

Društvo za Zavarivanje Crne Gore



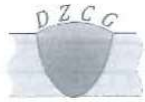
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TEHNOLOGIJE SPAJANJA MATERIJALA

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MATERIJALA”

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Za izdavače:

Prof. dr Darko Bajić
Prof. dr Radoje Vujadinović

Editori:

Prof. dr Nikola Šibalić
Prof. dr Nebojša Tadić

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PREDGOVOR

Sa zadovoljstvom predstavljamo zbornik radova „Tehnologije Spajanja Materijala“, 2026. posvećene savremenim dostignućima i izazovima u oblasti tehnologije zavarivanja i zavarenih konstrukcija. Ova konferencija okuplja stručnjake iz akademske zajednice, industrije i istraživačkih institucija sa ciljem razmjene znanja, iskustava i inovativnih rješenja u jednoj od ključnih grana savremenog inženjerstva.

Tematski okvir konferencije obuhvata širok spektar oblasti, uključujući tehnologije zavarivanja, razvoj i primjenu dodatnih materijala, metode i postupke kontrole kvaliteta zavarenih spojeva, kao i analizu pouzdanosti zavarenih konstrukcija. Poseban akcenat stavljen je na savremene pristupe edukaciji kadrova u oblasti zavarivanja, kao i na sve značajniju ulogu informacionih tehnologija u optimizaciji procesa, praćenju kvaliteta i unapređenju proizvodnih sistema.

Radovi predstavljeni u ovom zborniku odražavaju aktuelna istraživanja i praktična iskustva autora, nudeći nova saznanja i rješenja koja doprinose unapređenju efikasnosti, sigurnosti i održivosti zavarenih konstrukcija. Integracija tradicionalnih inženjerskih principa sa naprednim IT alatima i digitalnim tehnologijama otvara nove perspektive razvoja, omogućavajući preciznije upravljanje procesima i donošenje pouzdanih odluka.

Vjerujemo da će sadržaj ovog zbornika biti od značajne koristi istraživačima, inženjerima, studentima i svim profesionalcima koji se bave ili su zainteresovani za oblast zavarivanja. Nadamo se da će prezentovani radovi podstaći dalju saradnju, inovacije i kontinuirani razvoj ove važne discipline.

Zahvaljujemo se svim autorima na doprinosu, kao i članovima organizacionog i naučnog odbora na uloženom trudu u realizaciji ove konferencije. Takođe, posebnu zahvalnost upućujemo učesnicima i partnerima koji su prepoznali značaj ovog skupa i svojim prisustvom doprinijeli njegovom uspjehu.

U uvjerenju da će ova konferencija predstavljati važan korak ka daljem razvoju i unapređenju oblasti zavarivanja, želimo vam uspješan i inspirativan rad.

