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Extended application of hardness prediction system for temper bead welding of A533B steel to various low-alloy steels

Proširena primena sistema za predviđanje tvrdoće kod zavarivanja čelika A533B za razne niskolegirane čelike

Originalni naučni rad / Original scientific paper
Rad je u izvornom obliku objavljen u okviru 72. IIW godišnje Skupštine i međunarodne konferencije održane u Bratislavi-Slovačka 07-12. Jula 2020
Rad primljen / Paper received:
Januar 2020.

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Ključne reči: Tvrdoća, Zavar za otpuštanje, Niskolegirani čelik, Sekindarno otvrdnjavanje, FEM (metoda konačnih elemenata)

Keywords: Hardness, Temper bead welding, Low-alloy steel, Secondary hardening, FEM

Abstract

Temper bead welding is one of effective repair welding methods in case that post weld heat treatment is not easily applied. In order to evaluate the effectiveness of temper bead welding, hardness in HAZ becomes important factor. The neural network- based hardness prediction system of HAZ in temper bead welding for A533B low-alloy steel has been constructed by the authors in the previous study. However, for HAZ hardness prediction of other steels, it is necessary to obtain hardness database for each steel which is time-cost consuming, if the same method is used. The present study has been conducted to develop the generalized hardness prediction method applicable for other steels by utilizing the hardness data-base of A533B steel assuming that the hardness in HAZ of steels after tempering have a linear relationship with LMP (Larson-Miller parameter). By using the newly proposed extended method, only a few hardness data-base for the other steels is needed to obtain. Hardness distribution in HAZ of temper bead welding for other steels was calculated by using the extended hardness prediction system. The thermal cycles used for calculation were numerically obtained by a finite element method. The experimental results have shown that the predicted hardness is in good accordance with the measured one for steels without secondary hardening. It follows that the currently proposed extended method is effective for estimating the tempering effect during temper bead welding for the steels without secondary hardening.

Rezime

Zavarivanje zavara za otpuštanje je jedna od efikasnih metoda popravljanja zavarivanjem u slučaju da se termička obrada nakon zavarivanja ne izvodi lako. Da bi se procenila efikasnost zavarivanja zavara za otpuštanje, tvrdoća u ZUT-u postaje važan faktor. Autori su u prethodnoj studiji konstruisali sistem predviđanja tvrdoće ZUT zasnovanog na neuronskoj mreži pri zavarivanju zavara za otpuštanje za niskolegirani čelik A533B. Međutim, za predviđanje tvrdoće ZUT kod drugih čelika, potrebno je dobiti bazu tvrdoće za svaki čelik, koja zahteva mnogo vremena, ako se koristi ista metoda. Ova studija je provedena sa ciljem da se razvije generalizovana metoda predviđanja tvrdoće koja se primenjuje na ostale čelike korišćenjem baze podataka o tvrdoći čelika A533B uz pretpostavku da tvrdoća čelika u ZUT nakon otpuštanja ima linearni odnos sa LMP (Larson-Miller-ov parametar). Upotrebom novo-predložene proširene metode potrebno je dobiti samo nekoliko baza podataka o tvrdoći za ostale čelike. Raspodela tvrdoće u ZUT zavara za otpuštanje za ostale čelike, izračunata je korišćenjem proširenog sistema predviđanja tvrdoće. Termički ciklusi korišćeni za proračun bili su numerički dobijeni, metodom konačnih elemenata. Rezultati eksperimenta su pokazali da je predviđena tvrdoća u dobrom skladu sa izmerenom za čelike bez sekundarnog otvrdnjavanja. Sledi da je trenutno predložena proširena metoda efikasna za procenu efekta otpuštanja tokom zavarivanj zavara za otpuštanje za čelike bez sekundarnog otvrdnjavanja.

1. Introduction

Low alloy steels have been widely applied for the production of pipes, automotive and aerospace bodies, railway lines and offshore and onshore structural engineering plates. Low-alloy steel ASTM A533B possessing superior low-temperature toughness and weldability is typically used as the material for pressurized water reactor vessels in nuclear power plants [1,2]. Based on the experimentally obtained hardness database, the neural network-based hardness prediction system of heat affect zone (HAZ) in temper bead welding for A533B steel has been constructed by the authors in the previous study [3-5].

However in actual industry, not only A533B steel but also the other low-alloy steels are required to temper bead welding. For HAZ hardness prediction of other steels, it is necessary to obtain hardness database for each steel which is time-cost consuming, if the same method is used. The present study has been conducted to develop the generalized hardness prediction method applicable for the other low- alloy steels by utilizing the hardness data-base of A533B steel assuming that the hardness in HAZ of low-alloy steels after tempering have a linear relationship with LMP (Larson- Miller parameter) [3]. By using the newly proposed extended method, only a few hardness data-base for the other steels is needed to obtain. Therefore, the extended method of the previously constructed hardness prediction system of A533B steel to the other low-alloy steels without secondary hardening was proposed from the view of engineering.

