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The Influence of Gas Heating on Material Properties of P92 Steel During Boiler Tube Alignment

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Preliminary note

The pipes and the pipe walls are of the utmost importance to all power plant facilities. Under exploitation, they are subjected to effects of aggressive media, high temperature corrosion and possible mechanical damage. Consequently, special attention is paid to the control of material properties during the power plant construction in order to minimize the risk of flaws or failures.
In this paper, the influence of gas heating on the structure and properties of P 92 martensite steel is examined, as occurring during tube alignment. The experiments have been performed on the polished and shot – blasted surfaces, and the obtained results have been compared with the values of specimens with the same surface treatment, but without heat treatment.

Utjecaj ravnanja plinskim zagrijavanjem na svojstva materijala kotlovske cijevi P92

Prethodno priopćenje

Cijevi i cijevni zidovi od vitalne su važnosti kod energetskih postrojenja. Tijekom eksploatacije izloženi su djelovanju agresivnih medija, visokotemperaturnoj koroziji i mogućim mehaničkim oštećenjima. Zbog toga se posebno vodi računa o kontroli svojstava materijala pri gradnji energetskih postrojenja kako bi se umanjile mogućnosti pojave pogrješke ili otkaza.
U ovom radu eksperimentalno je istražen utjecaj ravnanja plinskim zagrijavanjem na strukturu i svojstva martenzitnog čelika P92. Ispitivanja su provedena na poliranim i na sačmarenim površinama, a rezultati su uspoređeni s rezultatima toplinski netretiranog čelika istih stanja površina.

1. Introduction

Worldwide industrial development implies progressive energy demands. With natural energy sources like coal, oil and natural gas reaching their exploitation limits, global economy shifts its focus towards combined power plant concepts.

Here, energy production is based on the incineration of waste in combination with other fuels. The concept offers multiple benefits since it secures energy while simultaneously serving waste disposal purposes.

The incineration is a high temperature process. The produced flue gases are very aggressive, thus facilities must meet the high criteria with respect to material quality and technology solutions.

All modern power plants require excellent mechanical and technological properties of selected materials at minimal weight and thickness of the tube walls. To meet those demands, steels for so-called supercritical performance envelopes are being designed. In terms of temperature and pressure, steam of above 650 ºC and 350 bar is considered supercritical. Reflecting all outlined requirements, chrome alloy steels such as P91 and P92 are increasingly selected in the power plant design [1, 3].

1.1. P91 and P92 martensite steel types

Boiler steels P91 and P92 are designed around the upper limit of the durability envelope known as USC (Ultra Super Critical). P92 steel is a modification of X9CrMoVNb (P91) and thus specified as X10CrWMoVNb9-2 with tungsten and micro alloy boron added at lowered molybdenum content share. This chemical composition partly inhibits carbide transformation and facilitates diffusion [2, 5].

Symbols/Oznake

t	- wall thickness, mm - debljina stjenke	HV0,1	- hardness - tvrdoća
ϑ_{ra}	- gas heating temperature, °C - temperatura plinskog zagrijavanja		

P92 steel has a high creep margin; it is resistant to intercrystalline corrosion, erosion and to the formation of cavities.

For the same exploitation parameters, P92 allows a 30 % decrease in tube wall thickness compared to P91 steel (Figure 1) [2].

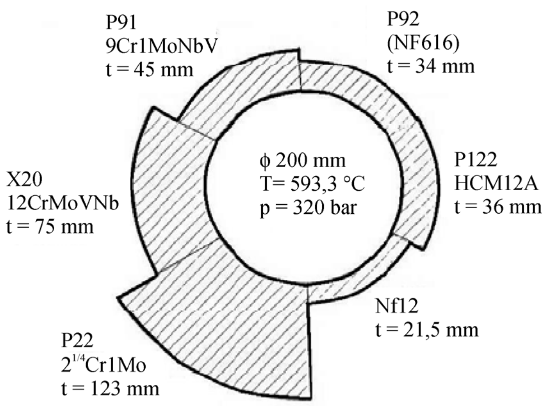


Figure 1. Comparison of wall thickness for different steel types under the same design parameters [2]

