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ZAVARIVANJE 9% Cr ČELIKA OTPORNOG NA PUZANJE NAMENJENOG OPREMI U ELEKTRANAMA

WELDING OF 9% Cr CREEP RESISTING STEELS FOR POWER ENGINEERING EQUIPMENT

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Izvod

U radu je razmatrano zavarivanje nove klase martenzitnih 9% Cr čelika otpornih na puzanje, koji se koriste u energetskim postrojenjima. Ispitivano je zavarivanje cevi od čelika X10CrMoVNb9-1(P91).

Prikazana je tehnologija elektrolučnog zavarivanja i ispitane su karakteristike zavarenog spoja.

Abstract

Welding of the new class of the martensitic, creep resistant steel, with 9% Cr, which are used in power plants, is discussed in this paper. Experimental welding was performed on tubes of X10CrMoVNb9-1(P91) steel.

Welding technology is presented and the properties of welded joint are tested.

UVOD

U izboru materijala namenjenih sistemima visokog pritiska u opremi elektrana, u poslednje vreme martenzitni čelici otporni na puzanje zauzimaju sve važnije mesto. Oni uspešno zamenjuju neke austenitne čelike u bojlerima velikog kapaciteta za dobijanje predgrejane pare. Takav je bio i slučaj 500 MW agregata izrađenog za elektranu Shen Tou Power Plant u Kini.

Sa druge strane, struktura ovog čelika zahteva posebnu pažnju sa aspekta zavarivanja. U ovom radu su prikazani neki problemi pri zavarivanju ovih čelika.

MARTENZITNI ČELICI OTPORNI NA PUZANJE

Martenzitni čelici otporni na puzanje su legirani sa 9-12% Cr. Prvi čelik koji je korišćen u elektranama je bio čelik sa 12% Cr, prema ČSN (STN) standardu oznake 17134. Ekvivalentna oznaka po EN 1007 normi je X20CrMoV121 (Wr.Nr. 1.4922). Značajna količina ugljenika (0.2%) i Cr do 12 % rezultira u dobijanju martenzita sa visokim sadržajem ugljenika, što u toku izrade stvara tehološke probleme, naročito kod zavarivanja.

Dalji intenzivni razvoj i optimizacija čelika legiranih sa 9-12% Cr je omogućio sniženje sadržaja kako ugljenika, tako i hroma, pre svega zahvaljujući legiranju niobijumom. Čelik P91 je razvijen od polaznog 9CrMo čelika, koji je uveden u upotrebu još

INTRODUCTION

Recently martensitic creep resisting steels have achieved an important place in design of material for high exposed pressure system parts of power plant equipment. They are successfully excluded some austenitic steels at the final stages of steam superheaters of boilers of large capacities. This is also the case of 500 MW unit manufactured for Shen Tou Power Plant in China.

However, its structure requires specific care in the view of the welding. Some problems occurring at welding of this steel type are presented in this paper.

CREEP RESISTANT MARTENSITIC STEELS

These steels are 9-12 % chromium alloyed. The first steel used in power engineering was 12 Cr steel known as 17 134 in accordance with ČSN (STN) standard. The European equivalent of this steel is X20CrMoV121 (Wr.Nr. 1.4922). Substantially high carbon content (0.2 %) with Cr content up to 12 % resulted in formation of martensite with high carbon content causing technological problems at processing however, particularly at welding.

The intensive development of steel based on 9-12 % Cr alloying addition, resulted in reduction of carbon and chromium content. The chemical composition was modified by niobium addition. Steel P91 was developed originally from 9Cr1Mo steel. The steel

1936. godine za potrebe petrohemijske industrije kao zamena za niskougljenični čelik 2.25Cr-1Mo otporan na koroziju [1]. Čelik P91 je odmah bio uključen u nacionalne i međunarodne standarde.

Primena novih čelika ima za posledicu pojednostavljenje tehnologije zavarivanja čelika sa 9-12% Cr, kao što je prikazano na slici 1.

Zavareni spojevi čelika sa 9%Cr omogućavaju hlađenje do sobne temperature pre dalje termičke obrade. Sa druge strane, čelici sa 12%Cr zahtevaju međuoperaciju zadržavanja u temperaturnom intervalu 80-120°C, kako bi se omogućio potpuni martenzitni preobražaj.

METAL ŠAVA

Iako su eksploatacione osobine metala šava donekle uslovljene karakteristikama osnovnog metala, one zavise od brojnih faktora, među kojima važnu ulogu ima hemijski sastav dodatnog materijala.

Za dodatne materijale, postoje standardi koji ih, prihvatajući mala odstupanja u sastavu, preporučuju za odgovarajući hemijski sastav onovnog metala.

was developed in 1936 for petrochemistry as replacement for low corrosion resistant steel 2.25 Cr-1Mo [1]. The steel P91 was gradually included in national standards.

Application of the new steel in practice resulted in simplification of welding procedures of 9-12% Cr steels, as shown on figure 1.

Welds of 9%Cr steels allow cooling to the ambient temperature before thermal treatment. On the other side the steels containing 12 % Cr require an inter-operating temperature of 80-120°C due to full martensitic transformation.

WELD METAL

Although working properties of a weld seam are determined by base material, weld metal has also an important influence. Its properties are depended of many factors, chemical composition among the others.

