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THE EFFECT OF MICROSTRUCTURE ON HIGH-STRESS ABRASION RESISTANCE OF Fe-Cr-C HARDFACING DEPOSITS

UTICAJ MIKROSTRUKTURE NA OTPORNOST PREMA VISOKOJ ABRAZIJI TVRDO NAVARENIH SLOJEVA OD Fe-Cr-C

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Key words: Surface preparation; Carbon steels; Covered electrodes; Microstructure; Wear resistance

Rezime

Modifikacija površine ugljeničnog čelika izvedena je sa dve obložene elektrode i dve punjene elektrode (cevaste elektrode). Elektrode su prema DIN 8555: E6-UM-60 i E10-UM-60GR; a punjene su E10-GF-60GR1 i E10-GF-60GR2. Sprovedena je hemijska analiza metala šava i XRD obloga kod elektroda i punjenja kod punjenih elektroda. Najznačajniji faktor za određivanje otpornosti na habanje je mikrostruktura nanetih slojeva. Kod elektroda sličnog ugljenikovog ekvivalenta E10-UM-60GR i E10-GF-60GR1, elektroda E10-GF-60GR1 (cevasta) pokazuje veći udeo površine sa većim karbidima i bolju otpornost na habanje nego elektroda E10- UM-60GR (obložena). Ovo se može pripisati manjem mešanju kod punjene elektrode u odnosu na obloženu elektrodu. Dve cevaste elektrode su pokazale veću opornost na habanje nego obložene elektrode što je uglavnom u vezi sa površinom taloženja većih Fe-Cr karbida.

Uvod

Polu i automatsko elektrolučno zavarivanje u zaštiti gasa (GMAW) punjenim i obloženim žicama se uobičajeno koristi za navarivanje novih i oštećenih mašinskih delova [1–3]. Ovakvo navarivanje se često koristi u velikom opsegu industrijskih oblasti

Abstract

Surface modification of mild steel was under-taken using two covered electrodes and two tubular electrodes. The two covered electrodes are DIN 8555: E6-UM-60 and E10-UM-60GR; however, the two tubular electrodes are E10-GF-60GR1 and E10-GF-60GR2. Chemical analysis for the weld metal and XRD of the flux covering for covered electrodes and flux core for tubular electrodes were conducted. The most important factor in determining the wear resistance is the micro-structure of the deposit layers. In similar carbon equivalent electrodes E10-UM-60GR and E10-GF-60GR1, electrode E10-GF-60GR1 (tubular) shows larger carbides area fraction and better wear resistance than electrode E10-UM-60GR (covered). This could be attributed to a lower dilution associated with tubular electrode compared with covered electrode. The two tubular electrodes showed higher wear resistance than the covered electrodes which is mainly due to the larger Fe-Cr carbide precipitation area fraction.

Introduction

Semi and automatic gas metal arc welding (GMAW) flux and cored wire surfacing is commonly used as surfacing for new and worn machine parts [1–3]. This surfacing is frequently applied in a wide range of industries to improve the wear resistance za unapređenje otpornosti na habanjekontaktnih površina. Izneto je da 50– 60 % elemenata mašina biva oštećeno usled abrazije koja ima mnogo oblika uključujući malo naprezanje, veliko naprezanje, abraziju u suvim ili mokrim uslovima Materijali za tvrdo navarivanje na bazi železa se često koriste zbog relativno malih troškova i lake primene. Među tim materijalima, visoko Cr legure su posebno atraktivne zato što karbidi obezbeđuju povećanu otpornost na habanje [6]. Kod tvrdih navara na bazi železa, postoji mnogo mikrostruktura kao i velike razlike u sastavu koje obezbeđuju različitu otpornost na abraziju. Kotecki i Ogborn su istraživali otpornost na abraziju pri malom naprezanju brojnih legura za tvrdo navarivanje na bazi železa; oni su zaključili da je mikrostruktura najznačajniji faktor za otpornost prema abraziji. Nasuprot tome, inženjeri u održavanju insistiraju na tome da povećanje tvrdoće pri tvrdom navarivanju rezultuje u boljoj otpornosti na abraziju. Mada povećana tvrdoća može da rezuluje u boljoj otpornosti na abraziju, različiti tvrdi navari sa sličnim tvrdoćama pokazuju različitu otpornost na abraziju [7].Mešanje depozita sa rastopljenim osnovnim materijalom je jedan od važnih parametara navarivanja. Mešanje se može kontrolisati zavisno od unete toplote i tehnike navarivanja [8, 9]. U ovoj studiji, modifikacija površine ugljeničnog čelika izvedena je sa dve komercijane obložene elektrode i dve komercijane punjene elektrode (cevaste elektrode). Ručno elektrolučno zavarivanje (MMA-REL) je korišćeno zbog prednosti malih troškova i lakšeg rukovanja nego kod GMAW. Da bi se dobile optimalne vrednosti tvrdoće i uporedili rezultati obloženih elektroda sa punjenim, primenjeni su jednoslojni depoziti.

of surfaces in contact [4, 5]. It is reported that 50–60 % of machine elements are worn due to abrasive wear which has many forms including low stress, high stress, dry or wet abrasion [6].

Iron-based hardfacing materials are commonly used due to its relatively low cost and ease of application. Among these materials, the high Cr alloys are particularly attractive because of the carbides which provide enhanced abrasion resistance [6]. In the iron-based hardfacings, there are many microstructures and wide differences in composition that provide different abrasion resistance. Kotecki and Ogborn [5] studied the low-stress abrasion resistance of numerous iron-based hardfacing alloys; they concluded that microstructure is the most important factor for wear resistance. On the contrary, maintenance engineers insist that increasing the hardness of the hardfacings results in better abrasion resistance. Although increased hardness can result in better wear resistance, different hardfacings with similar hardness show different wear resistance [7]. Dilution of the deposit by melted base metal is one important surfacing parameter. Dilution can be controlled depending on heat input and technique of surfacing [8, 9]. In this study, surface modification of mild steel is undertaken using two commercially covered electrodes and two commercial tubular electrodes. Manual metal arc (MMA) process is used which has the advantages of low cost and ease of application over the GMAW. Single layer deposit was applied to obtain the optimum hardness values, and the results of the covered electrodes were compared to that of the tubular ones.

