



Damir Sadibašić, Nenad Radović, Vencislav Grabulov, Milorad Zrilić

## UTICAJ POLAZNOG STANJA NA OSOBINE REL ZAVAREN OG SPOJA ČELIKA 14MoV 6 3

### INFLUENCE OF INITIAL STATE ON PROPERTIES OF MMA WELDED 14MoV 6 3 STEEL

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#### **Izvod**

*U radu je ispitan uticaj stanja osnovnog metala na osobine REL zavarenog spoja čelika 14MoV 6 3. Zavarene su tri kombinacije uzoraka: (i) nekorišćen-nekorišćen; (ii) korišćen-korišćen; i (iii) korišćen-nekorišćen. Korišćeni uzorci su bili u upotrebi preko 52000 sati. Utvrđeno je da do loma dolazi uvek u osnovnom metalu korišćenog uzorka.*

*Pretpostavljeno je da kritični uslovi nastaju usled puzanjem izazvanog rasta zrna i/ili taloga. Najviši nivo zatezne čvrstoće je u kombinaciji dva nekorišćena uzorka.*

#### **UVOD**

Niskolegirani čelik za izradu parovoda 14MoV 6 3 je u eksploataciji izložen radnoj temperaturi od preko 500°C, uz period eksploatacije i do 120000 sati. Struktura čelika 14MoV 6 3 se na početku eksploatacije sastoji od gornjeg beinita, koji se u toku eksploatacije transformiše u mešavinu ferita i karbida uz konstantno povećanje zrna. Delovi parovoda se spajaju zavarivanjem.

U toku dugotrajne eksploatacije na povišenim temperaturama, u čeliku 14MoV 6 3 se stvaraju uslovi za izdvajanje karbida vanadijuma koji su veoma skloni brzom rastu. Na taj način se čvrstom rastvoru u kome se pored vanadijuma nalazi i molibden snižava otpornost na puzanje i snižava čvrstoća, kako na radnoj, tako i na sobnoj temperaturi [1-3].

Sa druge strane, kada je potrebno izvršiti zamenu nekog dela ili reparaturno zavarivanje, obavezna kvalifikacija tehnologije zavarivanja se izvodi prema utvrđenoj proceduri, ali na uzorcima koji nisu bili u upotrebi – nekorišćeni uzorci. Kako je u toku eksploatacije parovoda došlo do promene u strukturi, postoji dilema o pouzdanosti tumačenja dobijenih rezultata pošto su u delovima koji produžavaju

**Adresa autora / Author's address:**

Mr Damir Sadibašić, dipl. ing. Metalna doo, Zenica, BiH.

Dr Nenad Radović, dipl. ing. Tehnološko metalurški fakultet Univerziteta u Beogradu, Srbija.

Dr Vencislav Grabulov, dipl. ing. Institut za ispitivanje materijala, Beograd, Srbija.

Dr Milorad Zrilić, dipl. ing. Tehnološko metalurški fakultet Univerziteta u Beogradu, Srbija.

**Keywords:** Steel 14MoV 6 3, welding repairment, grain growth.

#### **Abstract**

*The aim of this work was to establish the influence of initial state of base metal on properties of mma welded 14MoV 6 3 steel. Three combinations of specimens were welded: (i) virgin-virgin (N-N); (ii) used-used (S-S); (iii) virgin-used (N-S). Used specimens were 52000 hours in exploitation. It has been established that the fracture is initiated in the zone of used part. It is assumed that the critical conditions were achieved as the consequence of creep induced grain growth and particle coarsening. On the other hand, testing of unused specimens revealed the highest level of strength.*

#### **INTRODUCTION**

Working temperature for çowalloyed hot steam pipe steel 14MoV 6 3 is over 500°C with service life up to 120000 hours. At the start of exploitation, microstructure of 14MoV 6 3 steel consists of upper bainite which during long exposition to high temperatures starts to change into mixture of ferrite and carbides, with simultaneous increase in grain size. Welding is the principal manufacturing method for these pipes.

During service life on elevated temperatures, nucleation of vanadium and/or molybdenum based carbides can occur in 14MoV 6 3 steel. This leads to decrease of the creep resistance on both elevated and room temperatures [1-3].

