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Mijat Samardžić[1], Mario Jagnjić[2], Dejan Marić[3,a], Božo Despotović[4], Marko Dunđer[3], Ivan Samardžić[3]

ZAVARIVANJE OKRETNIH POSTOLJA PRIMJENOM VISOKOUČINSKOG POSTUPKA ZAVARIVANJA

WELDING OF BOGIES USING HIGH EFFICIENCY WELDING PROCEDURE

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Rezime

Okretna postolja su sastavni elementi vagona koji omogućuju lakši prolazak željezničkih vozila kroz zavoj smanjujući trenje i trošenje između kotača i tračnice. Na okretno postolje vezani su osovinski sklopovi i vučni motor vozila. U skadu sa normom EN 15085-2 klasifikacijski nivo CL1 postavljeni su zahtjevi za kvalitetu zavarenih spojeva željezničkih vozila, a tako i određenih komponenti, s obzirom na zahtjeve danas se u tvrtci ĐĐSV proizvode okretna postolja primjenom konvencionalnih postupaka zavarivanja. U radu je prezentirana primjena dosadašnje tehnologije pri zavarivanju okretnih postolja, te su prikazani rezultati ispitivanja i primjena robotiziranog TWIN procesa zavarivanja.

Abstract

Bogies are integral elements of wagons that enable easier passage of railway vehicles through a curve by reducing friction and wear between the wheels and the rail. The axle assemblies and traction motor of the vehicle are attached to the bogie. In accordance with the standard EN 15085-2 classification level CL1, requirements have been set for the quality of welded joints of railway vehicles and certain components, with regard to the requirements, today bogies are produced in the company ĐĐSV using conventional welding procedures. The paper presents the application of current technology in the welding of turntables, as well as the test results and application of the robotic TWIN welding process.

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1. Uvod

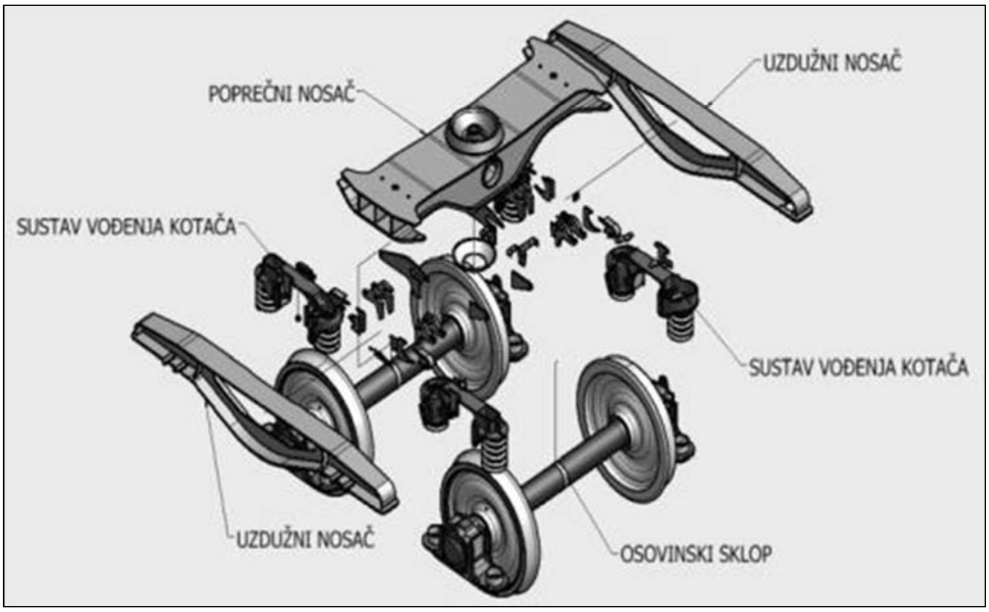
Teretni vagoni su željeznička vozila koja se sastoje od više sklopova, podsklopova i komponenti čija izvedba u cjelini mora udovoljiti funkcijskim zahtjevima i te normama EN 15085-2 classification level CL1. Vagon se u osnovi sastoji od vagonske karoserije koja ujedno ima funkciju prijevoza određenog tereta. Ostali elementi su vozna postolja, vučno - odbojni uređaji, kočioni sustav i dodatna oprema specijalne namjene. Jedan od sastavnih sklopova su i okretna postolja. Općenito, okretno postolje je element vagona koji omogućuje lakši prolazak željezničkih vozila kroz zavoj smanjujući trenje i trošenje između kotača i tračnice. Na okretno postolje vezani su osovinski sklopovi i vučni motor vozila. Na slici 1 prikazano je okretno postolje u sklopu teretnog vagona.

Slika 1. *Okretno postolje u sklopu teretnog vagona*

Figure 1. *The bogie as part of the freight car*

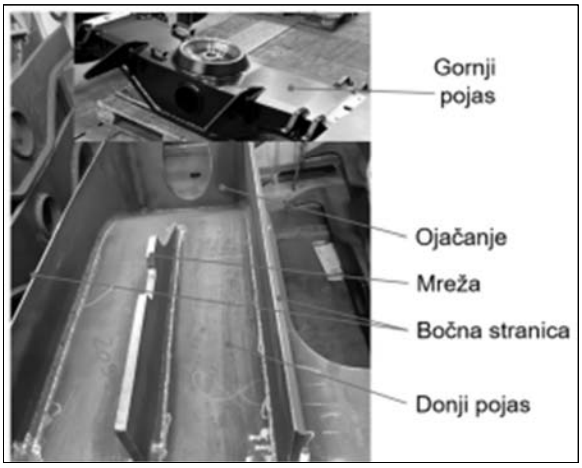
2. Okretno postolje

Osnovni elementi okretnog postolja su osovinski sklop, sustav vođenja kotača, uzdužni nosač i poprečni nosač što je i vidljivo na slikama 2 do 4. Elementi koji su ovim radom obuhvaćeni, a zahtjevaju najveću pozornost prilikom zavarivanja ali i kontrolnih aktivnosti su uzdužni nosači i sam poprečni nosač. Ovi sklopovi izrađeni su od čelika S355J2+N.



Slika 2. *Osnovni sklopovi okretnog postolja*

Figure 2. *Basic assemblies of the bogie*



Slika 3. *Izgled poprečnog nosača pri ručnom zavarivanju u napravi*

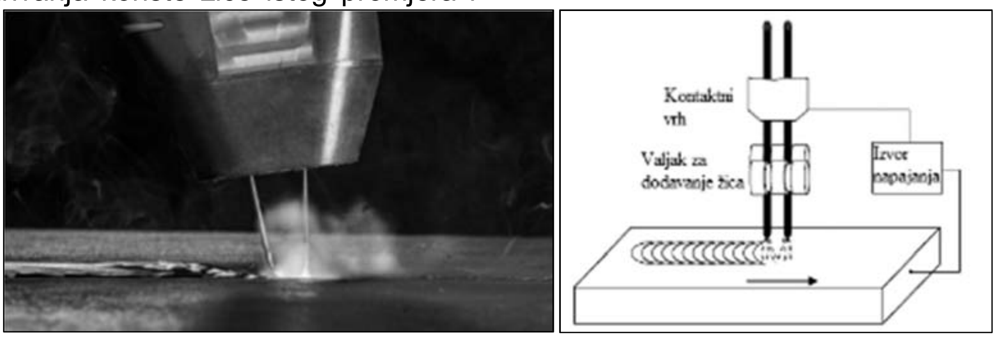
Figure 3. *Appearance of the transverse support during manual welding in the device*

Slika 4*. Sastav poprečnog nosača u napravi*

Figure 4. *Composition of the transverse support in the device*

Kako bi se omogućilo postizanje veće kvalitete zavarenih spojeva na navedenim sklopovima i podigli proizvodni kapacitet uvodi se zamjena ručnog procesa s robotiziranim TWIN procesom zavarivanja. Sustav se može sastojati od zajedničkog ili zasebnog izvora napajanja za pojedinu žicu. Korištenje oba izvora napajanja je najčešće potrebno ukoliko je potrebno ostvariti maksimalne vrijednosti struje za zavarivanje. Kada se tokom zavarivanja koriste žice istog promjera i ista brzina dodavanja žice, tada je dovoljna samo jedna jedinica za dodavanje žice (s dvotračnim valjcima za dodavanje žice) slika 5.

Rad twin sustava značajno pojednostavljuje činjenica da su obje žice istog električnog potencijala te je time olakšano postavljanje parametara zavarivanja. [1]



Slika 5. *Zavarivanje twin sustavom [2, 3]*

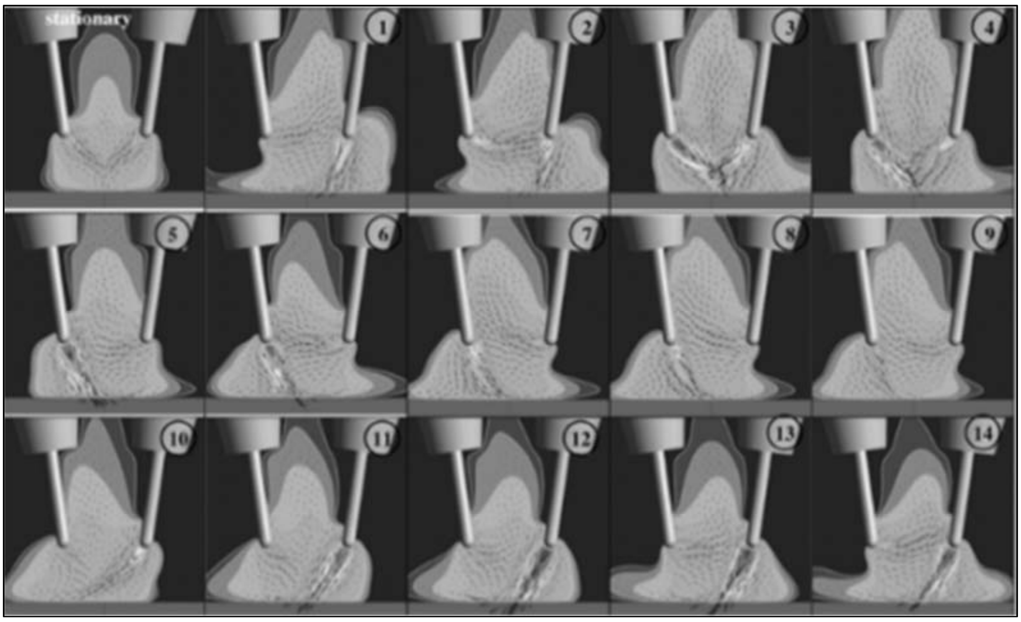
Figure 5. *Twin system welding [2, 3]*

Zavarivanjem s dvije žice moguće je ostvariti velike brzine zavarivanja i time se smanjuju deformacije materijala koje su uzrokovane velikim unosom topline. Također, kada je u pitanju unos topline, twin sustav učinkovito koristi toplinu koja se unosi tokom zavarivanja jer prateći električni luk zagrijava žicu u zajedničku rastaljenu kupku. U postupcima gdje se koristi više pištolja za zavarivanje, rastaljeni metal nakon prvog luka očvrsne i ponovno zagrijava sljedećim lukom [4]. Prilikom taljenja obje žice, rastaljena kupka koja nastaje je izdužena i time se omogućuje duži vremenski period izlaska štetnih plinova, a samim time smanjuje se poroznost u zavarenog spoja.

Prema istraživanju DINSE G.m.b.H. [2], količine depozitnog materijala dosežu vrijednosti do 12,7 kg/h kada se koristi puna žica promjera 1 mm. Takav maksimalan unos dodatnog materijala osigurava visoku pouzdanu izvedbu i izvrsno premošćivanje velikih razmaka tokom zavarivanja. Za naprednije twin sustave uz računalno kontrolirani nadzor, često se koristi drugi dodavač žice koji omogućuje različite brzine dodavanja i promjere žica. Međutim, ograničena je mogućnost upotrebe različitih žica zbog činjenice da obje koriste isti napon pri zavarivanju.

Korištenjem različitih tipova električnih lukova postiže se optimizirana geometrija zavara. Kombinacijom klasičnog tipa žice (bez ikakvog punjenja) s žicom koja je punjena ostvaruje se zavareni spoj u kojemu vodeća puna žica osigurava dovoljnu penetraciju dok punjena žica naknadno osigurava dobro spajanje bočnih stijenki materijala [1].

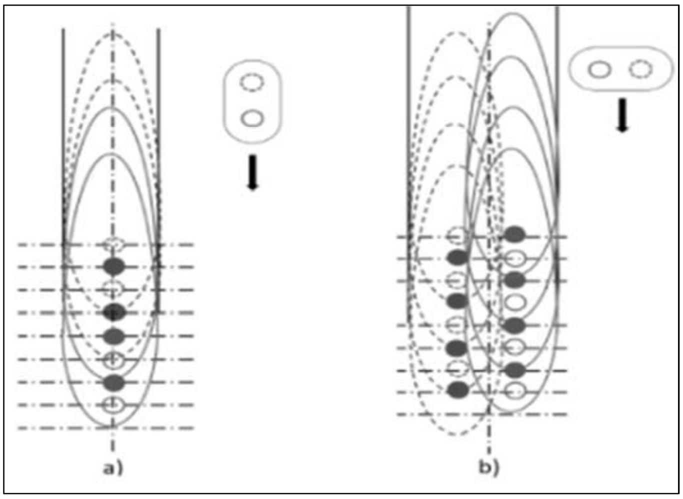
Primarna žica je ona žicu koja prva uspostavi električni luk u procesu zavarivanja. Iz slike 6. vidljivo je kako žica koja se u određenom trenutku ne napaja impulsnom strujom i dalje ostaje električki aktivna u atmosferi zaštitnog plina i vrši utjecaj na žicu do koje se dovodi impulsna struja.