Metal	Hemijski sastav						Debljina
Ugljenični čelik	C	Si	Mn	S	P	Fe	10 mm
	0,15	0,12	0,94	0,02	0,03	98,06	

Table 1 Chemical composition of mild steel plate, wt%
Tabela 1: Hemijski sastav čeličnog lima , %

Korišćena su dva tipa elektroda za tvrdo navarivanje . Prvi tip je korišćen kao obložena elektroda (DIN8555: E6-UM-60, elektroda: A), drugi tip kao obložena elektroda (DIN8555: E10-UM-60GR, elektroda: B) i kao cevasta elektroda (DIN8555: E10-GF-60GR1, elektroda: C), i (DIN8555: E10-GF-60GR2, elektroda: D). I obložene i cevaste elektrode su za postupa REL zavaraivanja .

Two types of iron-based hardfacing electrodes alloys were used as hardfacing materials. The first type is used as a covered electrode (DIN8555: E6-UM-60, Electrode: A), the second type is used as coveredelectrode (DIN8555: E10-UM-60GR, Electrode: B) and as a tubular electrode (DIN8555: E10-GF-60GR1, Electrode: C), and (DIN8555:E10-GF-60GR2, Electrode: D). Both of covered and tubular electrodes are electrodes for MMAwelding process.

2 Eksperimentalni rad

2.1 Materijali

Limovi od uljeničnog čelika debljine 10mm odabrani su kao osnovni materijal za deponovanje materijala za tvrdo navarivanje. U tabeli 1je prikazan hemijski sastav ugljeničnog čelika.

2.2 Tehnologija zavarivanja

Postupak REL zavarivanja kao materijale za tvrdo navarivanje koristi obložene i cevaste elektrode. Nanošenje je obavljeno bez predgrevanja a uslovi zavarivanja dati su u tabeli 2. Jedan sloj je nanet uz blago njihanje da bi se nanela po tri navara..

2.3 Hemijska analiza

Analiza žica i topitelja izvedena je korišćenjem optičkog emisionog spektrometra i analize difrakcije X-zraka (XRD), za oba tipa elektroda. Posle zavarivanja, finalni sloj je izbrušen i analiziran korišćenjem optičkog emisionog spektrometra.

2.4 Mikrostruktura i tvrdoća

Uzorci su isečeni iz tvrdo navarenog lima korišćenjem mašine sa hlađenim diskom, potom brušeni i polirani a onda su uzorci nagriženi i fotografisani. Raspodela tvrdoće je određena korišćenjem ispitivanja mikrotvrdoće. Opterećenje je bilo 1,000 g a vreme opterećenja 15 s.

2.5 Ispitivanje habanja

.

Ispitivanje abrazivnog habanja sprovedeo je testom „šipka na disku“ korišćenjem mašine za tribometriska ispitivanja; svi testovi su sprovedeni pod uslovima čistog klizanja između epruveta i abrazivnog diska. Epruvete za ispitivanje abrazijedimenzija (7.5×11.5×12 mm) isečene su iz zavarenih uzoraka. Ispitne epruvete su brušene brusnim papirom 60-SiC kako bi se osigurali isti uslovi ispitivanja. Epruvete su očišćene u acetonu korišćenjem ultrazvučnog čistača, pre i posle testa su merene na četvrtu decimalu. Uslovi ispitivanja habanja su bili 70 N u trajanju od 10 min sa brzinom rotacije od 125 rpm. Abrazivni disk je prečnika 73-mm a korišćeni su parčići silicijumkarbida veličine 60-µm meša. Mlaz komprimovanog vazduha je usmeren na ivicu diska za brušenje tokom ispitivanja radi izbegavanja nakupljanja habajućih parčića na disku.

2 Experimental work

2.1 Materials

Plates of mild steel of 10-mm thickness were selected as a base metal for deposition of hardfacing materials. Table 1 shows the chemical composition of mild steel plate.

2.2 Welding procedure

MMAwelding process is used to apply hardfacing

materials using covered electrode and tubular electrode. Deposition without preheating is used and the welding conditions are shown in Table 2. One layer was deposited using tight bead spacing technique with three passes.

2.3 Chemical analysis

Analysis of wires and fluxes is carried out using optical emission spectrometry and X-ray diffraction (XRD) analysis, respectively, for both types of electrodes. After welding, the final layer was grinded and analyzed using optical emission spectrometry.

2.4 Microstructure and hardness

Samples were cut out from the hardfacing steel plate using a cooling disc machine then grounded and polished, and then, the samples were etched and photographed. The hardness distribution was determined using micro hardness test. The load was 1,000 g and loading time was 15 s.

2.5 Wear test

Abrasion wear test pin-on-disc was conducted using tribometer testing machine; all tests were carried out under pure sliding condition between specimens and abrasive disc. The abrasion test samples of dimension (7.5×11.5×12 mm) were cut out from the welded specimens. Test surfaces were all ground using 60-SiC grit paper to ensure equal condition for testing. Test specimens were cleaned in acetone using ultrasonic cleaner, before and after test then weighted to four decimals. The wear testing conditions were 70 N for 10 min with 125 rpm rotational speed. Abrasive disc of 73-mm diameter and 60-µm mesh size silicon carbides particles was used. A stream of compressed air was pointed to the edge of the grinding disc during test to avoid accumulation of wearing particles on the disc.

3 Rezultati i diskusija

3.1 Hemijski sastav elektroda i metala šava

XRD je sprovedeno na oblogama elekktroda i prašku cevastih elektroda. XRD je pokazao za obloge elektrode (A) da su glavne komponente kalcit i ferohrom. XRD obloge elektrode (B) je pokazao slične rezultate kao i za praškasto punjenje cevastih elektroda (C) i (D); sve one sadrže ferohrom, grafit i kalcit.

Analize žica za elektrode A, B, C i D prikazane su u tabeli 3. Sve su one od ugljeničnog čelika sličnog hemijskog sastava. Zavarivanje je sprovedeno korišćenjem četiri elektrode uz uslove koji su dati u tabeli 2. Jedan sloj je izveden od tri prolaza vrlo blisko postavljenih jedan uz drugi, (50 % preklop). Analiza metala šava na vrhu površine sloja data je u tabeli 4.

