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BEHAVIOUR OF P91 STEEL SIMULATED HAZ AT 600°C

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ABSTRACT
An investigation has been carried out into the behaviour of type IV cracks region in heat affected zone (HAZ) of P91 steel at 600°C. Microstructure zones where type IV failures may occur have been studied in details. Results are reported on the simulated specimens 11x11x70 mm tested at operating temperature. The results of comparison of mechanical characteristics and microstructure have been analysed using two types of specimens: with postweld heat treatment (PWHT) and without PWHT. It has been found the presence of precipitates at the grain boundaries in simulated type IV zone of HAZ exposed to subsequent PWHT.
Keywords: P91 steel, simulated HAZ, ICHAZ, PWHT.

1. INTRODUCTION
Even though there is no scientific consensus on the causes and final effects of global warming, the most commonly accepted theory is the one according to which global warming is the result of the carbon-dioxide emission and methane resulting from fossil fuel power plants and the increased emission of which in the air results to the green-house effect in the atmosphere. Thus, the need to reduce CO_2 emission gave further motive to increase the efficiency of fossil fuel power plants. Having in mind that the plant efficiency is a powerful function of the steam temperature and pressure, scientists world wide are developing high temperature steel fit for those ultrasupercritical steam conditions. As a result, nowadays the steam temperatures of the most efficient fossil power plants are now in the 600°C range, with steam pressure up to 35 MPa, representing an increase of about 60°C in the last 30 years.
This paper presents results of mechanical testing of P91 steel performed at operating temperature of 600ºC and microstructural investigations by light microscopy analysis and electron microscopy.

2. MATERIAL AND EXPERIMENTS
For present investigation, the 9CrMoV (X 10CrMoVNb 9-1, Grade P91) hot rolled pipe with inner diameter of Ø 292 mm and a wall thickness of 14 mm was used. The hardness and the mean value of the prior austenite grain size were 230 (HV1) and 37.8 μm, respectively. The chemical composition of material tested is shown in Table 1.

Table 1. Chemical composition of the investigated material (wt %).

Material	C	Si	Mn	P	S	Cr	Ni	Mo	V	Nb
As-received material	0.120	0.289	0.396	0.009	0.002	8.04	0.080	0.850	0.242	0.073

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A series of thermal simulations using thermal simulator SMITWELD were carried out to produce microstructures appearing in the actual HAZ of the welded pipe. To do this the specimens of 11x11x70 mm were used. Different heat affected zone (HAZ) were obtained by simulation of single-pass welding at austenitizing temperatures of 1386°C, 1300°C, 1250°C up to 950°C, graded by 50°C, 925°C, 900°C and 850°C and with cooling time between 800°C and 500°C, $t_{8/5}$, 40 sec. The material was then subjected to the post weld heat treatment (PWHT) by tempering at 730°C for 1 hour followed by air cooling. Detailed simulation procedure is given in [3]. Typical temperatures of transformation during the welding cycle were determined from dilatometric curve, Fig 1, and these are A_{c1}=835°C and A_{c3}=930°C. Heating rate was 53.8 °C/s. During cooling, formation of martensite started at temperature of 375°C, while martensite transformation completed at temperature of 210°C. Martensite formation was preceded by separation of a smaller quantity of bainite, Fig 2.

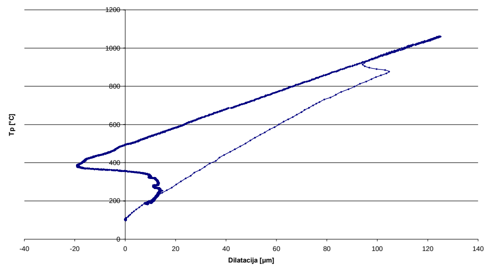


Figure 1. Dilatometric curve for P91 steel obtained at simulation temperature of 1050°C.