On the other hand, when a reparature is necessary, obligatory qualification of welding technology should be done in accordance with standardized procedure, but on steel that was not in service – virgin steel. Due to the changes in microstructure triggered by long service at elevated temperatures, there is an uncertainty on the reliability of obtained results, since mechanical properties are expected to be changed [1-5].



eksploataciju promenjena struktura i odgovarajuće mehaničke osobine [1-5].

Da bi se ovaj problem rasvetlio, u radu su zavarene REL postupkom i ispitane tri kombinacije uzoraka čelika 14MoV 6 3: (i) nekorišćen-nekorišćen; (ii) korišćen-korišćen; i (iii) korišćen-nekorišćen.

**EKSPERIMENTALNI DEO**

Hemijski sastav čelika 14MoV 6 3 (korišćeni uzorci su bili u eksploataciji više od 52000 sati) ispitano u ovom radu je dat u tabeli 1. U tabeli 2 su date mehaničke osobine čelika koje odgovaraju korišćenom i nekorišćenom stanju. Zavarivanje je

In order to investigate the problem, three combinations of 14MoV 6 3 steel specimens were welded: (i) virgin-virgin (N-N); (ii) used-used (S-S); (iii) virgin-used (N-S). Specimens were MMA welded using adequate filler materials.

**EXPERIMENTAL**

Chemical composition of 14MoV 6 3 (used samples were more than 52000 hours in service) steel tested in this work is given in table 1. Mechanical properties related to used and virgin material state are given in table 2. Samples were MMA welded using E MoV B 4 2 H5 filler material (chemical composition is given in

**Tabela 1:** Hemijski sastav čelika 14MoV6 3 (korišćena (S) i nekorišćena (N) cev) i elektrode E MoV B 4 2 H5 (tež. %)

**Table 1:** Chemical Composition of 14MoV 6 3 steel (used (S) and virgin (N) state) and E MoV B 4 2 H5 filler material (wt%)

Materijal	C	Si	Mn	P	S	Cr	Mo	V
Korišćena cev (S)	0,14	0,30	0,56	0,019	0,015	0,58	0,39	0,23
Nekorišćena cev (N)	0,15	0,22	0,48	0,012	0,010	0,39	0,47	0,24
E MoV B 4 2 H5	0,065	0,35	1,2			0,4	1,0	0,5

**Tabela 2:** Mehaničke osobine čelika 14MoV 6 3 (korišćeno (S) i nekorišćeno (N) stanje) i dodatnog materijala E MoV B 4 2 H5

**Table 2:** Mechanical Properties of 14MoV 6 3 steel (used (S) and virgin (N) state) and E MoV B 4 2 H5 filler material

Oznaka	Rm, MPa	Re, MPa	A, %	Z, %
Korišćena cev (S)	567	377	24,1	76
Nekorišćena cev (N)	564	444	26,1	78
E MoV B 4 2 H5	660	510	22,0	-

**Tabela 3:** Korišćeni parametri zavarivanja

**Table 3:** Welding parameters applied in experimental welding

Broj prolaza /Pass No	Dodatni materijal, mm	Struja zavarivanja, A	Napon zavarivanja, V
1	Ø 2,5	60	19,5
2	Ø 3,25	80	22

izvršeno REL postupkom, korišćenjem elektrode, E MoV B 4 2 H5. Hemijski sastav elektrode je dat u tabeli 1. Korišćene su elektrode Ø 2.5mm (za koreni prolaz) i Ø 3.25mm (za ispunu šava), sa parametrima datim u tabeli 3.

Termička obrada zavarenih spojeva u cilju smanjenja zaostalih napona je urađena prema sledećem režimu (slika 1): progrevanje 1h na 400°C, zagrevanje do 710°C za 2h i progrevanje 2h na 710°C. Uzorci su zatim hlađeni u peći do temperature od 200°C, nakon čega su izvađeni iz peći i hlađeni na mirnom vazduhu do sobne temperature.

Izvršena su mikrostrukturna ispitivanja polaznog materijala (S i N stanje) i termički obrađenih zavarenih spojeva. Uzorci su brušeni, polirani i nagriženi u nitalu

table 1). Root pass was performed using Ø2.5mm electrode and Ø3.25mm for filling the butt, with parameters presented in table 3.

Stress relieving post welding heat treatment was done according to procedure shown on figure 1: annealing 1h at 400°C, heating to 710°C in 2h, annealing for 2h at 710°C. Samples were then furnace cooled to 200°C and afterwards taken out of furnace and cooled to room temperature at still air.