2. Materials and experimental procedures

The chemical compositions of A533B, A508, 1.5%Ni, SM490 and A336 low-alloy steels used in this study are shown in **Table 1**, together with the filler material of Alloy690. Specimens of low-alloy steels (5×5×5 mm) were heated by a high frequency induction heating device to synthesize the as-welded and temper-processed HAZ. The peak temperature (Tp) of the simulated thermal cycle were changed from 400 ℃ to 1350℃, and the cooling rate (CR) in the range between 800 ℃ and 500℃ of the thermal cycle varied from 3 ℃/s to 2 000 ℃/s (water quenching). For the temper thermal cycle, temper temperature is lower than Ac1, thus it was changed in the range of 400 °C~650 °C.

The temper bead welded samples of low-alloy steels were produced by TIG welding with the welding conditions shown in **Table 2**. The temper bead welding was performed using the consistent layer technique [6,7]. The cross-sectional surfaces

1. Uvod

Nisko legirani čelici se široko primenjuju za proizvodnju cevi, automobilskih i vazduhoplovnih delova, železničkih pruga i morskih i obalnih konstrukcijskih elemenata. Nisko legirani čelik ASTM A533B koji ima vrhunsku žilavost na niskim temperaturama i zavarivljivost obično se koristi kao materijal za posude vodenih reaktora pod pritiskom u nuklearnim elektranama [1,2]. Na osnovu eksperimentalno dobijene baze podataka o tvrdoći, autori su u prethodnoj studiji konstruisali sistem predviđanja tvrdoće preko neuronske mreže na zoni uticaja toplote (ZUT) zavara za otpuštanje za čelik A533B [3-5].

Međutim, u stvarnoj industriji, zavari za otpuštanje potrebni su ne samo za čelik A533B, nego i za druge niskolegirane čelike. Za predviđanje tvrdoće ZUT kod ostalih čelika, potrebno je dobiti bazu podataka o tvrdoći za svaki čelik, koja zahteva mnogo vremena, ako se koristi ista metoda. Ova studija je sprovedena kako bi se razvila metoda opšteg predviđanja tvrdoće primenljiva na ostale niskolegirane čelike korišćenjem baze podataka o tvrdoći čelika A533B uz pretpostavku da tvrdoća u HAZ-u niskolegiranih čelika nakon otpuštanja ima linearni odnos sa LMP (Parametar Larson-Miller) [3]. Upotrebom novo- predložene proširene metode potrebno je dobiti samo nekoliko baza podataka o tvrdoći za ostale čelike. Stoga je sa stanovišta inženjeringa predložena proširena metoda ranije konstruisanog sistema predviđanja tvrdoće čelika A533B na ostale niskolegirane čelike bez sekundarnog otvrdnjavanja.

2. Materijali i eksperimentalne procedure

Hemijski sastavi niskolegiranih čelika A533B, A508, 1,5% Ni, SM490 i A336 korišćenih u ovom istraživanju prikazane su u tabeli 1, zajedno sa dodatnim materijalom Alloy690. Uzorci niskolegiranih čelika (5 × 5 × 5 mm) zagrevani su visokofrekventnim indukcionim grejnim uređajem za sintetizaciju ZUT zavarenog i otpuštanog. Najviša temperatura (Tp) simuliranog toplotnog ciklusa izmenjena je sa 400 ℃ na 1350 ℃, a brzina hlađenja (CR) u opsegu između 800 ℃ i 500 ℃ termičkog ciklusa varirala je od 3 ℃ / s do 2 000 ℃ / s (kaljenje u vodi). Za termički ciklus otpuštanja, temperatura otpuštanja je niža od Ac1, pa je promenjena u opsegu od 400 ° C do 650 ° C.

