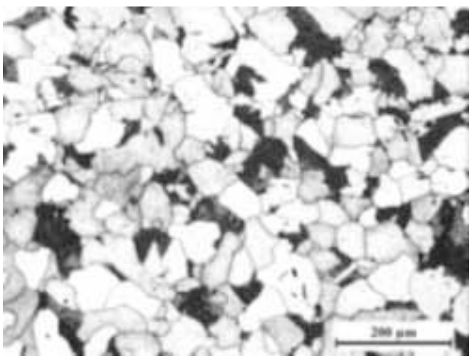


Figure 4. Microstructure of exploited PM, ferrite-perlite structure

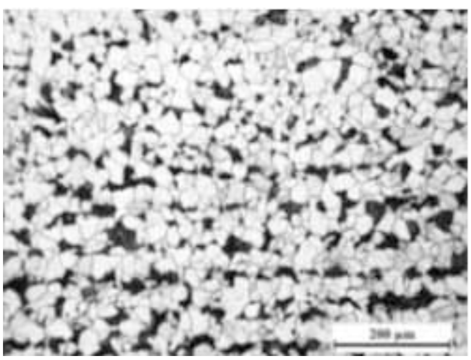


Figure 5. Microstructure of new PM, ferrite-perlite structure

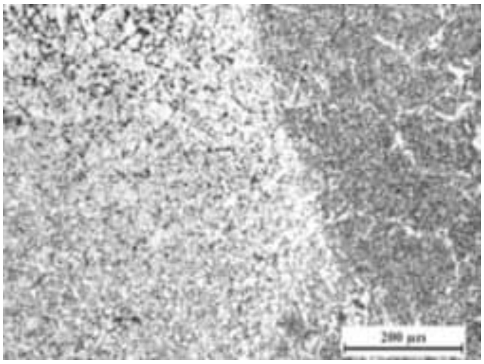


Figure 6. HAZ microstructure on exploited PM side on the left

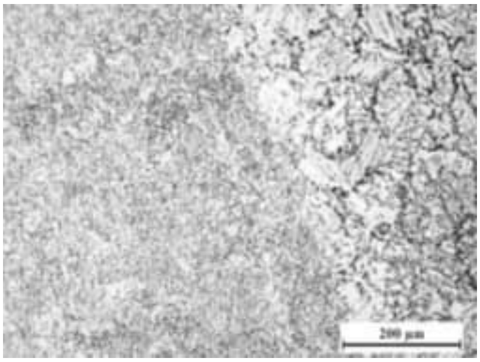
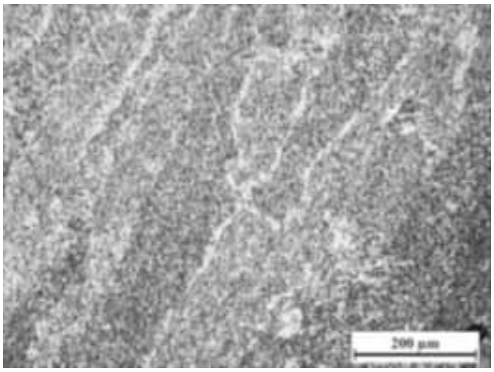


Figure 7. HAZ microstructure on exploited PM side on the right

Weld metal structure with large dendrite created as consequence of the foundry bath size and dimensions of welded plates is shown in fig. 8, [1].

Higher magnification (500x and more), enabled revealing differences in structural properties of exploited and new PM. Exploitation period of more than 40 years affected the significant presence of carbide on a grain borders and within a grain, fig. 9, [1]. The carbide amount in new PM is significantly fewer and they are smaller, fig. 10, [1].