3 Results and discussion

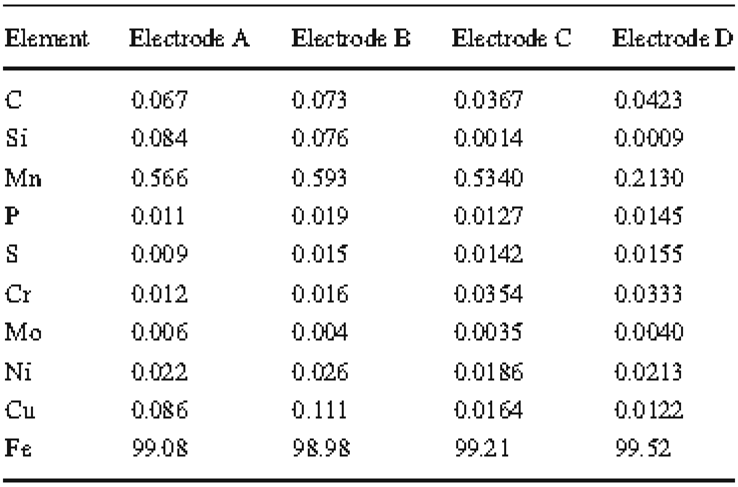
3.1 Chemical composition of electrodes and weld metal

XRD was conducted to the covering of electrodes and the flux in the core of the tubular wire. The XRD pattern of the covers for electrode (A) shows that the main components are calcite and ferrochromium. XRD pattern of electrode (B) covering shows similar results to that of the flux core of tubular electrode (C) and tubular electrode (D); all of them shows the existence of ferrochromium, graphite, and calcite. Analysis of the wires for electrodes A, B, C, and D isshowninTable3. All of them are mild steel wires with similar chemical composition. Welding was conducted using the four electrodes with the welding conditions mentioned in Table 2. One layer is formed from three passes welded with tightly bead spacing (50 % overlap) technique. Analysis of the weld metals at the top surface of the layer is shown inTable 4.

Tip elektrode	Prečnik (mm)	Tehnika	Jačina struje (A)	Napon (V)	Brzina zavarivanja (cm/min)
E6-UM-60	4	Blago njihanje	140	20	12
E10-UM-60GR	4	Blago njihanje	140	20	12
E10-GF-60GR1	Unutrašnji 4,1 spoljašnji 6,3	Blago njihanje	140	20	86
E10-GF-60GR2	Unutrašnji 4,1 spoljašnji 6,3	Blago njihanje	140	20	82

Table 2 Welding conditions

Tabela 2. Uslovi zavarivanja



Element	Electrode A	Electrode B	Electrode C	Electrode D
C	0.067	0.073	0.0367	0.0423
Si	0.084	0.076	0.0014	0.0009
Mn	0.566	0.593	0.5340	0.2130
P	0.011	0.019	0.0127	0.0145
S	0.009	0.015	0.0142	0.0155
Cr	0.012	0.016	0.0354	0.0333
Mo	0.006	0.004	0.0035	0.0040
Ni	0.022	0.026	0.0186	0.0213
Cu	0.086	0.111	0.0164	0.0122
Fe	99.08	98.98	99.21	99.52

Table 3 Chemical analysis of the core wire for electrodes A and B and the tubes for electrodes C and D, wt%

Tabela 3. Hemijska analiza žica za elektrode A i B i cevi za elektrode C i D (tež.%)

Electrode	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	W	Fe
A	0.26	0.58	0.38	0.0050	0.0002	10.4	0.03	0.04	0.03		Bal.
B	3.76	0.85	1.24	0.0010	0.0002	30.9	0.04		0.02	0.25	Bal.
C	3.70	1.42	1.35	0.0100	0.0003	25.8	0.03	0.09	0.34	0.16	Bal.
D	5.00	0.86	0.33	0.0003	0.0003	24.5	0.05	0.77	0.08	0.13	Bal.

Table 4 Chemical composition of the weld metals using the fourelectrodes, wt%

Tabela 4. Hemijski sastav metala šava korišćenjem četiri elektroda (tež. %)

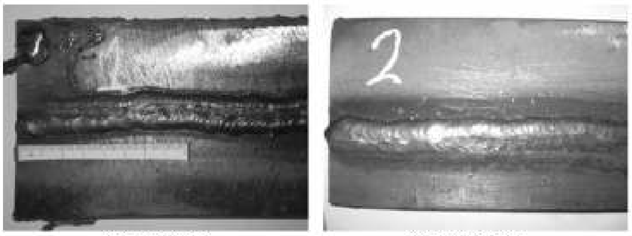
Analiza metala šava, punjenih žica, i materijala cevi indikuju to da su glavne komponente metala šava uglavnom nastale od obloge elektrode kod obloženih elektroda (A) i (B) ili topitelja u punjenju cevastih elektroda (C) i (D). Korišćena je jednoslojna tehnika zato što daje optimalne rezultate tvrdoće. Ugljenikov ekvivalent se može koristiti za određivanje kada je tvrdo navarivanje podeutektičko ili nadeutektičko. Formula je [10]:

CE = %C + 1/3 (%Si + %P) – 0,03 (%Mn) tež.% (1)

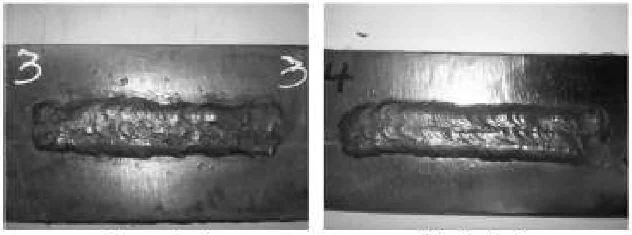
Bazhenov i Pikunov [11] su odredili ugljenikov ekvivalent na osnovu politermalnog preseka sistema Fe-C-Si-P-Mn-S datog pomoću „thermo-Calc“ programa. Regresionom analizom, oni su dobili sledeću formulu za ugljenikov ekvivalent:

CE = %C +(0,3 %Si) + 0,33(%P)+ 0,015 (%Mn) + 0,26 (%S) tež% (2)

Korišćenjem jednačine 2, ugljenikovi ekvivalenti za metal šava elektroda B, C i D su 4, 4,1 i 5,25.