Uzorci otpuštenih zavara kod niskolegiranih čelika proizvedeni su TIG zavarivanjem uz uslove zavarivanja prikazanih u tabeli 2. Zavarivanje zavara za otpuštanje izvršeno je korišćenjem metode konzistentnog sloja [6,7]. Površine after 1-layer and 6-layer welding were cut from the multi-pass welded samples. The Vickers hardness was measured in the cross-section of the specimens after polishing and etching with 3% nital solution. The Vickers hardness measurement was performed at a load of 9.8N, and the mean value was taken after excluding the maximum and minimum values from each multiple measurement. The thermal cycles in temper bead welding were calculated using finite element analysis code developed by the authors specifically for welding simulation [8].

poprečnog preseka nakon jednoslojnog i 6-slojnog zavarivanja isečene su iz zavarenih uzoraka sa više prolaza. Tvrdoća po Vikersu je izmerena u preseku uzoraka nakon poliranja i nagrizanja sa 3% rastvorom nitala. Merenje tvrdoće po Vikersu izvršeno je pri opterećenju od 9,8 N, a srednja vrednost je uzeta nakon što su iz svakog višestrukog merenja isključene maksimalne i minimalne vrednosti. Toplotni ciklusi pri zavarivanju zavara za otpuštanje izračunati su korišćenjem analize konačnih elemenata koji su autori posebno razvili za simulaciju zavarivanja [8].

Material	**Chemical composition (mass. %) Hemijski sastav**																
	C	**Mn**	**P**	**S**	**Si**	**Ni**	**Cr**	**Mo**	**Cu**	**V**	**Ti**	**Ca**	**B**	**Al**	**Nb**	**Co**	**Fe**
A533B	0.12	1.43	0.006	0.002	0.26	0.53	0.01	0.51	0.02					0.038		-	Bal.
A508	0.18	1.48	0.005	0.002	0.18	0.76	0.12	0.5	0.2	0.003	0.015	0.015	0.003	0.0025	0.01	-	Bal.
1.5%Ni	0.08	1.01	0.011	0.003	0.25	1.93	0.16	0.07	0.05	0.02	-	-	-	-	0.009	-	Bal.
SM490	0.17	1.37	0.018	0.018	0.33	0.07	0.06	0.008	0.01	0.002	-	-	-	-	-	-	Bal.
A336	0.15	0.55	0.003	0.0006	0.05	0.20	2.54	1.03		0.30				0.011	0.030		Bal.
Alloy690	0.02	0.27	0.0021	0.015	0.15	Bal.	29.59	0.02	-	-	-	-	-	0.216	-	0.05	10.13

Table 1. *Chemical composition of materials used (mass. %)*
Tabela 1. *Hemijski sastav korišćenih materijala*

Layer Sloj	Current [A] Jačina struje	Voltage [V] Napon	Wire sending speed [mm/s] Brzina dodavanja žice	Welding speed [mm/s] Brzina zavarivanja	Heat Input [kJ/mm] Uneta toplota	Number of passes Broj prolaza
1st	250	15.3	50	1.67	2.3	3
2nd	120	12.5	25	5	0.3	5
3rd	120	12.5	25	5	0.3	4
4th	200	14.5	42	1.67	1.7	3
5th	200	14.5	42	1.67	1.7	3
6th	200	14.5	42	1.67	1.7	3

Table 2. *Welding condition of multi-pass welding of the low-alloy steels*
Tabela 2. *Uslovi zavarivanja kod višelojnog zavarivanja niskolegiranih čelika*

3. Extended application method of hardness prediction system of A533B steel

The expansion of the previously constructed hardness prediction system of A533B steel to the other low-alloy steels without secondary hardening was proposed in this study. For the thermal cycle without temper (1-cycle, 2-cycle), because the hardness decrease monotonously with the decrease of T_p, as shown in **Fig. 1** [3], Quenching Index (QI) can be proposed, as expressed in the following formulas (1) and (2):

$$\mathrm{QI} = (\mathrm{Hv}_\alpha - \mathrm{Hv0}_\alpha)/(\mathrm{HvM}_\alpha - \mathrm{Hv0}_\alpha) \tag{1}$$

$$\mathrm{Hv}_\beta = \left(\mathrm{HvM}_\beta - \mathrm{Hv0}_\beta\right) \times \mathrm{QR} + \mathrm{Hv0}_\beta \tag{2}$$

where, α indicates A533B steel and β indicates the other steels; HvM is the maximum hardness (Full Martensite), and Hv0 is the minimum hardness (Full-Annealed). Through this method, based on the obtained A533B hardness database [3,5], the QI prediction system can be constructed by neural network [9-11], as illustrated in **Fig. 2**.