For consumables, there are draft standards which with small deviations correspond to requirements of chemical composition of base material. The table 2

Table 1: Review of the modified 9Cr1Mo steel designation

Tabela 1: Pregled označavanja modifikovanih 9Cr1Mo čelika

ASTM	EN 10216-2
A 200 (T91) tubes D > 51 mm A 213 (T91) tubes D > 127 mm A 335 (P91) piping A 336 (F91) forgings A 387 (Gr.91) plates	X10CrMoVNb9-1 W.nr. 1.4903

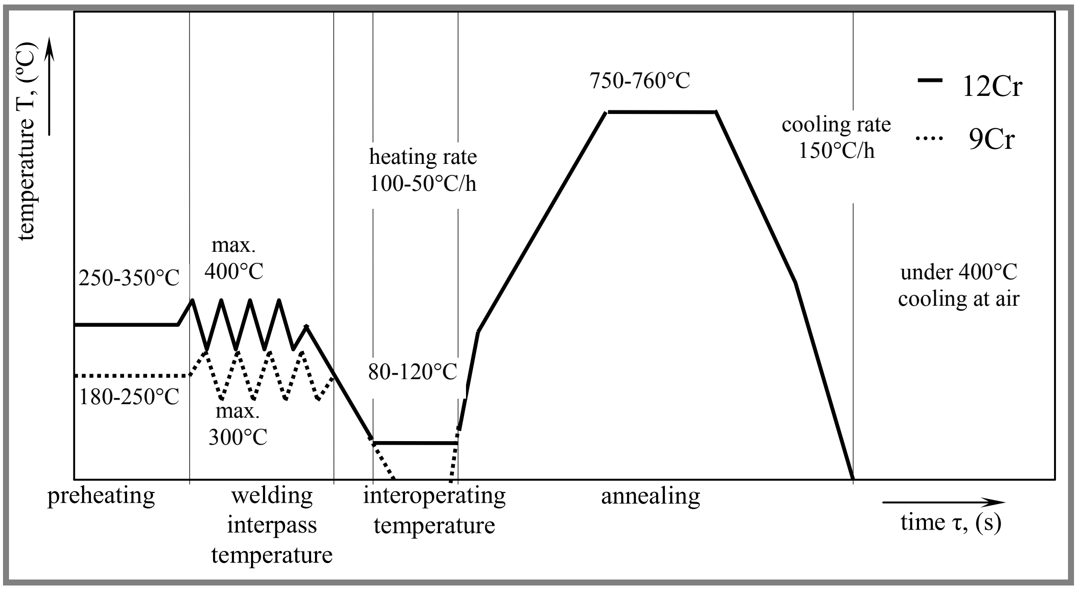

Figure 1: Thermal modes of 9-12% Cr steel welding

Slika 1: Termički režim zavarivanja čelika legiranog sa 9-12%Cr

U tabeli 2 su dati hemijski sastavi dodatnih materijala zasnovani na različitim standardima i preporukama različitih proizvođača.

Neki proizvođači dodatnog materijala pomeraju granice hemijskog sastava datog u tabeli 2. U literaturi [2] opisani su dodatni materijali sa sniženim sadržajem ugljenika, vanadijuma i niobijuma i povećanim sadržajem mangana i nikla.

Sadržaj ovih elemenata ima uticaj na mehaničke i tehnološke osobine spoja. U toku razvoja dodatnih materijala za zavarivanje čelika P91 nisu primećeni problemi vezani za postizanje zahtevanih vrednosti Re, Rm i A.

Sa druge strane, bilo je problema u postizanju žilavosti. Interesantno je da specifikacije AWS (American Welding Society), ASME Code IX ne zahtevaju ispitivanje energije udara prilikom kvalifikacije tehnologije zavarivanja. Evropska pravila EN 288-3 obuhvataju ovaj zahtev.

Table 2: Chemical composition of filler materials for 9-12%Cr steels

Tabela 2: Hemijski sastav dodatnog materijala za čelike legirane sa 9-12%Cr

Filler		%C	%Si	%Mn	%P	%S	%Cr	%Mo	%Ni	%V	%W	%Nb	%N
9Cr1Mo	min	.08	.20	.40	.020	.010	8.00	.85	1.00	.18		.04	.030
	max	.12	.50	.80			9.50	1.05		.25		.08	.070
12Cr1Mo	min	.17	.20	.40	.025	.020	10.50	.80	.80	.20	.40		
	max	.24	.60	1.00			12.00	1.20		.40	.60		

U EN 1599, 1997 kriterijum žilavosti prilikom ispitivanja 9Cr1Mo čelika na sobnoj temperaturi iznosi 47J kao srednja vrednost, ali da minimalna izmerena vrednost ne može biti manja od 38J [3]. Takođe, problem nedovoljne žilavosti se može javiti u radu sa dodatnim materijalima svih proizvođača.

Žilavost metala šava 9Cr1Mo čelika

Hemijski sastav ima odlučujući uticaj na žilavost metala šava. Prilikom odabira hemijskog sastava potrebno je osvtariti optimalan kompromis sadržaja legirajućih elemenata, pošto npr. elementi koji imaju veoma povoljan uticaj na ponašanje pri dugotrajnoj eksploataciji ne moraju imati istovremeno i povoljan uticaj na žilavost. Ugljenik, vanadijum, niobijum i azot imaju dominantan uticaj.