Slika 1. Usporedba debljine stijenke cijevi za različite čelike pri istim konstrukcijskim uvjetima [2]

1.2. Heat treatment in boiler construction

Although boiler steels are designed to be heat resistant, the mechanisms and values of heat input must be controlled. Consequently, the correct choice of the heat treatment method adds to the very selection of material. The optimal heat treatment secures structural homogeneity and improves material properties both before and after the technological processing steps (mostly welding).

The most common methods of heat treatment in boiler constructions are: annealing (to relieve residual stresses), hardening, tempering, in combination with thermal methods of surface treatment, such as preheating and heat alignment.

Annealing methods are used to correct the flaws that originate from metal or alloy processing. Among these methods, stress reduction annealing, recrystallization annealing and normalizing annealing are frequently chosen.

The purpose of hardening is to transform the steel structure to martensite while cooling the metal from its austenitisation temperature, thus securing homogeneous surface hardness across the material.

Tempering is performed after hardening by heating the material to a temperature below A1 to increase martensite toughness and to decrease residual stresses.

Preheating implies heating the welding zone to a predefined temperature prior to the welding operation and securing that temperature throughout the sequence. The method prevents cold cracking and decreases both residual stresses and the content of diffused hydrogen in the weld.

Heat alignment is a method of correcting deformation zones on a construction by means of local heating. When heated up locally and suddenly, steel material tends to expand, while its colder surrounding material prevents that. Ultimately, that plastic compression of the heated zone aligns the deformation [4, 6].

2. Experimental Work

The experiment was designed to simulate gas heating alignment of a chamber tube.

The outer diameter of the tube was 168 mm and the wall thickness 16 mm. The chamber was fabricated from martensite steel X10CrWMoVNb9-2 (W.Nr.1.4901; T/P92, hereinafter P92). Its chemical composition is given in Table 1.

Table 1. Chemical composition of P92 martensite steel, %

Tablica 1. Kemijski sastav martenzitnog čelika P92, %

C	Si	Mn	P	S	Ni	Cr
0,09	0,21	0,46	0,015	0,002	0,26	8,84
Mo	**W**	**V**	**Nb**	**Al**	**N**	**Fe**
0,47	1,72	0,21	0,07	0,04	0,06	balanced

The goal of this experiment was to determine the gas heating influence on the structure and steel properties of a polished or shot-blasted P92 chamber tube surface. Figure 2 shows the plan of surface preparation and heat treatment for a specimen length of 250 mm.

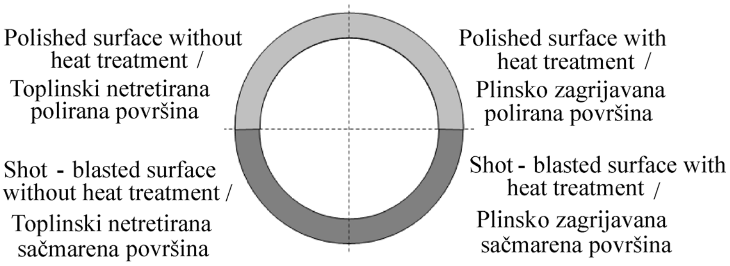


Figure 2. Plan of surface preparation and heat treatment for a chamber tube specimen

Slika 2. Plan pripreme površine i provedbe toplinske obradbe na uzorku cijevi komore

Table 2 shows the experiment plan with defined parameters and specimen marks.