3. Proširena metoda primene sistema predviđanja tvrdoće za čelik A533B

U ovoj studiji je predloženo širenje ranije konstruisanog sistema predviđanja tvrdoće čelika A533B na ostale niskolegirane čelike bez sekundarnog otvrdnjavanja. Za termički ciklus bez otpuštanja (1-ciklus, 2-ciklusa), jer se tvrdoća monotono smanjuje sa smanjenjem Tp, kao što je prikazano na slici 1 [3], može se predložiti indeks kaljenja (QI), izražen u sledećim formulama (1) i (2):

$$\mathrm{QI} = (\mathrm{Hv}_\alpha - \mathrm{Hv0}_\alpha)/(\mathrm{HvM}_\alpha - \mathrm{Hv0}_\alpha) \tag{1}$$

$$\mathrm{Hv}_\beta = \left(\mathrm{HvM}_\beta - \mathrm{Hv0}_\beta\right) \times \mathrm{QR} + \mathrm{Hv0}_\beta \tag{2}$$

gde α označava A533B čelik i β označava ostale čelike; HvM je maksimalna tvrdoća (potpuni martenzit), a Hv0 je minimalna tvrdoća (potpuno žarena). Pomoću ove metode, na osnovu dobijene baze podataka o tvrdoći A533B [3,5], sistem predviđanja QI može se konstruisati neuronskom mrežom [9-11], kao što je prikazano na slici 2.

For the thermal cycle with temper (1-cycle+temper, 2- cycle+temper), because the hardness after temper has a linear relationship with LMP for the low-alloy steels without secondary hardening as shown in Fig. 3 [3], Temper Index (TI) can be proposed, as expressed in the following formulas (3) and (4):

$$TI = (Hv_{\alpha} - Hv0_{\alpha})/(HvM_{\alpha} - Hv0_{\alpha}) \tag{3}$$

$$Hv_{\beta} = (HvM_{\beta} - Hv0_{\beta}) \times TI + Hv0_{\beta} \tag{4}$$

where, α indicates A533B steel and β indicates the other steels; HvM is the hardness before temper, and Hv0 is the minimum hardness after temper (Full-Annealed). Through this method, the TI prediction system can be constructed by neural network based on the A533B hardness database, as shown in Fig. 4.

By using the newly proposed extended hardness prediction method, the generalized hardness prediction method applicable for other steels can be developed, with only a few hardness data-base for the other steels needed to obtain.

Za termički ciklus sa otpuštanjem (1-ciklus + otpuštanje 2-ciklus + otpuštanje), jer tvrdoća nakon otpuštanja ima linearni odnos sa LMP-om za niskolegirane čelike bez sekundarnog otvrdnjavanja, kao što je prikazano na slici 3 [3], Indeks otpuštanja (TI) može se predvideti, izraženo sledećim formulama (3) i (4):

$$TI = (Hv_{\alpha} - Hv0_{\alpha})/(HvM_{\alpha} - Hv0_{\alpha}) \tag{3}$$

$$Hv_{\beta} = (HvM_{\beta} - Hv0_{\beta}) \times TI + Hv0_{\beta} \tag{4}$$

gde α označava A533B čelik i β označava ostale čelike; HvM je tvrdoća pre otpuštanja, a Hv0 je minimalna tvrdoća nakon otpuštanja (pitpuno žareno). Kroz ovu metodu, sistem predviđanja TI može se konstruisati neuronskom mrežom na osnovu baze tvrdoće A533B, kao što je prikazano na slici 4.

Korišćenjem novo predložene proširene metode predviđanja tvrdoće, može se razviti generalizirana metoda predviđanja tvrdoće koja se primjenjuje na ostale čelike, sa samo nekoliko potrebnih baza podataka tvrdoće za ostale čelike.

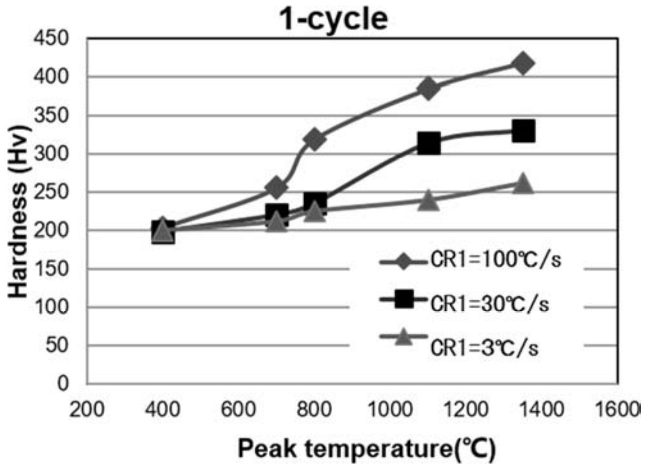

Fig. 1 *Relationship between the hardness of 1-cycle and peak temperature*
Sl.1. *Međusobni odnos tvrdoća 1. ciklusa I vršne temperature*