Predsjednik Organizacionog odbora
Prof. dr Darko Bajić



SADRŽAJ

1. Aleksandar Sedmak, Taško Maneski, Predrag Mitić, Svetlana Jocić, Simon Sedmak REKONSTRUKCIJA OŠTEĆENOG OKLOPA ROTORA U RHE BAJINA BAŠTA	1
2. Dragan Milčić, Miodrag Milčić, Janez Kramberger, Damjan Klobčar STATISTIČKA ANALIZA ZAMORNOG VEKA FSW ZAVARENIH SPOJEVA LEGURE ALUMINIJUMA AA2024.....	9
3. Tihomir Marsenić, Iva Deanović, Dean Lesan, Božo Despotović, Mario Jagnjić, Krešo Didić ZAHTJEVI ZA KVALIFIKACIJU SUČEONOG SPOJA NA KOMPOZITNOJ KOTLOVSKOJ CIJEVI PREMA ASME BPVC SEKCIJA IX, EDICIJA 2023	19
4. Aleksandra Krstevska, Filip Zdraveski, Maja B. Poser, Martin Petreski ZAVARIVAČKA RJEŠENJA ZA MONTAŽNE, REPARATURNE I NAVARENE SPOJEVE	31
5. Aleksandar Sedmak, Milan Miladinov, Milan Ostojin, Nenad Milošević, Simon Sedmak PROCENA INTEGRITA KOLENA NAPOJNOG CEVOVODA U HE PERUĆICA.....	39
6. Mersida Manjgo, Sabahudin Muharemović, Mirza Manjgo, Jasmin Halilović DOPRINOS U OCJENI PONAŠANJA KONSTRUKCIJE U PRISUSTVU GREŠKE TIPA PRSLINE.....	45
7. Aleksija Đurić, Srđan Samardžić, Dragan Milčić, Damjan Klobčar, Miodrag Milčić, Biljana Marković ANALIZA SPOJEVA KOMPOZITNIH MATERIJALA POD USLOVIMA UDARNIH OPTEREĆENJA.....	53
8. Resul Hamzić, Namik Džibrić, Alen Hodžić SANACIJA PUKOTINE NA ČEONOJ STIJENI MLINA CEMENTA.....	59
9. Maja Lindič, Nikolaj Mole, Aleš Nagode, Borut Žužek, Tomaž Vuherer, Miodrag Milčić, Dragan Milčić, Nataša Zdravković, Aleksija Đurić, Marek Polanski, Damjan Klobčar UTICAJ NAKNADNE TERMIČKE OBRADNE NA MEHANIČKA SVOJSTVA STRUKTURE OD MAREJDŽING ČELIKA DOBIJENE WAAM POSTUPKOM.....	67
10. Darko Šarančić, Luka Kuč, Darko Bajić TEHNOLOŠKI POSTUPAK UGRADNJE NOSAČA KOČIONE MLAZNICE NA KUĆIŠTE TURBINE AGREGATA A6 I A7 HE „PERUĆICA“	77
11. Edvard Bjelajac, Andrej Skumavc, Tomaž Vuherer, Nenad Gubelj, Jak, Damjan Klobčar, Gorazd Lojen POREĐENJE ZAVARENIH SPOJEVA DOBIJENIH LASERSKIM POSTUPKOM ZAVARIVANJA U ATMOSFERI RAZLIČITIH ZAŠTITNIH GASOVA.....	83

12. Marko Frajzman, Zoran Kožuh, Jadranka Eržišnik, Natalija Dolić SPECIFIČNOSTI FIBER LASERSKOG ZAVARIVANJA TITANIJA.....	97
13. Mirza Manjgo, Gorazd Lojen, Rene Peklar, Jure Bernetič, Tomaž Vuherer ISPITIVANJE MEHANIČKIH SVOJSTAVA ZAVARENOG SPOJA OD OKLOPNOG ČELIKA OSTVARENOG UPOTREBOM AUSTENITNOG NERĐAJUĆEG DODATNOG MATERIJALA.....	103
14. Đorđe Hadži Đokić, Mladen Mitić, Nikola Jović, Dragan Mitić UPOREĐIVANJE POSTUPAKA MAG-IBE-135 I SS-FCAW 114 ZAVARIVANJE BLOKOVA TRAMVAJSKIH SKRETNICA OD COGIDURA	111
15. Josip Pavić, Dejan Marić, Ivan Samardžić, Tomislav Šolić, Marko Dunder, Josip Mijić KOMPENZATORI ZA TLAČNU PRIMJENU - PROJEKTIRANJE I PRIMJENA.....	121
16. Marko Maričić, Ivan Stojčić, Marija Vukšić Popović, Stefan Dikić, Milorad Kočić KLASE IZVOĐENJA PREMA EN 1090-2 I NJIHOVA PRIMENA U PROJEKTOVANJU PREMA EN 1993 (EVROKOD 3)	129
17. Muhidin Kozica WELD ME - PROGRAM ZA PROCJENU ZAVARLJIVOSTI I TERMIČKIH USLOVA ZAVARIVANJA ČELIKA.....	137
18. Miro Uran, Vital Uran, Miloš Jovanović SAVREMENI PRISTUPI U OBUCI KOORDINATORA I INSPEKTORA ZA METALNE KONSTRUKCIJE U SKLADU SA ZAHTEVIMA EU CPR	149
19. Zoran Nikolić EFIKASNOST PRIMENE ULTRAZVUČNE TEHNIKE (TFM) ZA ISPITIVANJE ZAVARENIH SPOJEVA.....	155
20. Srđan Bulatović, Zorica Kovačević, Vujadin Aleksić MIKROSTRUKTURE PERLITNE ŠINE SUČEONO ZAVARENE VARNIČENJEM	161
21. Martin Petreski, Dobro Runchev, Gligorche Vrtanoski, Aleksandra Krstevska UTICAJ SINHRONIZACIJE GMAW I LBW PROCESA NA KVALITET ZAVARA I MEHANIČKE KARAKTERISTIKE KONSTRUKCIONOG ČELIKA	167