Table 2. Experiment plan

Tablica 2. Plan pokusa

Specimen mark / Oznaka ispitnog Uzorak	Surface treatment / Stanje površine	Heat treatment / Toplinska obrada	Testing method / Vrsta ispitivanja
1.1	Polished / Polirana	Not treated / Toplinski netretiran	- bending / savijanje - metallographic / metalografija - hardness HV0,1 / tvrdoća HV0,1
1.2	Polished / Polirana	Gas heating, / Plinsko zagrijavanje ϑ_{ra}=730-740 °C	
2.1	Shot-blasted / Sačmaren	Not treated / Toplinski netretiran	
2.2	Shot-blasted / Sačmaren	Gas heating, / Plinsko zagrijavanje ϑ_{ra}=730-740 °C	

2.1. Heat treatment

The experiment was designed to simulate gas heating alignment of a chamber tube as a method of thermal surface preparation.

One segment of the polished and shot-blasted end of the chamber tube was heated up to 730 °C using a gas burner with a mixture of butane (1,5 bar) and oxygen (7,5 bar). The width of the heating zone was 20 mm, the distance between the burner nozzle and the specimen surface was 15 to 20 mm (flame on metal), and the heating speed was 400 – 500 cm/min (with oxidation flame).

The other polished and shot-basted segment of the same specimen end was not heat treated.

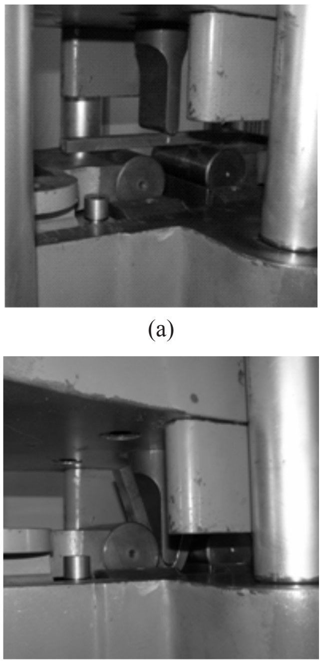
2.2. Bending test

The purpose of the bending test was to investigate the effect of gas heating on metal deformability.

The bending was performed according to the standard HRN EN 910, using triple point load – the thorn with a 15 mm diameter acts mid-span between the two specimen supports. The specimen fixture in the test unit and the appearance of the specimen at maximal bending are illustrated in Figure 3.

The bent specimens (Figure 4) were inspected in the zone of maximal tensile deformation using a magnification glass of 10× in order to establish the appearance of porosity or micro cracks.

None of the examined specimens exhibited any porosity or micro cracks.



(a)

(b)

Figure 3. Specimen fixture in the test unit (a) and maximal bending position (b)

Slika 3. Način postavljanja epruveta u uređaj (a) i krajnji položaj savijanja (b)

2.3. Metallographic examinations

Following the experiment plan (Table 2) and specific preparation of the specimens, the structural state of their boundary layers was examined using an optical microscope and a magnification ratio of 100×. Figures 5 to 7 show the metallographic images for the respective specimens.

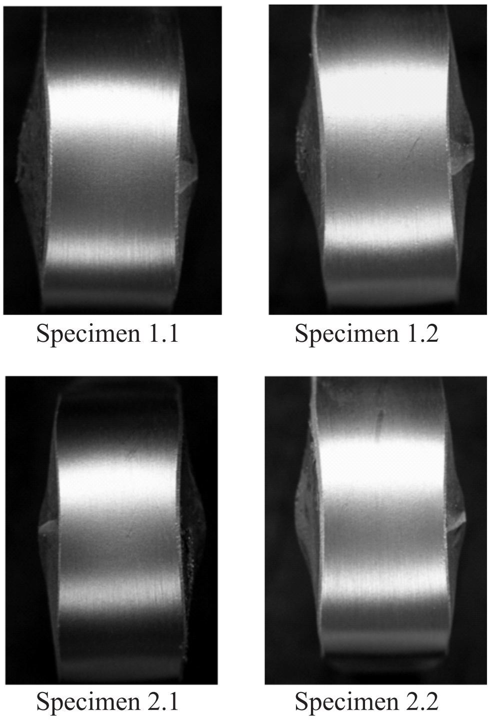
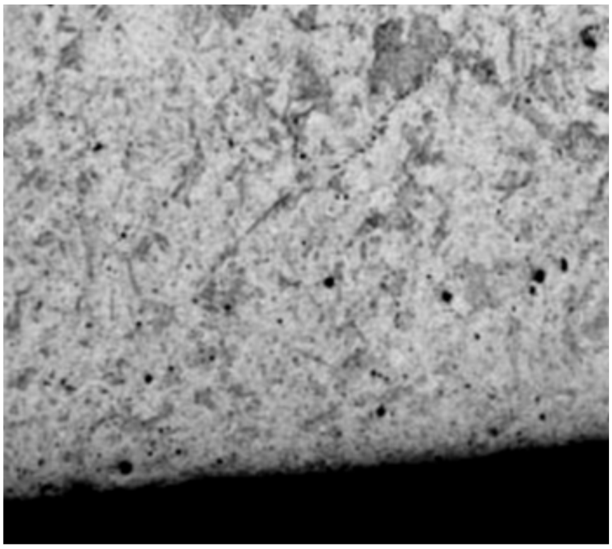


