J. Viňáš, L. Kaščák   *Prevod: B. Katavić*

REVITALIZACIJA KRANSKOG TOČKA TEHNOLOGIJOM NAVARIVANJA

CRANE WHEEL RENOVATION BY THE WELD REPAIRING TECHNOLOGIES

Adresa autora / Author's address:
J. Vinaš, L. Kaščak

Department of Technology and Materials, Faculty of Mechanical Engineering, Technical University of Košice, Slovakia

Izvod

Članak se bavi analizom kvaliteta reparaturno navarenih kranskih točkova od materijala Gr. 90-60 po ASTM A148. Pri reparaturnom navarivanju korišćene su tri tehnologije navarivanja sa različitim dodatnim materijalima. Na točak, nakon habanja, navareni su jedan međusloj (izrađen kombinacijom dodatnog materijala, žice A 106 i potrošnog materijala, praška F 11) i dva pokrivna sloja (izrađena kombinacijom dodatnih materijala, žice A 508 i potrošnog materijala F 13). Posle navarivanja površina kranskog točka je otvrdnuta (zakaljena) na dubinu od 3 mm. Druga tehnologija navarivanja podrazumevala je kombinaciju dodatnog materijala, žica A 106 i potrošnog materijala, praška F11 za prvi sloj, a dva pokrivna sloja su izrađena kombinacijom dodatnog materijala, žice RD 520 i potrošnog materijala, praška F 56. Treća tehnologija je realizovana nanošenjem prvog sloja navarivanjem sa dodatnim materijalom, žicom C 113 u zaštitnoj atmosferi sastava 80% Ar + 20% CO$_2$. Dva pokrivna sloja su izvedena sa samozaštitnom žicom Lincore 40-O. Osobine revitalizovanih (navarenih) kranskih točkova su upoređene sa osobinama novih kranskih točkova sa otvrdnutim površinskim slojem. Ispitana je otpornost na adhezivno habanje navarenih površina kranskih točkova merenjem gubitka mase. Uticaj pojedinih elemenata na hemijski sastav navara ispitan je EDX analizom.

Abstract

The article deals with analysis the quality of traverse crane wheels made of weld repaired Gr. 90-60 material, ASTM A148. Three types of weld repair technologies with various filling materials were used. Weared wheel was welded with one interlayer in combination of additional materials wire A 106 with F 1, and two cover layers made in combination of A 508 wire with F 13 addition. Wheel surface was hardened after welding to depth of 3 mm. As a second technology was combination of A 106 wire with F 11 addition. Two cover layers were made by combination of RD 520 wire with F 56 addition. Third technology was realized with one layer of C 113 wire in inert atmosphere 80 % Ar + 20% CO$_2$. Two cover layers were made by wire with self protect Lincore 40-O. Properties of repaired traverse crane wheels were compared with the properties of new wheels with surface hardened layer. The welds were exposed to adhesive wearing where surface resistance was examined by the weight loss. Influence of particular elements on the welds chemical composition was examined by EDX analyses.

UVOD

Najčešći uzroci otkaza delova i sklopova mašina su procesi habanja površinskih delova. To je razlog zašto su tribološke osobine upotrebljenih materijala od velikog značaja za funkcionisanje delova mašina i konstrukcija. Interakcija radnih površina pri relativnom kretanju može dovesti do neželjenih promena u površinskim slojevima materijala, do njihovog habanja i oštećenja pri habanju [1-3].

Revitalizacija je primenjena kao metoda koja je finansijski povoljna u održavanju mašina i uređaja. Različite tehnologije koje se koriste za revitalizaciju delova mašina i konstrukcija omogućavaju funkcionalnost, a u nekim slučajevima i produženje njihovog radnog veka. Kranski točkovi su u radu

INTRODUCTION

The most common causes of machine component parts and structures breakdowns are tribological processes that take place in functional surfaces. That is why tribological characteristics of used materials are of great significance for proper functioning of machine component parts and structural elements. Interaction of functional surfaces in relative motion results in unwanted changes in surface layers and their wear and tear [1-3].

Renovation was applied as a method of financially favourable maintenance of machines and operational equipment. A variety of different technologies is used in renovation, which enable recovery of machines or in some cases help prolong machine service life.

izloženi značajnom habanju kao posledica visokih površinskih pritisnih naprezanja. Zbog visoke cene zamene kranskih točkova oštećenih usled habanja novim točkovima, težnja je da se produži radni vek što je moguće više [4-7].

Ovaj članak razmatra mogućnost revitalizacije kranskih točkova mostne dizalice tehnologijom navarivanja i proceni radni vek navarenih slojeva u zahtevanim uslovima habanja. Cilj ovoga rada je da uporedi kvalitet navara nanešenih različitim tehnologijama; da ispita uticaj strukture i mešanja različitih slojeva navara na otpornost na adhezivno habanje; da analizira rezultate ispitivanja navara sa osobinama materijala novih točkova i na osnovu tih rezultata da preporuči odgovarajuću tehnologiju revitalizacije kranskih točkova navarivanjem i termičkom obradom, odnosno da preporuči izmene u postojećoj tehnologiji navarivanja.

EKSPERIMENTALNI DEO

Materijal

Ispitani kranski točkovi mostne dizalice izrađeni su od materijala Gr. 90-60, ASTM A148, hemijskog sastava i mehaničkih osobina datih u tabeli 1 i 2, respektivno.

Odlivci od feritno - perlitnog čelika se uglavnom koriste u uslovima visokih pritisnih sila i napona. Kranski točkovi se kreću po šinama proizvedenim od čelika ČSN 41 0425 - konstrukcionog čelika bez garantovanog hemijskog sastava sa čvrstoćom $R_{m\,min}$ = 420 MPa i sadržajem S i P od max. 0.050 %. Tvrdoća od 230 HV je u korelaciji sa navedenom čvrstoćom.

Tehnologija revitalizacije, dodatni i potrošni materijali

I. Elektrolučno navarivanje pod praškom (SAW - EPP)

Međusloj: elektrodna žica A 106 ϕ=3.2 mm, prašak F 11

Traverse crane wheels in engineering practice are exposed to significant wear as a result of their high surface compression stress. It is expensive to replace worn out wheels by new ones, that is why efforts are made to prolong their service life as long as possible [4-7].

The submitted article deals with possibility of renovation of traverse crane wheels by welding-on technology and evaluation of welded-on layers in demanding tribological conditions. The aim is to compare the quality of welds-on carried out with addition and in protective gas atmospheres, to find out the influence of structures and mixing of different layers on adhesive wear resistance, to analyse the results of weld-on tests with properties of new traverse wheels and based on the results to recommend suitable welding-on technology of wheel renovation and their heat treatment, to recommend changes of the present situation in wheel welding-on.

EXPERIMENTAL

Used materials

The examined traverse crane wheels were manufactured from the material Gr. 90-60, ASTM A148, its chemical composition is given in Table 1 and its mechanical properties in Table 2.

This is ferritic-perlitic carbon steel for cast products, which is generally used for higher pressures and stress. Crane wheels roll along the rails manufactured from steel class ČSN 41 0425 – structural steel without guaranteed chemical composition with strength limit $R_{m\,min}$ = 420 MPa, S content is max. 0,050 % and P content is max.0, 050 %. Hardness number 230 HV corresponds to the given strength limits.