**Aleksandra Krstevska^{1,*}, Filip Zdraveski¹, Maja B. Poser¹,
Martin Petreski¹**

ZAVARIVAČKA RJEŠENJA ZA MONTAŽNE, REPARATURNE I NAVARENE SPOJEVE

***Rezime:** U radu su predstavljene različiti primjeri iz prakse, tri rješenja zavarivanja za različite montažne, reparaturne i navarene spojeve. Prvi slučaj se odnosi na montažni spoj primjenjen u pregrijaču pare. Izveden je heterogeni zavareni spoj između kolektorskih cijevi napravljenih od beinitnog feritno-perlitnog čelika tipa 12HMF i cijevnog sistema napravljenog od martenzitnog čelika tipa X10CrMoVNb9-1. Prilikom izrade spoja korišćen je prelazni komad (stucer) od feritnog čelika 10CrMo9-10 kako bi se izbjegla termička obrada tokom montaže, tj. prilikom izrade direktnog spoja. Na ovaj način omogućeno je tehnološki pojednostavljeno i ekonomski povoljnije rješenje.*

Drugi primer predstavlja popravku oštećene konstrukcije strijele bagera, oštećene klizištem tokom eksploatacije uglja. Razmatran je popravni zavar sa posebnom legurom nikla, Castolin Eutectrode Xuper NucleoTec 2222, koja formira austenitnu strukturu, sa visokim i zadovoljavajućim mehaničkim svojstvima i ne zahtijeva termičku obradu posle zavarivanja (Post-Weld Heat Treatment - PWHT). Rješenje je primijenjeno kao hitna popravka kako bi se redovno isporučivao ugalj termoelektrani do dolaska rezervnih djelova.

Treći primer se odnosi na izvođenje međuslojnog i zaštitnog zavara na zubu bagera izloženom intenzivnom abrazivnom habanju tokom eksploatacije. Iako manganski čelik pokazuje deformaciono ojačavanje, njegova otpornost na habanje pri radu u pijesku je ograničena. Korišćenjem tvrdih legura za navarivanje postiže se značajno poboljšanje otpornosti na habanje. Prikazan je primer navarivanja legurom 33Cr, sa ciljem povećanja vijeka trajanja komponente.