Slika 6. *Interakcija električnih lukova pri zavarivanju (primarna žica se nalazi lijevo) [4]*

Figure 6. *Interaction of electric arcs during welding (primary wire is on the left) [4]*

Struje malih vrijednosti koje izlaze iz pasivne žice (do koje se ne dovodi el. struja) privlače se prema aktivnoj žici sve dok se električni luk ponovno ne upali. Raspršene kapljice unutar električnog luka mogu se u određenim uvjetima spojiti (tvoreći zajednički električni luk) u letu i formirati u veće kapi. Također, u drugim slučajevima kapi će imati slobodan let do radnog komada koji se zavaruje i opet približno pasti u rastaljeni bazen. U ovim postupcima zavarivanja, pištolj za zavarivanje može biti orijentiran na više načina. Jedan od načina orijentacija pištolja za zavarivanje je taj da žice stoje serijski, odnosno da je položaj žica u istoj ravnini kao i smjer zavarivanja. Drugi način orijentacije je taj da žice stoje paralelno jedna pored druge i tako tvore znatno širi zavareni spoj. U takvom položaju su žice orijentirane okomito na ravninu smjera zavarivanja.

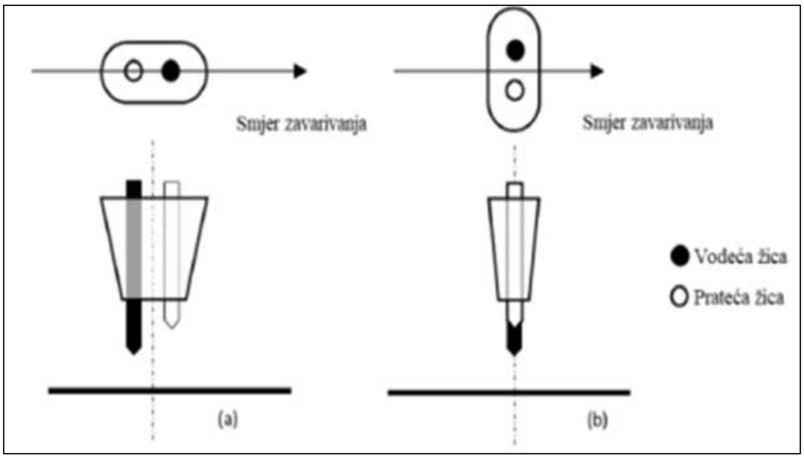


Slika 7. *Twin sustav s a) orijentacijom žica u ravnini smjera zavarivanja i b) orijentacijom žica okomitom na smjer zavarivanja [3]*

Figure 7. *Twin system with a) wire orientation in the plane of the welding direction and b) wire orientation perpendicular to the welding direction [3]*

Primjerice, pri zavarivanju tankih limova teži se ponajprije postići veću brzinu zavarivanja i tada se koristi orijentacija pištolja kako je prikazano u slučaju slike 7 a), dok pri zavarivanju debljih limova i premošćivanju širokih žlijebova je cilj ostvariti bolju penetraciju i veće stope proizvodnje depozitnog materijala i tada se koristi orijentacija kako je prikazano u slučaju slike 7 b).

Kako je ranije navedeno, ako su obje žice na istom polaritetu, dva luka se međusobno privlače i djeluju poput jednog izduženog luka. Ta činjenica je bitna i kada je riječ o orijentaciji žica tokom zavarivanja. U slučaju da su žice orijentirane u smjeru zavarivanja, luk na vodećoj žici biti će izložen udaru sa stražnje strane, dok je na pratećoj žici luk izložen udaru od naprijed. U takvom rasporedu, prateća žica određuje konačni oblik zavara [3]. Odabrana razina isticanja žica i kutovi žica u pištolju za zavarivanje također imaju utjecaj na proces zavarivanja. Elektrode tj. žice za zavarivanje se često uvode kroz kontaktni vrh pod određenim kutom tako da su blago usmjerene jedna prema drugoj dok prolaze kroz pištolj. Udaljenost između elektroda izmjerena na izratku naziva se međuelektrodna udaljenost i najčešće za MIG/MAG sustave iznosi 4 - 8 mm [1]. Na slici 8, vidljiva su različita isticanja žica u serijskom i paralelnom orijentacijom.



Slika 8. *Različita isticanja žica u a) zavarivanju sa serijskom i b) paralelnom orijentacijom žica [5]*

Figure 8. *Different wire going out in a) welding with serial and b) parallel wire orientation [5]*

Prednosti twin sustava: Mogućnost korištenja jednog izvora energije i dodavača žice (po potrebi i dodatni). Povećanje brzine zavarivana i količine depozitnog materijala. Sposobnost potpune robotizacije sustava i upravljanja putem software-a. Pištolj za zavarivanje do 50 % manjih dimenzija nego u tandem sustavu [2]. Manja cijena opreme za zavarivanje u odnosu na tandem sustav. Žice mogu biti postavljene u ravnini sa smjerom zavarivanja i okomito u odnosu na isti. Manji unos topline zbog toga što oba električna luka tvore istu rastaljenu kupku. Fleksibilnost sustava u smislu da ukoliko nije potrebno, može se koristiti samo jedna žica. Smanjeno vrijeme pripreme zavarivanja zbog jednostavnijih parametara. Omogućavanje konstantne kvalitete zavara pri visokim brzinama.

3. Primjena TWIN sustava pri zavarivanju sklopova okretnog postolja

Sklopovi koji su zavarivani izrađeni su od nelegiranog i normaliziranog konstrukcijskog čelika S355J2+N. U tabeli 1 je prikazan kemijski sastav vruće valjanih ploča od čelika S355J2+N.

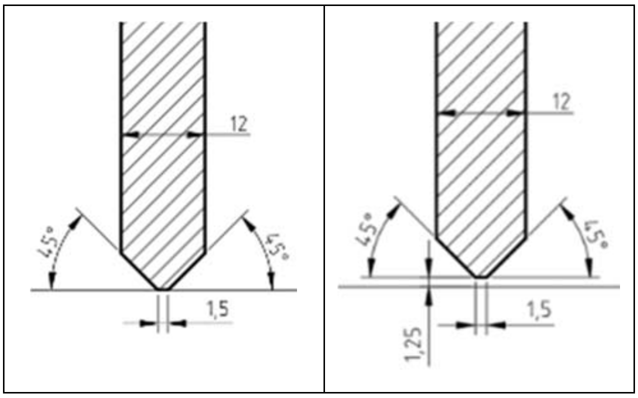
Nedostatci twin sustava: Cijena opreme i software-a koji podržavaju robotsko zavarivanje. U sustavu gdje su žice postavljene pod određenim kutom može doći do otklona luka ukoliko međuelektrodna udaljenost nije pravilno postavljena. Žice ne mogu koristiti potpuno neovisne postavke kao u tandem zavarivanju. Potrebna obuka radnika za upravljanje robotom.

***Tabela 1**. Kemijski sastav čelika S355J2+N*

***Table 1.** Chemical composition of steel S355J2+N*

C, %	Si, %	Mn, %	P, %	S, %	Cu, %	Fe, %
< 0,22	< 0,55	< 1,6	< 0,035	< 0,035	< 0,06	ostatak

Priprema žlijeba za zavarivanje izvršena je sa i bez zazora. Skica pripreme žlijeba bez zazora uzorak U1 je prikazana na slici 9 a), sa zazorom uzorak U2 1.25 mm slika b).

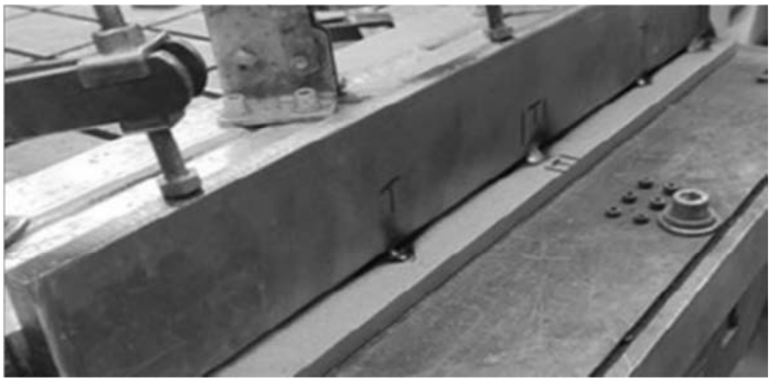


a) b)

***Slika 9.** Skica pripreme žlijeba za zavarivanje*

***Figure 9.** Sketch of the preparation of the groove for welding*

Kako bi se sve moguće varijante proizvodne provjerile ovoga procesa jedna priprema je izvršena bez zazora ali su izvedeni pripoji preko kojih se vršilo zavarivanje.Za ovaj slučaj žlijeb se priprema na isti način kao i u slučaju zavarivanja bez zazora, ali se radni komadi spajaju pripojima prije zavarivanja kako je prikazano na slici 10, uzorak U3.



Slika 10. *Zavarivanje preko pripoja*

Figure 10. *Welding over the joint*

Zavarivanje bez zazora izvedeno je sa sledećim parametrima:

Žica G3Si1, Φ 1,2 mm, zaštitni plin M21 (18% CO2 + 82% Ar), 1. žica I_1 = 374 A, U_1 = 27,2 V, 2. žica I_2 = 229 A, U_2 = 26,2 V, brzina zavarivanja: v = 85 m/min, pozicija zavarivanja: PB.

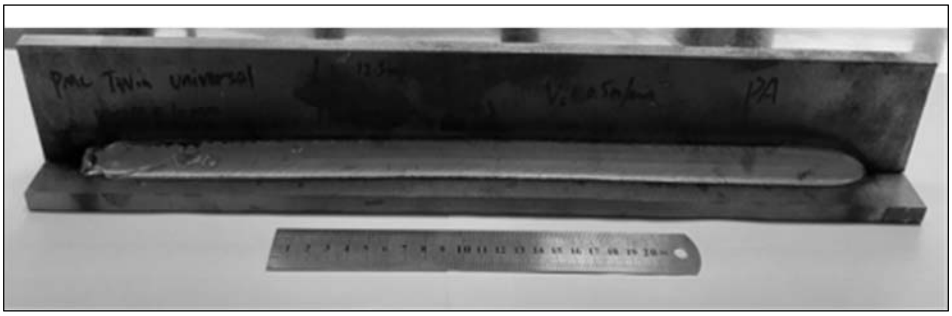
Zavarivanje sa zazorom od 1,25 mm izvedeno s parametrima:

Žica G3Si1, Φ 1,2 mm, zaštitni plin M21 (18% CO2 + 82% Ar), 1. žica I_1 = 359 A, U_1 = 27,6 V, 2. žica I_2 = 230 A, U_2 = 25,4 V, brzina zavarivanja: v = 85 m/min, pozicija zavarivanja: PB

Zavarivanje preko pripoja se izvodilo s parametrima:

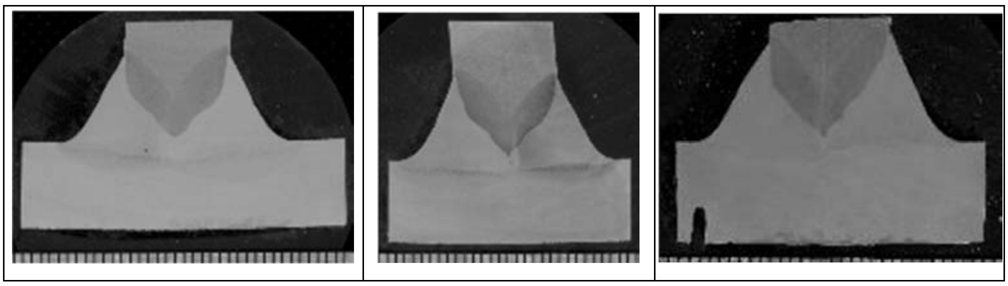
Žica G3Si1, Φ 1,2 mm, zaštitni plin M21 (18% CO2 + 82% Ar), 1. žica I_1 = 359 A, U_1 = 27,6 V, 2. žica I_2 = 230 A, U_2 = 25,4 V, brzina zavarivanja: v = 85 m/min, pozicija zavarivanja: PB.

Na slici 11. su prikazani zavareni radni uzorci.



Slika 11. *Zavareni uzorak*

Figure 11. *Welded sample*



a) uzorak U1 b) uzorak U2 c) uzorak U3

Slika 13. *Dimenzionalna kontrola zavarenih uzorka a)U1, b)U2, c)U3*

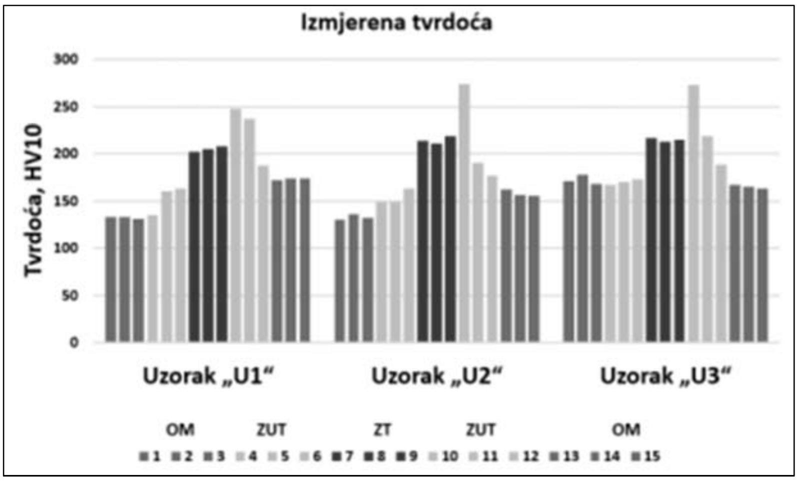
Figure 13. *Dimensional control of welded samples a)U1, b)U2, c)U3*

Rezultati mjerenja tvrdoće na uzorcima prikazani su u Tabeli 2, i dijagramski na Slici 14.