Figure 4. Bent P92 steel specimens

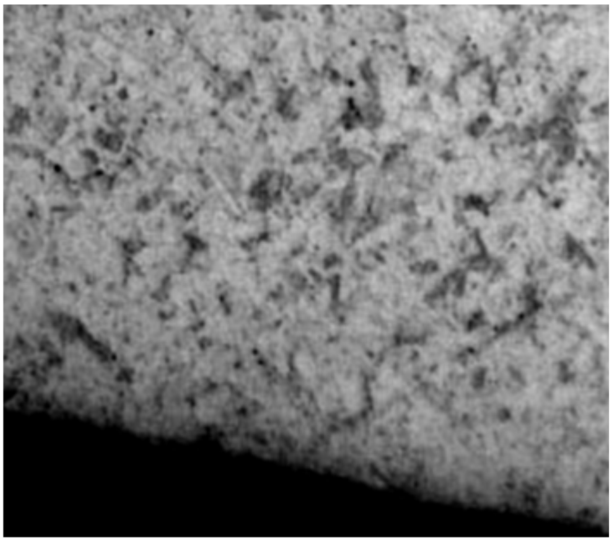
Slika 4. Savijeni ispitni uzorci čelika P92



Etching acc. Adler magnification 100×

Figure 5. Specimen 1.1

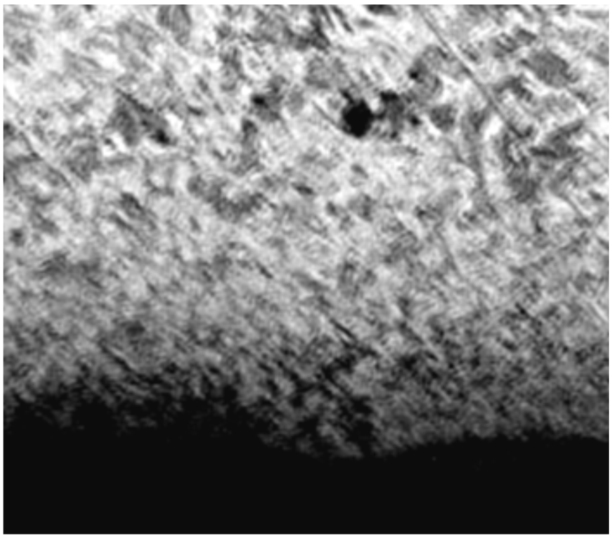
Slika 5. Uzorak 1.1



Etching acc. Adler magnification 100×

Figure 6. Specimen 1.2

Slika 6. Uzorak 1.2

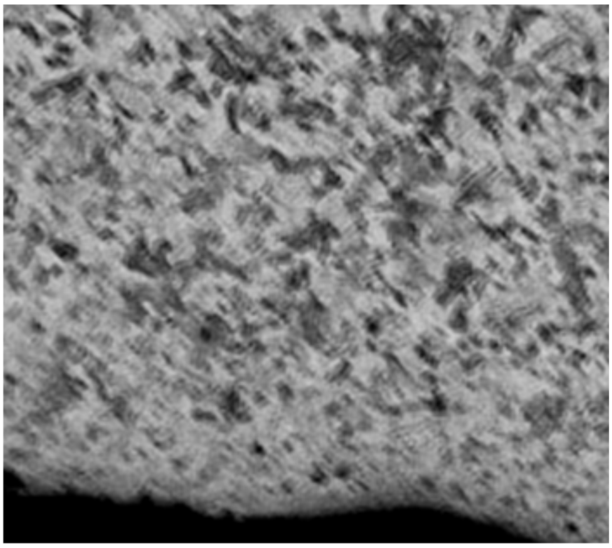


Etching acc. Adler magnification 100×

Figure 7. Specimen 2.1

Slika 7. Uzorak 2.1

The metallographic images of the heated specimens (Figures 6 and 8) do not exhibit any visible structural transformations of the boundary layer, when compared to thermally untreated specimens (Figures 5 and 7). The surface unevenness as a characteristic of the specimens 2.1 and 2.2 is to be attributed to shot-blasting during the preparation sequence.



Etching acc. Adler magnification 100×

Figure 8. Specimen 2.2

Slika 8. Uzorak 2.2

2.4. Hardness testing per Vickers HV0,1

To test microhardness according to the Vickers HV0,1 method, the polished specimens were used and a load of 1 N was applied.

The results of this test are given in Table 3.

