British Journal of Applied Science & Technology
17(3): 1-12, 2016, Article no.BJAST.28339
ISSN: 2231-0843, NLM ID: 101664541

SCIENCEDOMAIN *international*
www.sciencedomain.org

Influence of Temperature and Time of Exploitation of Welded Joints in the Operation of Static and Dynamic Loads

I. Camagic[1], P. Zivkovic[1*], S. Makragic[1], M. Radojkovic[2] and A. Radovic[3]

[1]Faculty of Technical Sciences, University of Pristina, Kosovska Mitrovica, Serbia.
[2]High Technical School of Professional Studies, Zvecan, Serbia.
[3]Technical School Mihailo Petrović Alas, Kosovska Mitrovica, Serbia.

Authors' contributions

This work was carried out in collaboration between all authors. Authors PZ and IC designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors SM, MR and AR managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2016/28339
Editor(s):
(1) Luigi Maxmilian Caligiuri, Faculty of Science, University of Calabria, Italy And Foundation of Physics Research Center (Director)- FoPRC, Italy.
Reviewers:
(1) Ahmad Changizi, Concordia University, Canada.
(2) Azuddin Mamat, University of Malaya, Malaysia.
(3) Alexandre Gonçalves Pinheiro, Ceará State University, Brazil.
(4) Hao Wang, Northeastern University, China.
Complete Peer review History: http://www.sciencedomain.org/review-history/16136

Original Research Article

Received 14th July 2016
Accepted 15th August 2016
Published 10th September 2016

ABSTRACT

Shown in this paper is the analysis of the effects of exploitation duration and temperature on the measure of fracture resistance of constituents of a welded joint between new and exploited low-alloyed *Cr-Mo* steel A-387 *Gr. B* subjected to static and variable loads. 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. Tensile curves necessary for stress analysis were determined, along with material strength properties and Wohler's curves were drawn, in other words permanent dynamic strength was determined as material resistance to crack initiation, on room and working temperature. Based on test results, the analysis of fracture resistance represents the comparison of values obtained for characteristic areas of the welded joint and justifiability of the selected welding technology.

**Corresponding author: E-mail: jomine@sbb.rs;*

Keywords: Welded joint; crack; yield stress; tensile strength; permanent dynamic strength.

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 (0,8-1,15)% *Cr* and (0,45-0,6)% *Mo.* For designed work parameters (p = 35 bar and t = 537℃), the material is in the area where it is prone to decarbonization of the surface in contact with hydrogen, [1]. As a consequence of surface decarbonization, material strength may be reduced, [2]. 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 of new and exploited parent metal (PM), as well as of welded joint components (weld metal-WM and heat affected zone-HAZ) and the low-alloyed steel the reactor was made of, included the determining of tensile properties of new PM, WM and butt welded joint between exploited PM and new PM, [3,4] and also the determining the parameters of high-cycle fatigue of butt welded joint between exploited PM and new PM and of new PM on room and working temperature of 540℃, [3,5].

2. MATERIALS AND METHODS

2.1 Material for Testing

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.

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 Table 3, whereas their mechanical properties, also according to the atest documentation, are given in Table 4.

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, [6], and SRPS EN ISO 9692-2:2008, [7].

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 designation	Yield stress, $R_{p0,2}$, MPa	Tensile strength, R_m, MPa	Elongation, A, %	Impact energy, J
E	320	450	34	155
N	325	495	35	165

Table 3. Chemical composition of additional welding materials

Additional material	% mas.						
	C	Si	Mn	P	S	Cr	Mo
LINCOLN SI 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

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

2.2 Determining of Tensile Properties

Base properties of material strength, as well as stress-elongation curves which are necessary for stress analysis are obtained by tensile tests. Tensile testing of butt welded joint on room temperature, including the shape and dimensions of specimens along with the testing procedure are defined by the standard SRPS EN 895:2008, [8]. This standard, above all, defines lateral tension, i.e. applying of the load lateral to the welded joint. Shape and dimensions of the specimen used for lateral tension of a butt welded joint are shown in Fig. 1.

Standard SRPS EN 895:2008 also requires the determining of tensile properties of PM and WM at room temperature. Determining of tensile properties of PM is defined by the standard SRPS EN 10002-1, [9]. Shape and dimensions of the specimen used for determining of tensile properties of PM and WM are shown in Fig. 2.