Microstructural evaluation was done on both initial steels (S and N state) and heat treated welded joints. Samples were grinded, polished and etched in nital (2% HNO<sub>3</sub> in ethanol). Tensile properties were tested on tensile testing machine on room temperature and on 450°C.



(2% HNO<sub>3</sub> u etanolu)). Za određivanje zateznih karakteristika korišćena je mašina za ispitivanje jednoosnim zatezanjem. Ispitivanja su izvedena na sobnoj temperaturi i na 450°C.

**REZULTATI I DISKUSIJA**

**Mehaničke osobine**

U tabeli 4 su date mehaničke osobine ispitanih zavarenih spojeva dobijene ispitivanjem na sobnoj i povišenoj temperaturi.

U svim slučajevima je utvrđeno da je zatezna čvrstoća izmerena na sobnoj temperaturi veća od zatezne čvrstoće na 450°C, što se objašnjava uticajem temperature na poprečno klizanje, pošto je poprečno klizanje termalno aktivirani proces [6,7].

Dobijene vrednosti zatezne čvrstoće sva tri zavarena spoja su veće od vrednosti osnovnog metala, pošto je cilj izbora dodatnog materijala bio da se postigne „overmatching“ efekat i pojava loma izazove van zone zavarenog spoja. Mesto loma je u svim slučajevima bio osnovni materijal; u N-S spoju, do loma je došlo u osnovnom metalu korišćene cevi.

Kako na veličinu zatezne čvrstoće najveći uticaj ima brzina deformacionog ojačavanja, jasno je da

**RESULTS AND DISCUSSION**

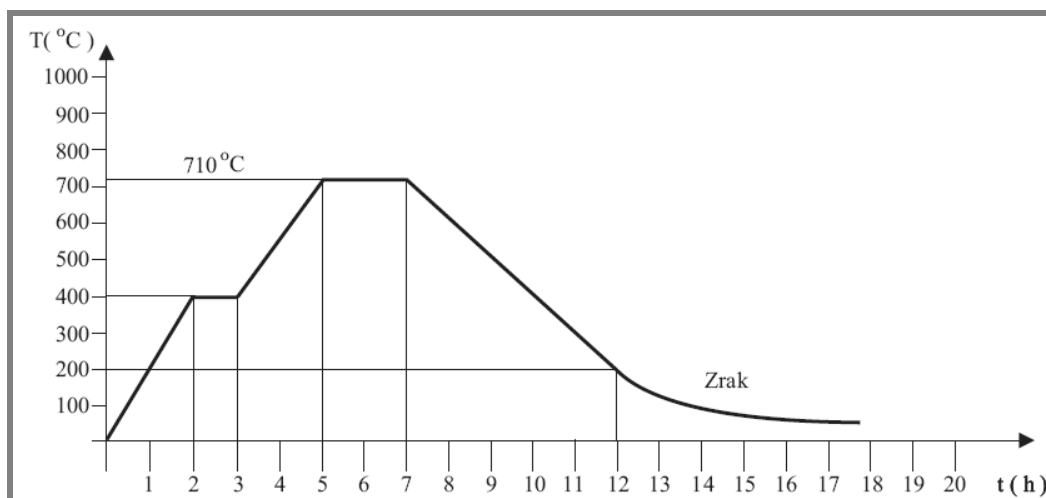
**Mechanical properties**

Mechanical properties of welded joints tested at room and elevated temperature are presented in table 4.

In all weldments, ultimate tensile strength determined on room temperature is higher in comparison to ultimate tensile strength determined at 450°C. This behaviour is attributed to temperature influence on cross slip, since it is thermally activated process.

In all three weldments, ultimate tensile strength is higher than in base metal. On of goals in filler material selection was to achieve overmatching effect in order to move fracture initiation out of weld metal and heat affected zone. Fracture was in all cases placed in base material, while in N-S weldment it is placed in used part.

