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WELDABILITY INVESTIGATION STEEL P 91 BY WELD THERMAL CYCLE SIMULATION

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Preliminary Note – Prethodno priopćenje

This paper elaborates results of hardness and impact energy of thermal cycle simulated specimens of high-alloy steel P 91 and their dependence on cooling time from 800 to 500 °C. Results were obtained by measuring hardness HV 1 and by experimental testing of Charpy notched specimens. Metallographic analysis of samples was performed on scanning electronic microscope.

Key words: welding, P 91, hardness, impact energy, cooling

INTRODUCTION

High–alloy steels are used in modern thermal power plants that operate on fossil fuels under high temperatures and aggressive gasses. Conventional Cr-Mo steels are not resistant to creep and oxidation at a temperature higher than 600 °C. Therefore, high-alloy steels (P 91 and P 92) have been recently used in modern thermal power plants, since they can be used at temperatures up to 600 - 625 °C, thus enhancing energy exploitation and lowering carbon dioxide emissions if compared to conventional thermal power plants. [1]. Advantage of using high-strength steels such as P 91 in thermal power plants is found in its reduced wall thickness, which affects lowering of costs of welding and transport, and facilitates environment preservation and construction of more compact structures. However, positive properties of steel are sometimes not expressed because in the heat affected zone (HAZ) of welds there may be faults caused by type IV creep cracking (Figure 1). Cracks of type I occur in weld metal (WM), cracks of type II can be initiated in weld metal and spread within WM, or outside of the zone, into HAZ.

Cracks of the type III occur in coarse grained HAZ, and cracks of type IV occur only in welded steel joints resistant to creep. They are characterized by quicker occurrence of creep voids in fine-grained HAZ (FGHAZ) and in intercritical area (ICHAZ). This leads to failure more quicker than in non-welded material. [2,3]

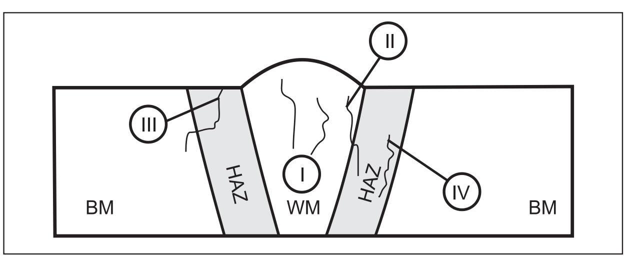

Figure 1 Classification of cracks in welded joints (BM - base material; HAZ - heat affected zone; WM – weld metal)

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RESEARCH METHOD

There are not many data about cracks of type IV and influence of heat input during welding and pre-heating temperature on creep. The authors carried out research on thermal cycle simulator in the Laboratory for welding of the Faculty of Mechanical Engineering in Maribor, by testing various cooling times from 800 to 500 °C ($t_{8/5}$), i.e. cooling speed and its impact on hardness and toughness of high-alloy steel P 91. The impact of cooling speed on hardness and toughness of single and double pass welds of tested steel shall be emphasized. Experiment was performed on martensitic steel P91 (9Cr1MoNbV) micro-alloyed by vanadium, niobium and nitrogen and accepted by the standard A335 as a steel for thick walled pipes [4].

Chemical composition of base material P91 is presented in the Table 1. Mechanical properties are overviewed in the Table 2.

Table 1 **Composition of P 91 steel [5]**

C	0,12
Si	0,16
Mn	0,41
P	0,016
S	0,006
Cr	8,85
Mo	0,48
Ni	0,17
Nb/Cb	0,067
V	0,195
Al	0,004
N	0,045
W	1,66
B	0,0025

Table 2 **Mechanical properties of P 91 steel [5]**

Yield Strength $R_{p0,2}$ / MPa		563
Tensile Strength R_m / MPa		732
Elongation A_5 / %		21
Toughness, K_V / J longitudinally	at 20 °C	158
	at 20 °C	151
	at 20 °C	160

Samples of 8 x 8 x 55 mm and 11 x 11 x 55 mm were cut out of P 91 steel seamless pipe ϕ 324 mm, of 39 mm wall thickness (pipe length was 1 680 mm). Some samples were used for recording dilation diagram and analysis of microstructure on optical scanning microscope. Other samples were used for measuring of hardness and for testing of impact energy on instrumented Charpy device. Figure 2 presents TTT diagram for P91 steel, and Figure 3 shows base material microstructure.

Structure of base material is tempered martensite of hardness 230 - 270 HV1.

Characteristic temperatures for welded steel structure are presented in Figure 4. It should be pointed out that there was no subsequent heat treatment after the weld thermal cycle simulation carried out by the authors.

RESEARCH RESULTS

Results of hardness testing

Testing of hardness HV1 was carried out on the testing machine shown on Figure 5.