Unlike room temperature tests, the procedure for testing at increased temperature of 540℃, as well as specimen geometry are defined by the standard SRPS EN 10002-5, [10]. Shape and dimensions of the specimen used for tensile tests on increased temperature are shown in Fig. 3.

Testing of welded joint specimen made of new PM and WM was preformed on an electro-mechanical tensile test machine in strain control. The rate of applying the load was 5 mm/min. Elongtion was recorded using a double extensometer and an inductive transducer [11,12,13,14].

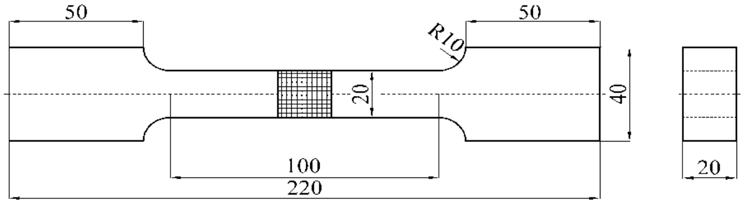

Fig. 1. Specimen for determining of tensile properties of a butt welded joint [8]

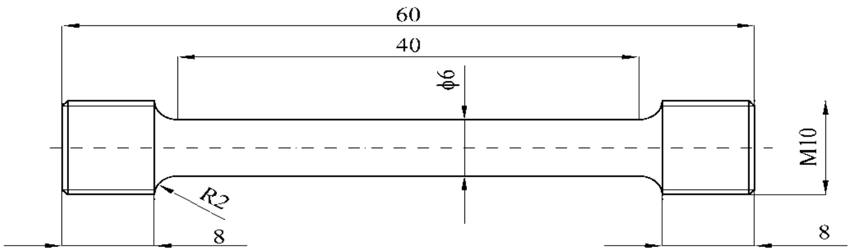

Fig. 2. Specimen for determining of tensile properties of PM and WM [9]

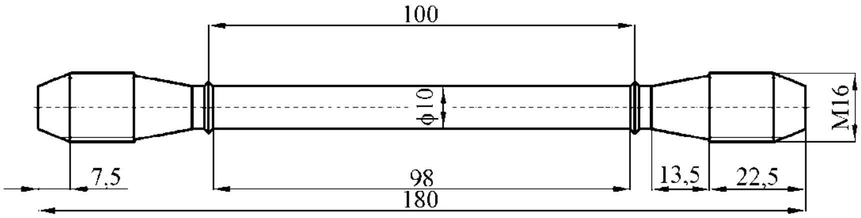

Fig. 3. Specimen used for tensile tests on increased temperature [10]

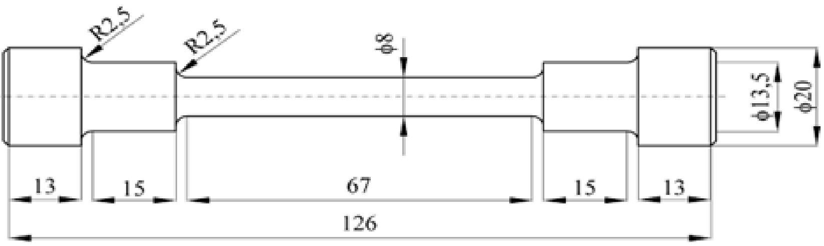

Fig. 4. Specimen for dynamic tests according to ASTM E466 [12]

The working temperature of 540℃ was achieved in a chamber electrical furnace. Temperature was measured at three positions along the specimen, due to the relatively long measured part (100 mm). The goal was to ensure approximately equal temperature along the whole specimen, by means of precise control and well-timed corrections, since addording to the standard SRPS EN 10002-5, allowed deviation is ±3℃.

2.3 Determining of Permanent Dynamic Strength

Metal fatigue is defined as the process of cumulative damage under the effect of variable load which is manifested in the occurrence of cracks and fracture. Fatigue strength of welded joints is determined from specimen testing with variable load that leads to cracks or fracture. In case of reactors, i.e. pressure vessels which operate in increased pressure and temperature conditions, high-cycle fatigue tests are of particular importance. Strength of welded joint under variable loads, such as the ones that occur in non-stationary reactor work modes during starting and stopping, is an important characteristic for assessing integrity and remaining life. At the same time, it should be taken into account that damage in form of cracks occurs after a large number of changes in the load at stresses much lower than the yield stress (high-cycle fatigue). At load levels lower than yield stress, characteristic for high-cycle fatigue, it is common practice to perform test in rigid mode, i.e. with a given stress amplitude, S_a, MPa.