Electrode A Electrode B



Electrode C Electrode D

The analysis of the weld metals, the core wires, and the tube materials indicates that the main components of the weld metal are mainly generated from the covering of the covered electrodes (A) and (B) or the flux in the core of the tubular electrodes (C) and (D). One-layer technique was used as it gives the optimum hardness values. The carbon equivalent may be used to determine whether the hardfacings are hypoeutectic or hypereutectic. The formula is expressed as the following [10]:

CE = %C + 1/3 (%Si + %P) – 0,03 (%Mn) wt.% (1)

Bazhenov and Pikunov [11] determined the carbon equivalent by means of poly-thermal cross sections of the Fe-C-Si-P-Mn-S system plotted using the thermoCalc program. By regression analysis, they obtain the following formula for the carbon equivalent:

CE = %C +(0,3 %Si) + 0,33(%P)+ 0,015 (%Mn) + 0,26 (%S) wt% (2)

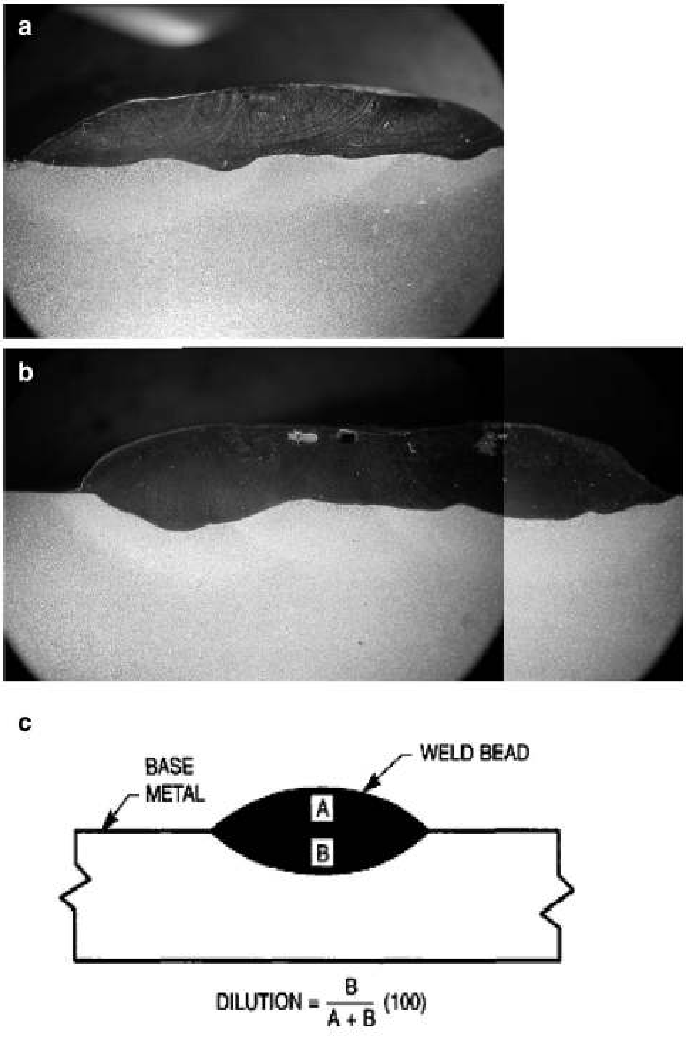
Using Eq. 2, carbon equivalents for weld metals of electrodes B, C,and D were found to be 4,4.1, and 5.25 , respectively.

Fig. 1 Weld beads using the four electrodes

Sl. 1.Navari u navarenom sloju korišćenjem četiri electrode

Međutim, sadržaj hroma u livenom gvožđu otpornom na habanje može da varira do 30 %; što jako utiče na eutktičku tačku [12]:

Radi istraživanja mogućih promena eutektičke tačke zavisno od legirajućih elemenata, Bazhenov i Pikunov [11] su odredili eutektičke tačke na politermalnom preseku sistema Fe-C-Si-Mn-Cr-V-Ti-P-S; Oni su koristili opseg hemijskih sastava od donjih do gornjih granica sastava livenog gvožđapo standardu GOST 7769–82 za ChKh22 [C (2.4–3.6), Si (0.2–1), Mn (1.5–2.5), S (max 0.08), P (max 0.1), Cr (19–25), V (0.15–0.35)i Ti (0.15– 0.35)]. Oni su ustanovili da se eutektička tačka premešta od 3.36 do 2.40 % C sa povećanjem legirajućih elementa od donjih ka gornjim limitima za liveno gvožđe ChKh22. Uzimajući ovaj nalaz u obzir, elektrode B, C i D se smatraju nadeutektičkim jer se eutektička tačka pomera do L.H.S sa povećanjem sadržaja Cr i to će se potvrditi dobijenom mikrostrukturom za različite elektrode. Politermalni preseci koje su dali Bazhenov i Pikunov pokazuju da je početak taloženja (Cr,Fe)$_7$C$_3$na oko 1.300 °C [11].



However, the chromium content in wear-resistant cast iron may vary up to 30 %; which affects greatly on the eutectic point [12]:

To investigate the possible change in the eutectic point due to alloying elements, Bazhenov and Pikunov [11] determined the eutectic points on the poly-thermal cross sections of the Fe-C-Si-Mn-Cr-V-Ti-P-S system; they used a range of chemical composition from the lower to the upper limits of ChKh22 cast iron [C (2.4–3.6), Si (0.2–1), Mn (1.5–2.5), S (max 0.08), P (max 0.1), Cr (19–25), V (0.15–0.35), and Ti (0.15– 0.35)] for standard GOST 7769–82. They found that the eutectic point shifts from 3.36 to 2.40 % C by increasing the alloying elements from lower to upper limit of ChKh22 cast iron. By taking this finding in consideration, electrodes B, C, and D are considered as hypereutectic as the eutectic point will be shifted to the L.H.S by increasing Cr content and this will be confirmed by the microstructure obtained for different electrodes. The poly-thermal cross sections shown by Bazhenov and Pikunov shows (Cr,Fe) 7 C precipitation starting at about 1,300 °C [11].