Od tehnoloških faktora, termička obrada, postupak i položaj zavarivanja imaju najveći uticaj.

Parametre termičke obrade (temperatura i vreme progrevanja) za čelik P91 najčešće preporučuje sam proizvođač čelika i to je najčešće dva sata na 760°C.

shows a scope of chemical analysis of filler metals based on requirements of various standards and typical values of various manufacturers.

Not all the manufacturers of filler materials observe the limits of chemical analysis given in the table 2. In the literature [2] are described fillers with lower carbon, vanadium and niobium content, but with higher Mn, Ni content.

The content of the elements have influence on the mechanical and technological properties. During development of fillers for P91 steel, were not experienced problems with observing the required values Re, Rm and A.

However, there were problems with achieving suitable toughness. It is interesting that specifications of AWS (American Welding Society), ASME Code IX require no evaluation of impact energy for welding procedure qualification. The European regulations EN 288-3 include this requirement.

In EN 1599, 1997 the criterion is an average value of impact energy at toughness test of 9Cr1Mo 47J (20°C) type weld metal and the minimal individual value of 38J [3]. Problems of low value of impact energy of weld metals can occur in fillers from all the manufacturers.

Factors affecting impact strength of 9Cr1Mo weld metal

The chemical composition is of decisive influence on weld metal toughness. In chemical composition it is important to create an optimal balance because elements have favourable effects on long-term properties of weld metal and do not always have positive effects on its toughness. Carbon, vanadium, niobium and nitrogen are dominant herein.

Important technological factors are heat treatment, position and welding technique.

Temperature and holding time during heat treatment of steel P91 usually are given by manufacturers as follows: 760°C and 2 hour holding time at the temperature.

Na slici 2 je prikazan uticaj vremena progrevanja na 760°C na energiju udara metala šava.

Skraćenje vremena progrevanja sa 2 sata na 1 sat snižava energiju udara ispitanu na sobnoj temperaturi za skoro 20J. Produženje progrevanja za još jedan čas, na ukupno tri, značajno povećava žilavost.

Na slici 3 je prikazan uticaj temperature progrevanja na energiju udara. Svi uzorci su progrevani 2 sata.

Iako povećanje temperature žarenja povećava udarnu žilavost, preporučuje se da temperature žarenja ne budu više od 760°C, pošto postoji opasnost od pregrevanja, čime bi se prekoračila Ac_1 temperatura, što ima veoma nepovoljne posledice na otpornost na puzanje. Zato se tempertura žarenja bira u saglasnosti sa temperaturom žarenja osnovnog metala. Ona ne sme biti viša od temperature žarenja metalurškog poluprpoizvoda, snižena za 30°C. Zato se u praksi koristi vreme progrevanja i žarenja.

Na slici 4 je prikazana zavisnost energije udara od položaja zavarivanja.

Sniženje energije udara u drugim pozicijama zavarivanja, osim horizontalnog, zahteva posebnu pažnju tokom zavarivanja, da bi se zadržao visok nivo žilavosti zavarenog spoja.

Uticaj tehnike zavarivanja na energiju udara dat je na slici 5.

Figure 2 shows influence of holding time at temperature 760°C on impact strength of weld metal.

Reducing holding time from 2 hours to 1 hour reduce absorbed energy at 20°C for almost 20J. Extended holding time for 1 hour have results in substantial increase of absorbed energy.

Figure 3 shows the tempering temperature influence on impact strength at constant holding time of 2 hours.

Although the increasing tempering temperature results in increasing of the impact energy, it is recommended to avoid the tempering temperature above 760°C as there is a risk of exceeding the temperature Ac1 with consequences on creep properties. The annealing temperature should be in accordance with tempering temperature of treatment of the base material in metallurgical works. It must not be higher than tempering temperature of semifinished product in metallurgical work reduced for 30°C. Therefore in practice it is used tempering time and annealing.

The toughness for various welding positions are shown in the figure 4.

The decrease of the absorbed energy in the other position than the horizontal, require special care during welding for providing high level of the absorbed energy of welded joints.

Welding technique influence on absorbed energy is shown in the figure 5.