It is clear that high-cycle fatigue strength depends on the properties of the welded joint constituents. At the same time, it should be noted that the characteristics of high-cycle fatigue start changing significantly only on temperatures above 400℃ in case of steel used for pressure vessels, and their welded joints, thus these tests are only justified for working temperature, which for this group of materials have a maximum of 550℃.

Testing of the effects of temperature and exploitation duration on the behaviour of the new PM as well as on the butt welded joint subjected to variable load was performed with the goal to determine the points in the S-N diagram (drawing of the Wohler's curve) and to determine the fatigue strength Sf. Welding procedure, as well as test specimens were defined according to standards ASTM E466, [15], ASTM E467, [16] and ASTM E468, [17]. The shape of the specimen that was tested using variable load is shown in Fig. 4.

Testing was performed on a high frequency pulsator. Achieved frequency ranged between 115 and 165 Hz, depending on the load magnitude and testing temperature. In order to fully evaluate the behaviour of materials subjected to variable load, while taking into account the dimension of the specimen, the most critical case of variable load was considered, with the use of variable load that alternated between tension and pressure (R=-1).

During this testing, it is a general rule to only determine the number of load changes until fracture under the load with a constant range, and the standard only requires data about the magnitude of stress for which crack initiation and fracture after a specific number of cycles does not occur (typically between 10^6 and 10^8 cycles). For steel materials, standard ASTM E466 defines fatigue strength, S_f, after 10^7 cycles.

In order to draw a Wohler's curve and determine the fatigue strength, it is necessary to test the specimens at 6 to 7 different levels of load. According to standard ASTM E 466 for every level of load, three specimens were tested, which makes a total of 21 specimens. Due to this, such tests are very expensive and is only justified when data for designing are necessary, above all from the aspect of fatigue and fracture mechanics, in other words when parts subjected to long-term variable loads are designed as a part of the total designed structure life [18,19,20].

3. RESULTS AND DISCUSSION

Results of testing butt welded joint specimens by lateral tension at room temperature of 20℃ and working temperature of 540℃ are given in Table 5, [3]. Typical tensile stress-elongation curve for but welded joint specimen denoted by WJ-1-1, tested at room temperature, is shown in Fig. 5, [3], and the curve for specimen WJ-2-1, tested at working temperature, is shown in Fig. 6 [3].

Results of new PM specimen testing at room temperature of 20℃ and at working temperature of 540℃ are given in Table 6 [3]. Testing of exploited PM was not performed, since during welded joint specimen testing, all specimens that were tested fractured in the PM, which provided us with the characteristic of the exploited PM. A typical tensile stress-elongation curve for specimen denoted by PM-1-1N, taken from the new PM and tested at room temperature is given in Fig. 7, [3], and for specimen PM-2-1N, also taken from the new PM, but tested at working temperature, is shown in Fig. 8, [3].

Table 5. Results of tensile tests of the welded joint

Specimen designation	Testing temperature, °C	Yield stress, $R_{p0.2}$, MPa	Tensile strength, R_m, MPa	Elongation[1], A, %	Fracture location
WJ-1-1	20	295	451	19.2	Expl. PM
WJ-1-2		285	448	20.4	Expl. PM
WJ-1-3		291	454	19.7	Expl. PM
WJ-2-1	540	217	293	26.3	Expl. PM
WJ-2-2		205	285	25.6	Expl. PM
WJ-2-3		211	287	26.9	Expl. PM

[1] *measured at L_0 = 100 mm, as comparative value (not as a material property)*