Fig. 2 a. Macrostructure of the weld deposit layer using electrode B. b. Macrostructure of the weld deposit layer using electrode C. c. Calculation of percent dilution= B/A+B %

Sl.2. a. Makrostruktura deponovanog sloja korišćenjem elektrode B. b. Makrostruktura deponovanog sloja korišćenjem elektrode C. c. Izračunavanje procenta mešanja = B/A+B %

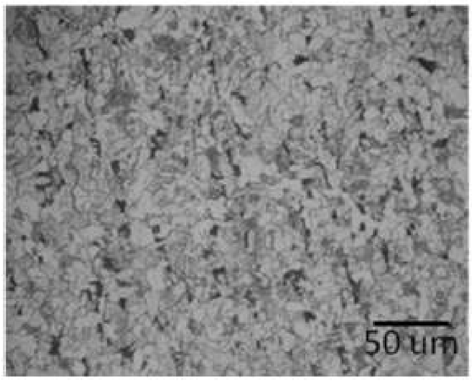


Fig. 3 Microstructure of the base metal
Sl. 3. Mikrostruktura osnovnog materijala Sl.

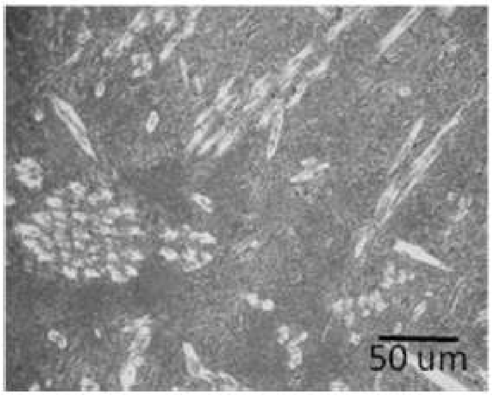


Fig. 5 Microstructure obtained for electrode B

Sl. 5. Mikrostruktura sa elektrodom B

Buchanan i dr. [13] su proučavali ponašanje prema abrazivnom trenju za REL tvrde navare koji se koriste u industriji šećerne trske iustanovili su da je otpornost na abraziju tvrdih navara određena primarno preko mikrostrukture. Podeutektički materijal su postigli svoju otpornost na habanje preko disperzije karbida unutar matrice injihove mogućnosti da deformaciono ojačavaju, sa dodatnim promenama u otpornosti prema mikrobrazdama i mikrorezovima. Sa druge strane, nadeutektički tvrdi navari otporni na habanje to postižu zahvaljujući svojim primarnim eutektičkim karbidima. Međutim, ako je obloga elektrode previše obogaćena ugljenikom i hromom, oni će proizvesti šav sa karbidima velike zapremine što eventualno smanjuje otpornost na habanje.

Prethodne studije [14, 15] insistiraju na tome da se otpornost na abrazivno trenje smanjuje nakon što zapreminski udeo karbida dostigne neku kritičnu vrednost. Ove studije indikuju da je kritična vrednost bila oko 30–35 % materijala. Iznad kritične vrednosti, matrica postajedominantni kontrolni faktor brzine habanja u odnosu na karbide.

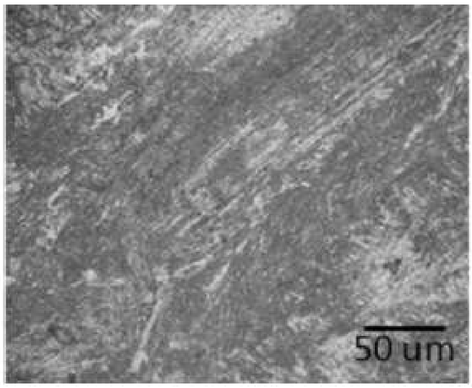


Fig. 4 Microstructure obtained for electrode A
Sl 4. Mikrostruktura sa elektrodom

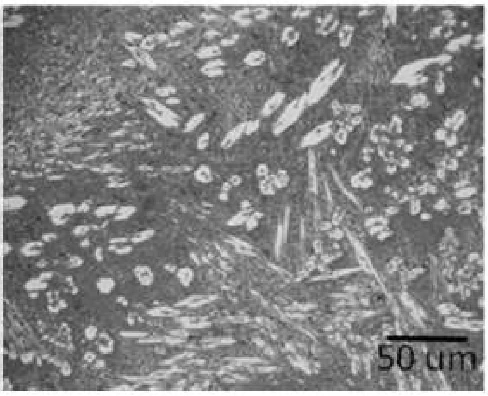


Fig. 7 Microstructure obtained for electrode D

Sl. 7. Mikrostruktura sa elektrodom D

Buchanan et al. [13] studied the abrasive wear behavior of MMA hardfacings used in sugarcane industry, and they found that the abrasion resistance of the hardfacings is determined primarily by the microstructure. The hypoeutectic material attained its wear resistance through the dispersion of the carbides within the matrix and its capacity to undergo strain hardening, with subsequent enhancement in its resistance to microploughing and microcutting. On the other hand, the hypereutectic resisted wear by virtue of its primary and eutectic carbides. However, if the electrode coating is too enriched with carbon and chromium, it will produce a weld with excess carbide volume that eventually reduces wear resistance. Previous studies [14, 15] insisted that abrasive wear resistance decreased after the carbide volume fraction exceeded some critical value. These studies indicated the critical value was approximately 30–35 % of the material. Beyond the critical value, the matrix became the wear rate controlling factor rather than the carbides.