Ključne riječi: montažne zavareni spojevi, reparaturni zavareni spojevi, navareni spojevi, pregrevač pare, zubi bagera

¹ University in Skopje, Faculty of Mechanical Engineering, Skopje, Republic of North Macedonia

* Corresponding author, mail: aleksandra.krstevska@mf.edu.mk

WELDING SOLUTIONS FOR ON-SITE, REPAIR AND COATING WELDS

Abstract: *The paper presents different practical examples, three welding solutions for different assembly, repair, and coating joints. The first case refers to an assembly joint applied in a steam superheater. A dissimilar metal weld was performed between header pipes made of bainitic ferritic-pearlitic steel type 12HMF and a piping system made of martensitic steel type X10CrMoVNb9-1. During fabrication, a transition piece (nozzle) made of ferritic steel 10CrMo9-10 was used in order to avoid post-weld heat treatment during installation when in the case of a direct joint. This approach enabled a technologically simplified and economically favorable solution.*

The second example addresses the repair of a damaged excavator boom structure, which was damaged during a landslide in coal excavation. A repair weld was performed using a special nickel alloy, Castolin EutecTrode Xuper NucleoTec 2222, which forms an austenitic structure with high mechanical properties and does not require post-weld heat treatment (PWHT). The solution was implemented as an emergency repair in order to ensure continuous coal supply to the thermal power plant until spare parts arrived.

The third example refers to the deposition of an intermediate layer and a protective hardfacing coating on an excavator teeth exposed to intensive abrasive wear during excavation. Although manganese steel has the property of deformation strengthening, it has limited wear resistance when operating in sand. By applying hardfacing alloys, a significant improvement in wear resistance can be achieved. An example of hardfacing coating with a 33% Cr alloy is presented, with the aim of increasing the service life of the component.

Keywords: on-site welding joints, repair welding joints, coating joints, steam superheater, bucket teeth

1. INTRODUCTION

Welding in energy systems, such as steam superheaters, often requires dissimilar metal welds between high temperature steels, especially when martensitic steels are used and post-weld heat treatment (PWHT) is needed. The transition piece enables metallurgical compatibility avoids PWHT making the process simple and reduce costs. These solutions allow high-temperature operation and reduce the risks like Type IV cracking in the heat-affected zone [1, 2]

Repair welding is used to fix in-service defects and maintain the integrity of components that have developed defects during service such as cracks, corrosion damage or wear. Instead of replacing the entire part this method allows for localized material deposition, reducing costs and downtime. This

method demands control of welding parameters to ensure that repaired weld meets the required mechanical and microstructural properties [3, 4]. Machines that perform excavation are exposed to abrasion which often leads to component failure, and this has a significant economic effect on the process[5]. As most exposed components to abrasive wear, excavator teeth are made of elements such as white cast iron, steel casting and hard alloys [6] that not always have enough anti-wear properties. The selected material should ensure a balanced combination of sufficient toughness and hardness to withstand abrasive environments. When the teeth are protected by hardfacing layers, operational stresses may initiate cracks that propagate through the deposited layer thickness or cause interfacial delamination between the coating and the base material, eventually leading to failure. In addition to mechanical properties, weldability is an important parameter when selecting the base material, as it enables effective application of protective coatings in areas exposed to abrasion [7]. Steel containing Cr, V and Nb can be welded to the steel surface as solution for excavator bucket teeth wear protection. Iron-based hardfacing consumables are subject of this case which are used for abrasive applications [8].

2. CASE STUDY 1

The first case is on-site dissimilar metal weld in a steam superheater system. The welds are between the collector pipes made of bainitic ferrite-perlite type 12HMF and pipe system made of martensitic steel X10CrMoVNb9-1 (P91). Direct weld of these materials on-site is a technological challenge due to the need for PWHT, which is often difficult to perform on-site. An overview of the base materials is given in Table 1.

Table 1. Base material

Element	Dimensions/material/standard
Pipe system	Ø 32x4 mm, X10CrMoVNb9-1, EN 10216-2
Transition piece (connector)	Ø 32x4 mm, 10CrMo9-10, EN 10216-2
Collector pipes	Ø 36x6 mm, 12X1MF, TY-14-3R-55-2001

To avoid PWHT during assembly, a solution was applied with a transition piece (connector) made of ferrite steel 10CrMo9-10. This material enables a metallurgically more compatible transition between base materials and reduces the risk of undesirable microstructures in the weld zone.