Use of renovation technology and filling materials

I. Welding-on technology (SAW)

Interlayer: weld-on wire A 106, ϕ=3,2 mm, addition F 11

Tabela 1: Hemijski sastav materijala Gr. 90 – 60, ASTM A148, mas. %
Table 1: Chemical composition of material Gr. 90-60, ASTM A148, mas %

Hemijski elementi	C	Mn	Si	Pmax	Smax	(P + S)max
%	0.40 – 0.50	0.40 – 0.80	0.20 – 0.50	0.050	0.050	0.090

Tabela 2: Mehaničke osobine materijala Gr. 90 – 60, ASTM A148
Table 2: Mechanical properties of material Gr. 90-60, ASTM A148

Re min MPa	Rm min MPa	A5 min %	Z min %	KCU3 min J cm^{-2}	HV10	E GPa
300	590 - 740	12	15	20	173 - 214	209.4

Pokrivni sloj: elektrodna žica A 508 ϕ=3.2 mm, prašak F 13

II. Elektrolučno navarivanje pod praškom (SAW - EPP)

Međusloj: elektrodna žica A 106　ϕ=3.2 mm, prašak F 11

Pokrivni sloj: elektrodna žica RD 520 ϕ=3.2 mm, prašak F 56

III. Elektrolučno navarivanje u zaštitnoj atmosferi (GMAW)

Međusloj: eletrodna žica C 113, ϕ=2 mm, zaštitna atmosfera je mešavina gasova (Ar 80% + CO_2 20%)

Pokrivni sloj: elektrodna žica Lincore 40-O, ϕ=2 mm

Navarivanje pohabanih kranskih točkova prečnika ϕ 800 mm je izvedeno prvo nanošenjem međusloja a zatim dva pokrivna sloja. Predgrevanje ispitivanih kranskih točkova je izvedeno rotacionim kretanjem gasnog gorionika na temperatiri od 180-250°C i brzinom zagrevanja od 300°C/h. Venci točkova, koji su učvršćeni zavrtnjima, su navarivani zavarima (gusenicama) širine 1/3 venca točka. Dimenzije točkova su doterane do početnih dimenzija sa dodatkom za mašinsku obradu.

Posle navarivanja kranskih točkova po uslovima prve tehnologije, izvedeno je izotermalno žarenje u indukcionoj peći koja je bila predgrejana do temperature od 800-840°C. Nakon žarenja na temperaturi od oko 840°C, točkovi su hlađeni u peći do temperature od oko 620°C u vremenu od 2-3 h, a zatim su hlađeni na vazduhu.

Posle hlađenja kranski točkovi su mašinski obrađeni na zahtevane mere, a zatim je izvedeno otvrdnjavanje navarenog sloja.

Otvrdnjavanje točkova je izvedeno zagrevanjem gasnim plamenom ($C_2H_2 + O_2$) i hlađenjem vodenim mlazom. Maksimalna debljina otvrdnutog sloja je 3 mm. Kod točkova koji se revitalizovani drugom i trećom tehnologijom navarivanja nije izvedeno otvrdnjavanje površinskog dela venca točka. Tehnološki parametri navarivanja su dati u radu [8].

Referentni materijal

Reparaturno navareni kranski točkovi su upoređeni sa novim točkovima od materijala Gr. 90-60, ASTM A148, čiji je hemijski sastav dat u tabeli 1. Kontaktna površina i venac novih kranskih točkova su otvrdnuti zagrevanjem gasnim plamenom ($C_2H_2 + O_2$) i hlađeni vodenim mlazom pri rotaciji istih. Temperatura kaljenja za materijal Gr. 90-60 po ASTM A148 je u intervalu od 870-890°C. Debljina otvrdnutog sloja je 3 mm.

Cover layer: weld-on wire A 508 ϕ=3,2 mm, addition F 13

II. Welding-on technology (SAW)

Interlayer: weld-on wire　A 106, ϕ=3,2 mm, addition F 11

Cover layer: weld-on wire RD 520, ϕ=3,2 mm, addition F 56

III. Welding-on technology with wire in inert atmosphere (GMAW)

Interlayer: weld-on wire C 113, ϕ=2 mm, inert atmosphere of mixed gas (Ar 80% + CO_2 20%)

Cover layer: weld-on wire Lincore 40-O, ϕ=2 mm

Welding-on of worn-out wheels diameter ϕ 800 mm was carried out first by creating one interlayer and subsequently by two cover layers. Preheating of the examined crane wheels was carried out by rotation of gas burner to the temperature 180-250°C, heating speed was 300ºC/h. Cylinder parts of the wheels were welded-on in screw shifting the caterpillar by 1/3 of it width. Wheel dimensions were adjusted by welding-on to the original dimensions with surplus material for machining.

After welding-on the wheels were renovated using technology I , i.e. by isothermal annealing in the induction furnace which was preheated to the temperature 800-840°C.

After heating the wheels to the temperature 840°C they were cooled to the temperature 620°C with subsequent holding for 2 - 3 hours. After the wheels had been removed from the oven they were cooled in open air. After cooling the wheels were machined by cutting operation to the required parameters and then the weld-on was hardened on the surface.

Surface hardening was carried out by flame $C_2H_2+O_2$. After heating by burner the weld-on was cooled by water spray. The thickness of the hardened layer was maximum 3 mm. In the second and third renovation technology the cover layer was not hardened on the surface. Technological parameters of welding-on are given in the paper [8].

Reference material

After welding-on the renovated crane wheels were compared with a new wheel manufactured from material Gr. 90-60, ASTM A148, its chemical composition is given in Table 1.

The contact area and tire of the new wheel were hardened by the flame $C_2H_2+O_2$ on the surface while the wheel was rotating. Hardening temperatures for Gr. 90-60, ASTM A148 were in the range from 870 to 890°C. The depth of through hardening of the material was 3 mm.

Uređaji za eksperimentalna ispitivanja

Struktura i EDX analiza navara

Strukturna analiza navarenih slojeva je izvedena na poprečno isečenim uzorcima kranskih točkova na svetlosnom mikroskopu Zeiss Neophot II i skening elektronskom mikroskopu Hitachi S-450. Hemijska analiza pojedinih slojeva i prelaznih zona je izvedena energo disperzivnim spektometrom Jeol JSM-35 CF I analizatorom Link AN 10000 .

Makrotvrdoća navara

Ispitivanje tvrdoće navara i referentnih materijala izvedeno je po standardu STN EN 1043-1 na mehanički isečenim uzorcima bez termičke obrade u skladu sa standardima ISO 6507-1 i ISO 6507-2. Uzorci za ispitivanje su uzeti iz kontaktne zone revitalizovanih kranskih točkova i šina. Ispitivanje je obavljeno na uređaju HPO 250. Tvrdoća je merena u poprečnom preseku venca točka u smeru od kontaktne zone točka i šina ka osnovnom materijalu točka. Linija **a** predstavlja smer merenja kroz presek venca točka, a linija **b** kroz horizontalni deo točka (slika 1).

Mikrotvrdoća navara

Mikrotvrdoća pojedinih navarenih slojeva i prelaznih faza je merena na poprečnom preseku isečenih uzoraka po standardu STN EN 1043-1. Ispitivanje je izvedeno na uređaju Shimadzu - DUH 202 sa opterećenjem od 0.01 N u vremenu od 5 s.

Uzorci su obeleženi na ovaj način:

A uzorci – navarivanje površinskog sloja je izvedeno kombinacijom elektrodne žice A 508 pod praškom F 13, a međusloja sa elektrodnom žicom A 106 pod praškom F 11,

R uzorci - navarivanje površinskog sloja je izvedeno kombinacijom elektrodne žice RD pod praškom F 56, a međusloj sa elektrodnom žicom A 106 pod praškom F 11,

Technique of experimental testing

Technique of structural and EDX analysis

Structural analysis of individual welded-on layers was carried out on cross scratch patterns of the examined samples. Structure evaluation as well as photo documentation were carried out by means of the light microscope Zeiss Neophot II and electron-scanning microscope Hitachi S-450. Chemical analysis of single weld-on layers and their transitional phases was carried out by the energy dispersive spectrometer Jeol JSM-35 CF and Link AN 10000 analyser.

Technique weld-on hardness evaluation

Tests of weld-on hardness and the reference material were carried out in compliance with standard STN EN 1043-1 on test samples taken mechanically without heat treatment in accordance with standards ISO 6507-1 and ISO 6507-2. The samples were taken from renovated traverse wheels from the region of the wheel and rail interface The test was carried out by the testing machine HPO 250. Hardness values were measured on scratch patterns in direction from the wheels and rails interface to the basic wheel material. Line **a** ran through the cut section of the tire of the examined wheel and line **b** ran through the horizontal part of the wheel, shown in Fig.1.

Technique of weld-on microhardness evaluation

Microhardness of individual weld-on layers and transient phases was measured on transverse scratch patterns of the taken samples in accordance with STN EN 1043-1. The test was carried out by the testing machine SHIMADZU – DUH 202. The applied load was 0,01 N and load time was 5 s.