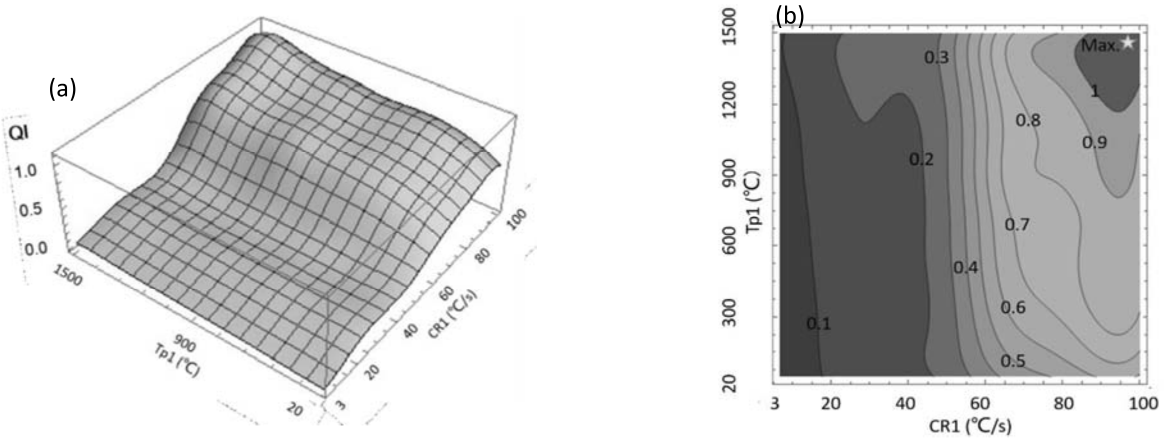

Fig. 2 *QI prediction system of 1-cycle: (a) 3D figure and (b) 2D-contour figure*
Sl. 2. *Sistem predviđanja 1.cilusa : (a) 3D slika i (b) 2D-slika kontura*

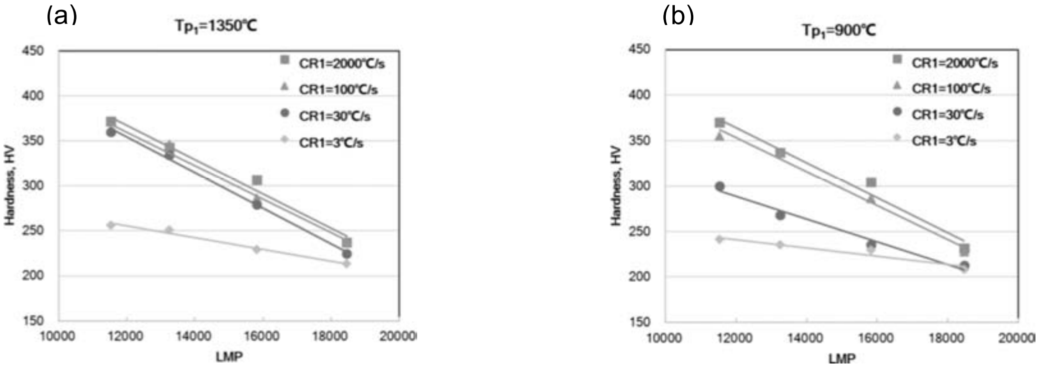

Fig. 3 *Relationship between the hardness of 1-cycle+temper and LMP: (a) Tp1=1350℃ and (b) Tp1=900℃*
Sl. 3. *Međusobni odnos tvrdoća 1. ciklusa+otpuštanje i LMP: (a) Tp1=1350℃ i (b) Tp1=900℃*

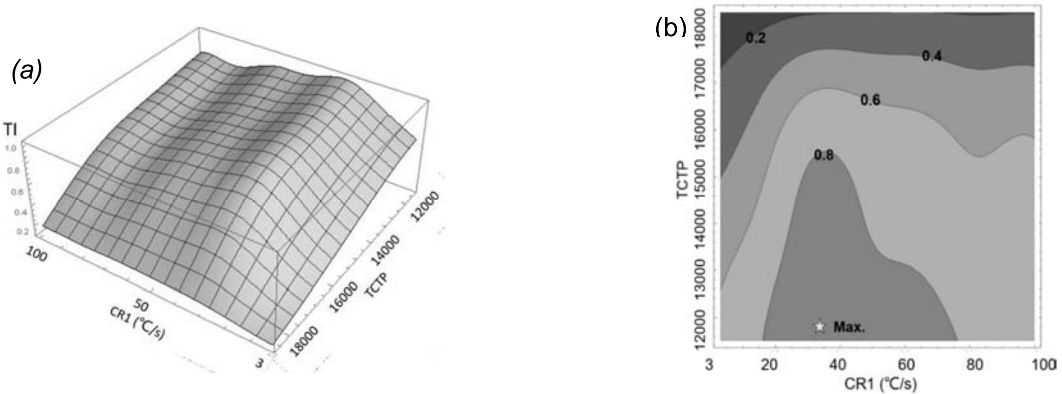

Fig. 4 *TI prediction system of 1-cycle+temper (with constant Tp1=1350℃): (a) 3D figure and (b) 2D-contour figure*
Sl. 4. *Sistem predviđanja TI 1-ciklus+otpuštanje (sa konstantnom Tp1=1350℃): (a) 3D slika i (b) 2D-slika kontura*