3.2 Bead shape

The bead shapes of the weld layers consisting of three overlapping beads using electrodes A, B, C, and D are shown in Fig. 1. Figure 2 shows the

3.2 Oblik navara Oblici navara slojeva spoja sastoji se od tri preklopljena navara korišćenjem elektroda A, B, C i D prikazani su na sl. 1. Na slici 2prikazan je poprečni presek depozita slojeva korišćenjem obložene elektrode B (sl. 2a) i cevasteelektrode C (sl. 2b). Procenat mešanja je izračunat korišćenjem jednačine koja je ilustrovana na sl. 2c. Procenat mešanja elektrode B (obložena) je oko 30 % u poređenju sa oko 20 % kod elektrode C (cevasta). Velika širina cevastih elektroda daje šire navare i pliće uvarivanje (manje mešanje) daje im prednost u procesima tvrdog navarivanja.

3.3 Mikrostruktura

Mikrostruktura osnovnog materijala i sloja korišćenjem elektrode A prikazana je na slikama 3i4. Osnovni materijal ima feritno-perlitnu strukturu kao što je prikazano na sl.3. Međutim, mikrostrukturana vrhu tri preklopljena prolaza pokazuje martenzitnu strukturu kako je prikazano na sl. 4. Mikrostruktura prolaza korišćenjem elektrode B je pokazana na sl.5; struktura pokazuje nadeutektičku strukturu sa karbidima koji prvi očvršćavaju u nadeutektičkoj matrici. Mikrostruktura prolaza korišćenjem elektrodeCprikazana je na sl.6. Struktura pokazuje nadeutektičku strukturu sa karbidima ali površina udela karbida je veća nego kod elektrode B što može biti usled većeg deponovanja sa malim uvarivanjem i pratećim malim mešanjem (20 %) metala šava sa osnovnim materijalom (ugljenični čelik) korišćenjem cevaste elektrodeC u poređenju sa velikim uvarivanjem i veliko mešanje (30 %) pri korišćenju elektrode B. Poređenjem elektrode B (obložena elektroda) sa elektrodom C (cevasta elektroda), gde obe imaju skoro isti ugljenikov ekvivalent ali elektroda C ima veći sadržaj Si u metalu šava što menja taloženje karbida i može biti jedan od razloga za zapaženi veći udeo karbida. Isti rezultat se dobija korišćenjem elektrode D (sl. 7) gde je udeo karbidnog taloga sličan kao kod elektrode C, a mikrostrukturaje takođe nadeutektička koja daje uporedivu tvrdoću i sličnu otpornost na abraziju o čemu će se kasnije diskutovati.

3.4 Raspodela tvrdoće

Raspodela tvrdoćekroz osnovni materijal, zonu uticaja toplote i metal šava korišćenjem elektrode A prikazana je na sl. 8. Metal šava ima srednju vrednost tvrdoće od 480 HV, što odgovara martenzitnoj mikrostrukturi. Ova mikrostruktura ima najmanju otpornost na habanje i u dobroj je saglasnosti sa rezultatima koje su dobili Buchanan i dr. [13].

cross section of the weld deposit layers using covered electrode B (Fig. 2a)and tubular Fig. 6 Microstructure obtained for electrode C Fig. 7 Microstructure obtained for electrode D electrode C (Fig. 2b). The dilution percentage was calculated using the equation illustrated in Fig. 2c.The dilution percentage using electrode B (covered) is about 30 % compared with about 20 % associated with electrode C (tubular). The large width of tubular electrodes that they have wider and shallower penetration (lower dilution) give them an advantage in hardfacing process.

3.3 Microstructure

Microstructure of base metal and the single layer using electrode A are shown in Figs. 3 and 4, respectively. The base metal has ferritic-perlitic structure as shown in Fig. 3.However, the microstructure at the top of the three overlapped passes shows a martensitic structure as shown in Fig. 4. Microstructure of the single layer using electrode B is shown in Fig. 5; the structure shows hypereutectic structure with carbides that solidify first in hypereutectic matrix. Microstructure of the single layer using electrode C is shown in Fig. 6. The structure shows a hypereutectic structure with carbides but the area fraction of carbides is higher than that of electrode B which may be due to high deposition with low penetration and the subsequent low dilution (20 %) of the weld metal with base metal (mild steel) using tubular electrode C compared with high penetration and high dilution (30 %) using covered electrode B. Comparing electrode B (covered electrode) with electrode C (tubular electrode), both have almost the same carbon equivalent but electrode C has higher content of Si in the weld metal which enhances the carbides precipitation and this may be one of the reasons for larger area fraction of carbides obtained. The same result was obtained using electrode D (Fig. 7) where the amount of carbide precipitation is similar to electrode C, and the microstructure is also hypereutectic structure which gives comparable hardness and similar abrasion resistance as it will be discussed later.

3.4 Hardness distribution

Hardness distribution through base metal, heat-affected zone, and weld metal using electrode A are shown in Fig. 8. Weld metal shows average hardness of 480 HV, which is corresponding

Raspodela tvrdoćekroz osnovni materijal, zonu uticaja toplote i metal šava korišćenjem elektrode Bprikazan je na sl. 9. Veće vrednosti tvrdoće se zapažaju u metalu šava i ima srednju vrednost oko 715 HV što odgovara nadeutektičkoj strukturi sa karbidima. Slična raspodela tvrdoća je zapažena za elektrodu C sa srednjom vrednošću tvrdoće od 720 HV u metalu šava kako je prikazano na sl. 10. Mikrostruktura postignuta sa elektrodom C pokazuje veću površinu frakcije karbida ali tako velika površina karbida nema uticaj na raspodelu tvrdoće koja mnogo više zavisi od mikrostrukture matrice. Raspodela tvrdoće korišćenjem elektrode D prikazana je na sl.11;ona pokazuje najveću vrednost u metalu šava koja dostiže vrednost od 820 HV. Ovo je nagla promena u tvrdoći kojoj može biti uzrok velika razlika sastava između osnovnog materijala (ugljenični čelik) i metala šava (liveno gvožđe). Slična površina frakcije karbida zapaža se i kod primene elektrode C i D što podrazumeva to da postoji razlika u porastu tvrdoće usled mikrostrukture matrice sa većim ekvivalentom ugljenika koja je nadeutektičke strukture. zone,