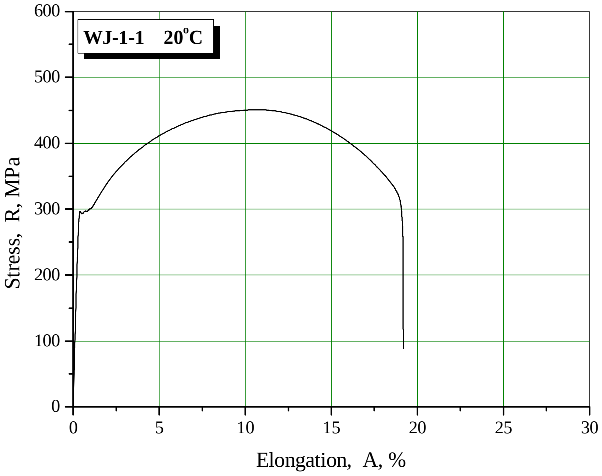

Fig. 5. Stress-elongation diagram of a butt welded joint specimen WJ-1-1

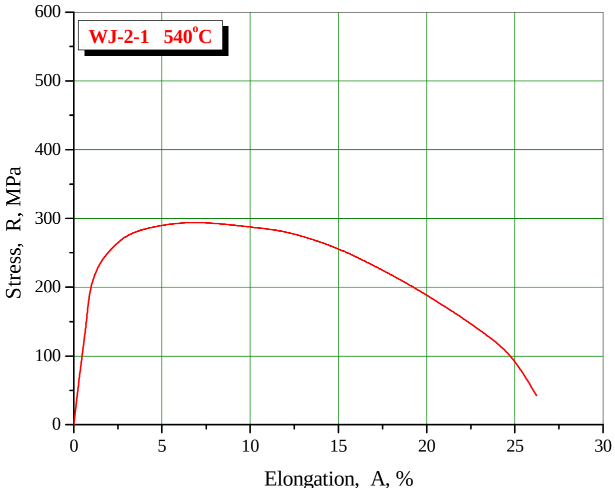

Fig. 6. Stress-elongation diagram of a butt welded joint specimen WJ-2-1

Table 6. Results of tensile tests of new PM specimens

Specimen designation	Testing temperature, °C	Yield stress, $R_{p0.2}$, MPa	Tensile stress, R_m, MPa	Elongation, A, %
PM-1-1N	20	342	513	27.5
PM-1-2N		339	505	28.3
PM-1-3N		335	498	28.6
PM-2-1N	540	251	323	29.1
PM-2-2N		242	316	30.8
PM-2-3N		247	320	30.4

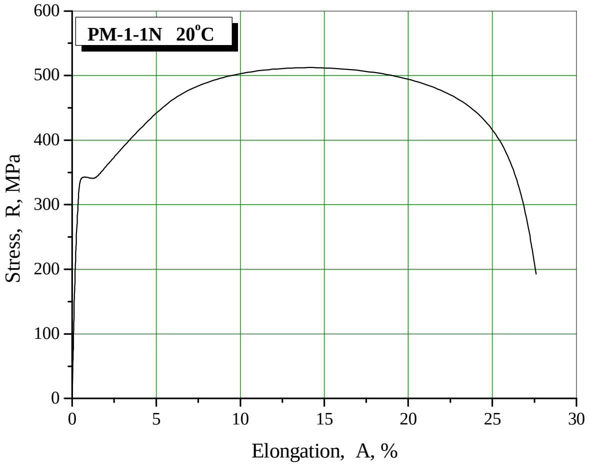

Fig. 7. Stress-elongation diagram for new PM specimen PM-1-1N

Results of WM specimen test performed at room temperature of 20℃ and at working temperature of 540℃ are given in Table 7, [3]. A typical tensile stress-elongation curve for WM specimen denoted by WM-1-1, tested at room temperature is shown in Fig. 9, [3], whereas for specimen WM-2-1, tested at working temperature, it is shown in Fig. 10, [3].

The effect of exploitation duration and temperature on values of fatigue strength S_f, i.e. maximum dynamic stress for which there is no initiation of crack-like defects in smooth structure shapes, is graphically shown in form of Wohler's curves (S-N diagrams) in Fig. 11 for butt welded joint specimens, [3], and in Fig. 12 for specimens taken out of the new PM, [3].

Testing of specimens taken out of the exploited PM was not performed, since all welded joint specimens cracked in the zone of exploited PM, hence these tests provided te characteristics of the welded joint and exploited PM.

The effect of testing temperature on values of fatigue strength S_f, obtained by testing of specimens taken out of a butt welded joint and the new PM is shown in Fig. 13, [3].