4. Hardness prediction of the other steels after temper bead welding using the extended application method

By using the three-dimensional finite element analysis code developed specifically for welding simulation [8], the peak temperature distributions produced by multi-pass thermal cycles in welds during temper bead welding were calculated as illustrated in **Fig. 5**. Using the neural network-based QI and TI prediction system, the hardness in HAZ of A508, 1.5%Ni, SM490 and A336 steels after temper bead welding was calculated, based on the simulated thermal history in HAZ.

The two-dimensional hardness distribution in the HAZ of A508 steel after 1-layer welding and 6-layer welding are shown as color contour maps in **Fig. 6**. Besides the red weld metal (WM) and grey base metal (BM) regions, the hardness in HAZ is shown with rainbow colors depending on the different hardness levels. Compared with the hardness after 1-layer welding, the hardness has decreased remarkably after 6-layer welding because of the temper effect.

In order to verify the effectivity of the extended hardness prediction method, the predicted hardness distribution has been compared with the measured result as shown in **Fig. 7**. It follows that not only the maximum hardness but also

4. Predviđanje tvrdoće drugih čelika nakon zavarivanja zavara za otpuštanje primenom proširene metode

Korišćenjem trodimenzionalnog koda za analizu konačnih elemenata razvijenog specijalno za simulaciju zavarivanja [8], raspodeljene vršne temperature dobijene više-prolaznim toplotnim ciklusima u šavovima za vreme zavarivanja zavara za otpuštanje izračunate su kao što je prikazano na slici 5. Korišćenje neuronske mreže - na osnovu QI i TI sistema predviđanja, izračunata je tvrdoća u ZUT kod čelika A508, 1,5% Ni, SM490 i A336 nakon zavarivanja zavara za otpuštanje, na osnovu simulirane termičke istorije u ZUT.

Dvodimenzionalna raspodela tvrdoće u ZUT čelika A508 nakon jednoslojnog zavarivanja i 6-slojnog zavarivanja prikazani su kao konturne karte u boji na slici 6. Pored područja crvenog metala šava (WM) i sivog osnovnog metala (BM), tvrdoća u ZUT je prikazana duginim bojama zavisno od nivoa tvrdoće. U poređenju sa tvrdoćom nakon jednoslojnog zavarivanja, tvrdoća se znatno smanjila nakon 6-slojnog zavarivanja zbog efekta otpuštanja.

Da bi se potvrdila efikasnost proširene metode predviđanja tvrdoće, upoređena je predviđena raspodela tvrdoće sa izmerenim rezultatom kao što je prikazano na slici 7. Iz toga sledi da se ne samo the hardness change tendency agrees well with the predicted result. And as presented in **Fig. 8**, the hardness profiles were measured along the dotted line, which is 1.0 mm far from the specimen surface. The blue points indicate the experimentally measured hardness, and the red points indicate the calculated hardness using our proposed method, based on the simulated thermal history. The calculated hardness is in good accordance with the experimentally measured result for A508 steel.

Similarly, the predicted hardness distribution and the comparison of the predicted hardness and experimentally measured hardness of 1.5%Ni, SM490 steels are illustrated in **Figs. 9-11** and **Figs. 12-14** respectively. It indicates that the predicted hardness is in good accordance with the experimentally measured hardness for not only A508 steel, but also 1.5%Ni and SM490 steels.

For A336 steel, the two-dimensional hardness distribution in the HAZ after 1-layer welding and 6-layer welding are shown as color contour maps in **Fig. 15**. The comparison of the predicted and the experimentally measured hardness distribution is illustrated in **Fig. 16**. It can be found that the predicted hardness is quite different from the experimentally measured result for A336 steel. And as presented in **Fig. 17**, the hardness profiles measured along the line of 1.0 mm far from the specimen surface do not agree with the calculated result. Above all, the predicted hardness is in good accordance with the experimentally measured hardness for A508, 1.5%Ni, SM490 steels, while the predicted hardness is quite different from the measured result for A336 steel. And the correlation coefficient between the predicted hardness and the experimentally measured hardness of 4 kinds of steel are summarized in **Table 3**, which also indicates that the proposed hardness prediction method is useful for A508, 1.5%Ni, SM490 steels, except A336 steel.

maksimalna tvrdoća, već i tendencija promene tvrdoće dobro slaže sa predviđenom rezultatima. I kao što je prikazano na slici 8, profili tvrdoće su izmereni duž isprekidane linije, koja je udaljena 1,0 mm od površine uzorka. Plave tačke označavaju eksperimentalno izmerenu tvrdoću, a crvene označavaju izračunatu tvrdoću pomoću naše predložene metode, zasnovane na simuliranoj termičkoj istoriji. Izračunata tvrdoća je u dobrom skladu sa eksperimentalno izmerenim za čelik A508 čelik.