Sample marking:

A samples – weld-on made by combination of A 508 wire with F 13 addition with an interlayer created by A 106 wire with F 11 addition,
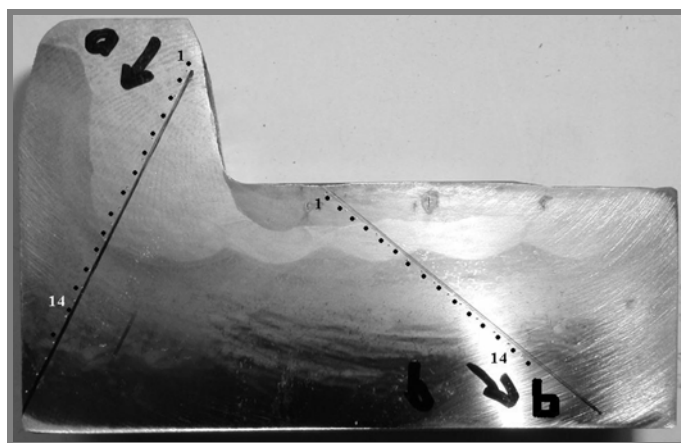
Slika 1: Merenje tvrdoće na ispitanom uzorku
Figure 1: Hardness measuring on tested samples

L uzorci - navarivanje površinskog sloja je izvedeno elektrodnom žicom Lincore 40-O, a međusloj sa elektrodnom žicom C 113 u atmosferi zaštitnog gasa (Ar + CO_2).

Adhezivno habanje

Kranski točkovi su u radnim uslovima izloženi visokom površinskom pritisku što prouzrokuje različite vidove habanja i cepanja (oštećenja) pri habanju. Pri proceni uzajamne reakcije kranskog točka i šina neophodno je uzeti u razmatranje vrste habanja i oštećenja pri habanju koji se mogu javiti kao rezultat njihovog međusobnog kontakta i kretanja. Adhezivno habanje ispitivanih materijala je izveden na uređaju Amsler. Pločice su napravljene od materijala za ispitivanje (kranski točkovi), a diskovi od čelika ČSN 41 0425 (kranske šine). Kontaktna površina diska i pločice podešena je na pritisno naprezanje preko opruge sa opterećenjem od 1.5 kN. Čelični disk rotira brzinom od 200 o/min. Veličina adhezivnog habanja je određena na osnovu promene težine ispitanih uzoraka u vremenu od 30 s^{-1}.

REZULTATI I DISKUSIJA

Makro i mikrotvrdoća

Maksimalne vrednosti tvrdoće su uočene blizu kontaktne površine ispitivanih uzoraka u oba pravca ispitivanja. Rezultati ispitivanja su ukazali da su maksimalne tvrdoće izmerene na otvrdnutim površinama novih kranskih točkova u intervalu od 669 HV 10 do 703 HV 10. Kod točkova koji su revitalizovani tehnologijom navarivanja izmerene tvrdoće su niže. Najviše tvrdoće u površinskom sloju navara od max. 459 HV 10 su izmerene na točkovima koji su revitalizovani EPP postupkom sa elektrodnom žicom A 508 pod praškom F 13, nakon termičke obrade navara – kaljenjem. Primenom druge i treće tehnologije navarivanja dobijene su maksimalne tvrdoće u površinskom sloju navara od 446 HV 10 i 442 HV 10, respektivno [8].

Kod uzoraka označenih sa A, R i L maksimalne mikrotvrdoće HV 0.01 su izmerene u površinskom delu pokrivnog sloja navara. Mikrotvrdoća kod uzorka A od 475 HV 0.01 je rezultat otvrdnjavanja površinskog dela pokrivnog sloja navara dok kod uzoraka R i L nije izvedena termička obrada posle navarivanja i vrednosti mikrotvrdoće navara su manje.

Vrednosti mikrotvrdoće međuslojeva najviše se razlikuju kod uzoraka R i L, a najmanje kod uzoraka A i R. Primena istih dodatnih materijala pri navarivanju međusloja (A 106 sa dodatnim materijalom F11) mogla bi biti uzrok uočene male razlike u mikrotvrdoćama uzoraka A i R. Očigledno je da međusloj kod uzorka L, koji je navaren žicom C 113 u atmosferi zaštitnog gasa, ima niže osobine čvrstoće nego uzorci A i R. Najmanje vrednosti mikrotvrdoće su izmerene na površini osnovnog materijala koji nije termički obrađivan posle navarivanja.

R samples – weld-on made by combination of RD wire with F 56 addition with an interlayer created by A 106 wire and F 11 addition,

L samples – weld-on made by combination of Lincore 40-O with an interlayer created by C 113 wire in gas (Ar + CO_2).

Technique of adhesive wear evaluation

Crane wheels in technical practice are strained up by high surface pressure, which results in different types of wear and tear. In assessing mutual interaction of the wheel and the rail it is necessary to consider mainly the type of wear and tear that results from their mutual contact and movement. Adhesive wear of the examined materials was tested by AMSLER machine with area contact, which enables dry testing of sliding pairs. Plates were made from the examined materials and the disc from ČSN 41 0425 steel (rail material). Bedding the disc and the plate was adjusted to the pressure in the contact surface by compressing the spring by load 1,5 kN. The steel disc rotated at the speed 200 revs per minute^{-1} . The size of adhesive wear was evaluated based on weight changes of the tested samples in individual phases of the experiment for the period of 30 s^{-1} and until seizure of the kinematics pair.

RESULTS AND DISCUSSION

Results of hardness and microhardness measurement

Maximum hardness values were discovered in places closest to the functional surface of tested samples in both examined directions. The obtained results indicated that the highest hardness was in new traverse crane wheels with surface hardening in which the maximum values were between 669 HV 10 and 703 HV 10. In wheels, which were renovated by welding-on, the measured hardness values were lower. The highest hardness value of all the evaluated welds-on was found in the weld- on made by A 508 wire with F 13 addition where the maximum hardness value was 459 VH 10 in the cover layer that could be reasoned by welds-on heat treatment - hardening. By applying the second technique the maximum hardness amounted to 446 HV 10 and in the third welding-on technology the maximum hardness amounted to 442 HV 10 in the cover layer of the weld-on [8].

In individual samples marked A, R, L microhardness values HV 0,10 were observed. The highest values were measured in cover layers of welds-on. In A type samples the microhardness value amounted to 475 HV 0,01 as a result of hardening of the crane wheel cover layer. Values of weld-on microhardness in R and L type samples were somewhat lower, it was without application of wheel heat treatment after welding-on.

In the interlayer area there were more distinctive

Rezultati metalografske i EDX analize strukture

Hemijska analiza je izvedena na navarenim uzorcima i uzorcima referentnog materijala. Mikrostruktura šina se sastojala od grubozrne perlitne strukture i minimalnog udela ferita. Struktura navarenih slojeva je prikazana i opisana na slikama 2, 3 i 4 [8].

Na slici 2 prikazana je mikrostruktura navara izvedenog tehnologijom I. Kako navar nije termički obrađen, površinski otvrdnuti sloj se može uočiti u gornjem sloju navara. Struktura ovog sloja je finozrni acikularni ferit sa tvrdoćom do 460 HV 10.

Struktura navarenog sloja se kontinualno menjala u beinitnu strukturu sa povećanjem rastojanja od površinskog sloja. EDX analizom u pokrivnim slojevima navara uočene su disperzne čestice karbida kroma. U isto vreme prisustvo elemenata Mn i Si u navaru je posledica primene dodatnog materijala A 508 i pomoćnog materijala F 13.

Mikrostruktura međusloja mogla bi se uglavnom indentifikovati kao beinitna, osim u nekim delovima gde feritno – perlitna struktura postepeno prelazi u beinitnu. Vrednosti izmerene mikrotvrdoće međusloja potvrđuju prethodna zapažanja.

Debljina međusloja je oko 2 mm. Hemijska analiza međusloja pokazuje pad sadržaja legirajućih elemenata u poređenju sa njihovim sadržajem u pokrivnom sloju. Ova pojava zavisi od intenziteta mešanja slojeva (prolaza) u navaru. Struktrura zone između međusloja i osnovnog materijala koja je pod uticajem toplote se sastoji od grubozrnog ferita i perlita, i kao rezultat termičke obrade dolazi do porasta zrna i debljine ove zone. Kontinualni porast i transformacija perlita u beinit je očigledna. U ovoj strukturi takođe je zapažen pločasti ferit i cementit po granicama zrna.

differences mainly in R and L type samples. The value measured in A type samples was close to values in R type samples. It could be because of application of the same filling materials for welding-on of the interlayer (A 106 wire with F 11 addition). It is obvious that the interlayer made by C 113 wire in the protective atmosphere of gases had lower strength properties than the layer in the above-mentioned A and R samples. The lowest microhardness values were found in the area of base material not affected by heat.