Since the ultimate tensile strength is strongly influenced by strain hardening rate, it is clear that grain coarsening in used steel does not lead to significant change un UTS: therefore, there are no considerable differences between values in table 4 obtained at room temperature. On the other hand,



Slika 1: Dijagram primenjene termičke obrade zavarenih spojeva

Figure 1: Applied PWHT of welded joints

Tabela 4: Zatezne osobine i mesto loma ispitanih zavarenih spojeva

Table 4: Tensile properties and fracture position in weld joint

Zavareni spoj	Temperatura, °C	Zatezna čvrstoća, MPa	Izduženje, %	Mesto loma
N-N	20	534	17.4	OM
	450	458	14.9	OM
N-S	20	545	12.6	OM (S)
	450	426	13.1	OM (S)
S-S	20	537	17.7	OM
	450	396	10.2	OM



povećanje zrna u korišćenom čeliku ne dovode do promene veličine zatezne čvrstoće, te se zbog toga ni u tabeli 4 ne javljaju značajne razlike za rezultate dobijene ispitivanjem na sobnoj temperaturi. Sa druge strane, dobro je poznat uticaj veličine zrna na granicu tečenja; sa povećanjem veličine zrna, smanjuje se granica tečenja, jer je u krupnijim zrnima olakšano kretanje dislokacija, te nije potrebno delovati većim spoljnim opterećenjem, tabela 2. [6-8]. Zbog nemogućnosti ponovljivosti struktura pri REL zavarivanju, određivanje granice tečenja zavarenog spoja nema fizičkog smisla [9].

Zatezna čvrstoća zavarenih spojeva dobijenih ispitivanjem na 450°C pokazuje direktnu zavisnost od vrste zavarenog spoja i opada nizom N-N, N-S i S-S. Snižanje zatezne čvrstoće u slučaju N-S u odnosu na N-N spoj iznosi 7,5%.

Pri deformaciji jednoosnim zatezanjem na povišenim temperaturama se olakšava proces poprečnog klizanja, čime se objašnjava smanjenje otpora deformaciji sa povećanjem temperature. Prisustvo povećane gustine dislokacija dovodi do ubrzavanja difuzije legirajućih elemenata, tako da može doći do izdvajanja karbida, dominantno po granicama zrna.

Na ovaj način se siromaši čvrsti rastvor, olakšava kretanje dislokacija i smanjuje brzina deformacionog ojačavanja, što za posledicu ima smanjenje zatezne čvrstoće. Ovaj efekat je najjače izražen u čelicima koji su bili dugo u eksploataciji, jer je količina stvorenih karbida (osiromašenje čvrstog rastvora) u njima najveća [1,2,10].

### Struktura

Na slici 2 je prikazana makrostruktura N-S zavarenog spoja na kojoj nisu uočene greške tipa poroznosti, prskotina i nemetalnih uključaka. Mikrostruktura je prikazana na slici 3.1 do 3.13.

Struktura ispitanog čelika u nekorišćenom stanju je u osnovi beinitna sa nešto ferita i ponekad perlita, slika 3, pozicija 9.

grain size strongly affect yield strength; increase in grain size leads to decrease of yield strength since the dislocation movement is enhanced in coarsened grains and does not need any auxiliary load, table 2 [6-8]. Also, due to very questionable repeatability of structures in MMA weldments, yield strength of weldment does not have physical meaning and was not performed [9].

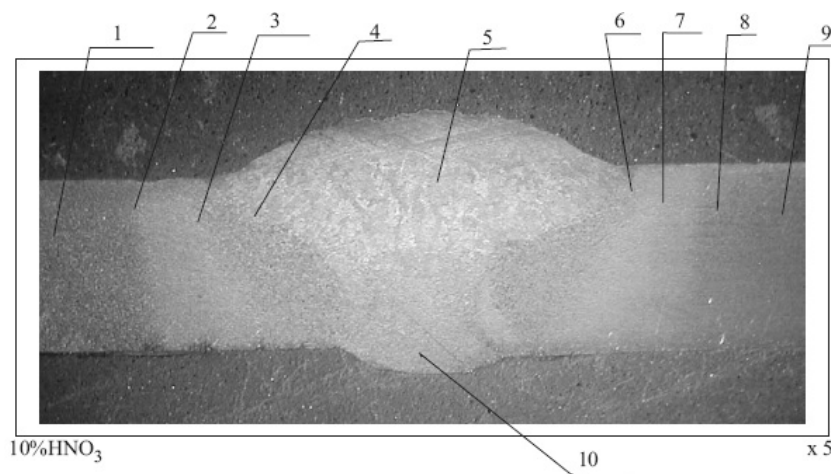
Ultimate tensile strength in weldments tested at 450°C is different in all three cases and it decreases following the line: N-N, N-S and S-S. Decrease of ultimate tensile strength in N-S weldment in comparison to N-N weldment is 7.5%.