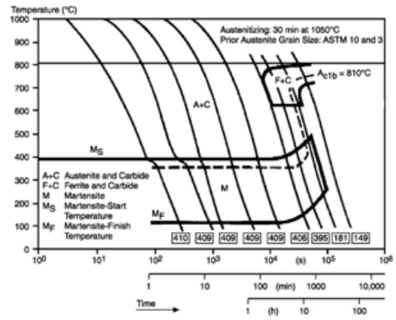
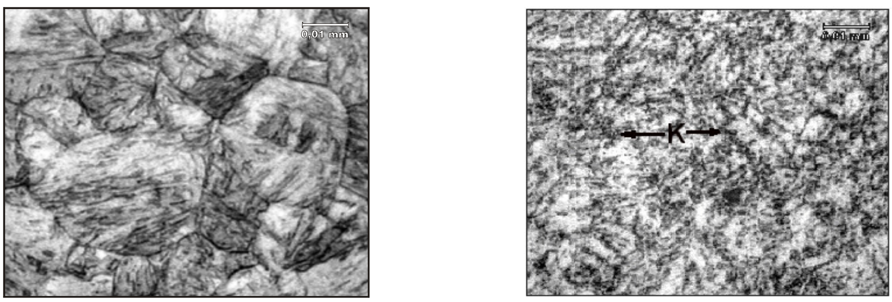


Figure 2. Time-temperature-transformation diagram of P91 steel.

Microstructures of simulated coarse grained HAZ (CGHAZ) and intercritical HAZ (ICHAZ) are shown in Fig.3.



a) T_p= 1386°C b) T_p= 925°C

Figure 3. Microstructure from light microscope of a) simulated CGHAZ at 1386°C and b) simulated ICHAZ at 925ºC (K-carbides)

3. RESULTS AND DISSCUSSION

Simulations show that both hardness and prior austenite grain size increased with increasing austenitizing temperature above 850ºC, Fig 4. The lowest hardness of 210 was found at the austenitizing temperature 925ºC, and this is the temperature which represents the ICHAZ and was chosen as typical for examination as possible location of type IV cracking formation to which welded joints of those steels class are susceptible.

To describe more precise the behaviour of material in ICHAZ, tensile and instrumented Charpy-V impact tests were performed. Mechanical properties of parent material and of samples simulated the HAZ region at 925ºC with PWHT and without PWHT, performed at 600ºC and obtained by tensile tests are given in Table 2.

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Figure 5 presents the impact energy curves for the PM and simulated specimens (SS) tested at operating temperature of 600ºC, [4].

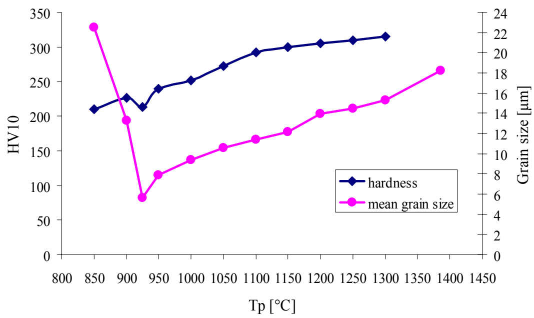

Figure 4 Distribution of hardness and mean grain size of the material tested

Table 2. Mechanical properties of material tested.

Material tested	T [ºC]	$R_{p0,2}$ [MPa]	R_m [MPa]	HV5	E_t [J]	E_i [J]	E_p [J]
PM	600	231	314		210	43	167
925ºC, PWHT	600	295	363		231	23	208
925ºC, no PWHT	600	407	498		194	29	165

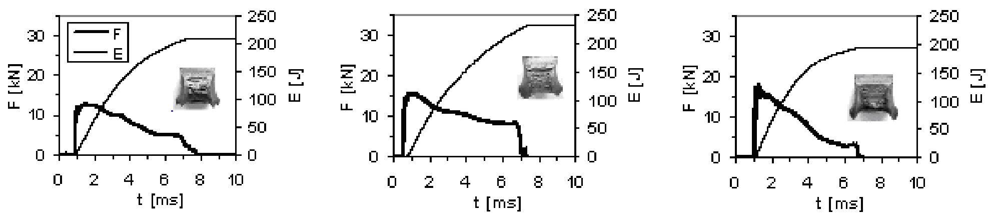

Figure 5. Maximum impact force and toughness of the PM, SS 925ºC with PWHT and no PWHT.