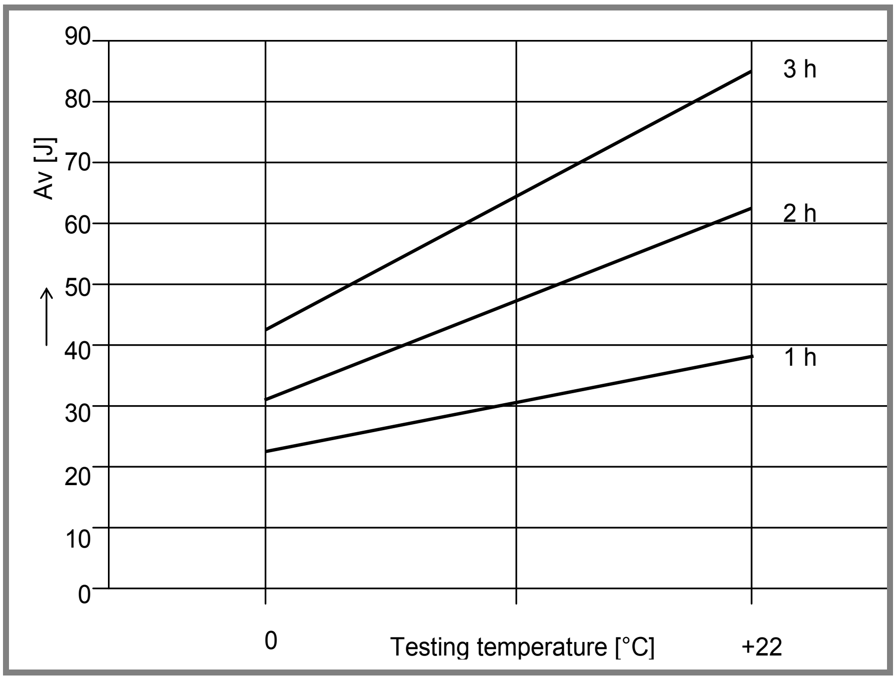

Figure 2: Influence of holding time at 760°C on absorbed energy [5]

Slika 2: Uticaj vremena progrevanja na 760°C na energiju udara [5]

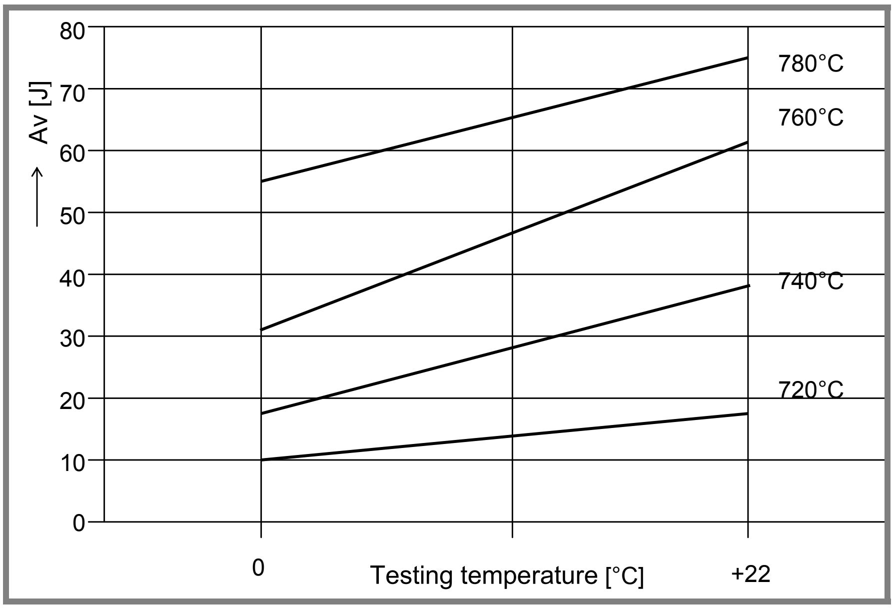

Figure 3: Influence of annealing temperature on absorbed energy at holding time of 2h [5]
Slika 3: Uticaj temperature žarenja na energiju udara (vreme progrevanja 2h) [5]

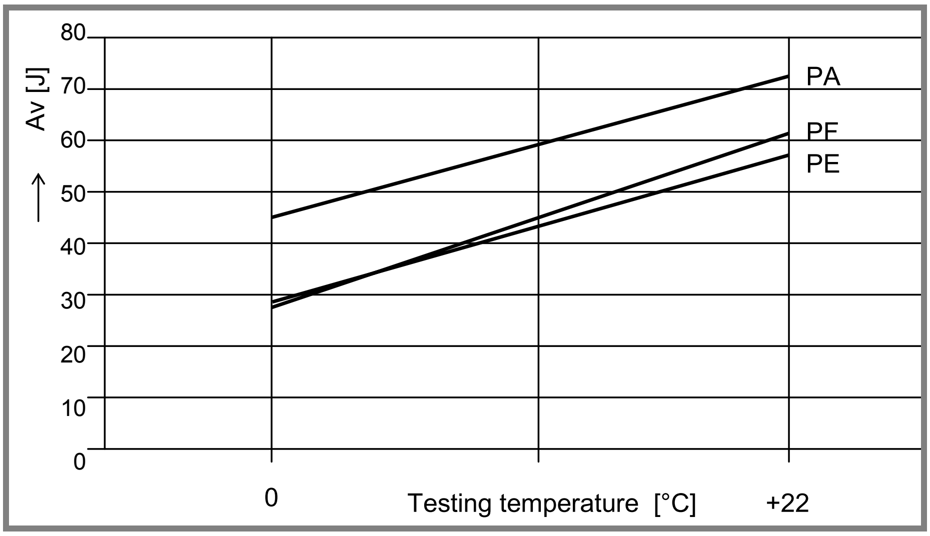

Figure 4: Influence of welding position on absorbed energy (ISO-V) of P91 [6] steel welds
Slika 4: Zavisnost energije udara metala šava čelika P91 od položaja zavarivanja (ISO-V) [6]

EKSPERIMENTALNI DEO

Cilj ovog rada je da potvrdi ponašanje metala šava zavarenog čelika P91 u realnim uslovima izrade cevi pri proizvodnji opreme za potrebe elektrana.