Tabela 2. *Mjerene tvrdoće na zavarenim uzorcima*

Table 2. *Results of the hardness measurement on welded samples*

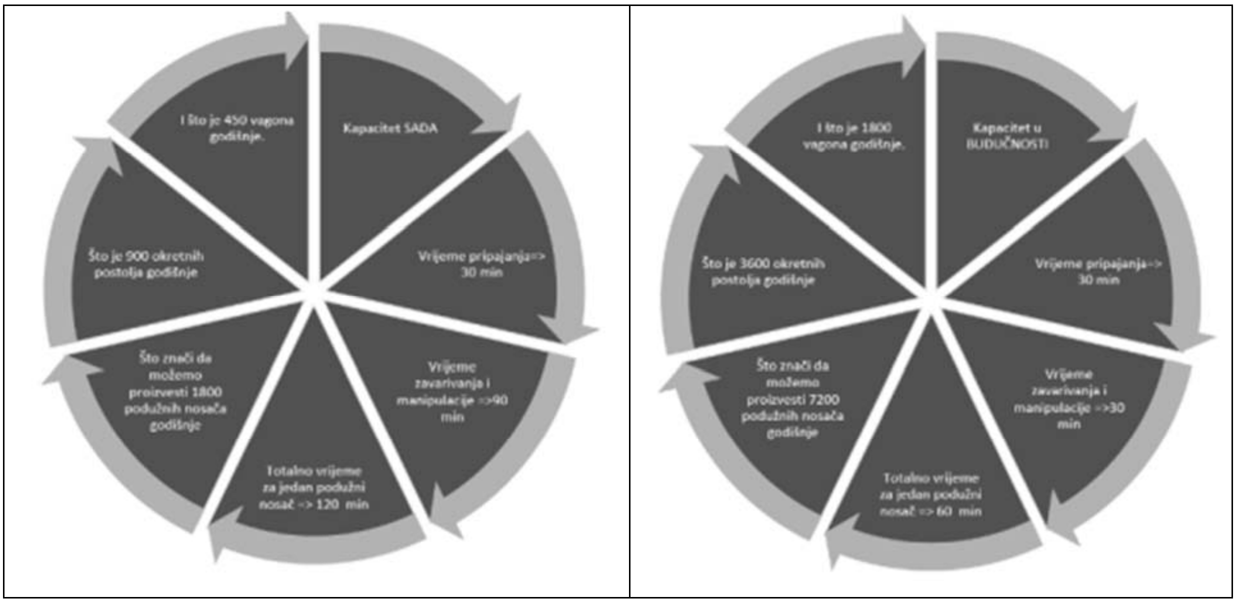
	Izmjerena tvrdoća, HV10		
Mjesto mjerenja	Uzorak „U1“	Uzorak „U2“	Uzorak „U3“
1	133,4	130,3	171,4
2	132,7	136,1	177,5
3	131	132,1	168,3
4	135,1	148,5	166,8
5	160,5	149	170,4
6	163,3	163,7	172,9
7	202,2	213,7	216,4
8	204,7	210,8	212,8
9	208	218,9	214,8
10	248,2	274,3	272,5
11	237,4	190,4	219
12	187,7	177,1	188,3
13	171,6	162,1	167,3
14	174,4	156,2	164,9
15	173,7	155,1	163



Slika 14. *Dijagram rezultata mjerenja tvrdoće na zavarenim uzorcima U1, U2, U3*

Figure 14. *Diagram of hardness measurement results on welded samples U1, U2, U3*

Kako je vidljivo na Slici 14, značajnijeg rasipanja podataka tj. vrijednosti tvrdoća nema pri promjena priprema zavarenih spojeva. Kako se uspješno može izvesti zavarivanje primjenom ovoga procesa zavarivanja ide se u primjenu navedene tehnologije koja će u konačnici primjenom u sustavu koji je robotiziran omogućiti podizanje kvalitete zavarenih spojeva sklopova okretnih postolja ali samim time i podizanje proizvodnih kapaciteta (slika 15).



a) b)

Slika 15. *Kapaciteti proizvodnje a) trenutno stanje tehnologije, b) primjenom nove tehnolgije zavarivanja TWIN*

Figure 15. *Production capacities a) the current state of technology, b) using the new TWIN welding technology*

5. Zaključak

Zbog budućeg povećanja proizvodnje vagona, a samimi time i potrebom sve većeg broja okretnih postolja uvođenje novih tehnologija zavarivanja i sama robotizacija pogona biti će neophodni.

Osim povećavanja kapaciteta u proizvodnji vagona razlozi su i sve češći odlasci i dolasci zavarivača (ostvarivanje kontinuiteta u procesu zavarivanja jako teško), kvaliteta zavarivača je sve niža, robotsko zavarivanje omogućuje konstantno kvalitetno zavarivanje što je kroz rad i prezentirano da je primjenom TWIN sustava zavarivanja to moguće postići bez obzira na promjene u pripremam zavarenih spojeva. Što je najvažnije brzina zavarivanja koja je veća od ručnog zavarivanja omogućiti će postizanje željene količine zavarenih spojeva.

5. Conclusion

Due to the future increase in the production of wagons and thus the need for an increasing number of bogies, the introduction of new welding technologies and the robotization of the drive itself will be necessary.

In addition to increasing the capacity in the production of wagons, the reasons are the more frequent departures and arrivals of welders (achieving continuity in the welding process is very difficult), the quality of welders is getting lower, robotic welding enables constant high-quality welding, which is demonstrated through the work and presentation that by applying the TWIN welding system it is possible to achieve regardless of changes in the preparation of welded joints. Most importantly, the welding speed, which is higher than manual welding, will allow the desired amount of welded joints to be achieved.

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ADVANCES AND THE FUTURE TRENDS IN WIRE AND ARC ADDITIVE MANUFACTURING (WAAM)

NAPREDAK I BUDUĆI TRENDOVI ADITIVNE PROIZVODNJE ŽICOM I ELEKTRIČNIM LUKOM (WAAM)

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Abstract

Over the past three decades, extensive research has been conducted on WAAM (Wire and Arc Additive Manufacturing), a production technology that traces its origins back almost a century with its initial patent. This technology has garnered increasing attention due to its capability to fabricate large near-net-shape metal products. The utilization of existing welding equipment for the heat source and material feedstock in WAAM offers the advantage of lower initial investment costs. Originally gaining prominence in the aerospace industry, it primarily focused on the utilization of lightweight metal alloys. However, recent advancements have broadened the scope of WAAM to encompass numerous products, including functionally graded materials (FGMs) and the combination of diverse alloys. This study seeks to unveil the latest breakthroughs and potential avenues in WAAM technology, offering valuable insights and recommendations for future research endeavors.

Rezime

Tokom protekle tri decenije, sprovedeno je opsežno istraživanje o Aditivnoj proizvodnji žicom i električnim lukom WAAM-u (Wire Arc Additive Manufacturing), proizvodnoj tehnologiji koja svojim početnim patentom vodi svoje poreklo skoro jedan vek unazad. Ova tehnologija privlači sve veću pažnju zbog svoje sposobnosti da proizvede velike metalne proizvode približnog oblika i dimenzija konačnog proizvoda. Korišćenje postojeće opreme za zavarivanje za izvor toplote i potrošnog materijala u WAAM-u nudi prednost nižih početnih troškova ulaganja. Postupak je prvobitno stekao značaj u vazduhoplovnoj industriji, prvenstveno se fokusirao na korišćenje lakih metalnih legura. Međutim, nedavni napredak proširio je obim WAAM-a kako bi obuhvatio brojne proizvode, uključujući funkcionalno graduisane materijale (FGMs) i kombinaciju različitih legura. Ova studija nastoji da otkrije najnovija otkrića i potencijalne puteve u WAAM tehnologiji, nudeći vredne pristupe i preporuke za buduće istraživačke poduhvate.

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1. Introduction

The constant evolution of the industry serves as a driving force, compelling researchers to always explore novel production technologies. In recent times, additive manufacturing technologies have gained significant popularity due to their ability to fabricate intricate components with enhanced efficiency. However, until the extensive development of Wire and Arc Additive Manufacturing (WAAM), the majority of additive manufacturing methods were unable to effectively produce metal parts. WAAM is the easiest to describe as a fusion of welding and additive manufacturing. It harnesses an electric arc as the primary heat source and employs welding wire as the feedstock material, all while being guided by robotic hands or CNC machines for precise movement [1]. Although the first patent related to WAAM dates back to 1925 [2], it wasn't until its potential for reducing raw material waste in the aerospace industry was discovered that researchers began to show heightened interest in this technology [3]. Consequently, much of the experimentation and research in the field has been concentrated on the production of aerospace components, thereby dictating the choice of materials predominantly used, such as titanium, aluminium, nickel-based alloys, and so forth [4].

Thanks to wider use and interest from researchers all over the world, more and more different metals and alloys are being produced using this technology. For example, one of the abilities which distinct WAAM from conventional technologies is production of functionally graded materials (FGM) - composite materials that exhibit a gradual variation in their composition, microstructure, or properties over their volume [5]. Unlike traditional homogeneous materials, they are engineered to possess tailored and smooth transitions from one constituent material to another, resulting in unique and desirable properties along the gradient. Furthermore, valuable insights have emerged from studies focusing on thermal management during the WAAM process, stress relief, and post-processing machining techniques. These endeavors aim to facilitate the production of parts that not only match the characteristics of conventionally manufactured counterparts but potentially surpass them in terms of quality and performance.

2. Latest findings and advances in WAAM

2.1. Stainless steels

Researchers are increasingly intrigued by stainless steels due to their versatile applicability. Wire Arc Additive Manufacturing (WAAM) presents a potential solution for various challenges encountered in traditional production processes.

Paper [6] presents the use of a TIG method with a novel current waveform comprising a mixture of AC and DC for the production of stainless steel components. An austenitic welding wire (G 18 8 Mn) was employed as an additional material. The current modes were varied, ranging from 100% DC to a combination of 70% DC and 30% AC, with the AC ratio gradually increasing. The microstructure exhibited refinement as the AC ratio increased, leading to a transformation in the morphology of austenite from columnar dendrites to equiaxed dendrites. Consequently, the average grain size decreased, indicating an enhanced degree of refinement with a higher AC ratio. Moreover, it resulted in improved tensile properties in both directions, likely attributable to the grain refinement effect.

One of the parameters that can be manipulated during research is the interpass temperature, as demonstrated in [7]. Super-duplex stainless steel wire ER2594 (25 9 4 N L) was used to fabricate two "walls." While all other parameters remained constant, the interpass temperature for the first wall was set at 150 °C, whereas for the second wall it was adjusted to 100 °C. As a result, the second wall exhibited a lower ferrite content, approximately 10% less, which subsequently led to higher maximum fatigue limit stresses. These findings are proof that even minor alterations to process parameters can exert a significant influence on the final product.

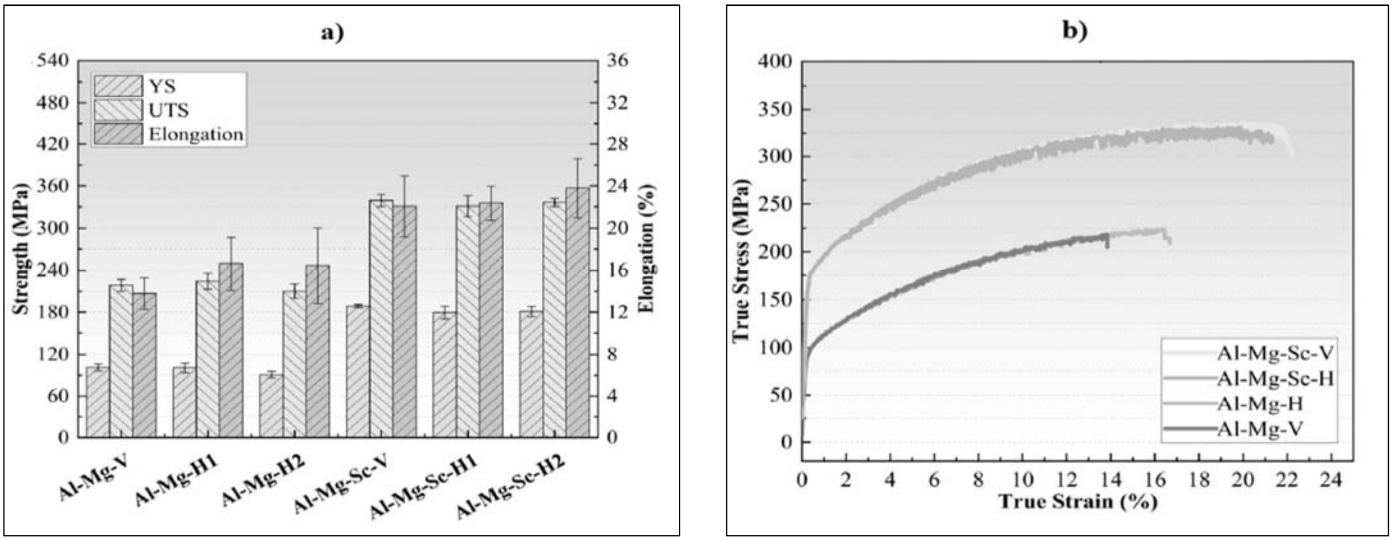
Fatigue life was an important characteristic for the authors of paper [8]. They compared their product with the forged 13Cr4Ni martensitic stainless steel typically employed in hydro turbine runners. Welding wire uses was ER410NiMo (G 13 4). For WAAM-produced component, fatigue strength of 10^7 cycles at room temperature was 468 MPa, surpassing the forged part's fatigue strength of 370 MPa. Furthermore, the WAAM part exhibited higher yield strength and ultimate tensile strength when compared to the forged counterpart.