to the martensitic microstructure. This microstructure shows the lowest wear resistance, and this is in good agreement with the results obtained by Buchanan et al. [13]. Hardness distribution through base metal, heat-affected and weld metal using electrode B are shown in Fig. 9. Fig. 10 Hardness distribution obtained with electrode C Fig. 11 Hardness distribution obtained with electrode D Higher hardness values were obtained in the weld metal, and it shows average of 715 HV which is corresponding to the hypoeutectic structure with carbides. Similar hardness distribution was obtained for electrode C with average hardness of 720 HV in the weld metal as shown in Fig. 10. The microstructure obtained for electrode C shows larger area fraction of carbides but this large area fraction of carbides has no effect on the hardness distribution which is more dependent on the microstructure of the matrix. Hardness distribution using electrode D is shown in Fig. 11; it shows the largest average value of weld metal which reaches 820 HV. There is an abrupt change in hardness which may be due to the large composition difference between base metal (mild steel) and weld metal (cast iron). Similar carbide area fraction is obtained for both electrodes C and D which imply that that the difference in hardness arises from the higher carbon equivalent microstructure of the matrix which is hypereutectic structure

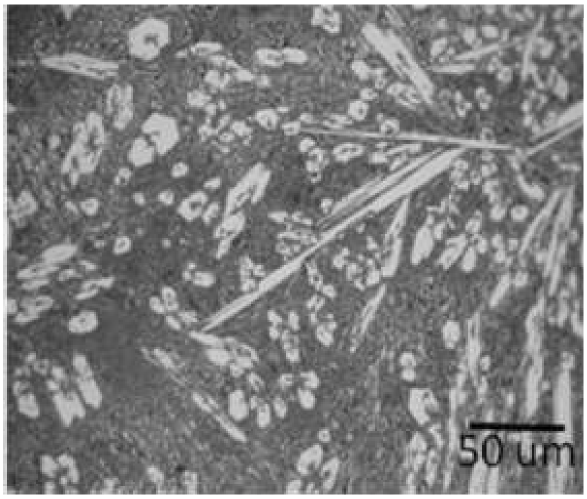


Fig. 6 Microstructure obtained for electrode C
Sl. 6. Mikrostruktura sa elektrodom C

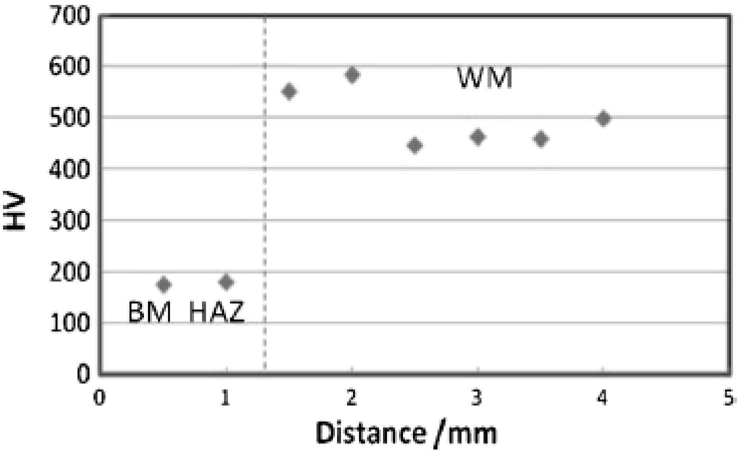


Fig. 8 Hardness distribution obtained with electrode A
Sl. 8. Raspodela tvrdoće kod elektrode A

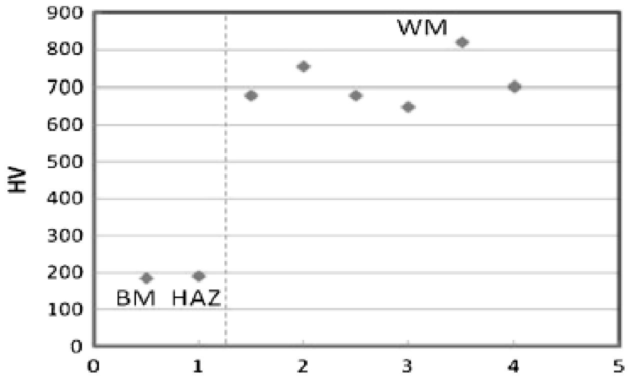


Fig. 9 Hardness distribution obtained with electrode B
Sl.9. Raspodela tvrdoće kod elektrode B

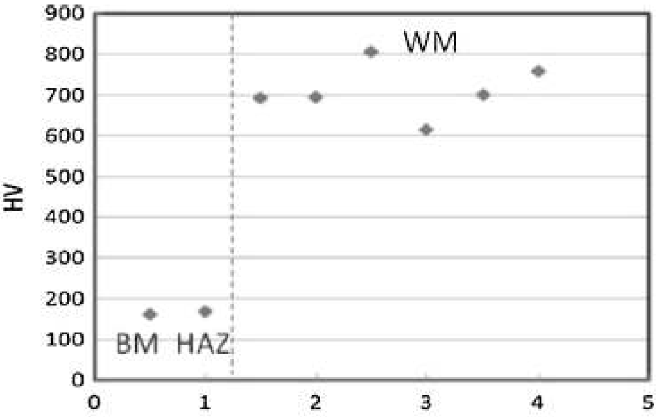


Fig. 10 Hardness distribution obtained with electrode C
Sl.10.Raspodela tvrdoće kod elektrode C

3.5 Otpornost na habanje elektroda

Otpornost na habanje metala šava izražena je preko indeksa trenja. Indeks trenja se izračunava deljenjem srednje vrednosti gubitka težine dve epruvete iz tvrdog navara i srednje vrednosti gubitka težine dve epruvete iz osnovnog materijala pod istim uslovima. Veći indeks trenja znači manju otpornost na habanje. Na slici 12pokazan je indeks trenja za metal šava deponovan korišćenjem elektroda A, B, C i D. Manji indeks trenja elektroda C i D indikuju veću otpornost na habanje. Ovo se objašnjava stvaranjem većeg procenta karbida u matrici. Elektroda A sa martenzitnom mikrostrukturom pokazuje najmanju otpornost na habanje, i nadeutektička matrica elektrode D pokazuje najbolju otpornost na habanje kada se upoređuje sa drugim nadeutektičkim (elektrodeB i C). U slučaju iste matrice (elektrode B i C), veći udeo frakcije karbida pokazuju bolju otpornost na habanje; ovi rezultati preporučuju da sve mikrostrukturne funkcije kontrolišu otpornost na habanje.