Za ipitivanje su korišćene termički obrađene cevi prečnika D 168,3 x 16 mm izrađene od čelika X10CrMoVNb9-1. Hemijski sastav materijala korišćenog za ispitivanje je dat u tabeli 3 i on je u saglasnosti sa standardom EN 10216-2.

Ispitane su mehaničke osobine osnovnog metala, a rezultati ispitivanja su dati u tabeli 4.

EXPERIMENTAL PART

The objective of the paper was to verify features of P91 steel weld seams on real dimensions of piping used in practice for manufacture of power plant equipment.

For testing were used heat treated tubes D 168,3 x 16 mm made of X10CrMoVNb9-1. The chemical composition of experimental material is shown in the table 3, and corresponds to the standard EN 10216-2.

Mechanical properties of the base material are tested and the results are shown in the table 4.

Tehnologija zavarivanja

Žljeb je klasičnog "V"-oblika. Detalji pripreme spoja su prikazani na slici 6.

Primenjene su dve tehnologije zavarivanja. Koreni zavar je izveden TIG postupkom, a zavari ispune E postupkom. Parametri procesa su dati u tabeli 5 i prikazani na slici 7.

Kod ovih čelika je termički ciklus od velike važnosti. U svakodnevnoj praksi su se izdvojila dva pristupa ovoj problematici [7]: prema prvom prilazu, zavaruje se iznad Ms temperature tj. unutar oblasti metastabilnog austenita, dok je po drugom zavarivanje unutar martenzitne oblasti.

Prvi metod je ipak napušten pošto je nakon završetka zavarivanja u strukturi prisutna velika količina zaostalog austenita. Na slici 8 je prikazan termički ciklus zavarivanih komada.

Welding technology

The weld seam was carried out in bevels for classical “V” joint. The detail of weld edges preparation is shown in figure 6.

To perform weld seams two technologies were used. The root was welded by TIG method, the other by MMA method. The scheme of welding layers and parameters are shown in figure 7.

The thermal welding mode is very important for this steel type. In technical practice there are known two approaches [7].

The first one means to weld above Ms temperature i.e. within the area of metastable austenite, the other under that temperature and it means within the area of martensite.

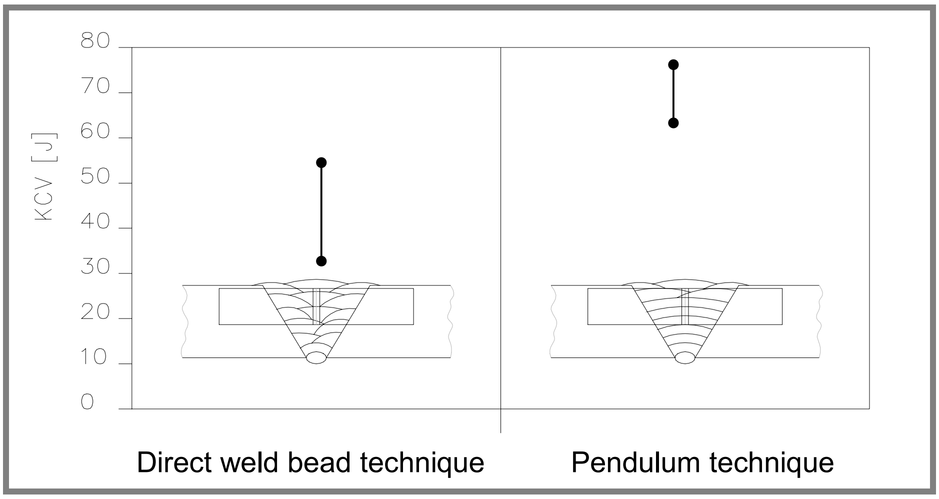

Figure 5: Welding technique influence on absorbed energy

Slika 5: Uticaj tehnike zavarivanja na energiju udara

Table 3: Chemical composition of base material of tested steel tubes and filler materials

Tabela 3: Hemijski sastav osnovnog materijala ispitivane cevi i dodatnih materijala

	Chemical composition [%]										
	C	Si	Mn	Cr	Ni	Mo	P max	S max	N	V	Nb
standard X10CrMoVNb9-1 (product)	0,07-0,14	0,17-0,54	0,27-0,64	7,9-9,6	max 0.45	0,81-1,09	0,025	0,015	0.025 0.075	0,15-0,28	0,05-0,12
tested tubes ϕ 168,3 x 16	0,103	0,36	0,46	9,03	0.12	0,93	0,015	0,001	0.032	0,226	0,061
filler OK 76.98	0,1	0,35	0,8	9,0	0,7	1,0	-	-	0,05	0,2	0,06
filler OK TIGROD 13.38	0,10	0,30	0,50	9,00	0,80	0,90	-	-	-	0,22	<0,08

Nakon završetka zvarivanja, posebna pažnja je posvećena zaštiti metala šava od vlage, pošto neotpušteni martenzit ima veliku sklonost ka pojavi površinskih prslina. Metal šava je odmah nakon zavarivanja (1 sat kasnije) otpuštan prema uslovima prikazanim na slici 8. Parametri žarenja su odabrani u saglasnosti sa zahtevima za žilavost metala šava.

The first method was ceased due to substantially high content of residual austenite in the structure after welding. The heating mode of welded test pieces is shown in the figure 8.