2.2. Aluminium

As previously mentioned, the aircraft industry has played a significant role in driving the development of Wire Arc Additive Manufacturing (WAAM). Given that aluminium is extensively utilized in the aircraft industry, it is not surprising that numerous research papers focus on this material.

In paper [9] a study is presented focusing on two aluminium alloys: Al-Mg and Al-Mg-Sc alloy. The inclusion of Sc was chosen due to its ability to refine grains and convert non-heat treatable strengthened alloys into heat-treatable strengthened alloys. Additionally, Sc enhances fatigue strength and resistance against microcrack growth in Al-Mg alloys. Following the production process, an additional heat treatment was applied. The addition of Sc was found to be crucial in increasing the nucleation rate and reducing the grain size. Depending on the heat treatment temperature, the grain size was reduced by 86-93%. The uniform precipitation of Al_3Sc particles during deposition through WAAM significantly impeded dislocation motion, leading to further improvements in the strength of the deposited Al-Mg-Sc alloy. The mechanical properties such as yield strength, ultimate tensile strength, and elongation were also enhanced, which was attributed to the refined grain structure and precipitation strengthening. Although there was only a slight improvement in hardness observed through heat treatment due to the absence of supersaturated Sc available for precipitation, the heat treatment temperatures did not have a significant influence on the mechanical properties, as shown in Picture 1.

The differences in mechanical properties among Al-Mg alloys with varying heat treatment temperatures were minimal, and the same trend was observed for Al-Mg-Sc alloys. However, significant differences in mechanical properties were attributed to the presence of Sc.



Picture 1. *Mechanical properties of a) Al-Mg alloys and b) Al-Mg-Sc alloys*

Slika 1. *Mehaničke karakteristike a) Al-Mg legura i b) Al-Mg-Sc legura*

Optimization of parameters to produce aluminium alloy of good quality was presented in the paper [10]. The MIG method was employed with a new hybrid arc technology that combined cold metal transfer and pulse transfer. The AA2024 filler wire was used in the process. Three key parameters were varied: wire-feed speed (WFS), travel speed, and the CMT/P ratio, which represents the ratio of the number of cold metal transfer stages to pulse stages in a cycle. Among the parameters studied, the wire-feed speed had the most significant influence on porosity. Initially, the porosity decreased with increasing WFS, but beyond a certain point, it started to increase again. Lower porosity levels were achieved with lower travel speeds, indicating higher heat input. Surface roughness was also greatly affected by the WFS and travel speed. Higher WFS resulted in lower surface roughness, while the relationship between surface roughness and travel speed was more complex, initially decreasing and then increasing with higher travel speeds. The CMT/P ratio played a major role in the formation quality of the parts. The best formation quality was achieved when the CMT/P ratio was in the middle range. With a higher ratio, surface roughness began to increase. In conclusion, the study demonstrated the importance of optimizing parameters such as WFS, travel speed, and CMT/P ratio to produce aluminium alloy parts of superior quality, ensuring minimal porosity, lower surface roughness, and better formation quality.

In paper [11], a similar investigation to that in paper [9] was conducted to study the impact of an alloying element on the characteristics of an aluminium alloy, with copper (Cu) being the element of interest. Three different welding wires with varying copper percentages (5%, 5.65%, and 6.3% Cu) were used in the study. Copper acts as the strengthening element, precipitating the θ' phase after solution ageing to enhance the mechanical properties of the alloy. The number and size of θ phases precipitated from the as-deposited Al-Cu alloy increased with higher copper content. However, when the Cu content exceeded 5.65%, larger remaining θ phases were observed under the solid solution treatment condition. Upon subjecting the alloy to T6 heat treatment, the mechanical properties reached their highest level at a Cu content of 5.65%. This suggests that an optimal balance is achieved with this specific copper percentage for obtaining desirable mechanical characteristics. An important consideration for limiting the Cu percentage to not exceed 5.65% is the anisotropy of mechanical properties. For parts produced with the welding wire containing 6.3% Cu, the vertical specimens exhibited a change in fracture mode from ductile to brittle fracture. Therefore, to maintain improved mechanical properties and avoid issues related to anisotropy, it is advisable to keep the copper content at or below 5.65%.

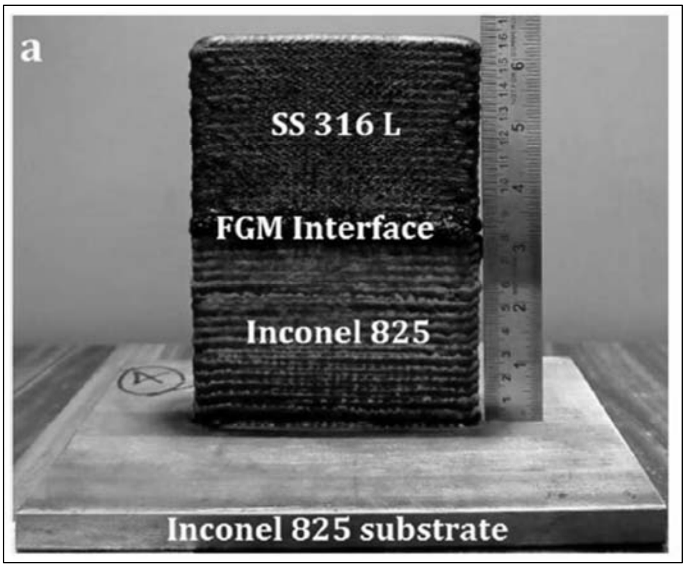
An interesting idea was suggested in the paper [12], where steel strip was inserted in the middle of the aluminium part. This steel strips serve as smart parts providing information to the user thanks to an embedded device. The study explored various combinations of steel strips and welding torch offset distances to assess their performance. The deterioration of the bimetallic interface was evaluated using X-ray tomography to generate thickness maps. To analyze the bonding quality between the steel strip and the aluminium alloy, scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) were employed. The results indicated that welding with an offset equal to or less than 2.0 mm led to a degradation of the steel strip, rendering it unsuitable for creating a high-quality bond. Upon observing the side view of the samples, it was found that an offset of 3.0 mm resulted in a bead and a strip separated by significant void space. Therefore, using an offset of 3.0 mm or more was also considered inappropriate. On the other hand, when an offset of 2.5 mm was employed, a bimetallic layer was identified through EDS analysis, indicating a sign of strong bonding between the steel strip and the aluminium part. In conclusion, the study highlighted that an offset of 2.5 mm proved to be the most appropriate for embedding a steel strip within an aluminium part, ensuring a robust and well-bonded connection, while offsets of 2.0 mm or less and 3.0 mm or more were not suitable for achieving the desired bonding quality.

2.3. FGM - Functionally Graded Materials

As it is already said, researches of FGM are gaining increased interest, since WAAM offers a viable and promising solution for the fabrication of components composed of two or multiple distinct materials in a gradual and continuous manner.

An intriguing approach was shown in paper [13], where the welding wire "3Dprint AM 718," (composed of Inconel 718 alloy) was deposited onto a substrate made of steel grade S275. Three sets of specimens were collected at different stages: without any heat treatment (referred to as AB, as build), solution-treated (ST), and aged (STA). The AB sample exhibited a considerable presence of the Laves phase on the deposited side, which was only partially dissolved even after the solution annealing process. Unfortunately, the solution treatment resulted in undesired grain coarsening in both the substrate and the deposited "wall." However, the ageing treatment did not show any noticeable grain growth. The hardness of the substrate decreased by more than half, and this reduction remained unchanged after ageing. On the other hand, the "wall" exhibited increased hardness only after ageing treatment. The elastic and shear moduli showed an increase at greater distances from the interface (first layer) for all treatment conditions. This behavior can be attributed to the relatively lower mixing of the alloying elements in this region.

Paper [14] also presents combination of an Inconel alloy with steel, but this research used Inconel 825 and austenitic stainless steel 316L (1.4404). Building manner was slightly different – the Inconel alloy served as the substrate, and then twenty layers of Inconel were deposited before an additional twenty layers of stainless steel were placed on top. The resulting structure formed the middle part, which represented the Functionally Graded Materials (FGM), as illustrated in Picture 2.



Picture 2. *Building of the FGM with WAAM*

Slika 2. *Izradjen FGM sa WAAM-om*

To evaluate the mechanical properties, specimens were extracted from all three sections for tensile testing. For fracture toughness testing, specimens were specifically taken from the middle part at the FGM interface. Tensile testing results did not exhibit significant differences among the sections, as all of them demonstrated plastic deformation, indicative of ductile fracture behavior. The Crack Tip Opening Displacement (CTOD) values were found to be similar, measuring 0.853 mm for the Inconel side and 0.873 mm for the stainless steel side. These comparable CTOD values imply that this FGM configuration could be effectively employed in tough and demanding environments.

In research [15] a distinct approach was taken, involving the production of a complex CoCrFeMoNiV alloy using flux-cored welding wire. The shell of the material was composed of FeNi36, while the other alloying elements were present in the filling. The study encompassed chemical and microstructural analysis, mechanical properties testing, and an examination of the material's behavior under abrasive wear using the G75 test. Chemical composition analysis revealed minimal differences between the nominal composition of the welding wire and the final product, with minor burn-off of Cr, Mb, and Co, which was expected during the manufacturing process. The material exhibited an average Young's modulus of 246 GPa, a yield strength of 530 MPa, and a tensile strength of 560 MPa. The hardness values ranged between 252 HV10 and 270 HV10. The most significant and noteworthy finding was the result of the G75 test, demonstrating that this material exhibited wear resistance comparable to cobalt-based alloys commonly used for producing wear-resistant claddings. The wear loss in the G75 test was approximately 110 mm3, further indicating the promising potential of this complex CoCrFeMoNiV alloy for wear-resistant applications.

Other complex alloy, Fe-Mn-Si-Cr-Ni-V-C, was used in the paper [16]. This alloy is shape memory alloy (SMA). The resulting fabricated component underwent a comprehensive characterization, focusing on microstructure, mechanical properties, and functional behavior assessment. The fabrication process exhibited desirable features, including low porosity and high deposition efficiency, leading to minimal surface waviness and reduced post-processing machining requirements. The measured mechanical properties were exemplary, with a yield strength of 472 MPa, fracture stress of 821 MPa, and elongation of 26%, indicating excellent material performance. These mechanical characteristics render the alloy and the manufacturing process suitable for various construction applications. Cyclic testing was performed, revealing a repeatable mechanical response, high levels of absorbed energy and maximum stress with low irrecoverable strain. These findings highlight the material's potential for applications in civil engineering, particularly in seismic systems, due to its ability to withstand repetitive loading and maintain its functional properties effectively.

3. Conclusions

The constant evolution of the industry has driven researchers to explore novel production technologies, leading to the growing popularity of additive manufacturing methods, particularly WAAM. The technology's potential for reducing raw material waste in the aerospace industry sparked heightened interest, resulting in much research focusing on aerospace applications and materials like titanium, aluminum, and nickel-based alloys. However, WAAM's versatility has enabled its expansion to various metals and alloys, including stainless steels and functionally graded materials (FGM), offering tailored material gradients with unique properties.

Studies have revealed valuable insights, such as the optimization of process parameters to achieve better part quality, the influence of alloying elements on mechanical properties, and the integration of steel strips as smart components. Additionally, the application of WAAM in producing complex alloys like Co-Cr-Fe-Mo-Ni-V and Fe-Mn-Si-Cr-Ni-V-C has shown excellent mechanical properties and wear resistance, offering potential for wear-resistant claddings and civil engineering applications.

Future work suggestions would be numerous, but some of the most important are:

- further material exploration: continue exploring the compatibility of WAAM with a broader range of materials, including specialized alloys for specific industrial applications, to expand the technology's potential in diverse fields;

- multi-material FGM development: research the production of complex FGM structures combining various materials with tailored properties, exploring new designs for enhanced performance in specific applications;

- industrial adoption and standardization: promote the adoption of WAAM technology in industrial sectors and collaborate on establishing standardized procedures and guidelines to ensure consistent quality and reliability of WAAM-produced components;

- integration of smart components: investigate the integration of more sophisticated smart components, beyond steel strips, to add additional functionalities to WAAM-produced parts for real-time monitoring and feedback systems;

- quality assurance: improvement of in-situ NDT techniques allow for real-time monitoring during the manufacturing process, helping to detect any defects or anomalies as they occur, leading to improved part quality and reduced scrap rates.

By addressing these future research areas, the potential and applicability of WAAM can be further advanced, contributing to the continuous improvement and growth of additive manufacturing technologies in the industry.