Resistance to deformation at high temperatures decreases with increase of temperature. This behaviour is related to more intensive cross-slip. Also, presence of high dislocation density accelerates the diffusion of alloying elements promoting carbide formation, preferentially at grain boundaries. In this manner, the solid solution becomes depleted. This decreases the solid solution strengthening effect due to easier dislocation movement, and lowers the strain hardening rate which results in decrease of ultimate tensile strength. This effect is most pronounced in steels that were exploited for long time since the amount of formed carbides is the greatest [1,2,10].

Initial microstructures in used and virgin materials are significantly different, dominantly in grain size. Used steel is characterized with larger grains and lower yield strength (377MPa i 444MPa, for used and unused materials, respectively).

### Structure

Figure 2 shows macrostructure of N-S weldment. No porosity, cracks or non-metallic inclusion were detected on the surface. Microstructure is presented on figures 3.1-3.13.



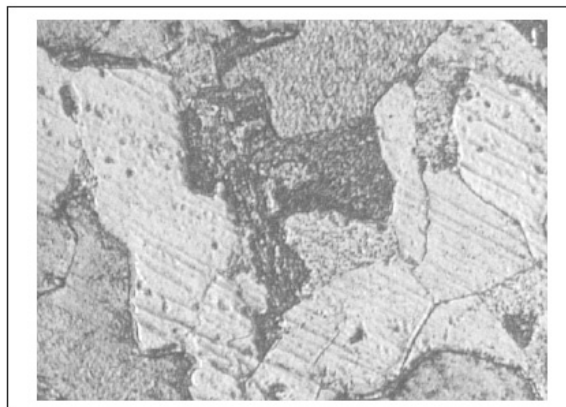
Slika 2: Makrostruktura uzorka S-N  
Figure 2: Macrostructure of N-S weldment



2% $\text{HNO}_3$

x 145

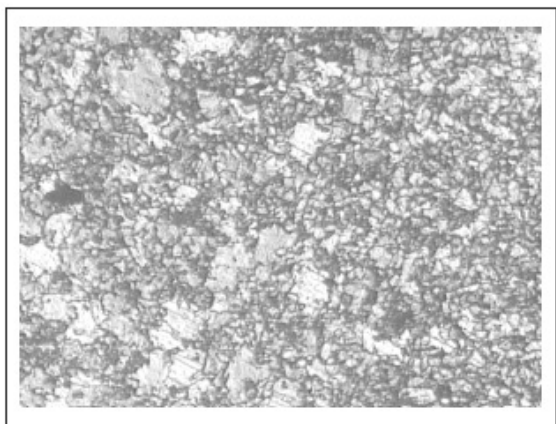
**Slika 3.1:** Pozicija 1 - osnovni materijal (beinit, ferit, perlit)  
**Figure 3.1:** Position 1 - base metal (bainite, ferrite, pearlite)



2% $\text{HNO}_3$

x 725

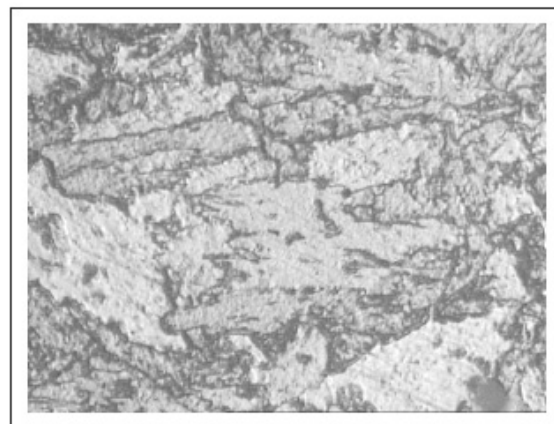
**Slika 3.2:** Pozicija 1 - osnovni materijal (beinit, ferit, perlit, karbidi)  
**Figure 3.2:** Position 1 - base metal (bainite, ferrite, pearlite, carbides)



2% $\text{HNO}_3$

x 145

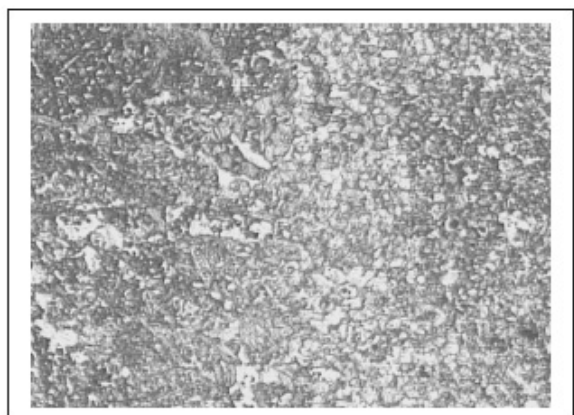
**Slika 3.3:** Pozicija 2 – prelaz osnovni materijal ZUT  
**Figure 3.3:** Position 2 – Transition area base metal-HAZ