After welding, special attention was carried on weld protection against humidity due to high susceptibility of un-tempered martensite to surface cracking.

Table 4: Test results of mechanical properties of the base material.

Tabela 4: Mehaničke osobine osnovnog metala

	Mechanical properties			
	Re [MPa]	Rm [MPa]	A5 [%]	K_V [J] Long.
standard X10CrMoVNb9-1	min. 450	620-850	min. 19	68
steel tube ϕ 168,3 x 16	572	727	20	229, 227, 222

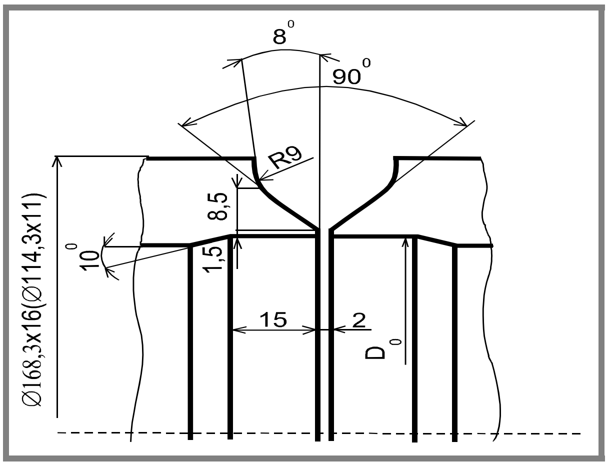

Figure 6: Preparation of weld edges

Slika 6: Priprema spoja

Table 5: Welding process parameters

Tabela 5: Parametri procesa zavarivanja

Layer	Welding method	Filler material ϕ [mm]	Weld. current [A]
1,2/K(1)	141	2,4	125
1,2/V(2–3)	111	3,2	115
1,2/Kr(4-n)	111	4,0	150
K – root layer V – filling layer Kr – covering layer			

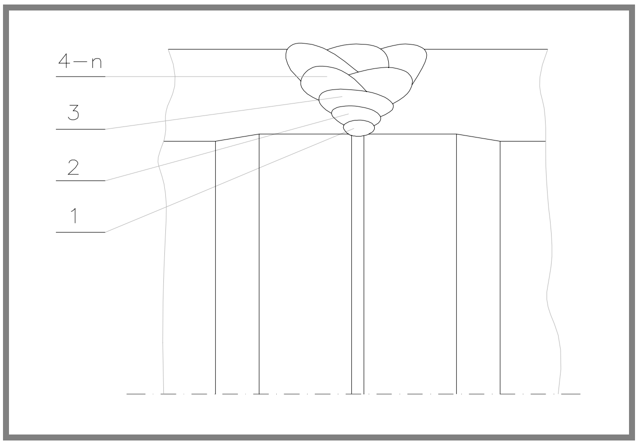

Figure 7: Composition of weld layers

Slika 7: Redosled zavarivanja

Ispitivanje zavarenog spoja

Evropski standard EN 288-3 (kvalifikacija tehnologije zavarivanja) i nemački standard za posude pod pritiskom [8] su bili osnova za ispitivanje zavarenih spojeva. Različite metode ispitivanja bez razaranja (vizuelna, magnetne, rentgen) nisu otkrile prisustvo grešaka u metalu šava.

Rezultati ispitivanja zateznih osobina i savijanja su dati u tabeli 6.

Merenje tvrdoće HV10 je izvršeno na različitim pozicijama, prema slici 9.

Merenje tvrdoće je izvršeno na dve paralelne linije, sa ciljem da se proveri da li usled žarenja postoji razlika u tvrdoći u području korenog prolaza i poslednjeg prolaza ispune. Nije primećena jasna razlika između izmerenih vrednosti u različitim prolazima. Na slici 10 su prikazane samo srednje vrednosti nekoliko izmerenih vrednosti na istom mestu.