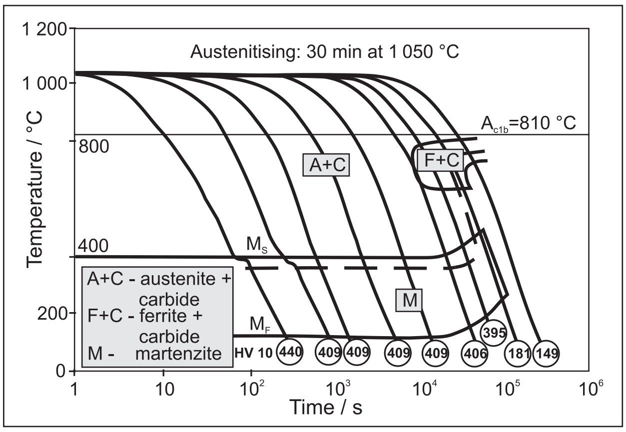

Figure 2 TTT - diagram for P 91 steel [2]

Figure 3 Base material structure P91 (magnified 200 x)

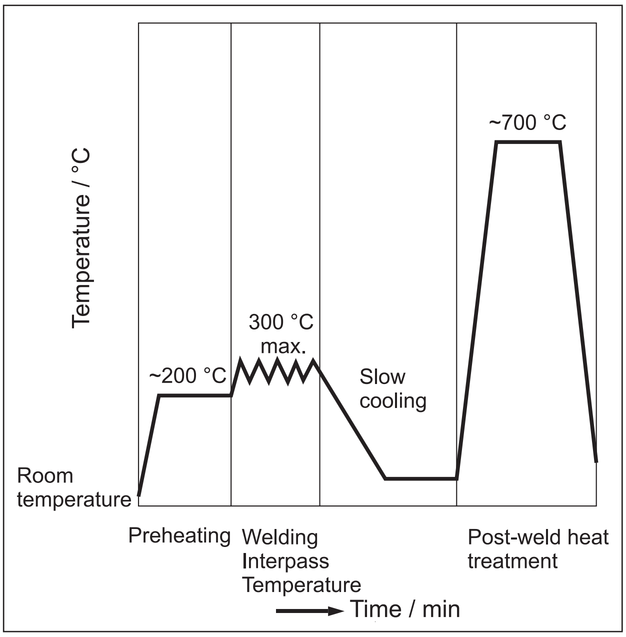

Figure 4 Characteristic temperatures for welded P 91 steel structure

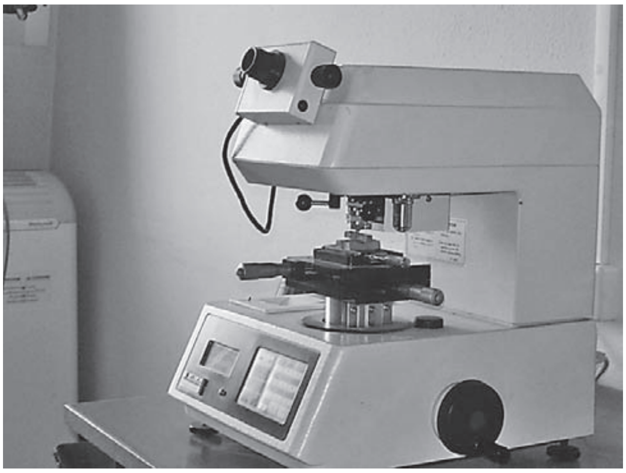

Figure 5 Hardness testing machine Shimadzu 2 000

Diagram of changes in hardness values with changes of simulation temperature (1 300, 1 200, 1 100, 1 000, 950, 925, 900, 875, 850, 825, 800, 750, 700, 600 °C) is presented on Figure 6.

As concluded from the diagram, there are no changes in hardness at a simulation temperature up to 800 °C.

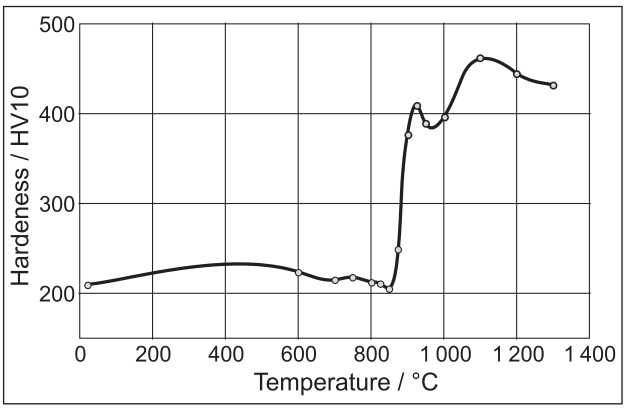

Figure 6 Diagram of hardness values as depending on simulation temperature and cooling time $t_{8/5}$

Slight change in hardness occurred at a simulation temperature of 900 °C. Along with increasing simulation temperature of the second cycle above 900 °C, hardness increases to reach the maximum at a temperature of 1 350 °C what is in expectation with [6].

Results of testing impact energy

Impact energy was tested by the Charpy-V notch method on instrumented Charpy hammer, by dividing energy into two components, i.e. energy needed for fracture occurrence and energy needed for fracture spreading.

Testing of impact energy was done at a temperature of 20 °C. Testing within $t_{8/5}$= 10 s are presented on Figures 7 and 8. There were three tests performed for each simulation temperature.