Results of metallographic and EDX structure analysis

Chemical analysis of elements was carried out on samples with welds-on and from reference material according to the above-mentioned technique. Rail microstructure was open-grain perlitic structure with minimum content of ferrite. The resulting structures of the individual layers of welds- on are shown and described in Fig. 2, 3 and 4 [8].

Fig. 2 shows the weld-on microstructure made by technology I. Since the weld-on was not heat treated, a surface-hardened layer can be observed in the upper layer. It is fine-grained acicular ferritic structure confirmed by hardness measurement, which amounted to 460 HV 10. The structure was continuously changing depending on the distance from the surface into bainitic structure. In the cover layers there were diffused soft chromium carbide particles confirmed by EDX analysis.

At the same time, the weld-on showed the presence of elements Mn and Si from filling material A 508, on the other hand it was also affected by application of siliceous manganese addition F 13. The interlayer structure can be identified as bainitic, in some regions ferritic- perlitic structure was observed gradually changing into bainitic structure confirmed by
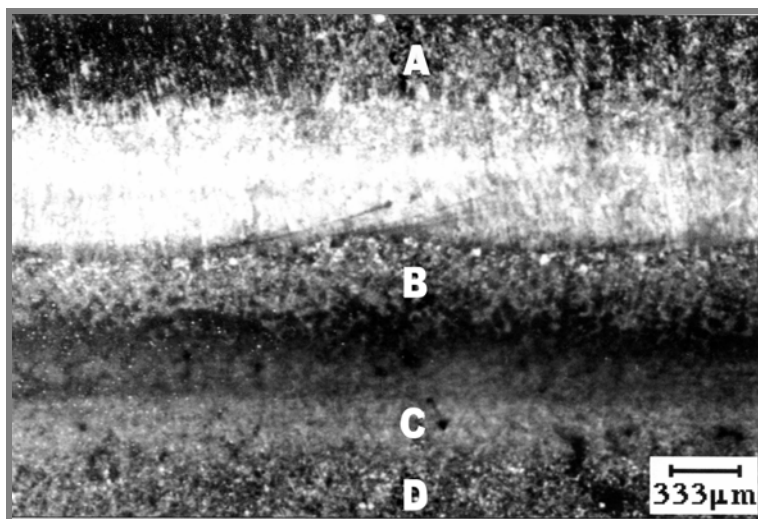
Slika 2a: Strukture navarenog sloja izvedenog tehnologijom I

Figure 2a: Structures of weld-on made by technology I
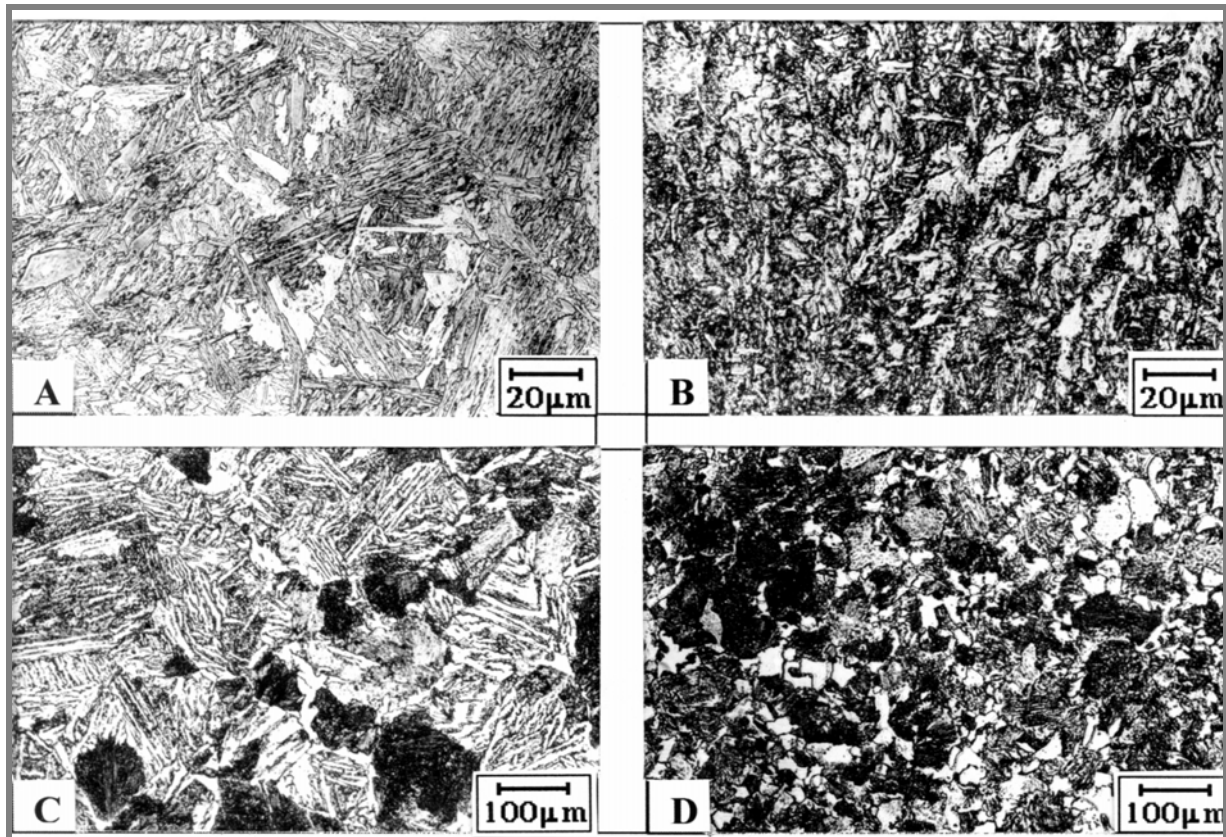
Slika 2b: Strukture navara izrađenih kombinacijom dodatnog materijala – žice A 508 sa dodatkom praška F 13 i međusloja od dodatnog materijala – žice A 106 sa dodatkom praška F11.

A - Beinitna struktura, detalj pokrivnog sloja, žica A 508 sa dodatkom praška F 13; **B -** Beinitna struktura, detalj međusloja izrađen od žice A 106 sa dodatkom praška F 11; **C -** Acikularna feritno – perlitna struktura, detalj ZUT-a u međusloju i osnovnom materijalu; **D -** Feritno – perlitna struktura osnovnog materijala Gr. 90 – 60, ASTM A148.

Figure 2b: Structures of welds-on made by combination of wire A 508 with addition F 13, with interlayer made by A 106 wire with F 11 addition.

A - Bainitic structure, cover layer detail, A 508 wire with F 13 addition; **B -** Bainitic structure, interlayer detail made by A 106 wire and F 11 addition; **C -** Acicular ferritic-perlitic structure, detail of heat-affected zone with interlayer and base material; **D -** Ferritic-perlitic structure of base material Gr. 90-60, ASTM A148.

Slika 3 daje prikaz mikrostrukture navara izvedenog tehnologijom II. Mikrostruktura pokrivnih slojeva debljine do 3.5 mm se sastoji od acikularnog i lamelarnog martenzita. Vrednosti makrotvrdoće i mikrotvrdoće ukazuju na prisustvo beinitne strukture. EDX analiza pokazala je da je navar najviše legiran Mn, kao i to da su u pokrivnim slojevima prisutni legirajući elementi Cr i Si. Navedeno legiranje navara izvedeno je pre svega dodatnim materijalom RD 520 a jednim delom i dodatkom praška F 56. Struktura međusloja je feritno – perlitna sa malim udelom beinita.