2% $\text{HNO}_3$

x 725

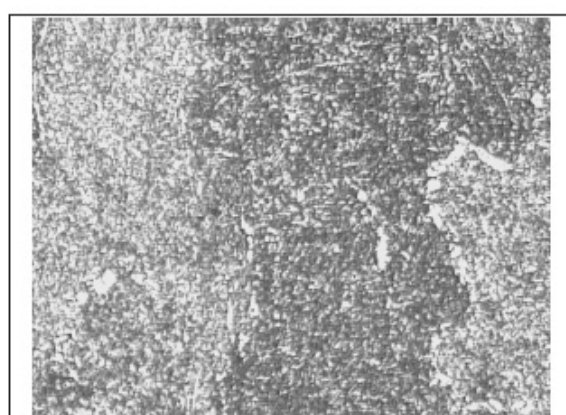
**Slika 3.4:** ZUT (beinit sa intragranularnim karbidima i ferit)  
**Figure 3.4:** Position 3 – HAZ (bainite with intragranular carbides and ferrite)



2% $\text{HNO}_3$

x 145

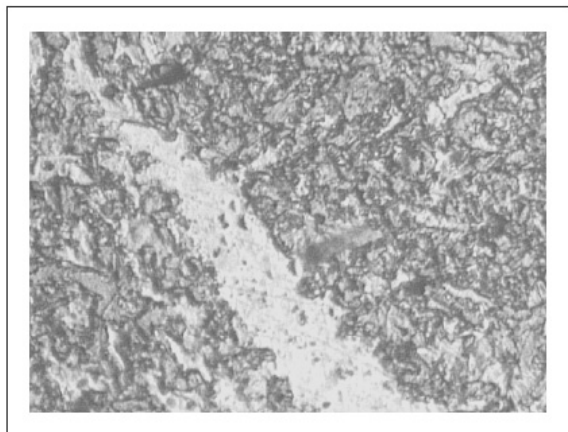
**Slika 3.5:** Pozicija 4 – prelaz ZUT – metal šava  
**Figure 3.5:** Position 4 – Transition area weld metal-HAZ



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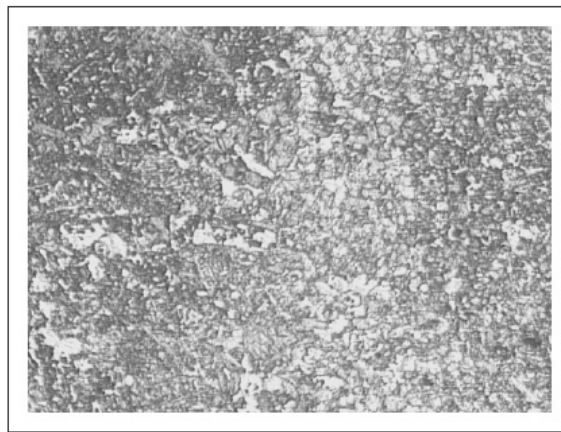
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**Slika 3.6:** Pozicija 5 – metal šava – ferit i beinit  
**Figure 3.6:** Position 5 – Weld metal (ferrite, bainite)



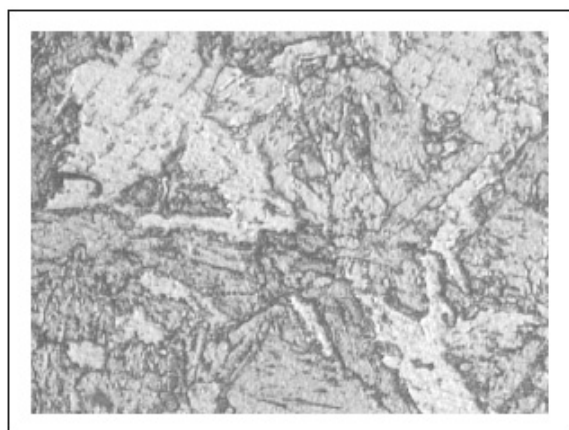
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**Slika 3.7:** Pozicija 5 – metal šava (ferit, beinit)  
**Figure 3.7:** Position 5 – Weld metal (ferrite, bainite)