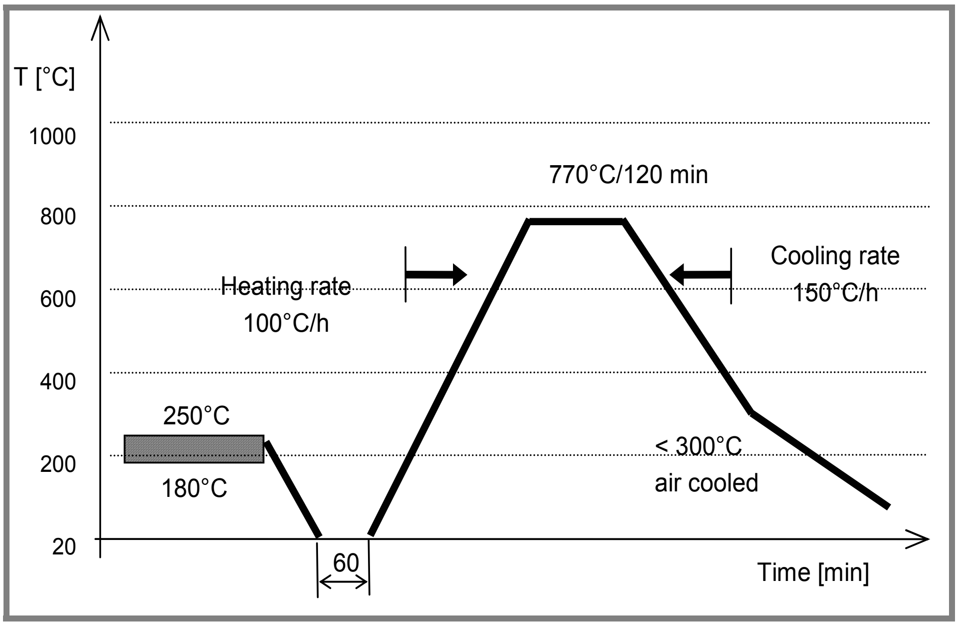

Figure 8: Heating mode of weld procedure

Slika 8: Termički režim zavarivanja

U slučaju energije udara, uzorci za ispitivanje su uzimani sa različitih mesta unutar zavarenog spoja, sa ciljem da se ispita uticaj na različite zone u zavarenom spoju. Dobijene vrednosti su date u tabeli 7.

DISKUSIJA

Vrednosti mehaničkih osobina dobijene ispitivanjem na sobnoj temperaturi su pokazale dovoljnu "rezervu" plastičnosti zavarenog spoja. Dobijena vrednost zatezne čvrstoće metala šava od 700 MPa se nalazi na sredini intervala zahtevanog prema odgovarajućem standardu.

The welds were immediately (after 1 hour) tempered in accordance to the mode shown in figure 8. The annealing parameters were chosen particularly with regard to weld metal toughness.

Weld testing

Basic regulations for testing were the standards EN 288-3 (tests of welding procedures for steel) and German boiler standard TRD 201 [8]. Non-destructive testing (visual, magnetic watering, X-ray) were not showed defects of weld seams.

The results of tensile and bending tests are given in the table 6. Hardness HV10 was measured at various welding positions (figure 9).

Hardness testing was carried out on two parallel lines. The purpose was to find hardness difference, if any, within the area of weld root and covering layers due to annealing effect. However, no distinctive difference of achieved hardness was noted.

Therefore the graphical presentation in figure 10 includes average values from the same point of relevant weld seam area.

In the case of energy absorbed test the samples were placed on various welding positions and absorbed energy was measured in different zones of welded joint. The obtained values are presented in the table 7.

DISCUSSION

Mechanical properties tested at ambient temperature showed sufficient reserve of weld metal plasticity. The reached values of weld tensile strength (700 MPa) are

Table 6: Results of tensile test at 20°C and bending test

Tabela 6: Rezultati ispitivanja mehaničkih osobina na 20°C

	Rm [MPa]	Remark	Bending [°]
steel tube ϕ 168,3 x 16	700	Standard : 620-850 MPa Breaking point at test : base material	All samples withstood the specified bending angle 180° without breaking
	700		
Average value	700		