3. Zaključci

Konstantna evolucija industrije navela je istraživače da istražuju nove proizvodne tehnologije, što je dovelo do sve veće popularnosti metoda aditivne proizvodnje, posebno WAAM-a. Potencijal tehnologije za smanjenje otpadnih sirovina u vazduhoplovnoj industriji izazvao je povećano interesovanje, što je rezultiralo velikim fokusom istraživanja na primenama u vazduhoplovstvu i na materijalima kao što su titanijum, aluminijum i legure na bazi nikla. Međutim, WAAM-ova svestranost je omogućila njegovu ekspanziju na različite metale i legure, uključujući nerđajuće čelike i funkcionalno graduisane materijale (FGM), nudeći prilagođene gradijente materijala sa jedinstvenim svojstvima.

Studije su otkrile bitne stvari, kao što su optimizacija parametara procesa za postizanje boljeg kvaliteta delova, uticaj legirajućih elemenata na mehanička svojstva i integracija čeličnih traka kao pametnih komponenti. Pored toga, primena WAAM-a u proizvodnji složenih legura kao što su Co-Cr-Fe-Mo-Ni-V i Fe-Mn-Si-Cr-Ni-V-C pokazala je odlične mehaničke osobine i otpornost na habanje, nudeći potencijal za obloge otporne na habanje i primenu u građevinarstvu.

Predlozi za budući rad bi bili brojni, ali neki od najvažnijih su:

- dalje istraživanje materijala: nastaviti da se istražuje kompatibilnost WAAM-a sa širim spektrom materijala, uključujući specijalizovane legure za specifične industrijske primene, kako bi se proširio potencijal tehnologije u različitim oblastima;

- razvoj složenih FGM materijala: istraživanje proizvodnje složenih FGM struktura koje kombinuju različite materijale sa prilagođenim osobinama, istražujući nove dizajne za poboljšane performanse u specifičnim primenama;

- industrijsko usvajanje i standardizacija: promovisati usvajanje WAAM tehnologije u industrijskim sektorima i sarađivati na uspostavljanju standardizovanih procedura i smernica kako bi se obezbedio dosledan kvalitet i pouzdanost komponenti koje proizvodi WAAM;

- integracija pametnih komponenti: istražiti integraciju sofisticiranijih pametnih komponenti, u kombinaciji sa čeličnim trakama, da bi se dodale dodatne primene delovima proizvedenim WAAM-om za sisteme za praćenje i povratne informacije u realnom vremenu;

- osiguranje kvaliteta: poboljšanje in-situ NDT tehnika omogućava praćenje u realnom vremenu tokom procesa proizvodnje, pomažući da se otkriju bilo kakvi nedostaci ili anomalije kada se pojave, što dovodi do poboljšanog kvaliteta delova i smanjene stope otpada.

Baveći se ovim budućim istraživačkim oblastima, potencijal i primenljivost WAAM-a mogu se dalje unaprediti, doprinoseći stalnom poboljšanju i rastu tehnologija aditivne proizvodnje u industriji.

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REPUBLIČKO TAKMIČENJE MLADIH ZAVARIVAČA

Smederevska Palanka, 10. i 11. maj 2024. godine

U okviru republičkog takmičenja učenika srednjih mašinskih škola Srbije (III stepen), koje organizuje Zajednica mašinskih škola Republike Srbije u skladu sa usvojenim kalendarom takmičenja Zajednice i Ministarstva prosvete, održano je i takmičenje mladih zavarivača u postupcima 111 – REL; 135 – MAG i 141 – TIG.

Takmičenje je organizovano u dva dana, 10. i 11. maja 2024. godine, a škola domaćin takmičenja je ove godine bila Mašinsko-elektrotehnička škola "GOŠA" u Smederevskoj Palanci. Praktični deo takmičenja u disciplini zavarivanje obavljen je u Institutu "GOŠA" u Smederevskoj Palanci, u petak, 10. 05. 2024. godine, uz zalaganje i pomoć osoblja Instituta "GOŠA", na čijoj se gostoljubivosti ovom prilikom još jednom zahvaljujemo.

Članovi DUZS koji su učestvovali u delu ocenjivanja uzoraka sa praktičnog dela, kao stručni žiri, radili su u sastavu: Branislav Lukić, Milan Prokolab, Marija Kovjanić i Zoran Nikolić, a za radiografsko snimanje uzoraka je bilo zaduženo osoblje Instituta "GOŠA".

Ukupno se takmičilo 52 učenika iz 27 srednjih mašinskih škola, što je 9 takmičara više i 7 više prijavljenih škola nego prošle godine. Po postupcima, broj prijavljenih takmičara bio je: 25 za MAG, 15 za REL i 12 za TIG. Osim praktičnog dela, učenici su radili test iz teorijskog dela, pa je konačna rang lista takmičara formirana na osnovu ukupnih rezultata postignutih na teorijskom i praktičnom delu.

Najuspešniji takmičari po postupcima:

135 - MAG						
R.br	**Ime i prezime učenika**	**Škola**	**Mentor**	**Praktični deo - rad**	**Teorijski deo - test**	**UKUPNO**
1	**Miloš Radojković**	Srednja škola "Svilajnac", Svilajnac	Tatjana Gavrilović	98	48,83	**146,83**
2	**Vladimir Nikolić**	TŠ "17 septembar" Lajkovac	Ratko Kipić	84	50	**134**
3	**Mihailo Vojčić**	TŠ "Mileta Nikolić" Aranđelovac	Siniša Marković	106	26,33	**132,33**
4	**Todor Ranimirov**	MEŠ "GOŠA" Smederevska Palanka	Zoran Jovanović	72	40,50	**112,50**
5	**Stefan Žižić**	TŠ "Kolubara" Lazarevac	Ivan Gajić	60	50	**110**

111 - REL						
R.br	**Ime i prezime učenika**	**Škola**	**Mentor**	**Praktični deo- rad**	**Teorijski deo–test**	**UKUPNO**
1	**Ognjen Platanić**	TŠ "Kolubara" Lazarevac	Ivan Gajić	102	30	132
2	**Pavle Pejčinović-Zlović**	TŠ "Sava Munćan" Bela Crkva	Jaroslav Hoc	66	49,33	115,33
3	**Marko Vig**	Srednja mašinska škola Novi Sad	Aleksandar Jankov	62	44,83	106,83
4	**Kristijan Radosavljević**	Mašinsko-tehnička škola "14. oktobar" Kraljevo	Marko Dragićević	60	46	106
5	**Vuk Savanović**	Mašinska škola "Pančevo", Pančevo	Saša Mančić	58	47,5	105,50

141 - TIG						
R.br	Ime i prezime učenika	Škola	Mentor	Praktični deo-rad	Teorijski deo–test	UKUPNO
1	**Strahinja Marković**	Tehnička škola Obrenovac	Vladimir Marković	146	50	196
2	**Nemanja Đurić**	Tehnička škola Loznica	Siniša Mihajlović	116	47	163
3	**Nikola Nikolić**	TŠ “Sava Munćan” Bela Crkva	Jaroslav Hoc	92	42	134
4	**Stefan Milanko**	Tehnička škola "Zmaj" Novi Beograd	Vlada Radovanović	90	38,66	128,66
5	**David Jonović**	Mašinska škola "Pančevo", Pančevo	Saša Mančić	66	47,33	113,33

Za takmičenje u zavarivanju prijavilo se čak 27 srednjih škola:

Srednja škola Svilajnac, TŠ "17 septembar" Lajkovac, TŠ "Mileta Nikolić" Aranđelovac, MEŠ “GOŠA” Smederevska Palanka, TŠ "Kolubara" Lazarevac, Mašinska škola "Pančevo" Pančevo, TŠ “Nikola Tesla” Velika Plana, TŠ “Sava Munćan” Bela Crkva, Tehnička škola Obrenovac, Tehnička škola "Zmaj" Novi Beograd, Srednja mašinska škola Novi Sad, Tehnička škola “Ivan Sarić” Subotica, Tehnička škola Mladenovac, TŠ “Mihailo Pupin” Inđija, Tehnička škola Zrenjanin, Mašinsko-tehnička škola “14. oktobar” Kraljevo, Srednja škola “Lukijan Mušicki” Temerin, Tehnička škola Valjevo, Mašinska škola Niš, Srednja škola "Dragačevo" Guča, Srednja tehnička škola Sombor, TŠ “Prota Stevan Dimitrijević” Aleksinac, Srednja stručna škola Kragujevac, Tehnička škola "9 maj" Bačka Palanka, Srednja škola “Dobrica Erić” Knić, Tehnička škola Loznica, Srednja škola Krupanj.

Fotografije sa takmičenja mladih zavarivača pogledajte u nastavku.

Autori: Vesna Jović i Branislav Lukić

71. GODIŠNJA SKUPŠTINA DUZS

Redovna 71. godišnja skupština DUZS zakazana je za sredu 26.06.2024. godine u 14h. u svečanoj sali Instituta IMS u Beogradu, Bulevar vojvode Mišića 43 sa sledećim dnevnim redom:

1. Otvaranje zasedanja Skupštine; izbor radnih tela
2. Verifikacija mandata članova Skupštine
3. Izveštaj o radu DUZS za period 2023 - 2024. godine.
4. Izveštaj o radu DUZS-CertPers za period 2023 - 2024. godine.
5. Izveštaj o finansijskom poslovanju u 2023. godini.
6. Diskusija po podnetim izveštajima i usvajanje izveštaja
7. Predlog plana rada za 2024-2025. godinu; diskusija i usvajanje
8. Razno

Mijat Samardžić [1], Tihomir Marsenić [1], Dejan Marić [2,a], Tomislav Šolić [2], Božo Despotović [3], Ivan Samardžić [2,b]

CAUSES OF THE MOST COMMON DEFECTS ON BOILER MEMBRANE WELDS

UZROCI POJAVE NAJČEŠĆIH GREŠAKA NA KOTLOVSKIM MEMBRANSKIM ZAVARIMA

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Key words: membrane welds, membrane weld defects, SAW welding, undercut, cavities

Ključne reči: membranski zavari, greške u membranskim zavarima, EPP zavarivanje, zajedi, poroznosti

Abstract

The paper describes causes of the most common defects on boiler membrane welds according to EN ISO 12952-5. The research is carried out on water tube boiler manufactured by the company Đuro Đaković Termoenergetska postrojenja d.o.o. This paper elaborates the most common defects like cavities and undercuts that appear on membrane welds.

Rezime

U radu su opisani uzroci najčešćih nedostataka na zavarenim spojevima membranskih zidova prema EN ISO 12952-5. Istraživanja se temelje na proizvodnji kotlova u tvrtki ĐĐ Termoenergetska postrojenja d.o.o. U ovom radu opisani su uzroci grešaka kao što su zajedi, poroznosti te drugi tipovi grešaka, a koje su ujedno najčešće greške na membranskim zavarima.

1. Introduction

The aim of this paper is to describe the causes of the most common defects that occur in boiler membrane welds. The most common defects dealt with in this paper are:

1. Cavities
2. Undercuts
3. Unwelded parts
4. Irregular geometric shape of the weld
5. Incorrect position of the welded connection plate

The valid standard that describes welding requirements for membrane welds on boiler wall panels is EN ISO 12952-5 [1] and EN ISO 12952-6 [2].

2. Research procedure

Welding foreman working in the production process is responsible for supervising the entire welding process on membrane welding. The welding process is also supervised by a quality engineer appointed by the quality assurance department and by a welding engineer authorised by the technical department. If noticing unacceptable deviations in the welding process, welding operations manager is obliged to stop the welding process and to notify the authorised welding engineer about occurrences.

Welding personnel (welders and operators) shall be certified and shall apply all technological measures as determined in the Welding Procedure Specification (WPS) and in the in-house instructions referring to welding and repairs of membrane welds applied at a company level. [3]

The paper was published in its original form in the Proceedings of the 32nd Conference with international participation "Welding 2022" held in Tara, Serbia from October 12 to 15, 2022.

2.1 Welding process

The company Đuro Đaković Termoenergetska postrojenja d.o.o. determines the membrane welding process as follows: when joining two tubes and a connection fin, welding is done first parallel on one side from the beginning to the end of the weld length, upon which the weld spatter is cleaned. The panel (two-tube, four-tube, eight-tube) is then turned over and the membrane welds are welded on the other side. This is followed again by the cleaning of spatter. The welding is supervised by the welding foreman. Welding is performed according to WPS, as determined by the company's welding techniques service. In addition to WPS, the welding process has to be in compliance with the parameters determined within the welding trial. During the welding process, the welder is obliged to monitor the process and, if noticing some deviations, he has to mark them with a pen or chalk, so that such deviations can be corrected later on manually by TIG welding.

The welder is obliged to handle welding flux and welding wire responsibly. Wire and flux have to be stored according to the manufacturer's specification. Before welding, welding flux should be dried according to the in-house instructions or the manufacturer's specification printed on the package. The welder keeps a log on drying the welding flux near the drying oven, in which he records the drying temperature, which has to be in line with the manufacturer's specification. [4, 5, 6]

If some unacceptable errors occur, such as tube burning or contamination with a copper tip, the welder is obliged to mark such errors with a red pen and inform the welding foreman about them. When such defects occur, the authorised controller from the control and quality department is obliged to make a deviation report, i.e. non-conformance report (NCR), and the welding technologist is obliged to define appropriate repair method on behalf of the welding techniques service.

Welders perform repairs manually by TIG welding according to the prescribed welding procedure specification (WPS) approved by the welding department. The welder is obliged to repair all defects on the membrane panel prior to the inspection of the controller.

Membrane welds are controlled by the controller authorised by the control and quality service. After welding, a 100% visual inspection and dimensional control of the panel is performed.