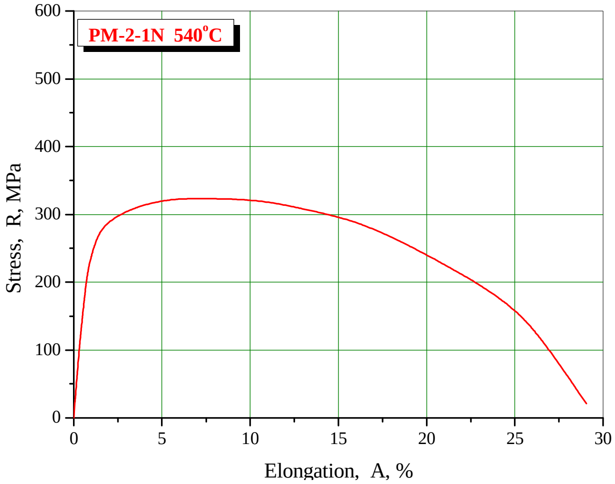

Fig. 8. Stress-elongation diagram for new PM specimen PM-2-1N

Table 7. Results of tensile testing of WM specimens

Specimen designation	Testing temperature, °C	Yield stress, $R_{p0.2}$, MPa	Tensile strength, R_m, MPa	Elongation, A, %
WM-1-1	20	518	611	20.9
WM-1-2		510	597	22.7
WM-1-3		514	605	21.3
WM-2-1	540	331	419	26.1
WM-2-2		319	406	27.3
WM-2-3		325	412	27.7

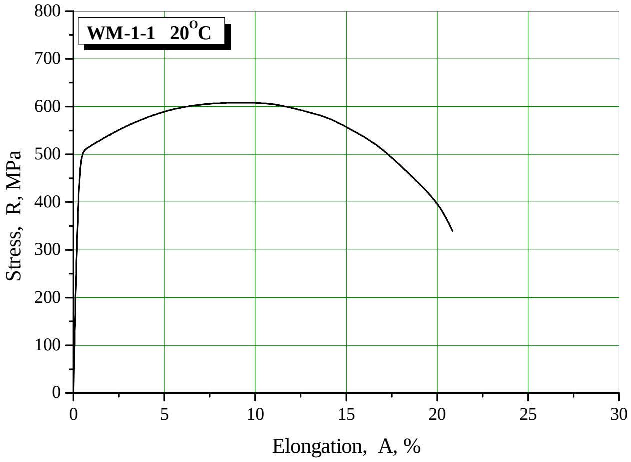

Fig. 9. Stress-elongation diagram for WM specimen, WM-1-1

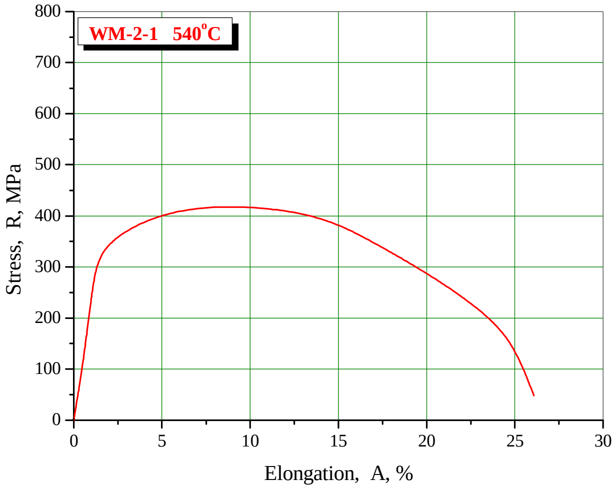

Fig. 10. Stress-elongation diagram for WM specimen, WM-2-1

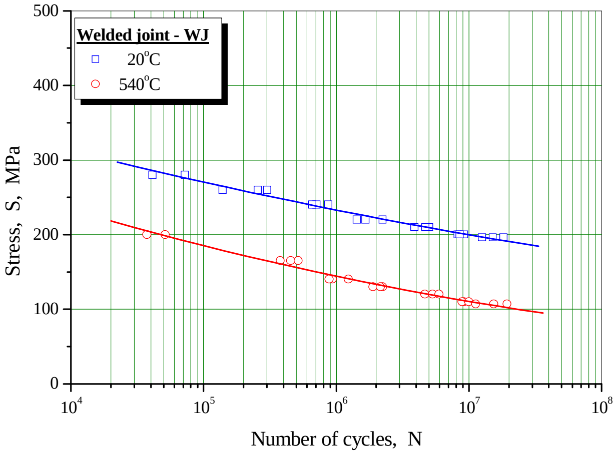

Fig. 11. S-N diagram for specimens taken out of the butt welded joint and tested at room and working temperature