Table 3. Measured hardness as per HV0,1 method

Tablica 3. Tablica izmjerenih tvrdoća HV0,1

Distance between measuring point and outer edge, mm / Udaljenost mjernog mjesta od vanjskog ruba, mm	Specimen No. / Broj uzorka			
	1.1	1.2	2.1	2.2
	Hardness HV0,1 / Tvrdoća HV0,1			
0,1	223	181	226	182
0,2	225	182	223	182
0,3	206	195	206	191
0,4	218	196	205	186
0,5	214	200	210	182
0,6	205	199	206	189
0,7	220	192	221	181
0,8	205	189	206	191
0,9	215	193	219	194
1	210	181	217	196
1,5	202	199	206	193
2	195	194	200	195
2,5	196	195	195	196
3	195	194	196	195

Figures 9 and 10 show diagrams of measured cross-cut hardness of the chamber tube wall for two differently heat treated specimens.

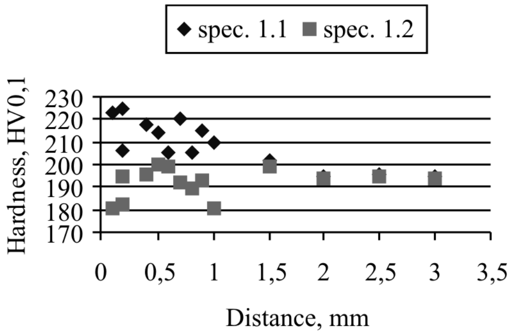


Figure 9. Measured cross-cut hardness for polished specimens 1.1 and 1.2

Slika 9. Izmjerene tvrdoće po presjeku poliranih uzorka 1.1 i 1.2

Figure 9 shows a comparison of measurement results for the specimens 1.1 (polished, not heat treated) and 1.2 (polished, heat treated).

Figure 10 shows a comparison of measurement results for the specimens 2.1 (shot-blasted, not heat treated) and 2.2 (shot-blasted, heat treated).