3. The most common defects in boiler membrane welds

Defects may occur during automated welding of boiler membrane welds, among which the most common are:

a. Surface cavity
b. Undercuts
c. Unwelded parts
d. Irregular geometric shape of the weld
e. Incorrect position of the welded connection plate

Automated welding uses rates from 800 - 1000 mm/min, which refers to high-speed welding during which the welder has to complete a considerable length of membrane welds in one shift.

a. Surface cavities as defects are elaborated in the group 200 of the standard EN ISO 6520-1. Smaller pores (less than 3 mm in diameter) can be repaired without grinding. Larger pores or those formed as nests have to be removed by grinding and welded again according to WPS (Figures 1 - 3). The maximum allowable surface cavity dimension that does not require any repair is ø2 mm, if such cavity does not occur at stopping or restarting of the welding.

Figure 1. *Cavity*
Slika 1. *Šupljina*

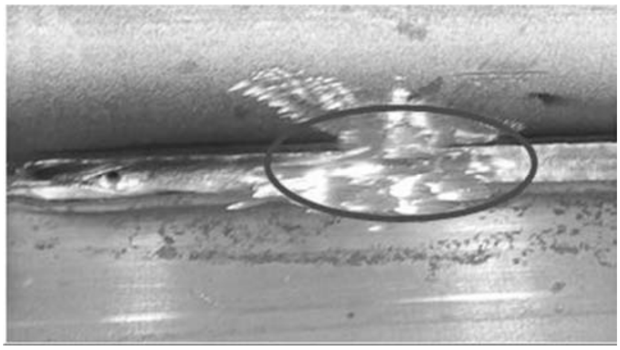

Figure 2. *Grinding of the defect*
Slika 2. *Brušenje greške*

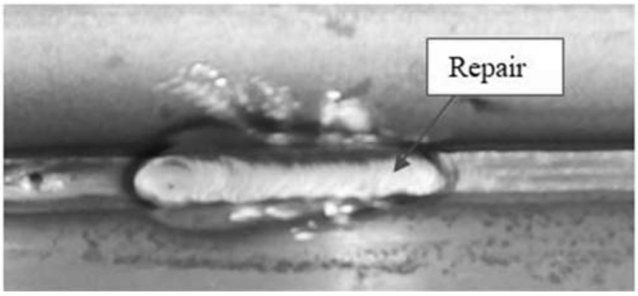

Figure 3. *Repair of the defect by TIG welding*

Slika 3. *Popravka greške TIG zavarivanjem*

b. Undercuts (Figure 4) - according to EN ISO 6520-1 [7], undercuts are classified as defects of the group 5011 and 5012. The maximum allowable undercut depth with a smooth transition is ≤ 0,5 mm. Undercuts with greater depths have to be repaired by grinding and/or welding according to WPS.

Figure 4. *Undercut*

Slika 4. *Zajed*

c. Unwelded parts - the occurrence of unwelded parts or discontinuities (Figure 5) happens due to welding interruption, i.e. when the welding machine stops. This causes a sort of skips on the membrane weld.

Figure 5*. Unwelded parts*

Slika 5. *Nezavareni delovi*

d. *Irregular geometric shape of the weld* - means that the appearance of the weld is inappropriate. The weld of improper geometry cannot not pass visual inspection because of that defect.

e. *Incorrect position of the welded connection plate* - refers to the position of the connection plate that is not in line with requirements set by the standard EN ISO 12952-5.

4. Causes of defects on boiler membrane welds

Membrane welding is a highly efficient process during which certain requirements must be fulfilled from the beginning to the end of the process in order to make welding successful. The base and filler material, tubes and fin in the panel have to be of good quality, and welding material has to be prepared well. Before welding, the tubes are shot-blasted by machine, while the wire coming from the welding wire reel is calibrated and cleaned with a chemical agent to remove all impurities, such as various greases and coatings. The welding flux is kept in a plastic bag, so it has to be dried to a temperature defined in the manufacturer's specification. The welding flux is used for a specific number of times, after which it is disposed of as no longer useful. The cleanliness of the surface to be welded is also one of the important factors to be dealt with prior to welding. Welding of dirty, greasy and poorly prepared material leads to the occurrence of welding defects, thus resulting in poor quality of welds.

4.1. Surface cavity

Surface cavities are classified into the group 200 according to EN ISO 12952-5. Cavities in welded joints occur as a consequence of residual gas that remains in the material because of impurities, dirt and grease on the surface of welded joints, moist base or filler material, poor welding performance, or non-compliance with the welding procedure specification (WPS). Surface cavities can appear individually, as shown in Figure 6, or in form of a nest, as shown in the Figure 7.

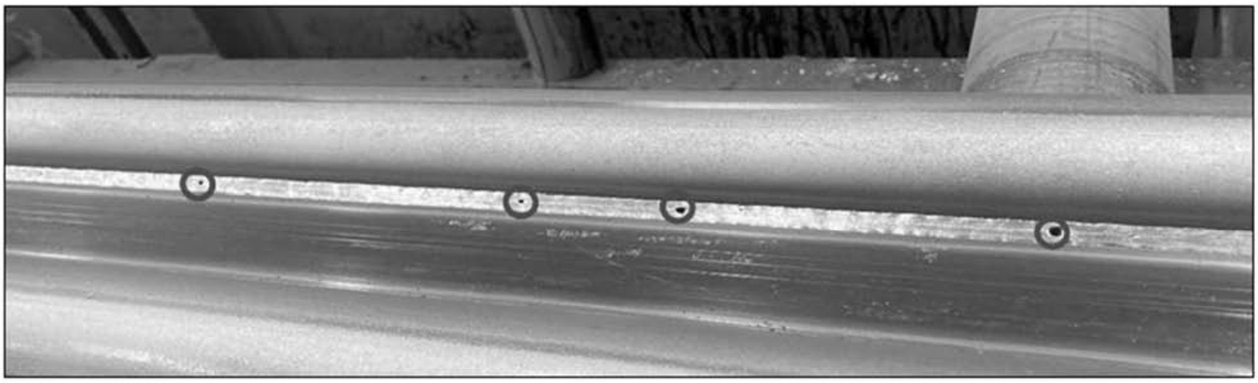

***Figure 6.** Individual cavities*
***Slika 6.** Pojedinačne šupljine*

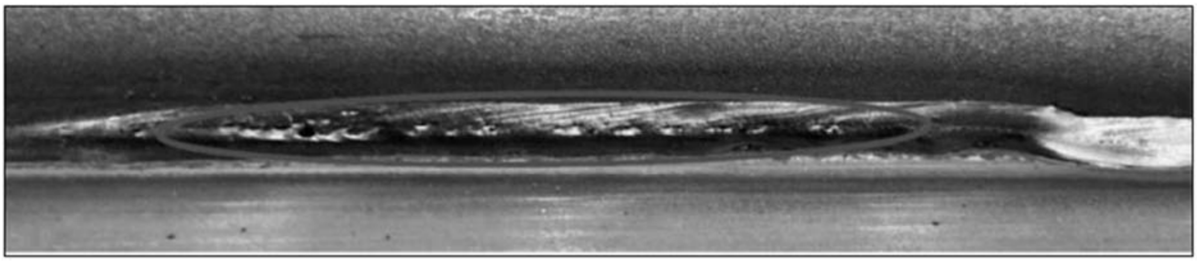

***Figure 7.** Nest of cavities*
***Slika 7.** Gnezdo šupljina*

4.2. Unwelded parts

Unwelded parts (discontinuities) refer to defects that occur during welding of a large amount of membrane welds. The most common causes of discontinuities in welds are:

- Lack of welding flux in a welding machine, due to which the welding process stops. The welding flux is stored in plastic bags, dried in a drying oven prior to welding, and then transferred into the welding machine flux container.

- Lack of welding wire - welding wire is coiled up in reels of two sizes, i.e. small reels (15 - 25 kg) and large reels (350 kg). Wire reels have to be replaced when running out of wire, yet it can happen that the wire runs out during welding, which causes discontinuity of welding and occurrence of unwelded parts.

- Changing the copper contact tip (nozzle) - the contact tip (nozzles) are usually replaced before the start of each shift, when it is noticed that they have been used up to the extent that they can no longer be efficient in welding, as the wire may stick to the copper tip of the contact tip or the tip may get in contact with the workpiece (Figure 8).

- Mechanical stopping of the welding machine occurs primarily because of the overload of the membrane welding line or because of poor welding machine maintenance.

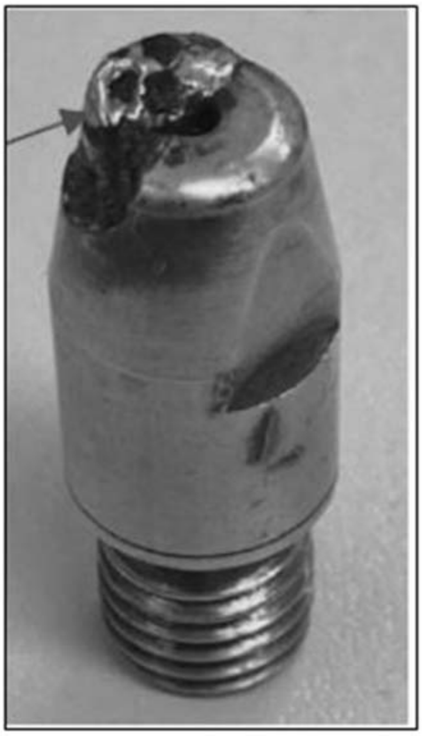

***Figure 8.** Damaged contact tip (nozzle)*

***Slika 8.** Oštećen kontaktni vrh (mlaznica)*

4.3. Undercuts

Defects like undercuts classified as 5011 and 5012 are elaborated in EN 12952-5, Table C.1. The maximum allowed depth of the undercut has to be less than or equal to 0,5 mm, regardless of the undercut length, provided that the undercut has a smooth transition. The Figure 9 shows a marked small undercut on a weld. Such defects are the most difficult ones to be determined as acceptable or unacceptable by visual inspection only, since such inspection is unreliable in terms of determining the undercut depth and its transition.

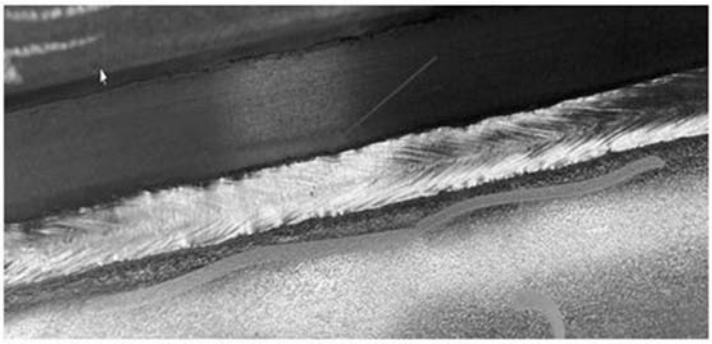

Figure 9. *Small undercuts*

Slika 9. *Mali zajedi*

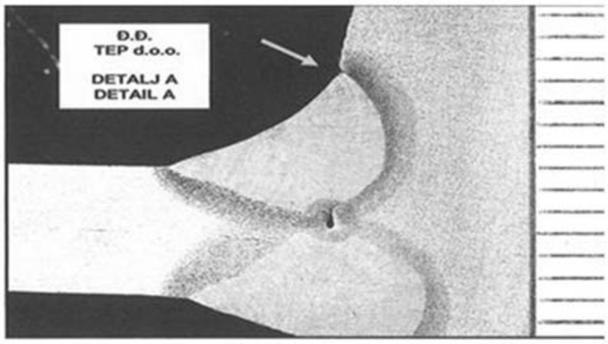

Figure 10. *Macrostructure of the undercut*

Slika 10. *Makrostruktura zajeda*

Performing the destruction test, i.e. testing the macrostructure is the only reliable way of determining the dimensions of the undercut and the type of its transition.

Dimensional control of the sample presented in the Figure 10 revealed the undercut depth of 0,21 mm. According to the standard and the macro cross section of the defect, as shown in the Figure 10, this undercut can be considered as acceptable.

Figure 11. *Larger undercut*

Slika 11. *Veći zajed*

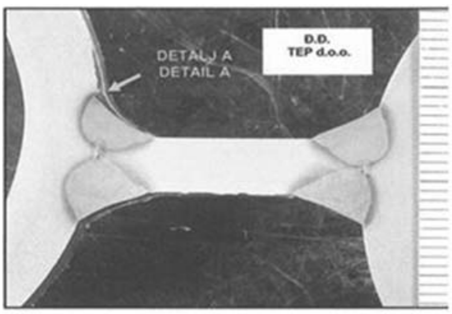

Figure 12. *Macrostructure of the undercut*

Slika 12. *Makrostruktura zajeda*

As presented by the sample in Figure 12, the undercut marked as the detail A shows sharp transition, because of which it is not acceptable according to EN ISO 12952-5. The undercut depth measures 0,45 mm on the marked undercut presented by the Figure 11, which is close to the upper value limit of acceptance set at 0,5 mm.

Since this undercut has a sharp transition, as shown in Figure 11, it is recommended for repair.

Testing of the macrostructure on the product is not possible, yet the visual inspection is not suitable for proper assessment of such type of weld defect in terms of determining whether its quality is acceptable or unacceptable. There is an attempt to apply the template with predetermined sizes of defects, which are visually compared with occurring undercuts on membrane welds. Sizes of the undercuts can be also determined by scanning the surface with Creaform Ametek and VXelements™ software. However, such scanning method is also questionable because it depends on the determination of points on the weld surface and on their mutual angle, which affects the determination of the undercut depth. The Figures 13a and 13b present the determined undercut dimensions, which are as follows: undercut length 2,5 mm, undercut width 0,956 mm, and the generated undercut depth 0,647 mm.