Kao posledica uticaja toplote iznad temperature A_{c1} dolazi do rasta zrna. Debljina međusloja je približno 2.0 mm. Hemijska analiza međusloja pokazala je relativno kontinuirani pad u sadržaju legirajućih elemenata Mn i Si u poređenju sa sadržajem u pokrivnim slojevima. Ovo je posledica manjeg sadržaja legirajućih elemenata u dodatnim materijalima koji su bili upotrebljeni pri navarivanju međusloja. Manji sadržaj Cr u međusloju je posledica

microhardness measurement in this area. The interlayer thickness was approximately 2 mm. Chemical analysis of the interlayer showed the decrease in the amount of the alloying elements in comparison with the cover layer. The decrease in the amount of the above-mentioned elements depends on the mixing of individual layers of welds-on. The area between the interlayer and the base material affected by heat is composed by open-grain acicular ferritic-perlitic structure, as a result of heat treatment grains grew and became thicker. Continuous growth and transformation of perlite into bainite were obvious. In the structure there also occurred plate ferrite and on grain boundaries there were visible cement phases.

Fig. 3 shows macrostructure of the weld-on made by technology II. Microstructure of cover layers up to 3,5 mm from the surface is created by martensitic structure with acicular and plate-shaped formations. Bainitic structure was confirmed by hardness and microhardness test. EDX analysis showed the presence of alloying elements such as Cr and Si in
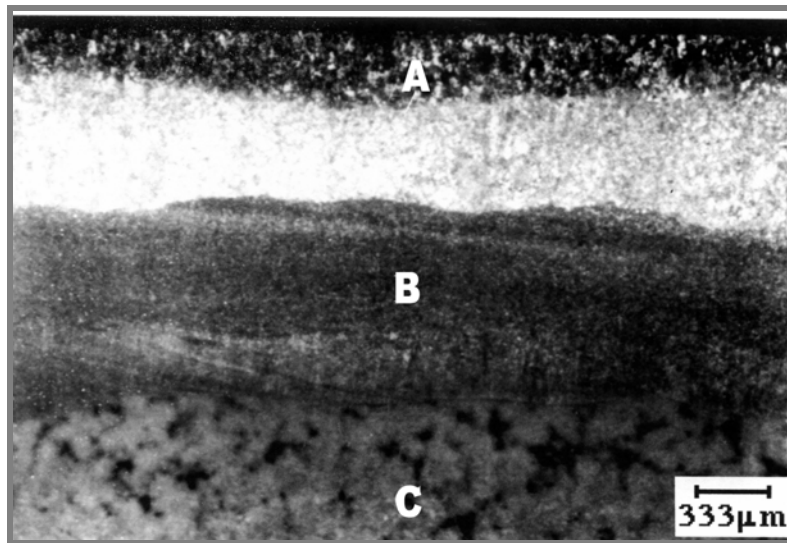
Slika 3a: Strukture navarenog sloja izvedenog tehnologijom II

Figure 3a: Structures of weld-on made by technology II
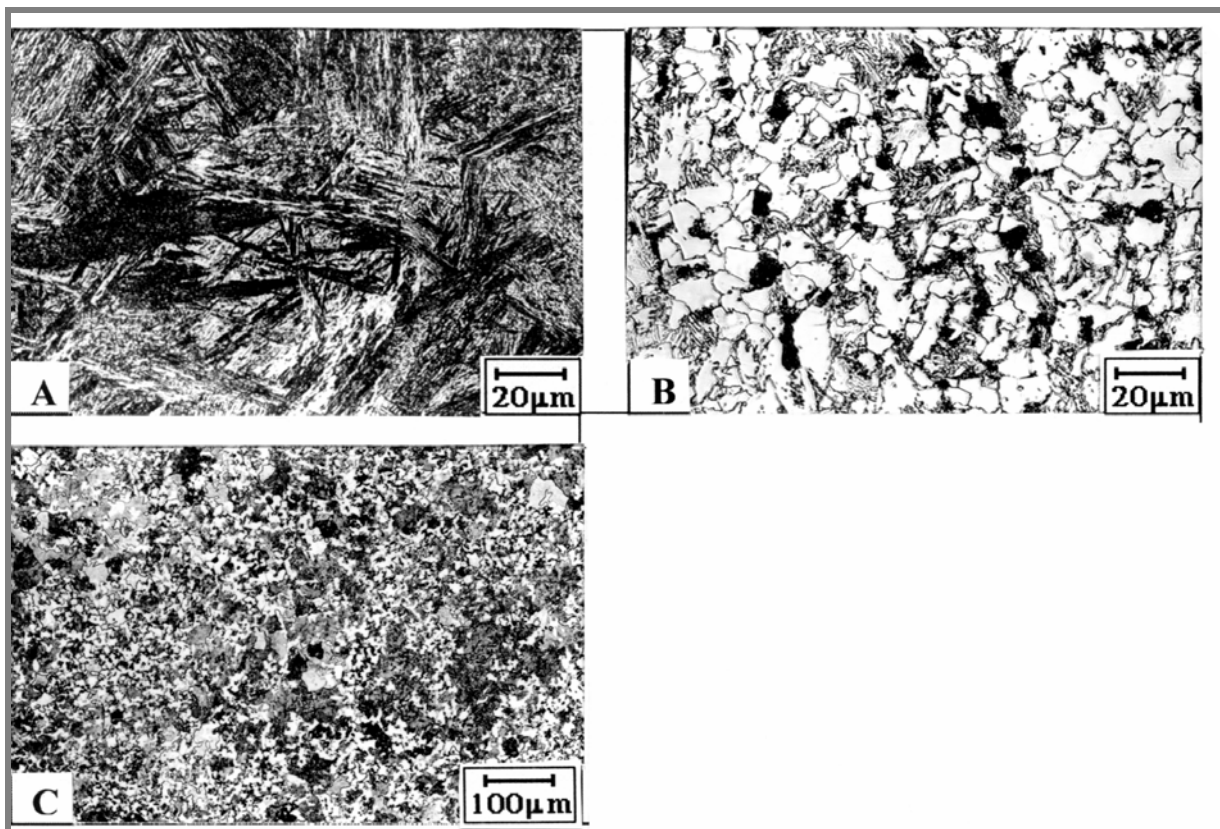
Slika 3b: Strukture navara izrađenih kombinacijom dodatnog materijala – žice RD 520 sa dodatkom praška F 56 i međusloja od dodatnog materijala – žice A 106 sa dodatkom praška F11.

A - Beinitna struktura, pokrivni sloj, žica RD 520 sa dodatkom praška F 56; B - Feritno – perlitna struktura, detalj međusloja izrađen od žice A 106 sa dodatkom praška F 11; C - Feritno – perlitna struktura osnovnog materijala.

Figure 3b: Structures of welds-on made by combination of wire RD 520 with addition F 56, with interlayer made by A 106 wire with F 11 addition.

A - Bainitic structure, cover layer RD 520 wire and F 56 addition; B - Ferritic-perlitic structure, interlayer detail made by A 106 wire and F 11 addition; C - Ferritic-perlitic structure of base material.

odsustva ovog elementa u dodatnom materijalu A 106. Pad njegovog sadržaja zavisi i od mešanja slojeva navara.

Na slici 4 prikazana je mikrostruktura navara izvedenog tehnologijom III. Mikrostruktura pokrivnih slojeva se sastoji od acikularnog ferita u kojem su prisutne disperzne čestice hrom karbida. Njihovo prisustvo je potvrdila i hemijska analiza navara. Rezultati merenja makrotvrdoće (maksimalne vrednosti 442 HV 10) i mikrotvrdoće faza potvrdile su prisustvo acikularnog ferita. EDX analiza pokazuje da je sadržaj Cr u pokrivnom sloju navara najveći, dok je sadržaj Mn i Al u navaru bio nešto manji [8].

Sadržaj Si je najmanji u površinskom sloju navara. U međusloju debljine 2.0 mm je dominantna sitnozrna feritna struktura. Hemijska analiza međusloja pokazala je kontinuirani pad sadržaja pojedinih legirajućih elemenata sa izuzetkom elemenata Cr i Al, koji nisu u sastavu dodatnog materijala žice C 113.

Prelazna zona između međusloja i osnovnog metala pokazuje beinitnu strukturu sa segregacijom cementita na granicama zrna. Debljina površine osnovnog metala koja je termički tretirana je relativno mala, približno 1.5 mm.

Na slici 5 data je otvrdnuta (zakaljena) struktura kranskog točka debljine do 3 mm od površine, koja se sastoji od disperznog acikularnog martenzita. U mikrostrukturi nisu prisutne karbidne čestice. Makro i mikrotvrdoća ovog sloja je od 700 i 790 HV 0.01 u odnosu na tvrdoću navarenih slojeva koja iznosi do 470, odnosno do 480 HV 0.01.