Slično, predviđena raspodela tvrdoće i poređenje predviđene tvrdoće sa eksperimentalno izmerenim tvrdoćeama za čelike 1,5% Ni, SM490 su ilustovane na sl. 9-11 i sl. 12-14. To pokazuje da je predviđena tvrdoća u dobroj usaglašenosti sa eksperimentalno izmerenim ne samo za čelik A 508, već i za ćelike 1,5%Ni i SM 490.

Za čelik A336, dvodimenzionalna raspodela tvrdoće u ZUT nakon jednoslojnog zavarivanja i 6-slojnog zavarivanja prikazana je kao konturne karte u boji na slici 15. Upoređivanje predviđene i eksperimentalno izmerene tvrdoće je ilustrovano na sl. 16. Može se utvrditi da je predviđena tvrdoća prilično različita od eksperimentalno izmerenih rezultata za čelik A336. I kao što je prikazano na slici 17, profili tvrdoće meren duž linije od 1,0 mm udaljene od površine uzorka, se ne slažu sa izračunatim rezultatima.

Pre svega, predviđena tvrdoća se dobro slaže s eksperimentalno izmerenom tvrdoćom za A508, 1,5% Ni, SM490 čelik, dok je predviđena tvrdoća prilično različita od izmerene vrednosti za čelik A336. A koeficijent korelacije između predviđene tvrdoće i eksperimentalno izmerene tvrdoće 4 vrste čelika sažet je u Tabeli 3, što takođe ukazuje da je predložena metoda predviđanja tvrdoće korisna za čelike A508, 1,5% Ni, SM490, osim čelika A336.

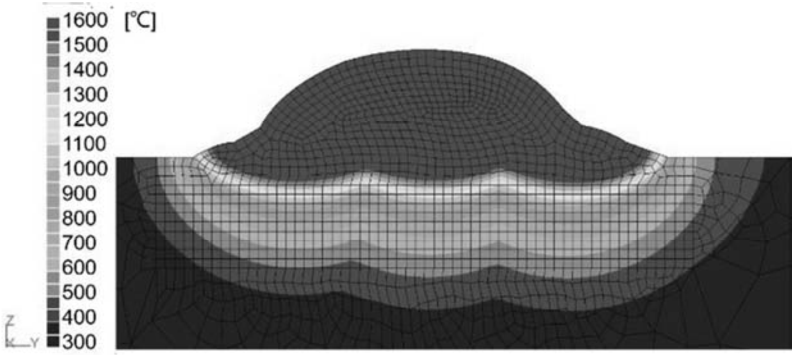

Fig. 5 *Simulated peak temperature distribution after 6layer- 21pass welding*
Sl. 5 *Simulirana raspodela vršnih temperature posle 6 slojeva- 21 prolaz zavarivanja*

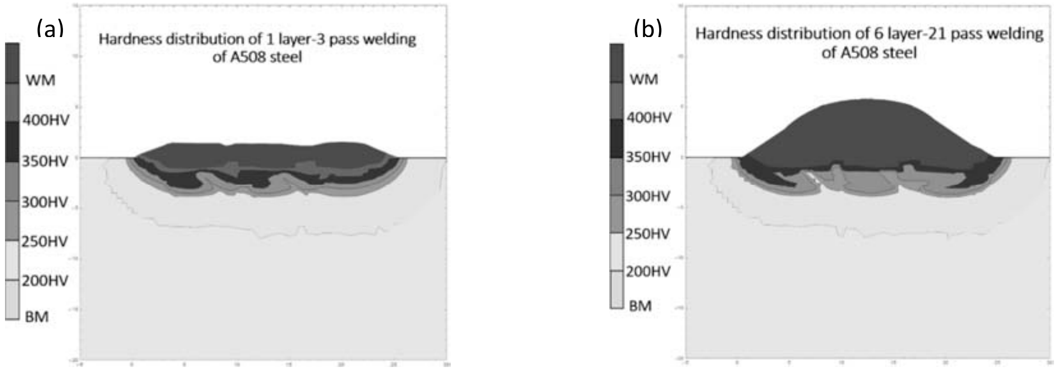

Fig. 6 *Predicted hardness distribution of A508 steel: (a) 1layer-3pass welding and (b) 6layer-21pass welding*
Sl. 6 *Predviđena raspodela tvrdoće ćelika A508: (a) 1 sloj-3 prolaza i (b) 6 slojeva-21 prolaz*