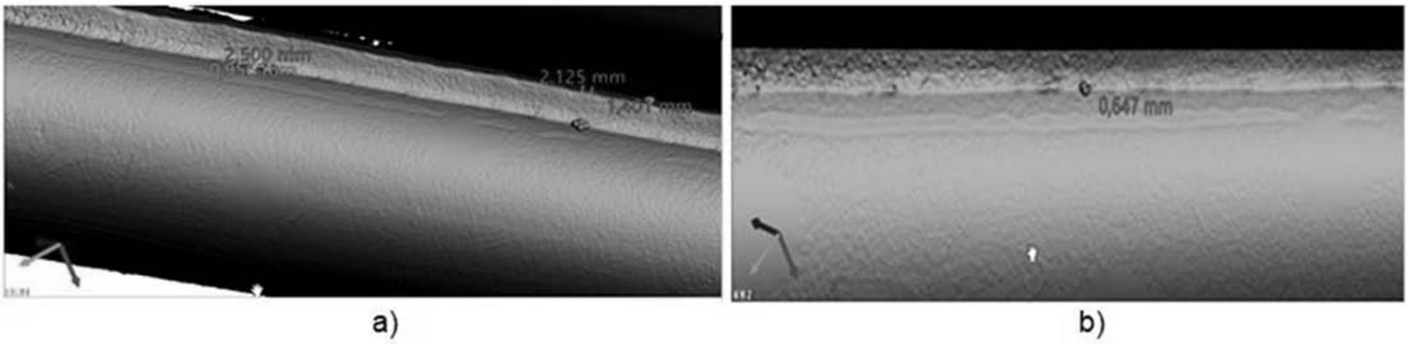

Figure 13. *Measuring of the undercut depth by scanning: a) undercut length 2,5 mm, width 0,956 mm, b) depth 0,647 mm*

Slika 13. *Merenje dubine zajeda skeniranjem: a) dužina zajeda 2,5 mm, širina 0,956 mm, b) dubina 0,647 mm*

In general, both methods, macrostructure testing and surface scanning, are not appropriate for assessment of the membrane weld undercut sizes in real production conditions.

The main causes of undercuts are the following:

- Impurity of the base material (tubes), oxidized surface of the tube along the weld.
- Welding parameters, such as excessive welding current or welding voltage, inappropriate welding speed.
- Inappropriate angle of the torch.

Incorrect position of the connection plate with respect to tube position, which causes a shift along the electric arc, thus causing an increase in voltage, i.e. greater length and width of the arc and eventually the formation of an undercut.

4.4. Irregular geometric shape of the weld

Irregular geometric shape of the weld refers to visually unacceptable weld geometry that does not conform to EN ISO 12952-5. Possible causes of such defect are machine jamming (mechanical problems with the welding machine), problems with the wire feeder because of which the melt is not distributed evenly, thus forming deviations in the weld geometry, incorrect position of the welding torch, incorrect handling with the welding torch and improper monitoring of the membrane welding process by a welder. The Figure 14 presents an irregular geometric shape of the weld at which the membrane weld went up the tube as a consequence of welding deviation.

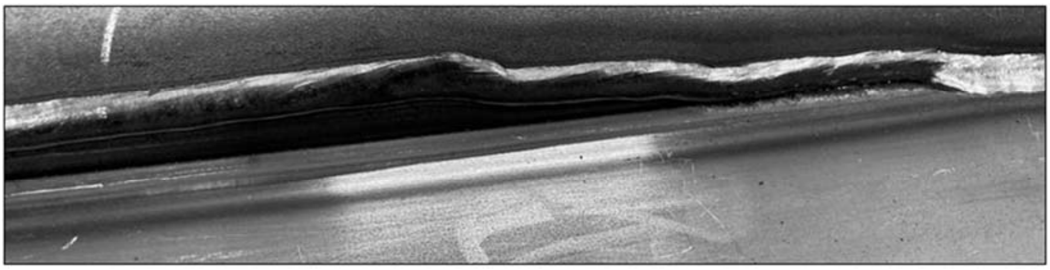

Figure 14. *Irregular geometric shape of the weld*

Slika 14. *Nepravilan geometrijski oblik šava*

4.5. Incorrect position of the welded connection plate

Incorrect position of the welded connection plate refers to the situation when the linear or angular displacement of the plate happens to be greater than the allowed, so the plate needs to be carefully cut and removed. Cutting of the connection plate is performed with a grinder with a cutting disc. During cutting, the cutting disc should be directed toward the plate, so that it cannot damage the tubes. The prepared plate is inserted into the membrane wall and welded according to the welding instructions (WPS). After welding, the joint is tested by applying the surface method [8].

Allowed linear and angular connection plate displacement is shown in the Figure 15.

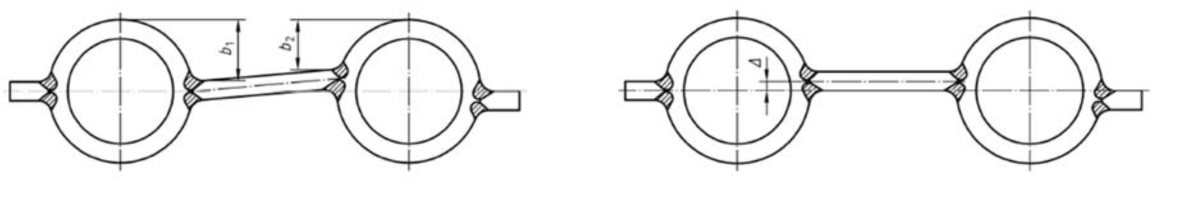

***Figure 15**. Connection plate displacement*

***Slika 15.** Pomeranje vezne ploče*

Incorrect position of the welded connection plate occurs during adjustment of the plate and the tubes. If the plate is not properly adjusted, it can shift during welding thus causing unacceptable defects. The Figure 16 shows an incorrect position of the welded connection plate.

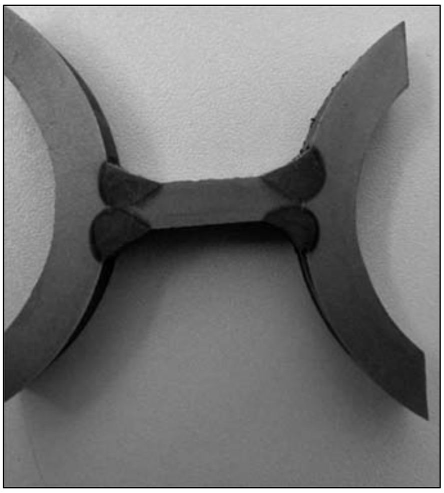

***Figure 16.** Incorrect position of the welded connection plate*

***Slika 16.** Nepravilan položaj zavarene vezne ploče*

5. Conclusion

Membrane welding is a highly efficient process that requires compliance with determined welding procedure in order for the welding to result in quality welds. Welding procedure and requirements are determined in the standards EN ISO 12952-5 [1] and EN ISO 12952-6 [2]. Compliance with the welding procedure and requirements defined by the standards facilitates efficient welding and results in a high-quality product. This refers also to completion and supervision of membrane welding in accordance with the standard, which is not an easy task to be performed. The welder has to monitor the process constantly in order to assure the highest quality of welding.

Defects such as cavities are very difficult to be completely fixed because of the considerable length of membrane welds. Clean welding is one of the basic prerequisites for a quality weld. Undercuts are also frequently appearing and are also difficult to be dealt with, primarily because of impossibility of visual inspection. Furthermore, two presented methods of controlling the undercut depth proved that it is very difficult for the controller to assess the size of the undercut, due to which they sometimes mark such undercuts as unacceptable defects, even when they could be acceptable without repair, as confirmed by the performed research tests. It is impossible to examine the macrostructure on the final product, while scanning procedure for each undercut or cavity is time-consuming. Therefore, training of controllers by the welding quality assurance service is necessary to make them skilled in efficient detection and assessment of defects that occur on membrane welds.

5. Zaključak

Membransko zavarivanje je visoko efikasan proces koji zahteva poštovanje utvrđene procedure zavarivanja kako bi zavarivanje rezultiralo kvalitetnim zavarenim spojem. Postupak i zahtevi zavarivanja određeni su standardima EN ISO 12952-5 [1] i EN ISO 12952-6 [2]. Usklađenost sa procedurom zavarivanja i zahtevima definisanim standardima omogućava efikasno zavarivanje i rezultira visokokvalitetnim proizvodom. Ovo se odnosi i na završetak i nadzor membranskog zavarivanja u skladu sa standardom, što nije lak zadatak. Zavarivač mora stalno da prati proces kako bi obezbedio najviši kvalitet zavarivanja.

Greške kao što su šupljine je veoma teško u potpunosti popraviti zbog velike dužine membranskih zavara. Čisto zavarivanje je jedan od osnovnih preduslova za kvalitetan zavar. Često se javljaju i zajedi koje je takođe teško sanirati, pre svega zbog nemogućnosti vizuelnog pregleda. Dalje, dve predstavljene metode kontrole dubine zajeda dokazale su da je kontroloru veoma teško proceniti veličinu zajeda, zbog čega ponekad takve zajede označavaju kao neprihvatljive nedostatke, čak i kada bi mogli biti prihvatljivi bez popravke, što je i potvrđeno. izvršenim istraživačkim ispitivanjima. Nemoguće je ispitati makrostrukturu na finalnom proizvodu, dok je procedura skeniranja za svaki zajed ili šupljinu dugotrajna. Zbog toga je neophodna obuka kontrolora od strane službe za obezbeđenje kvaliteta zavarivanja kako bi bili osposobljeni za efikasno otkrivanje i procenu nedostataka koji se javljaju na membranskim zavarenim spojevima

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PA ULTRAZVUČNO ISPITIVANJE TRAČNICA ZAVARENIH AT POSTUPKOM

PA ULTRASONIC TESTING OF AT WELD JOINTS IN RAILS

Stručni rad / Professional paper

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Ključne reči: ultrazvučno ispitivanje, aluminotermijski zavareni spoj, ispitivanje tračnica

Rezime

U ovom radu provedeno je usporedno ispitivanje s dva različita ultrazvučna sistema na aluminotermijskim zavarenim spojevima tračnice. Ispitivanje je provedeno konvencionalnim sistemom i sistemom višestrukog pretvarača. Podešavanje osjetljivosti provedeno je na umjetno napravljenim reflektorima na uzorku tračnica, dok je usporedbeno ispitivanje provedeno na tračnici sa stvarnim pogreškama. Zbog složene geometrije tračnice i vrste pogrešaka koje mogu nastati samo ispitivanje može biti izazov u odabiru sistema i tehnike ispitivanja. Cilj rada je prikazati s obzirom na ograničenja ultrazvučnih sistema rezultate ispitivanja koji ukazuju na prednost ultrazvučnog sistema višestrukog pretvarača u odnosu na konvencionalni sistem.

Keywords: ultrasonic testing, aluminothermic welded joint, rail inspection.

Abstract

In this paper, a comparative test with two different ultrasonic systems was performed on the aluminothermic welded joints of the rail. The test was carried out with a conventional system and a phased array system. Sensitivity adjustment was carried out on artificially made reflectors on rail and a comparative test on the rail with real imperfections. Due to the complex geometry of the rail and the type of errors that can occur, the test itself can be a challenge in selecting the test system and technique. The aim of the paper is to show, considering the limitations of ultrasound systems, test results that indicate the advantage of a phased array ultrasound system compared to a conventional system.

Rad je u originalnom obliku objavljen u Zborniku radova sa Međunarodnog naučnog i stručnog skupa: Zavarivanje spaja – „Zavarivanje i zavarene konstrukcije 2023“ održanog u Sarajevu, BiH, od 25. do 27. oktobra 2023. godine.

1. Uvod

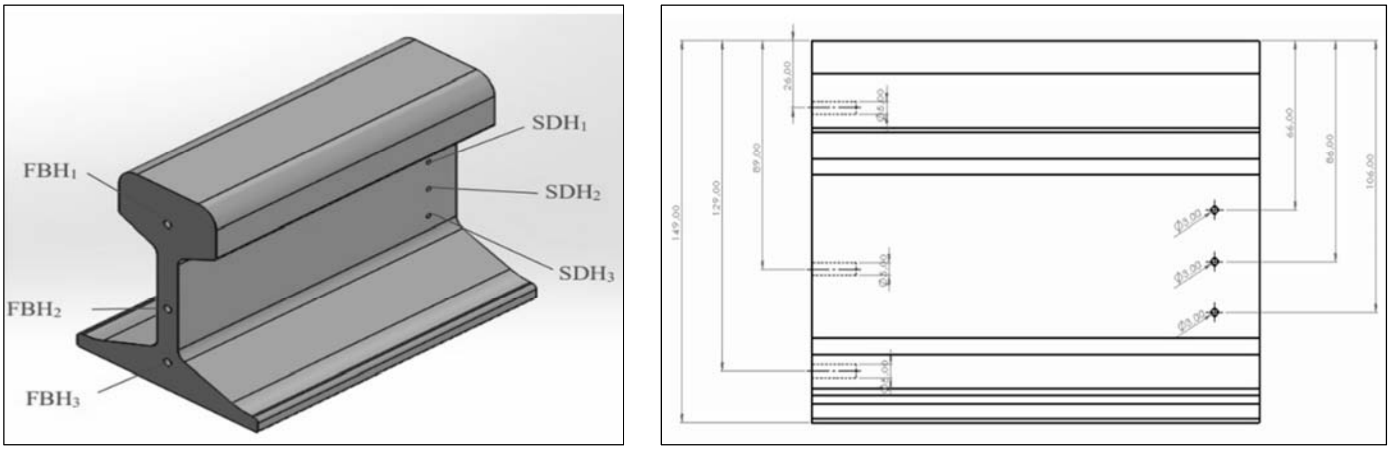
Aluminotermijsko zavarivanje je postupak zavarivanja tračnica termitnom smjesom pri čemu se uslijed egzotermne reakcije oduzima kisik željeznom oksidu te nastaje rastaljeno željezo koje služi kao dodatni materijal. Osnovni materijal i kalup se predgrijavaju plinskim plamenom (acetilen-kisik ili propan butan-kisik) na temperaturu oko 900-1000 °C. Egzotermnom reakcijom se postiže temperatura od približno 2450 °C te se nakon ciklusa predgrijavanja i formiranja taline otvara ispust pa uz gravitacijsko djelovanje dolazi do popunjava kalupa. Kvalitetna priprema kalupa i pregdrijavanje nužni su za miješanje taline i osnovnog materijala tračnice te formiranje zavarenog spoja. Nakon završene aluminotermijske reakcije kalup se razbija i višak materijala se mehanički uklanja. Kao posljedica neodgovarajuće metode i tehnologije zavarivanja ovisno o postupku, pripremi i kvaliteti materijala mogu nastati nepravilnosti u zavarenom spoju koje se mogu detektirati metodama ispitivanja bez razaranja.