U zoni koja je bila termički tretirana prisutna je disperzna beinitna struktura, čiji se udeo kontinuirano menja u zavisnosti od termičkog tretmana, odnosno od temperature kalenja. U ovoj zoni prisutne su martenzitne faze i prelazna zona između osnovnog materijala sa kontinuiranim ukrupnjavanjem zrna,

the cover layers of the weld-on but in the weld-on itself the most abundant alloying element was Mn. These alloying elements were added to the weld-on from filling material RD 520, there was also a considerable role played by the applied addition F 56 in alloying the weld-on. The interlayer structure is formed by ferritic-perlitic structure, in which bainitic transformations can be observed. As the result of heat effect over the temperature A_{C1} the grains became ticker. The interlayer thickness is approximately 2,00 mm. Chemical analysis of the interlayer shows relatively continuous decrease of the alloying elements Mn and Si in comparison with cover layers. It is caused by lower amount of alloying elements in filling materials used for welding-on the interlayer. The decrease in Cr content in the interlayer was due to the absence of this element in the filling material A 106. It's content in the interlayer decreases depending on the mixing of welded-on layers.

Fig.4 shows the microstructure of a weld-on made by technology III. The macrostructure shows a distinct pattern of weld beads. The microstructure of cover layers is made by soft acicular ferritic structure in which the diffused soft grains of chromium carbide are confirmed by the weld-on chemical analysis. The presence of the acicular ferritic structure was confirmed by hardness (maximum values was 442 HV10) and microhardness evaluation. EDX analysis shows that the Cr content in the weld-on in the area of cover layers was the highest, the content of Mn and Al in the weld-on was somewhat was lower [8].

Si had the lowest content in the cover layer of the weld-on. The interlayer is created predominantly by soft-grained ferritic structure. The interlayer thickness was 2.0 mm. Chemical analysis of the interlayer showed that a decrease in the content of individual alloying elements in this area was continuous with exception of the elements Cr and Al, which are not contained in the filling material of C 113 wire. The
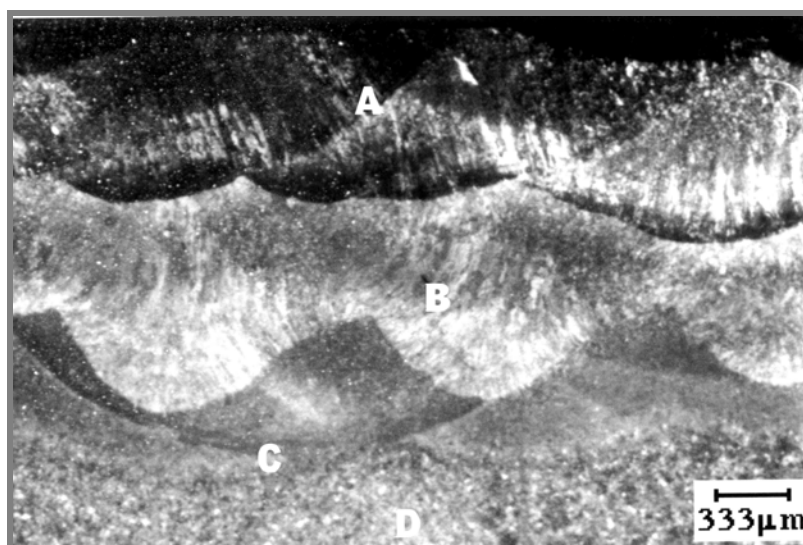
Slika 4a: Struktura navara izvedenog tehnologijom III
Figure 4a: Structures of welds-on made by technology III
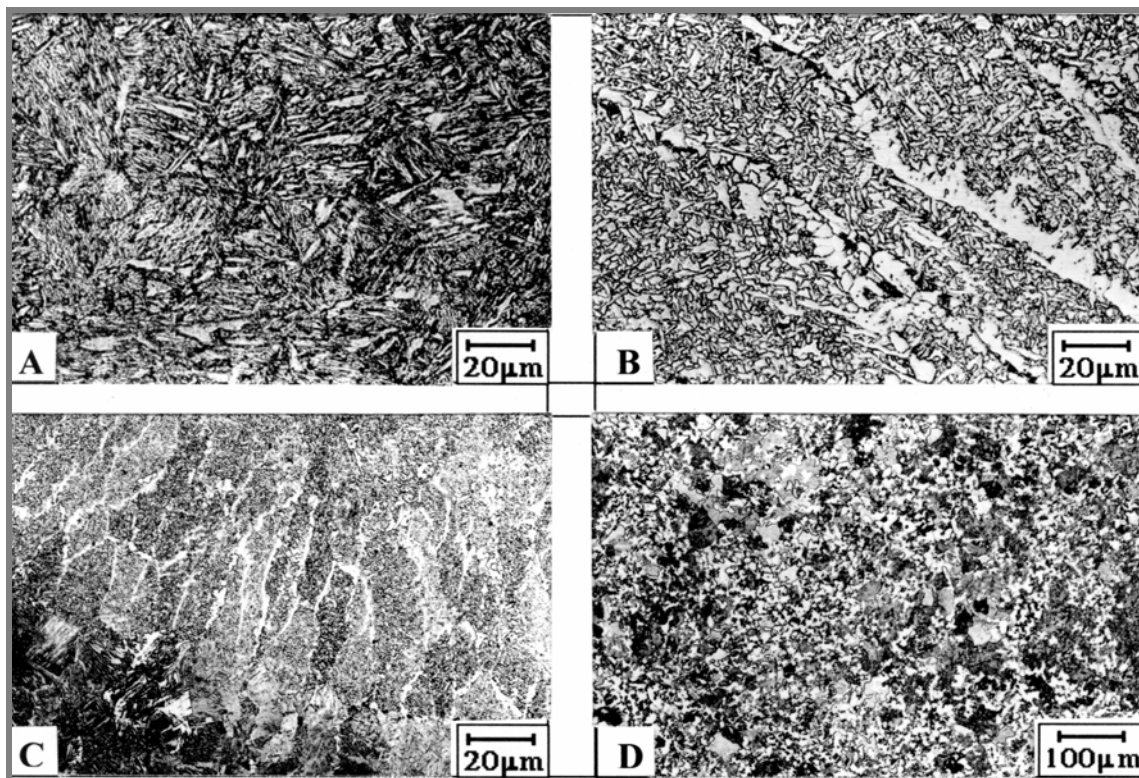
Slika 4b: Strukture navara izrađenih kombinacijom dodatnog materijala – samozaštitne žice Lincore 40-O i međusloja od dodatnog materijala – žice C 113 u zaštitnoj atmosferi 80% Ar + 20% CO_2.

A - Finozrni acikularni ferit, pokrivni sloj, žica Lincore 40-O; B - Feritna struktura sa feritnim zrnom koja segregiraju u obliku mreže na granicama primarnog zrna, detalj međusloja izrađen od žice C 113 u atmosferi zaštitnog gasa; C - Zona uticaja toplote između međusloja i osnovnog materijala; D - Feritno – perlitna struktura osnovnog materijala Gr. 90 – 60, ASTM A148.

Figure 4b: Structures of welds-on made by combination of wire with its own protection Lincore 40-O, interlayer made by wire C 113 in inert atmosphere 80 % Ar + 20% CO_2.

A - Fine-grained acicular ferritic structure, cover layer Lincore 40-O wire; B - Ferritic structure with ferritic grain netting segregated on primary grain boundaries, interlayer detail made by C 113 wire in protecting gas; C - Heat-affected zone between interlayer and base material; D - Ferritic-perlitic structure of base material Gr. 90-60, ASTM A148.

porastom udela i transformacijom perlita u beinit. Širina zone pod uticajem toplote je 2.2 mm.

Rezultati adhezivnog habanja

Na uzorcima isečenim od otvrdnutog kranskog točka izrađenog od čelika Gr. 90 - 60, ASTM A148 izmeren je najmanji gubitak težine od 0.00199g po uzorku, slika 6. Otvrdnuta površina kranskog točka i disperzna martenzitna struktura, osnovni je razlog malog gubitka težine.

Najmanje gubitke težine kao i najduža vremena do granice primene frikcionih parova izmeren je na uzorcima uzetih sa točkova koji su navareni sa žicom Lincore 40-O.