With the WPS the parameters of welding, preheating temperature and welding process are selected (Table 2). Special attention is paid to temperature control during welding to prevent the formation of cold cracks and ensure a stable microstructure in the heat-affected zone.

The application of the transition piece in this case enabled process optimization, without PWHT on-site, which presents a significant advantage

from the aspect of economy and time of implementation of works. On Figure 1 is shown PWHT in workshop between X10CrMoVNb9-1 and 10CrMo9-10, on Figure 2 is presented on-site direct weld between the transition piece and collector pipes.

Table 2. WPS for DMW in steam superheater system

Passes	Welding process	Filler material	Current (A)	Polarity	Preheating	PWHT
<i>WPS for X10CrMoVNb9-1 and 10CrMo9-10</i>						
Root pass	141 (TIG)	Bohler DMV 83-IG (Ø 2.4 mm)	80-110	DC/-	≥200 - 250°C	740 ± 10°C / 30 min
Fill passes	141 (TIG)	Bohler DMV 83-IG (Ø 2.4 mm)	90-120	DC/-	≥200 - 250°C	740 ± 10°C / 30 min
<i>WPS for X10CrMoVNb9-1 and X10CrMoVNb9-1</i>						
Root pass	141 (TIG)	Bohler DMV 83-IG (Ø 2.4 mm)	80-110	DC/-	≥200 - 250°C	740 - 770°C / 30 min
Fill passes	141 (TIG)	Bohler DMV 83-IG (Ø 2.4 mm)	90-120	DC/-	≥200 - 250°C	740 - 770°C / 30 min
<i>WPS for 10CrMo9-10 and 12X1MF</i>						
Root pass	141 (TIG)	Bohler DMV 83-IG (Ø 2.4 mm)	80-110	DC/-	/	/
Fill passes	141 (TIG)	Bohler DMV 83-IG (Ø 2.4 mm)	90-120	DC/-	/	/



Figure 1. PWHT of X10CrMoVNb9-1 and 10CrMo9-10

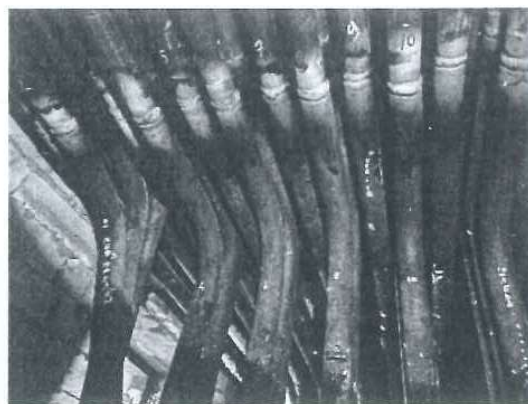
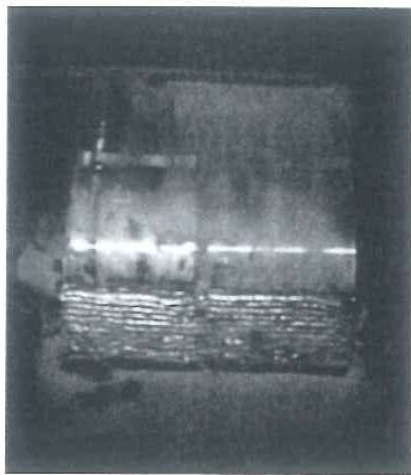


Figure 2. On-site welds (10CrMo9-10 and 12X1MF)

3. CASE STUDY 2

Subject of this case is urgent repair of an old shaft of a wheel for excavation which is made of steel 26 NiCrMoV 14 5. The part has abrasive damage and the possibility was considered to perform repair welding with appropriate technology until the procurement of spare parts has been considered. For urgent repair, buttering layer was created using austenitic nickel electrode, type Castolin NucleoTec 2222, and the weld metal with an electrode with an austenitic structure type EDUR EZ-400 TN with a similar hardness as the shaft. The result is a layer that is resistant to abrasion and is suitable for the required purpose.