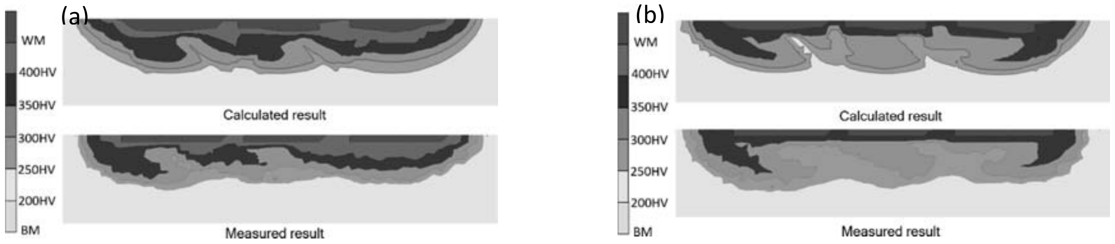

Fig. 7 *Hardness distribution comparison of A508 steel: (a) 1layer-3pass welding and (b) 6layer-21pass welding*
Sl. 7 *Upoređenje raspodele tvrdoće čelika A508: (a) 1 sloj-3 prolaza i (b) 6 slojeva-21 prolaz*

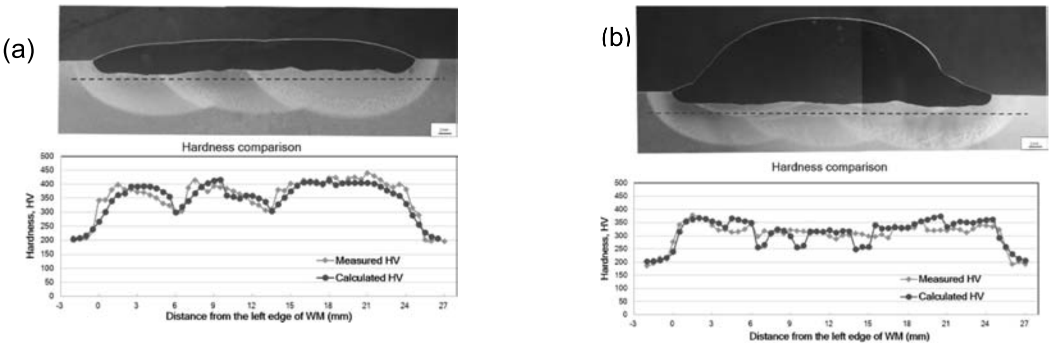

Fig. 8 *Hardness comparison after 1-Layer and 6-Layer welding of A508 steel: (a) 1layer-3pass welding and (b) 6layer-21pass welding*
Sl. 8 *Upoređenje tvrdoće posle 1-slojnog i 6-slojnog zavarivanja čelika A508: (a) 1sloj-3 prolaza i (b) 6slojeva -21 prolaz*

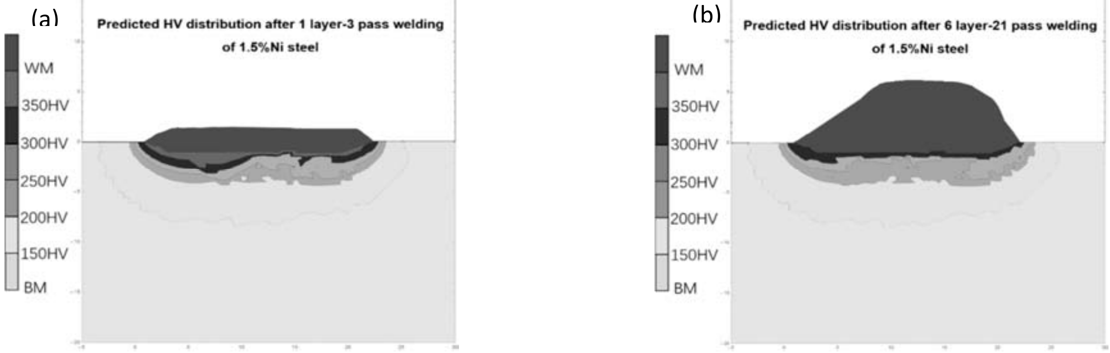

Fig.9 *Predicted hardness distribution of 1.5%Ni steel: (a) 1layer-3pass welding and (b) 6layer-21pass welding*
Sl.9 *Predviđena raspodela tvrdoće čelika 1.5%Ni: (a) 1 sloj-3 prolaza i (b) 6 slojeva-21 prolaza*

-Kraj 1. dela NASTAVAK U SLEDEĆEM BROJU