U ovom slučaju prisustvo Cr i njegovih karbida kao i Al u frikcionom sloju kranskih točkova najverovatnije je imalo uticaj na povećanu otpornost na adhezivno habanje. Na slikama 7 i 8 prikazan je gubitak težine pri habanju i oštećenja pri habanju [8].

detail of metal microstructure in the transition area between the interlayer and the base material shows the bainitic structure. On grain boundaries segregation of cementite was observed. The area of base material treated by heat is relatively small (approx. 1,5 mm).

Fig. 5 gives evidence of the hardened wheel structure. The microstructure up to 3 mm deep from the surface was created by soft-grained martensitic structure with acicular formations. The microstructure contained no carbidic particles. Martensitic structure was also confirmed by hardness and microhardness test in which the values 700 and 790 HV 0,01 were measured in comparison with hardness of welded-on layers which amounted to 470 and 480 HV 0,01. In the area treated by heat there was soft-grained bainitic structure; its content was changing continuously with respect to its treatment by heat. Bainitic structure was close to the influence of hardening temperatures, it contained numerous
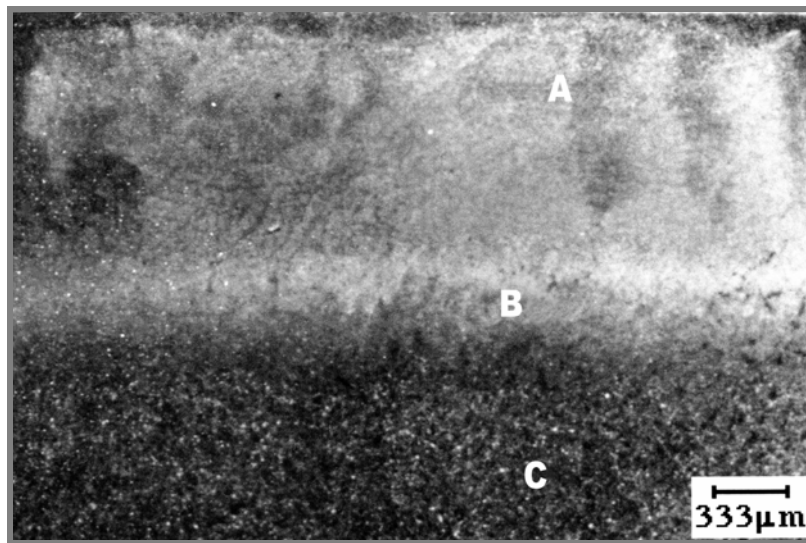
Slika 5a: Strukture kaljenog kranskog točka
**Figure 5a:** Structures of hardened crane wheel
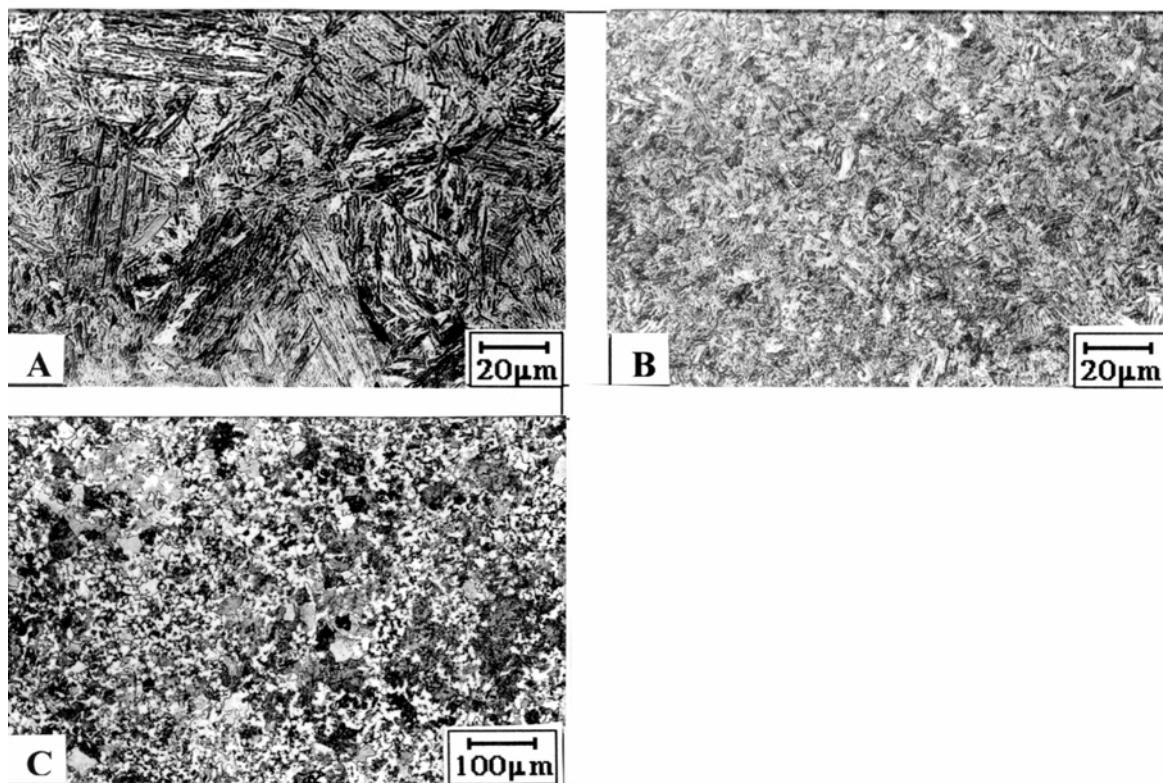
Slika 5b: Strukture kaljenog kranskog točka.

A - Finozrna martenzitna struktura kaljenog sloja kranskog točka; B - Beinitna struktura u ZUT-e između kaljenog sloja i osnovnog materijala; C - Feritno – perlitna struktura osnovnog materijala Gr. 90 – 60, ASTM A 148.

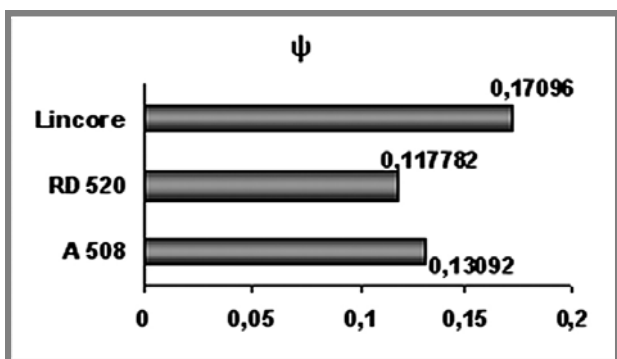**Figure 5b:** Structures of hardened crane wheel.

A - Fine-grained martensitic microstructure of hardened layer of wheel; B - Bainitic structure in heat-affected zone between hardened layer and base material; C - Ferritic-perlitic structure of base material Gr. 90-60, ASTM A148.
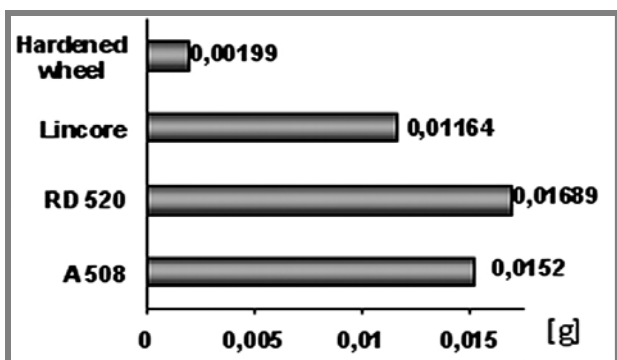
Slika 6: Adhezivno habanje posle 30 sec.

Figure 6: Course of adhesive wear after 30 sec.

Slika 7: Relativni gubitak težine pri habanju ispitivanih materijala.

Figure 7: Relative weight wear of examined materials.

martensitic phases and the transition area between the base material showed continuous grain thickening of the structure, growth and transformation of perlite into bainite. The heat-affected zone was 2,2 mm wide.

Results of adhesive wear tests

The lowest weight losses in the evaluated materials were found in samples taken from the hardened wheel made from Gr. 90-60, ASTM A148 material, Fig. 6. The value of weight loss was 0,00199 g per sample.