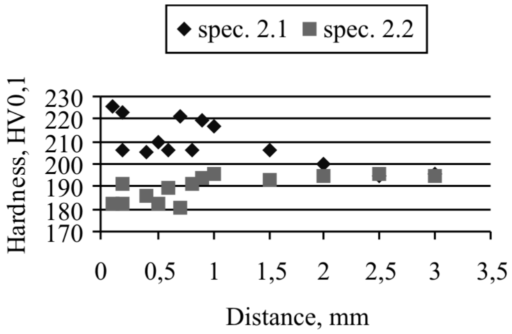


Figure 10. Measured cross-cut hardness for shot-blasted specimens 2.1 and 2.2

Slika 10. Izmjerene tvrdoće po presjeku sačmarenih uzoraka 2.1 i 2.2

Both figures indicate a hardness drop up to the depth of 1 mm for heat treated specimens, as opposed to those not heat treated. At a distance above 1 mm, hardness values level out to an average of 195 HV0,1.

Figures 11 and 12 show diagrams of measured cross-cut hardness of the chamber tube wall for two specimens with different surface treatment.

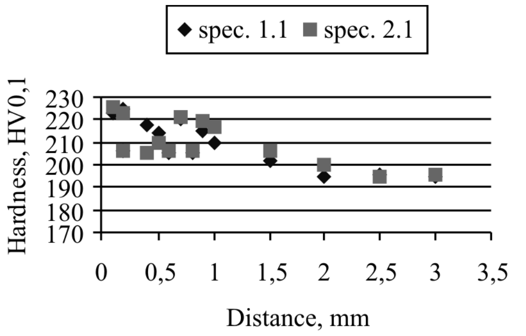


Figure 11. Cross-cut hardness for not heat treated specimens 1.1 and 2.1

Slika 11. Izmjerene tvrdoće po presjeku toplinski netretiranog uzorka 1.1 i 2.1

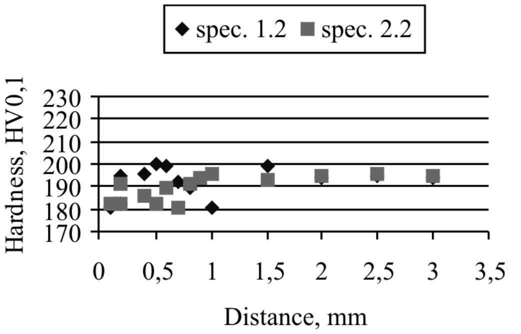


Figure 12. Cross-cut hardness for heat treated specimens 1.2 and 2.2

Slika 12. Izmjerene tvrdoće po presjeku plinsko zagrijavanih uzorka 1.2 i 2.2

Figure 11 shows a comparison of measurement results for the specimens 1.1 (polished, not heat treated) and 2.1 (shot-blasted, not heat treated).

Regardless of the surface treatment, the specimens which were not heat treated exhibit surface hardening up to the depth of 1,5 mm. Deeper in the material, hardness values level out equally to around 195 HV0,1.

Figure 12 shows a comparison of measurement results for the specimens 1.2 (polished, heat treated) and 2.2 (shot-blasted, heat treated).

For the heat treated specimens, hardness drops up to a depth of 1 mm. The drop in value is less significant for the specimen with a polished surface than for the one that was shot-blasted.

3. Conclusions

The experimental research of the influence of superficial heat treatment of chamber tube steel P92 has established the following:

Superficial heat treatment does not affect the bending properties significantly. Regardless of the surface properties, neither porosity nor micro cracks could be detected in the zone of maximal tensile stresses.

An analysis of metallographic images could not detect any structural transformations in the surface layer. During gas heating at relatively high feed rate, the high temperature zone ($\vartheta > A_1$) of possible (visible) structural transformation is notably narrow and remains undetected under the optical microscope. The metallographic analysis of the surface layer only exhibits the surface unevenness related to shot–blasting.

The measured hardness values suggest an effect of gas heating on the boundary layer hardness, which decreases up to the depth of 1 mm. Heat transfer through that layer causes martensite yield and consequently hardness decrease.

The conducted research work, the analysis and the drawn conclusions suggest that material properties and the structure of P92 steel are not affected by the surface properties or superficial gas heating in a significant way.

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