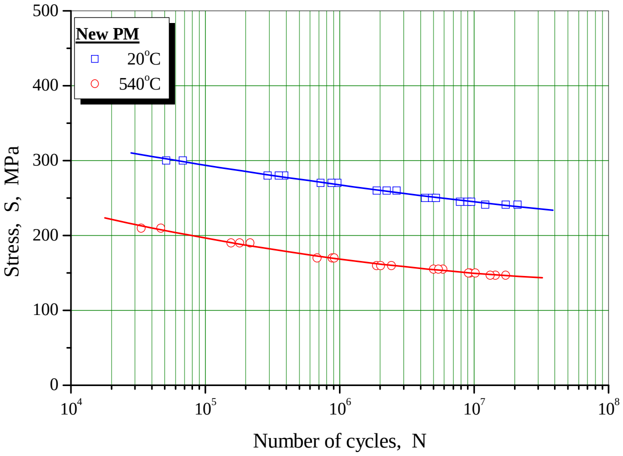

Fig. 12. S-N diagram for specimens taken out of the new PM and tested at room and working temperature

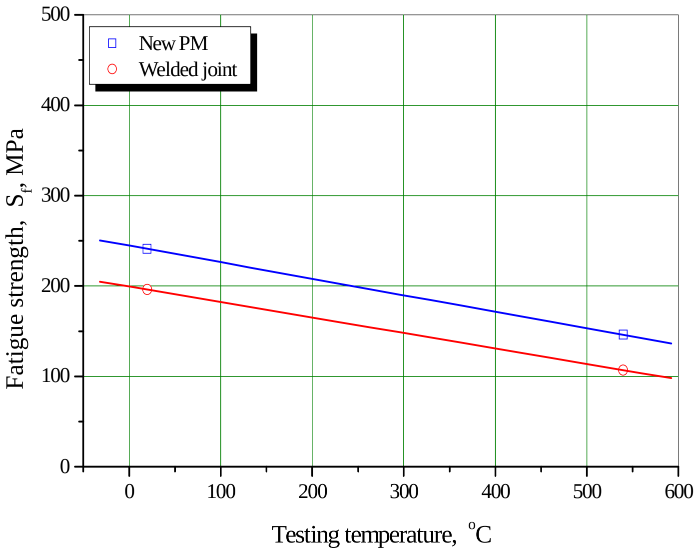

Fig. 13. Change of values of fatigue strength S_f for specimens taken out of the new PM and a butt welded joint depending on the temperature

Based on the obtained results for tensile properties of specimens taken out of a welded joint between new PM and WM on selected temperatures, it can be concluded that the increase in temperature lead to reduced strength properties, i.e. yield stress and tensile strength. Likewise, an increase in temperature leads to increased elongation. Elongation increase with the temperature is explained by the increased total plasticity of the material at higher temperatures, but can also be explained by a much less favourable ratio of homogeneous to non-homogeneous elongation. In addition, exploitaiton duration greatly affects the reduction of strength and strain properties, which can be related to the micro-structures of the exploited and new PM, [3].

Testing welded joint specimens by applying lateral load to the welded joint provided the necessary data for determining how the chosen welding technology and exploitation duration affect the strength of the welded joint, as well as its components. Results obtained by welded joint specimen testing by applying lateral load to the welded joint, Table 5, have shown that all of the specimens that were tested cracked in the exploited PM. This information is of great importance, since it indicates the weakening of the exploited PM. Fracture of specimens in the PM clearly points out the character of the welded joint. In this case, it was „over-matching“, which means that the weld metal strength was higher than that of the parent metal, [3]. Character of obtained tensile curves at room temperature corresponds to a ductile material with approximate share of homogeneous and non-homogeneous elongation with a ratio of 1/2:1/2, where homogeneous elongation includes elongation up to the maximum force, whereas non-homogeneous elongation involves elongation from maximum force to fracture, meaning the moment when a neck starts forming on the specimen, i.e. when unstable growth of the initial crack in the material starts. For testing of welded joint specimens at room temperature, there is a similar tendency of strength properties change as in case of room temperature testing, however there is a difference in strain (elongation) properties. Namely, here we have the case where the ratio of homogeneous to non-homogeneous elongation of approximately 1/4:3/4, which is rather unfavourable from the aspect of exploitation properties. The homogeneous plasticity reserve of the material is considerably smaller, thus the hazard of consequences of potential installation malfunction on the PM is quite real. By analyzing the results obtained by tensile tests at room temperature of specimens taken out f the new PM, given in Table 6, it can be concluded that the test results for the new PM are within the boundaries of values defined by the standard for that material, i.e. they correspond to the values given in the atest documentation provided by the manufacturer. Results obtained by tensile tests of WM specimens, given in Table 7, confimr that the proper welding technology, i.e. welding parameters, were chosen. Yield stress and tensile strength satisfy the values provided by the standard, whereas strain properties are much better than those contained within the standard for this type of additional materials, [21]. This indicates that the post-weding thermal processing mode was chosen in an adequate way. Behaviour of the HAZ in the welded joint subjected to load was conditioned by its small volume portion, as well as by the heterogeneity of the structure and different mechanical properties of specific areas within the HAZ. A well made welded joint, designed according to the principle of higher WM strength, should break in the PM during tensile tests, which is exactly what happened during the tests discussed here, [3,4].