Figure 8. WM microstructure, dendrite structure of weld metal



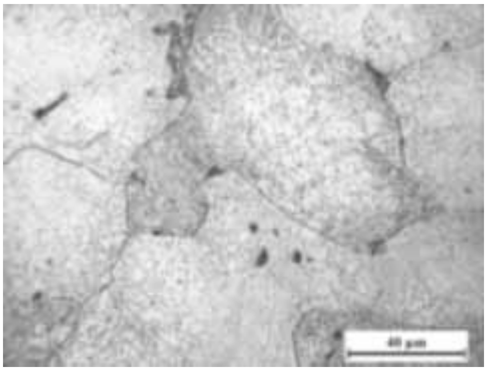


Figure 9. Exploited PM microstructure, large bright ferrite grains, dark beinite, carbide at borders and within grain

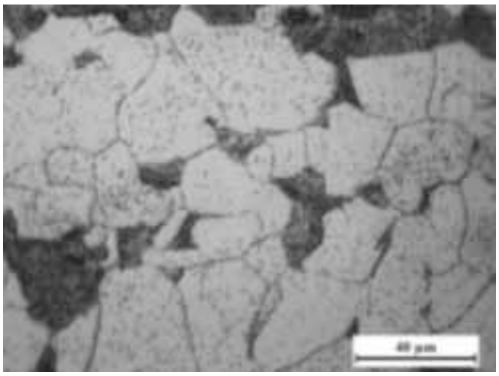


Figure 10. New PM microstructure, large bright ferrite grains, dark beinite, carbide at borders and within grain is minimal

5. Conclusions

Measuriong of welded joint hardness determined the influence of exploitation time on a decrease in its values, along with the effect of exploitation time on the weakening of the PM and HAZ. Measured hardness values for the butt-welded joint ranged from 180 to 189 HV in the WM. In the HAZ, obtained values were slightly lower compared to the WM. There is a noticeable difference in the HAZ for the new and exploited PM. New PM had shown higher hardness values, ranging from 167 to 175 HV, whereas the hardness of the exploited PM was between 157 and 167 HV. Different hardness values were determined for both new and exploited PM, 143-156 HV for the former and 131-140 HV for the latter [1].

Never the less both parent metals shows uniform structure that consists of bright polygonal ferrite crystals and transformed areas, basic difference between new and old material is in grain size. Newly installed parent metal has a structure with grain size 5 according to ASTM scale, while exploited material has a structure with grain size 3 according to ASTM scale, as the result of higher temperature and pressure influence in longer time period, [1]. The amount of segregated carbide at a grain border, as well as within a grain, is especially significant in a PM behaviour in presence of variable load, [1, 8].

Test results and their analysis have justified the choice of welding technology for the purpose of replacing the part of the reactor mantle.

6. Acknowledgements

Parts of this research were supported by the Ministry of Sciences and Technology of Republic of Serbia through Mathematical Institute SANU Belgrade Grant OI 174001 Dynamics of hybrid systems with complex structures. Mechanics of materials and Faculty of Technical Sciences University of Pristina residing in Kosovska Mitrovica.

References

[1] Ivica Čamagić, Investigation of the effects of exploitation condi¬tions on the structural life and integrity assessment of pressure vessels for high temperatures (in Serbian), doctoral thesis, Fakultet tehničkih nauka, Kosovska Mitrovica, 2013.
[2] SRPS EN ISO 9692-1:2012, Welding and allied processes - Recommendations for joint preparation - Part 1: Manual metal-arc welding, gas-shielded metal-arc welding, gas welding, TIG welding and beam welding of steels (ISO 9692-1:2003), 2012.
[3] SRPS EN ISO 9692-2:2008, Welding and allied processes - Joint preparation - Part 2: Submerged arc welding of steels (ISO 9692-2:1998), 2008.
[4] EN 1043, Destructive tests on welds in metallic materials-Hardness test Part 2, Micro hardness testing on welded joints, 1996.
[5] "Classification of Microstructures in Low C, Low Alloye Steel Weld Metal and Terminology", MIZ, IX-1282-83.
[6] METALS HANDBOOK, Metalography, Vol. 6, ASM International, pp. 1124, 1998.
[7] "Weld Metal Microstructures", A State-of-the Art review.
[8] Ivica Čamagić, Nemanja Vasić, Srdjan Jović, Zijah Burzić, Aleksandar Sedmak, Influence of temperature and exploitation time on tensile properties and microstructure of specific welded joint zones, 30th International Congress of Serbian Society of Mechanics, Arandjelovac, Serbia, June 15-17, 2015.