Figure 7 indicates that impact energy was lower at lower temperatures. There were no changes in values of impact energy at a simulation temperature of 700 and 800 °C Simulation temperature of 900 °C caused more intensive reduce in toughness, and above that temperature there was slight increase of impact energy, which was a consequence of structural changes that occurred in simulation of weld thermal cycle. Slight reduce in impact energy occurred again within simulation of weld thermal cycle at 1 350 °C. Figure 8 presents portions of ductile fracture for samples of Figure 7.

As seen in the diagram, percentage of ductile fracture was the highest at a temperature of weld thermal cycle simulation at 800 °C. The same values of ductile

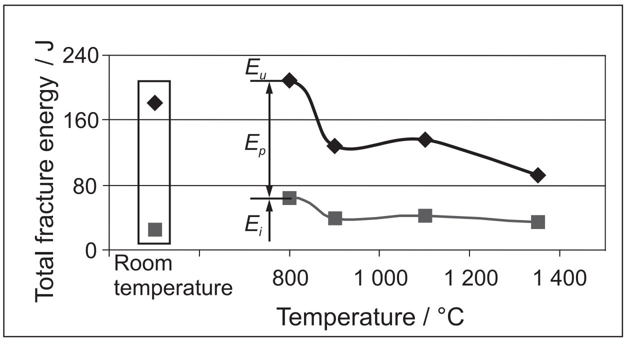

Figure 7 Total fracture energy E_u at a temperature of 20 °C and difference between total fracture energy, initiation energy E_i and propagation energy E_p of fracture

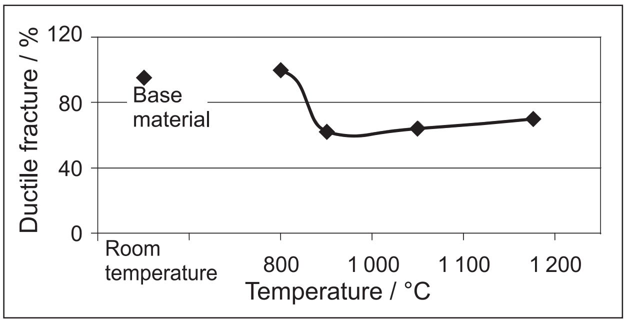

Figure 8 Ductile fracture percentage depending on maximum thermal cycle temperature for samples of Figure 7. (testing performed at room temperature, samples without heat treatment)

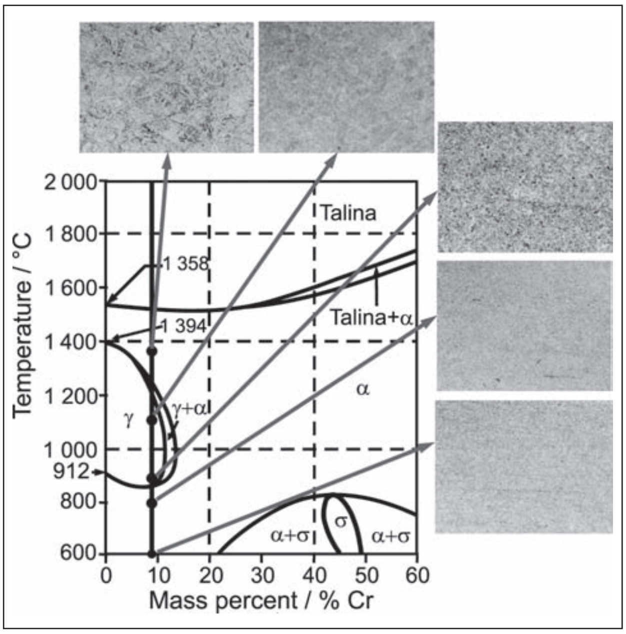

Figure 9 Overview of structures after weld thermal cycle simulation at temperatures 600, 800, 900, 1 100 and 1 350 °C

fracture percentage were obtained also for base material. Structures obtained by weld thermal cycle simulation are presented at Figure 9. By observing structures in electronic scanning microscope it was noticed that acicular (*needle*-shaped) martensite existed at a weld thermal cycle simulation of 1 350 °C. That structure is fragile and values of impact energy are reduced. Lowering of simulation temperature to 900 °C causes occurrence of tempered martensite, a structure with higher impact energy values.

CONCLUSION

Steels 9 – 12% Cr such as P 91 are used mostly in the last decade for pipelines and pipes operating at a service temperature of 600 – 625 °C. Weld thermal cycle simulation can be used for optimizing the welding technology since it enables some mechanical testing for properties that cannot be made on real welded joints because of small width of HAZ. Weld thermal cycle simulation facilitates gaining of results needed for optimization of high-alloy steel welding parameters, which can be further used for real-conditioned welding. Performed testing indicated the highest values for hardness at a simulation temperature of the second cycle of 1 100°C. The lowest values for impact energy were obtained at a weld thermal cycle simulation temperature of 1 350 °C, being in dependence with *needle*-shaped martensite, since conditioned by hardness from 380 to 420 HV (Figure 6). Testing of heat treatment shall be presented in a separate research on the stated steel group.

Acknowledgement

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