Comparison of the PM properties and the properties of the specimen simulated at 925ºC with PWHT, both examined at the operating temperature of 600ºC indicates that total energy E_t and crack propagation energy E_p are both higher in the case of the specimen simulated at 925ºC with PWHT than in the case of the considered PM. Crack initiation energy E_i and maximum impact force are practically the same in both cases.

Comparison of the PM properties and properties of the specimen simulated at 925ºC, without PWHT, both examined at 600ºC, indicates that total energy E_t, crack initiation energy E_i and crack propagation energy E_p are all somewhat higher in the case of the PM. However, the maximum impact force of the PM is lower than the same parameter recorded for the simulation specimen, but without significant difference between the two values. The specimen simulated at 925ºC without PWHT has been tempered at lower temperature and although characterized by smaller grain size, the two effects compensated one another.

TEM image of simulated specimens 925ºC with PWHT, [6], are shown in Fig. 6. The microstructure of simulated specimen 925ºC with PWHT is characterized by segregated carbides which assume a more equiaxial shape and are present not only along the lath boundaries, but in the laths as well, Fig. 6 (a) and (b). The lath boundaries are clearly separated, indicating that there are no stresses in the grains. Equiaxial grains occur, followed by the gradual solution of martensite laths, and noticeable dislocations at the boundaries, Fig. 6 (c). Fine precipitates are observed at the grain boundary, Fig. 6 (d).

4. CONCLUSIONS

ICHAZ represents the weakest microstructure with respect to creep resistance. Performed analysis has shown that the finest grains were formed at the simulation temperature of 925ºC.

The fractographic analysis has indicated partially brittle-like behaviour of material in the simulation specimens without PWHT. The observed behaviour indicates that simulation specimens without PWHT could be prone to brittle fracture due to residual tensile stresses or metallurgical flaws, specially during the cold start or cooling of a power unit (particularly during the unit outage).

The test results revealed the presence of precipitates at the grain boundaries in specimens simulated at 925°C with PWHT. These precipitates interfered with plastic deformation processes at grain boundaries during creep by increasing the resistance against plastic deformation at grain boundaries and so increasing the creep resistance.

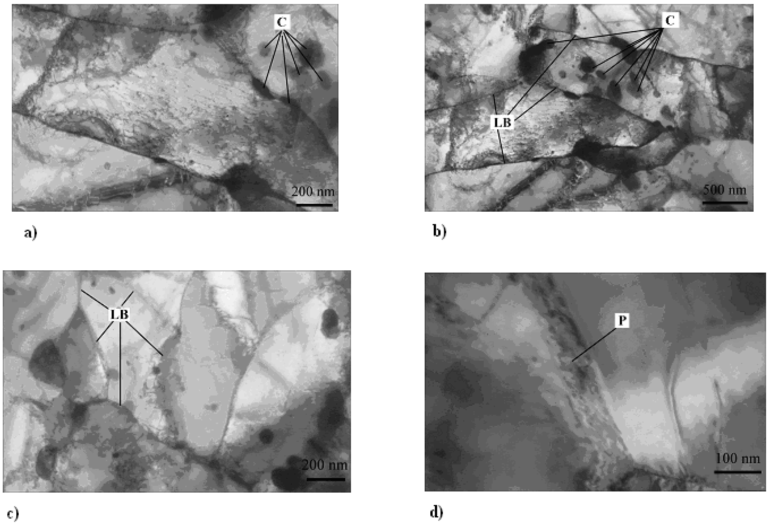

Figure 6 Simulated specimen microstructure 925ºC with PWHT obtained by TEM (a) and (b) carbides in the laths, (c) occurrence of the equiaxial grains and the disappearance of martensite laths, (d) boundary precipitate(C-carbide particle; LB-lath boundary; P-precipitation).

5. ACKNOWLEDGEMENTS

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