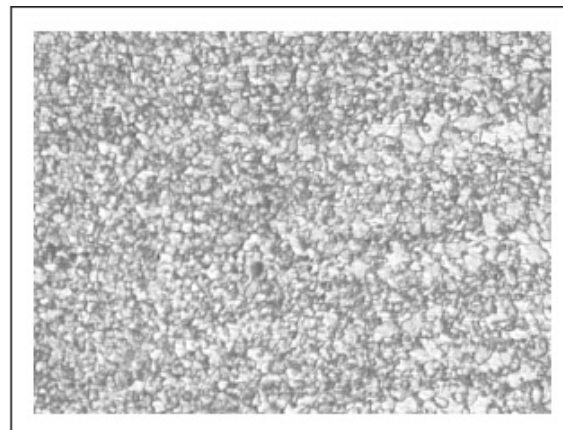
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**Slika 3.8:** Pozicija 6 – prelaz metal šava – ZUT  
**Figure 3.8:** Position 6 – Transition area weld metal-HAZ



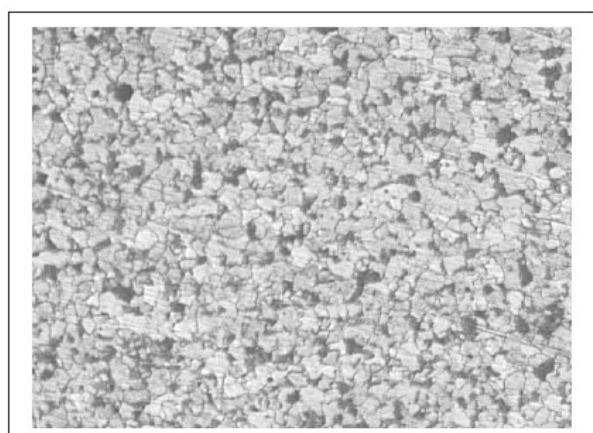
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**Slika 3.9:** ZUT (beinit sa intragranularnim karbidima i ferit)  
**Figure 3.9:** HAZ (bainite and intragranular carbides and ferrite)



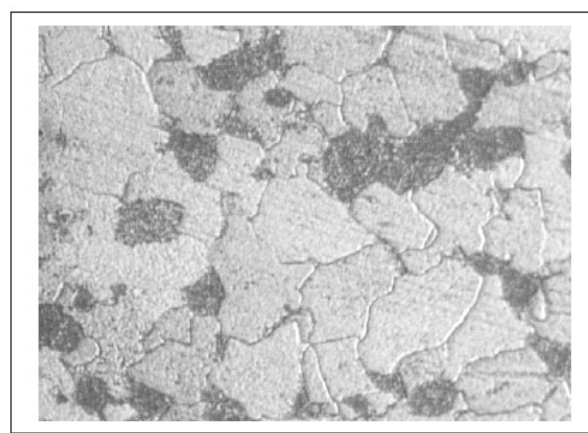
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**Slika 3.10:** Prelaz osnovni materijal - ZUT  
**Figure 3.10:** Position 8 – Transition area base metal-HAZ



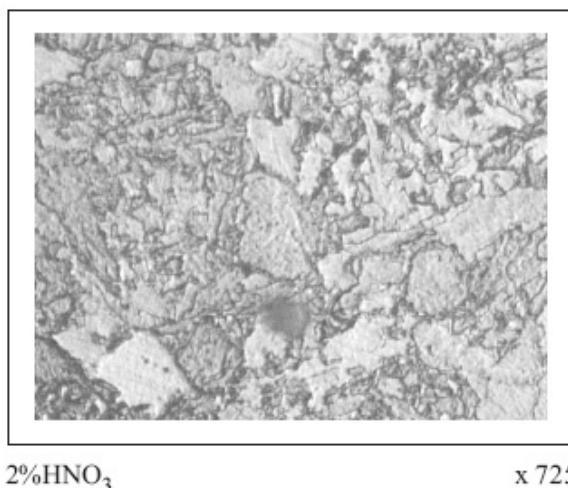
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**Slika 3.11:** Pozicija 9 - osnovni materijal (beinit, ferit, perlit)  
**Figure 3.11:** Position 9 - base metal (bainite, ferrite, pearlite)