The reason of low weight losses was the hardened surface of the material and soft-grained martensitic structure highly resistant to adhesion. The lowest weight losses from the evaluated samples with welds-on as well as the longest times till seizure of friction pairs were measured in samples taken from wheels welded-on by Lincore 40-O wire.

Adhesion resistance in this case was influenced by presence of Cr and its carbides in the friction layer as well certain influence had the presence of Al. Respective weight wear and tear is shown in Fig.7 and Fig.8 [8].

CONCLUSIONS

The submitted article deals with the possibility of traverse crane wheels renovation aimed to prove suitability of examined filling materials in demanding tribological conditions. Properties of welded-on layers were evaluated and compared with the properties of new surface-hardened wheels manufactured from Gr. 90-60, ASTM A148 material.
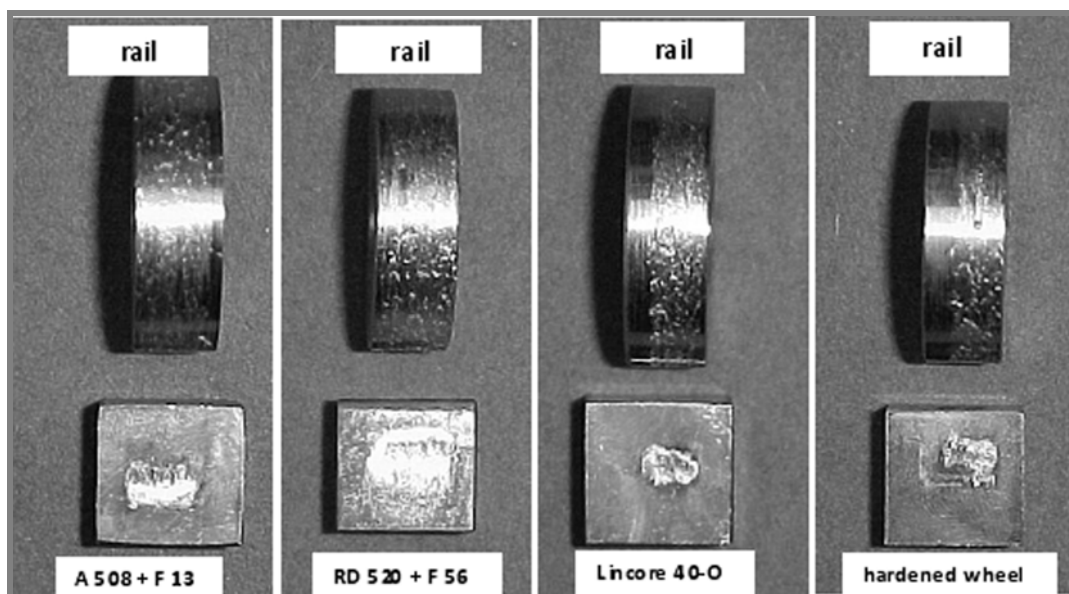
Slika 8: Frikcioni par – prsten i ploča posle adhezivnog habanja.

Figure 8: Friction pair – ring and plate after adhesive wear.

ZAKLJUČCI

Rad razmatra mogućnost revitalizacije točkova mostnog krana sa ciljem pokazivanja primeljivosti ispitivanih dodatnih materijala u zahtevanim tribološkim uslovima (uslovima habanja). Osobine navarenih slojeva su ispitane i upoređene sa osobinama otvrdnutih slojeva novih točkova izrađenih od čelika Gr. 90 - 60, po ASTM A148.

Ispitan je hemijski sastav navara na poprečno isečenim uzorcima u pravcu od osnovnog materijala preko međusloja do površinskih slojeva u zavisnosti od upotrebljenih dodatnih materijala i stepena mešanja materijala u slojevima. Analiza mikrostrukture pokazala je da osnovni materijal ima feritno – perlitnu strukturu. Posle kalenja osnovni materijal karakteriše martenzitna struktura. Navarivanjem po uslovima prve tehnologije, otvrdnuti površinski deo pokrivnog sloja imao je beinitnu strukturu. Drugom tehnologijom navarivanja dobija se površinski sloj sa beinitnom strukturom. Površinski sloj izveden trećom tehnologijom navarivanja ima disperznu strukturu acikularnog ferita.

Najvišu tvrdoću pokazuju uzorci površinski otvrdnutih novih točkova (703 HV 10 ili 780 HV 0.01). Makro i mikrotvrdoća uzoraka navarenih točkova su za oko trećinu manji u odnosu na tvrdoću novih točkova. Struktura uzoraka u poprečnom preseku navara pokazuje uticaj stepena mešanja materijala i termičke obrade na makro i mikrotvrdoću.

Adhezivno habanje je ispitano na laboratorijskoj mašini. Uzorci su ispitani na osnovu gubitka težine kao i vremenskog perioda do granice primene frikcionog para. Rezultati ispitivanja su pokazali da su struktura i hemijski sastav materijala imali presudan uticaj na otpornost materijala u odnosu na ispitanu vrstu habanja i oštećenja pri habanju. Najveću otpornost na habanje, ali i najkraće vreme do dostizanja granice primene frikcionih parova pokazali su uzorci površinski otvrdnutih novih kranskih točkova. Najbolje rezultate su pokazali navareni uzorci kod kojih je pokrivni sloj izveden sa dodatnim materijalom žicom Lincore 40-O. Ovaj materijal pokazao je najmanji gubitak težine i najduže vreme izmereno do dostizanja granice primene koje je dva puta duže u poređenju sa površinski otvrdnutim slojem novih točkova.

Na osnovu eksperimentalnih rezultata i analiza, moglo bi se smatrati da je treća tehnologija navarivanja, to jest GMAW tehnologija kojom je navaren međusloj sa dodatkom žice C 113 u zaštitnoj atmosferi mešavine gasova (80% Ar + 20% CO_2) i dva pokrivna sloja navarena samozaštitnom žicom Lincore 40-O, najprimenljivija za revitalizaciju oštećenih točkova mostne dizalice. Nedostatak treće tehnologije je oštar prelaz između pokrivnih slojeva, za čije je uklanjanje neophodno predgrevanje svakog sloja.

Chemical composition of welds-on carried out in transverse scratch patterns in the direction from base material through the interlayer up to cover layers corresponds to the type of used filling materials and mixing of the material in the layers. Analysis of microstructures shows that basic unaffected material is created by the ferritic-perlitic structure. After hardening the base material structure transformed into martensitic.

In the first welding-on technology, in which the cover layer was hardened on the surface, the structure was bainitic. In the second welding-on technology the cover layer was created by bainite. In the third technology the cover layer was created by soft-grained acicular ferritic structure.

The highest hardness values showed the samples taken from new surface-hardened wheels (703 HV 10 or 780 HV 0,01). Hardness and microhardness measured in samples taken from welds-on was one third lower than the values measured in samples from new wheels. Cross sections of the evaluated welds-showed the influence of material mixing and heat treatment on hardness and microhardness.

Adhesive wear was examined on the laboratory machine. Testing samples were evaluated on the basis of weight differences as well as the time period till seizure of friction contact pairs. The obtained experimental results showed that the material structure and its chemical composition had a decisive influence on material resistance to the evaluated type of wear and tear.

The highest resistance showed the samples taken from new surface-hardened wheels but the time until seizure of the friction pairs was the shortest. In samples taken from welds-on the best results were obtained in the weld-on with the cover layer made with Lincore 40-O wire. This material showed the smallest weight losses and at the same time the longest times till seizure, where in comparison with the surface-hardened layer of new wheels the time was twice as long as that.

Based on the obtained experimental results and analyses, the third welding-on technology, i.e. technology where the interlayer was made by GMAW technology with C 113 welding-on wire in protective atmosphere of mixed gases (80% Ar + 20% CO_2) and two cover layers were welded-on with welding-on wire with its own protection Lincore 40-O, could be considered the most suitable technology for renovation of worn-out traverse crane wheels. A certain drawback of the third welding-on technology is a sharp transition between cover layers, which will be necessary to eliminate in the future by preheating of each of the layers.

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GASNO ZAVARIVANJE - PRIRUČNIK

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Informacije:

Dr Vukić Lazić, vanredni profesor, vlazic@kg.ac.yu,

Tel. 034.335990 lok. 680 (Mob. tel. 064-8288737)

Mašinski fakultet u Kragujevcu

Sestre Janjić 6

34000 Kragujevac