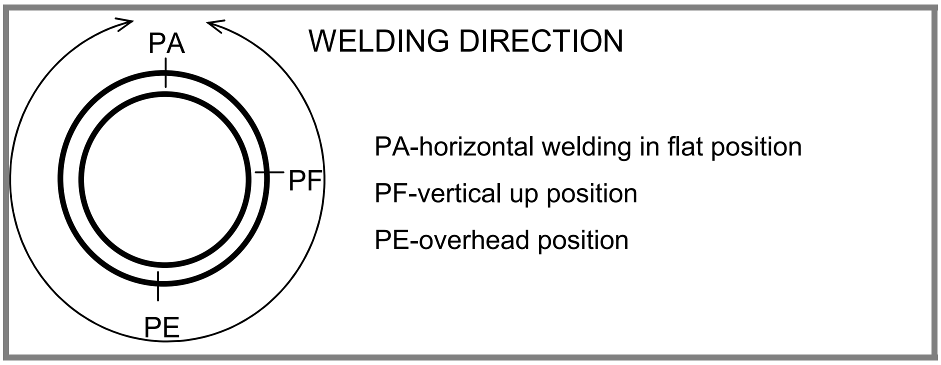

Figure 9: Location of samples for hardness measurement

Slika 9: Mesta merenja tvrdoće

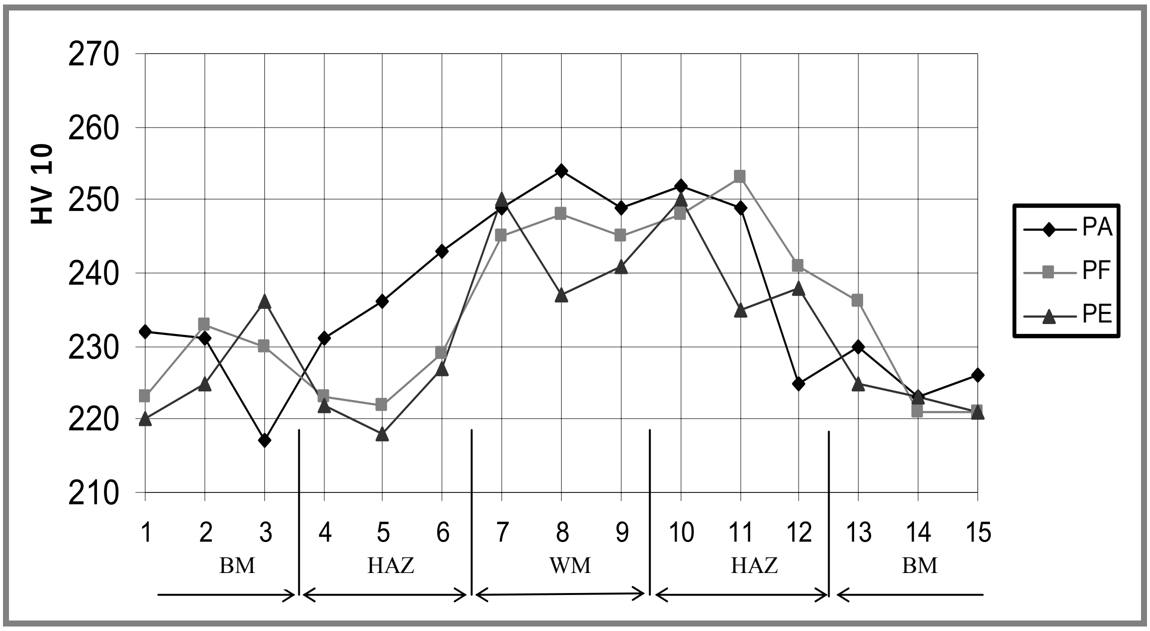

Figure 10: Hardness distribution in welded joints (WM-weld metal, HAZ-heat affected zone, BM-base metal)

Slika 10: Raspodela tvrdoće kroz zavareni spoj (WM-metal šava, HAZ-zona uticaja toplote, BM-osnovni metal)

Vrednosti tvrdoće od 256 HV10 , kao maksimalne vrednosti, dobijene su u metalu šava.

Minimalna razlika u tvrdoći kod svih položaja zavarivanja nije potvrdila sumnje da će sklonost ka lomu biti izražena u slučaju zavarivanja u položaju iznad glave (PE). Takođe, iz izmerenih vrednosti je jasno da su sve vrednosti tvrdoće ispod 280 HV10, što se u nekim internim standardima proizvođača striktno uzima kao granična dozvoljena vrednost za ove konstrukcije [9,10]. Sa druge strane, Evropski

in the middle of the standardized values specified by the requirements of evaluated standards.

The hardness values were close to the value of 250 HV10 in weld metal.

The minimal difference in hardness values of individual welding positions did not prove any doubts of failure in above head position (PE). It could be seen that the hardness achieved levels are below 280 HV10. This limit frequently specified in internal

Table 7: Impact energy of welded joint

Tabela 7: Udarna žilavost zavarenog spoja

Welding position	K_V [J]							
	Weld metal			Σ n/n [J]	HAZ			Σ n/n [J]
PA	95	100	94	96	164	192	190	172
PF	75	97	72	81	82	84	93	86
PE	91	98	95	95	193	126	90	136

standard EN288-3 prihvata gornju granicu i do 350 HV ukoliko su svi ostali prametri zadovoljili zahteve.

Kao što je već napomenuto, žilavost metala šava u čelicima sa 9-12% Cr, sa aspekta njjihove mikrostrukture, je problematična. Dobijene vrednosti od 81-96 J za metal šava i 86-172 J za zonu pod uticajem toplote se veoma dobro slažu sa zahtevima koje materijal mora da ispuni, a koji su nametnuti od strane proizvođača.

Iako u ovom radu nisu prezentirana, metalografska ispitivanja su u potpunoj saglasnosti sa ovim rezultatima.

Potvrđena je efektivnost tzv. martenzitnog zavarivanja. Sa druge strane, nije potvrđena neophodnost međuoperacijskog zagrevanja pre same termičke obrade, koju zahtevaju neki standardi.

ZAKLJUČAK

Ovaj rad predstavlja doprinos saznanjima i rešavanju problema pri zavarivanju čelika sa 9% Cr, označenog kao P91. Primenjena termička obrada i pravilan izbor dodatnog materijala obezbeđuju zadovoljavajuće osobine metala šava uključujući i žilavost za koju su uvek prisutne nedoumice. Uzorci su odgovarali najčešće korišćenim dimenzijama. Otpornost metala šava na puzanje nije ispitivana, pošto je pretpostavljeno da će ona biti ispunjena time što je dodatni materijal otporan na puzanje.

standards of manufacturers is very strict [9,10]. The European standard EN288-3 accepts the limit of 350 HV, if the other features are satisfied.

Toughness of weld seams of 9-12% Cr steels with regard to their structure is problematic as it was mentioned above, particularly in a case of weld metal. However, the results achieved (81-96 J – weld metal, 86-172 J - HAZ) are in accordance with the requirements of material specifications of manufacturers, classified companies.

Although is not presented in this paper, the metallographic analysis corresponds with the achieved results of mechanical properties. It is proved efficacy of so-called martensitic welding. On the other hand, it was not proved a necessity of inter-operating heating before heat treatment as required by some regulations.

CONCLUSION

This paper analysed welding problems of 9% Cr steel known as P91. Obtained weld joint properties satisfied requirements of standards for verz often used steel tubes dimension.The applied heating mode proved that this technology can produce welds of satisfactory quality. It was also supported by optimal selection of ESAB filler metal. Creep resisting features of weld seams were not investigated. It was supposed that base material, as well as filler material, were sufficiently creep tested before.

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