(a)



(b)

Figure 3. Repair welding of KU 300 excavator wheel shaft; a - Machined surface in the zone of abrasive damage, b - Completed weld

4. CASE STUDY 3

In this case, the use of hard-facing alloys for excavator teeth coating is presented. On Figure 4 is shown schematic diagram of hard-facing, performed in minimum two steps. The first layer is directly applied over the metallic base, with high percent of dilution and present basic bonding interlayer. With the second layer the dilution is avoided, especially with the carbon, and this layer resists abrasion. A hardfacing electrode, type OK 84.78, with 33% of Cr is used for coating of high tensile steel 22Mn6. The welding parameters are given in Table 3. The dilution rate is with three layered multi-pass welding, with 2 mm thick layer. After the hardfacing process a field test was done. The wear rate and wear rate indices (WRI) are shown in Table 4.

Table 3. Welding parameters of case study 3

Welding parameters	Hardfacing electrode OK 84.78
Electrode diameter (mm)	3.2
Acr Voltage (V)	26
Welding current (A)	128
Welding speed (mm/min)	90-110
Preheating for 1 hour (°C)	180
Deposition rate (kg/h)	2.4

The wear damage starts from the end of the leading edge and moving inwards, towards the base of the tooth were very little or no wear can be observed. The hard-faced excavator tooth, coated with 33Cr alloy shows almost no wear damage. This is due to the high abrasive wear resistance of the chromium carbides in the coated layers.

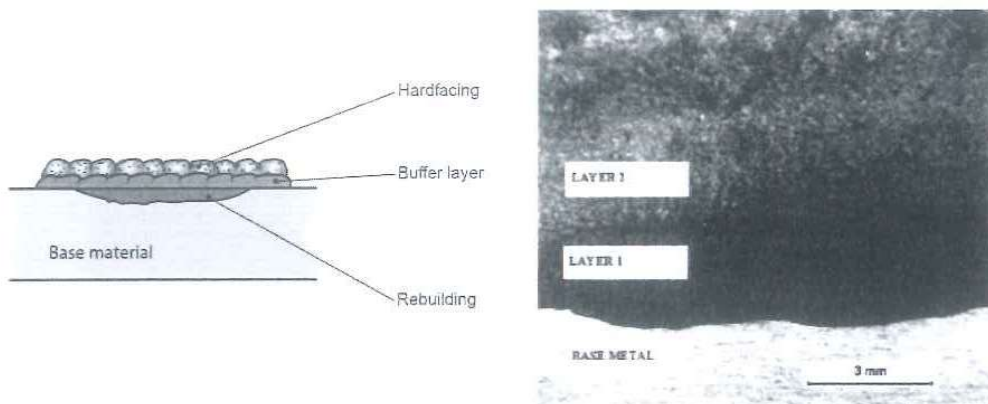


Figure 4. Schematic diagram and micrograph of application of hard-facing alloys in two layers

Table 4. Wear rates and wear rate indices (WRI)

Hard-facing electrode	Wear rate (gr/hr)	WRI
Uncoated tooth	1.900	1
OK 87.78	0.110	17.27

5. CONCLUSION

The paper presents review of selected welding technologies for solutions on-site, repair and coating welds for components operating under demanding service conditions. The use of transition piece proved to be an effective approach for achieving metallurgical compatibility without PWHT during on-site installations. The results are cost reduction and technological process optimization while maintaining structural integrity.

The repair welding of the excavator shaft using a nickel-based electrode demonstrated that emergency repair strategies can successfully restore functionality and extend service life without requiring PWHT, which is particularly important in time-critical industrial operations. The hard-facing

of excavator teeth with high-chromium alloys confirmed that coating technique significantly enhance wear resistance in abrasive environments.

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