Material resistance to crack initiation is determined by testing of the fatigue strength of materials. This is the maximum value of stress for which crack initiation on smooth specimens does not occur. The higher the ratio of fatigue strength to yield stress value, the better its resistance to crack initiation. By analysing the results obtained by high-cycle fatigue testing of smooth specimens for the purpose of drawing of Wohler's curves and determining of fatigue strength, it can be seen that exploitation and duration have a dominant effect on the obtained values of fatigue strength. In case of testing of welded joint specimens made of exploited PM at room temperature, the ratio of fatigue strength to yield stress value of 0.68, i.e. the obtained value of fatigue strength represents 68% of the yield stress. All welded joint specimens that were broken while being tested with loads higher than the fatigue load, were cracked either in the exploited PM or HAZ on the side of the exploited PM. Resistance to crack initiation in case of new PM was better, and the ratio of fatigue strength to yield stress is 0.71, [3]. The effect of testing temperature is such that an increase in temperature leads to reduced fatigue strength. Also, in this case, the welded joint specimens were cracked either in the exploited PM or its HAZ. The value of fatigue strength that was obtained by testing of new PM specimens at the temperature of 540℃ is about 37% higher than the fatigue strength value obtained for welded joint specimens, [3]. Crack initiation resistance for tests at 540℃ decreases, i.e. their tendency towards brittle fracture increases. The ratio of fatigue strength to yield stress for welded joint specimens was 0.51, whereas for new PM specimens it was 0.60, [3,5,22].

4. CONCLUSION

Test results obtained by high-cycle fatigue, as well as the tensile test results point towards the conclusion that the effect of exploitation duration and testing temperature is much more significant for dynamic tests, compared to static tests. Exploitation period of approximately 40 years lead to reduced value of fatigue strength in welded joint specimens, i.e. exploited PM for around 19%, which can represent very important information, assuming that the conditions in which the reactor operates are known (p = 35 bar and t = 537℃).

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

ETHICAL APPROVAL

We hereby declare that the paper titled "the Effects of temperature and exploitation duration of a low-alloyed steel welded joint on its tensile properties and permanent dynamic strength",the author work by Ivica Camagic, Predrag Zivkovic, Slobodan Makragic, Mladen Radojkovic and Aleksandar Radovic part of research within the project OI 174001 Dynamics of hybrid systems with complex structures. Mechanics of materials (01.01.2011-31.12.2016), Faculty of Technical Sciences University of Pristina residing in Kosovska Mitrovica, conducted at the Military Technical Institute in Belgrade, represents the result of the regular teaching activities at the faculty as well as the lecturer involvement in scientific research projects and their contribution to the development of scientific research activity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Camagic I, Vasic N, Jovic S, Burzic Z, Sedmak A. Influence of temperature and exploitation time on tensile properties and microstructure of specific welded joint zones, Fifth Serbian (30th YU) Congress on Theoretical and Applied Mechanics, Arandjelovac, Serbia; 2015.

2. Ivica Camagic, Nemanja Vasic, Bogdan Cirkovic, Zijah Burzic, Aleksandar Sedmak, Aleksandar Radovic. Influence of temperature and exploitation period on fatigue crack growth parameters in different regions of welded joints. Frattura ed Integrita Strutturale. 2016;10(36):1-7.

   ISSN: 1971-8993.