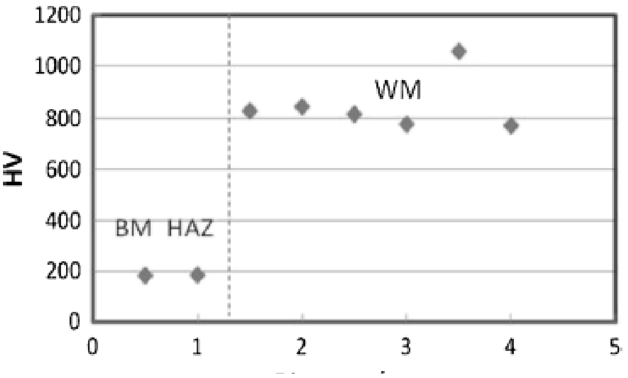


Fig. 11 Hardness distribution obtained with electrode D
Sl.11. Raspodela tvrdoće kod elektrode D

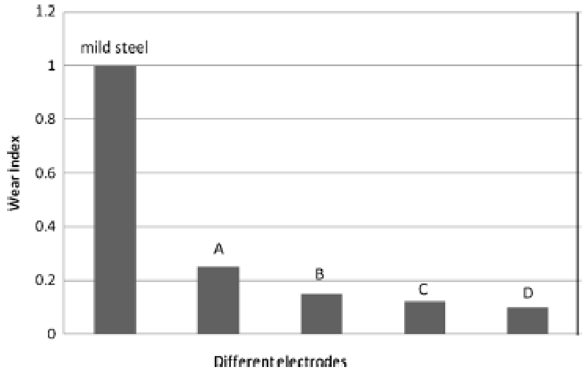


Fig. 12 Wear index for all electrodes used
Sl.12. Indeks trenja za sve elektrode

3.5 Wear resistance of the electrodes

Wear resistance of the weld metal is expressed by wear index. The wear index is calculated by dividing the average weight loss of two specimens of hard facing deposits by the average weight loss of two specimen of mild steel base metal at the same conditions. The higher the wear index the lower the wear resistance. Figure 12 shows wear index for the weld metal deposited using electrodes A, B, C, and D. The lower wear index of electrodes C and D indicates higher wear resistance. This is attributed to the formation of higher percentage of carbides in the matrix. Electrode A with martensitic microstructure shows the lowest wear resistance, and the hypereutectic matrix of electrode D shows the best wear resistance when compared with the hypoeutectic ones (electrodes B and C). In case of the same matrix (electrodes B and C), higher area fraction of carbides shows better wear resistance; these results recommend that all the microstructure features control the wear resistance.

4 Zaključci

1. Elektroda A sa martenzitnom mikrostrukturom pokazuje najmanju otpornost na habanje i najmanju tvrdoću u metalu šava. .
2. Kod sličnih ekvivalenata ugljenika (elektrode B i C), elektroda C (cevasta) pokazuju veće površine karbida i bolju otpornost na habanje nego elektroda B (obložena). Ovo se može pripisati većem udelu karbida koji su rezultat manjeg mešanja materijala kod cevastih elektroda.
3. Kod sličnih površina udela karbida i iste nadeutektičke strukture, elektroda D pokazuje blago veću otpornost na habanje nego elektroda C što se može pripisati većem ekvivalentu ugljenika što rezultuje u većim eutektičkim karbidima.
4. Komercijalna cevasta elektroda D (DIN8555: E10-GF-60GR2) primenom REL postupka zavarivanja uspela je da proizvede najbolju otpornost na habanje tvrdih navara među ostalim elektrodama.

4 Conclusions

1. Electrode A with martensitic microstructure shows the lowest wear resistance and the lowest hardness distribution in weld metal.
2. In similar carbon equivalent (electrodes B and C), electrode C (tubular) shows larger carbides area fraction and better wear resistance than electrode B (covered). This could be attributed to larger area fraction of carbides as a result of low dilution for tubular electrode.
3. With similar carbides area fraction and same hypereutectic structure, electrode D shows slightly larger wear resistance than electrode C which may be attributed to the higher carbon equivalent which results in larger eutectic carbides.
4. Commercial tubular electrode D (DIN8555: E10-GF60GR2) using MMA process succeeded in producing the best wear resistant hardfacing among other electrodes.

References

1. Welding handbook: Materials and applications, Pt.1, Vol. 3 (1996) ,8th ed., AWS, Miami, Florida, pp. 252–254.
2. Welding handbook, materials and applications, Pt.2, Vol. 4 (1998), 8th ed., AWS, Miami, Florida, pp. 409–412
3. Bundinski K.G (2004) Surface coating technology, pp. 188–189.
4. Wu JBC, Redman JE (1990) Welding Journal 73(9):63–68
5. Kotecki DJ, Ogborn JS (1995) Welding Journal 74(8):269–288
6. Gregory E.N (1975) Welding research bulletin pp. 69–71.
7. Berns H, Fischer A (1985) Proceedings of the fifth International Conference on Wear of Materials, Vancouver, Canada, Vol. 5 , pp. 625–633
8. Murugan N and . Parmar R.S (1997) Welding Journal, Vol. 76, No. 10, pp. s.391–s.403.
9. Mitchell K (1998) Weld. Metal fabrication, Vol. 66 , No. 7, pp. s.16–s.20.
10. Klimpel A, Dobrzanski LA, Janicki D, Lisiecki A (2005) J Mater Process Technol 164–165:1056–1061
11. Bazhenov V, Pikunov M (2011) Steel in Translation 41(11):896–899
12. Sil'man G (2002) Metallov. Term. Obrab. Met., , no. 1, pp. 26–29.
13. Buchanan VE, Shipway PH, McCartney DG (2007) Wear 263:99–110
14. Dwivedi DK (2004) Mater Sci Technol 10:1326–1330
15. Dogan ON, Hawk JA, Laird G II (1997) MetallMater Trans A 28A: 1315–1328