2% $\text{HNO}_3$  x 725

**Slika 3.12:** Pozicija 9 - osnovni materijal (beinit, ferit, perlit)  
**Figure 3.12:** Position 9 - base metal (bainite, ferrite, pearlite)



**Slika 3.13:** Pozicija 9 - osnovni materijal (beinit, ferit, perlit)  
**Figure 3.13:** Position 9 - base metal (bainite, ferrite, pearlite)

Na korišćenoj cevi, mikrostruktura osnovnog metala se principijelno sastoji od istih mikrokonstituenata, ali je karakterišu značajno krupnije zrno. Takođe, kako je došlo do otpuštanja beinita, on se pretvara u smešu ferita i karbida koji su izdvojeni unutar beinitnih zrna – pozicija 1. Pretpostavljeno je da su ove pojave izazvane puzanjem u toku eksploatacije [1,2,10-12]. U ostalim delovima zavarenog spoja se može smatrati da je struktura simetrična, tj. da početno stanje nema uticaja na dobijene strukture.

Struktura je u metalu šava beinitna sa nešto ferita (pozicije 5 i 10). U ZUT-u (pozicije 2-4 i 6-8) se zapaža prisustvo beinita iz koga je tokom termičke obrade došlo do izdvajanja karbida unutar zrna. To je osnovni razlog za povišenu čvrstoću koja ima za posledicu da do loma dolazi u zoni osnovnog metala [1,2,10-12].

### ZAKLJUČAK

U radu je ispitana razlike u kvalitetu i osobinama zavarenog spoja koje su posledica razlike u strukturi realnih komada koji se zavaruju u termoenergetskim postrojenjima i nekorišćenih komada koji se zavaruju u laboratoriji. Dobijena zatezna čvrstoća opada od vrednosti dobijene ispitivanjem spojeva dobijenih spajanjem nekorišćenih cevi, preko kombinacije korišćene i nekorišćene do najniže vrednosti dobijene za zavareni spoj dve korišćene cevi.

Utvrđeno je da do loma dolazi uvek u zoni korišćenog dela, što je dovedeno u vezu sa povećanjem veličine zrna i ogrubljanjem taloga usled dugotrajnog izlaganja na povišenim temperaturama. Mikrostruktura u zoni uticaja toplote nije pokazala zavisnost od početnog stanja.

Structure of tested steel in virgin state is basically bainite with some ferrite and even small presence of pearlite, figure 3 – position 9.

On used pipe, microstructure of base material essentially consists of the same microconstituents, with some differences: (i) grains are coarsened, (ii) due to annealing, bainite evaluated in the mixture of ferrite and intragranularly nucleated carbides – figure 3 - position 1. It is assumed that these differences are introduced by creep. In other parts of welded joint, microstructure seems to be symmetrical, i.e. no influence of the initial state was recorded.

Microstructure in weld metal is dominantly bainitic with some ferrite (figure 3 – positions 5 and 10). In the heat affecting zone (figure 3 – positions 2-4 and 6-8) main feature is presence of carbides in bainite. This is the main reason for higher strength which resulted in crack initiation and fracture in base metal [1,2,10-12].

### SUMMARY

Differences in weldments properties between previously unused (virgin) 14MoV 6 3 steel pipes and weldments that include previously exploited 14MoV 6 3 steel pipes (used) were evaluated in this work. Ultimate tensile strength decreases from virgin-virgin, virgin-used to used-used weldment. Also, when present, the fracture occurred always in the used material.

This behaviour is related to increase of grain size due to long exposition at high temperatures. Microstructures in heat affected zone was not influenced by initial state of material.



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**Članstvo u strukovnoj asocijaciji DUZS  
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**Uplatom članarine stičete pravo na GRATIS godišnje izdanje  
časopisa "ZAVARIVANJE I ZAVARENE KONSTRUKCIJE"**

Tekući račun DUZS: 355-1025530-87

### Informacije



+ 381 (11) 2850-794 (10-16 h)



[duzs@eunet.rs](mailto:duzs@eunet.rs)



**SAJAM TEHNIKE**



**56. MEĐUNARODNI SAJAM TEHNIKE I TEHNIČKIH DOSTIGNUĆA (UFI)**

14.05.2012 - 18.05.2012

Bulevar vojvode Mišića 14, 11000 Beograd, Srbija

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