   DOI: 10.3221/IGF-ESIS.36.01,

   GRUPPOITALIANOFRATTURA,
   VIAGDIBIASIO, CASSINO, ITALY, 03043.
3. Ivica Camagic. Investigation of the effects of exploitation conditions on the structural life and integrity assessment of pressure vessels for high temperatures (in Serbian), doctoral thesis, Faculty of Technical Sciences, Kosovska Mitrovica; 2013.
4. Camagic I, Burzic Z, Sedmak A, Dascau H, Milovic L. Temperature effect on a low-alloyed steel welded joints tensile properties, The 3rd IIW South – East European Welding Congress, “Welding & Joining Technologies for a Sustainable Development & Environment”, Timisoara, Romania, Proceedings; June 3-5. 2015; 77-81.

   ISBN: 978-606-554-955-5.
5. Burzic Z, Camagic I, Sedmak A. Fatigue strength of a low-alloyed steel welded joints, The 3rd IIW South – East European Welding Congress, “Welding & Joining Technologies for a Sustainable Development & Environment”, Timisoara, Romania, Proceedings; June 3-5. 2015; 135-38.

   ISBN: 978-606-554-955-5.
6. 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.
7. SRPS EN ISO 9692-2:2008, Welding and allied processes - Joint preparation - Part 2: Submerged arc welding of steels (ISO 9692-2:1998); 2008.
8. SRPS EN 895:2008, Destructive tests on welds in metallic materials - Transverse tensile test; 2008.
9. SRPS EN 10002-1, Metallic materials - Tensile testing - Part 1: Method of test (at ambient temperature); 1996.
10. SRPS EN 10002-5, Metallic materials - Tensile testing - Part 5: Method of Testing at elevated temperature; 1997.
11. Magudeeswaran G, Balasubramanian V, Madhusudhan Reddy G, Balasubramaian TS. Effect of welding processes and consumables on tensile and impact properties of high strength quenched and tempered steel joints. J Iron Steel Res Inter. 2008;15(6):87-94.
12. Lakshminarayanan AK, Balasubramanian V. An assessment of microstructure, hardness, tensile and impact strength of friction stir welded ferritic stainless steel joints. Mater Des. 2010;31:4592-00.
13. Xu Lianghong, Zhang Jun, Chen Yanqing. Effect of heat input on the microstructure and mechanical properties of 07MnCrMoVR weld joints. Chinese Journal of Mechanical Engineering, Published Electronically on December; 2010.
14. Dobrzanski J, Zielinski A, Krzton H. Mechanical properties and structure of the Cr-Mo-V low-alloyed steel after long-term service in creep condition. Journal of Achievements in Materials and Manufacturing Engineering. 2007;23(1):39-42.
15. ASTM E466-89. Standard practice for conducting constant amplitude axial fatigue tests of metallic materials. Annual Book of ASTM Standards. 1989;03.01: 571.
16. ASTM E467-89. Standard practice for verification of constant amplitude dynamic loads in an axial load fatigue testing machine. Annual Book of ASTM Standards. 1989;03.01:577.
17. ASTM E468-89. Standard practice for presentation of constant amplitude fatigue test results for metallic materials. Annual Book of ASTM Standards. 1989;03.01:582.
18. Burzic Z, Gaco DZ, Islamovic F, Burzic M, Bajramovic E. The effect of variable loading on integrity of a welded joint of high Alloy-Steel X20, Metalurgija. 2013; 52(2):181-84.

    ISSN: 0543-5846 (printed edition),

    ISSN: 1334-2576 (Online).
19. Verreman Y, Bailon JP, Masounave J. Fatigue life prediction of welded joints a reassessment, fatigue fract. Engng. Mater. Struct. 1987;10(1):17-36.
20. Miller KJ. The behaviour of short fatigue cracks and their initiation part I and part II,

Fatigue Fract. Engng. Mater. Struct. 1987; 10(1):75-91 and 2, 93-13.

21. Burzic Z. Savremene metode provere mehanicko-tehnoloskih osobina zavarenih spojeva-Deo 2", Zavarivanje i zavarene konstrukcije. Serbian. 2002;47(3):151-58.

22. Burzic M, Burzic Z, Kurai J. Fatigue behaviour of alloyed steel for high temperature, first Serbian (26th YU) Congress on Theoretical and Applied Mechanics, Kopaonik, Serbia. 2007;1085-90.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/16136