U ovom radu razmatrana je problematika detekcije jedne vrste pogrešaka u aluminotermijskom zavaru tračnice konvencionalnim ultrazvučnim (UT-Ultrasonic Testing) ispitivanjem i višepretvorničkim ultrazvučnim (PA-UT – Phased array ultrasonic testing) ispitivanjem. Ispitivanje su se provodila po gaznoj površini tračnice simulirajući situacije ispitivanja zavarenih spojeva kada nije moguće provoditi ispitivanje na vratu ili stopi tračnice zbog nedostupnosti ili neodgovarajuće površine potrebne za provedbu ultrazvučnog ispitivanja.

Provjera oba sustava provedena je na referentnom uzorku poznatih umjetno napravljenih reflektora. Nadalje, usporedba rezultata ispitivanja provedena je na aluminotermijskom zavarenom spoju s realnom pogreškom u vratu tračnice.

1.1 Referentni uzorak za provjeru osjetljivosti sustava

Prije početka provođenja ispitivanja odabrani ultrazvučni ispitni sustav potrebno je odgovarajuće podesiti. S ciljem provjere podešavanja osjetljivosti ultrazvučnog sustava izrađen je referentni etalon s bočnim provrtima oznaka SDH_1, SDH_2 i SDH_3 promjera 3 mm prema slici 1 [2].



Slika 1. *Referentni uzorak i nacrt umjetno napravljenih reflektora*

Figure 1*. Reference sample and design of artificially made reflectors*

Podešavanje osjetljivosti ultrazvučnog sustava

Odabrani ultrazvučni sustav u okviru ovog istraživanja sastoji se od dva ultrazvučna uređaja Krautkramer GE USM36 i GE Mentor UT 32:128, te svaki od uređaja ima pripadajuće ultrazvučne sonde odgovarajućih karakteristika kako bi se osiguralo prozvučavanje ispitivanog volumena tračnica [2]. Odabrani ultrazvučni sustav s pripadajućim etalonima za podešavanje i odabranom vrstom kontaktnog sredstva prikazan je u Tabeli 1.

***Tabela 1.** Korištena oprema i sredstva UT i PAUT sustava*

***Table 1.** Used equipment and resources of UT and PAUT systems*

Sustav	Naziv uređaja	Sonda	Etalon	Kontaktno sredstvo
UT	Krautkramer GE USM36,	MWB 45 -2 SWB 45 - 2	V2 V1	GE – ZG-F
PA-UT	GE Mentor UT 32:128,	PA-2M8E1P,	PAUT IIW block	

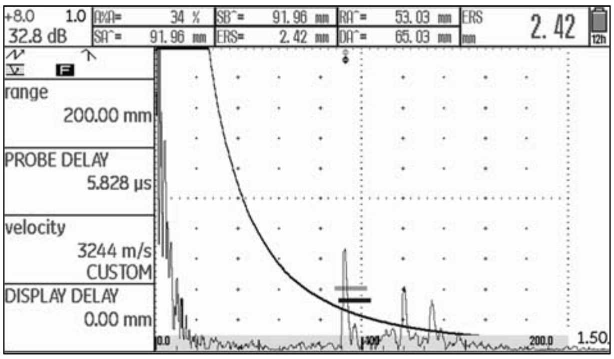
Za svaki odabrani ultrazvučni sustav provedena je provjera podešavanja osjetljivosti na izrađenom referentnom etalonu (slika 1). U tom smislu za svaku kombinaciju odabira ultrazvučnog uređaja i pripadajuće ultrazvučne sonde provjera osjetljivosti je provedena na ukupno tri bočna provrta oznaka SDH_1, SDH_2 i SDH_3. Rezultati podešavanja osjetljivosti nalaze se u Tabeli 2.

***Tabela 2.** Prikaz provjere osjetljivosti na radnom etalonu ovisno o sustavu i referentnom mjestu*

***Table 2.** Presentation of the sensitivity check on the working standard depending on the system and reference location*

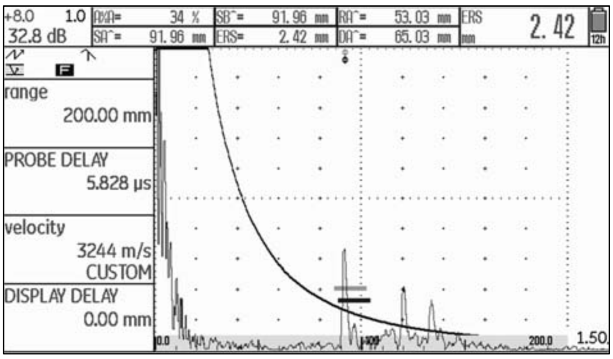
Sistem	Reflektor	Prikaz reflektora na radnom etalonu		Procjena veličine Ø mm (ERS)/dubina mm (DA)	
		MWB 45 -2	SWB 45 - 2	MWB 45 -2	SWB 45 - 2
UT	SDH1	Slika 2	Slika 5	2.42/65	3.29/66
	SDH2	Slika 3	Slika 6	2.62/86	2.81/85
	SDH3	Slika 4	Slika 7	2.37/109	2.70/106

PAUT		PA-2M8E1P	Dubina indikacije mm (DA)
	SDH1	Slika 8	66,6
	SDH2	Slika 9	85,8
	SDH3	Slika 10	106,7



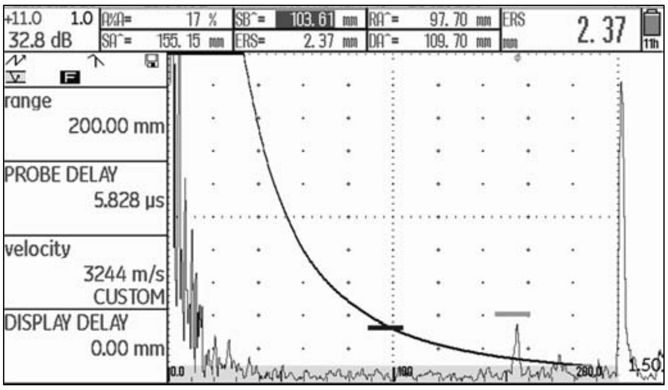
***Slika 2.** Prikaz odjeka od referentnog reflektora SDH1 (MWB 45-2)*

***Figure 2.** View of the echo from the reference reflector SDH1 (MWB 45-2)*



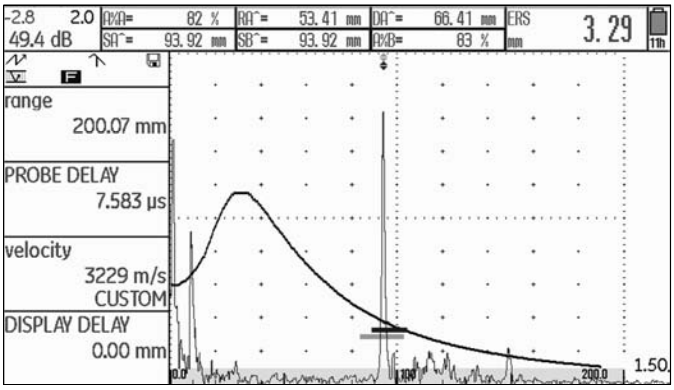
***Slika 3.** Prikaz odjeka od referentnog reflektora SDH2(MWB 45-2)*

***Figure 3.** View of the echo from the reference reflector SDH2 (MWB 45-2)*



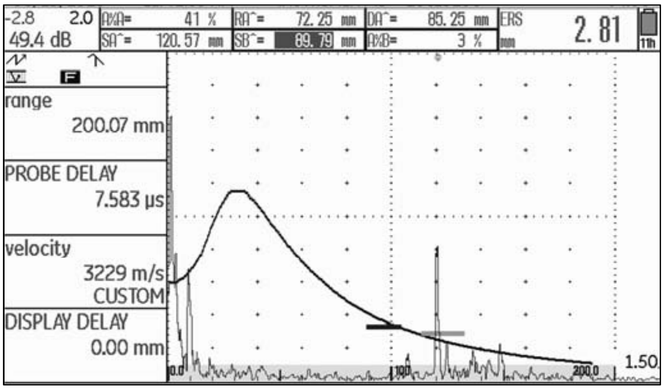
Slika 4. *Prikaz odjeka od referentnog reflektora SDH3 (MWB 45-2)*

Figure 4. *View of the echo from the reference reflector SDH3 (MWB 45-2)*



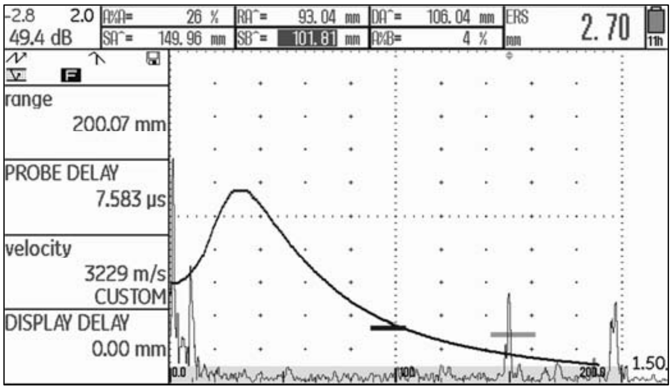
Slika 5. *Prikaz odjeka od referentnog reflektora SDH1 (SWB 45-2)*

Figure 5. *View of the echo from the reference reflector SDH1 (SWB 45-2)*



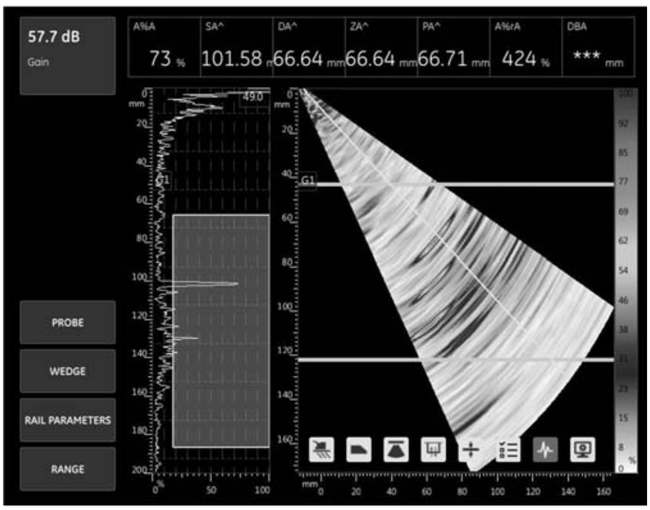
***Slika 6**. Prikaz odjeka od referentnog reflektora SDH2 (SWB 45-2)*

***Figure 6**. View of the echo from the reference reflector SDH2 (SWB 45-2)*



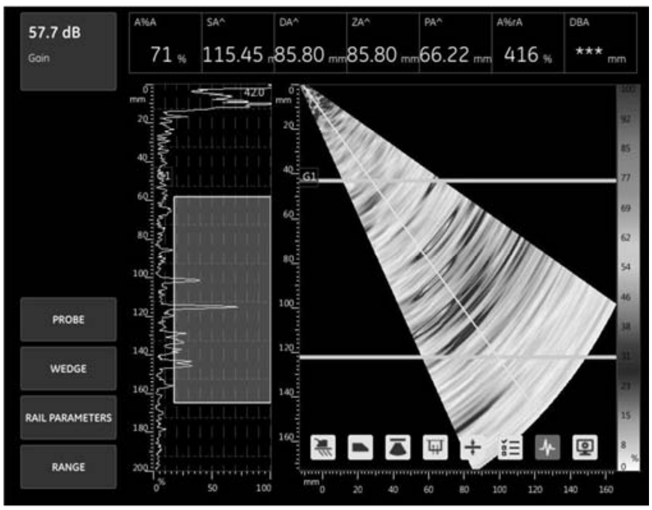
Slika 7. *Prikaz odjeka od referentnog reflektora SDH3 (SWB 45-2)*

Figure 7. *View of the echo from the reference reflector SDH3 (SWB 45-2)*



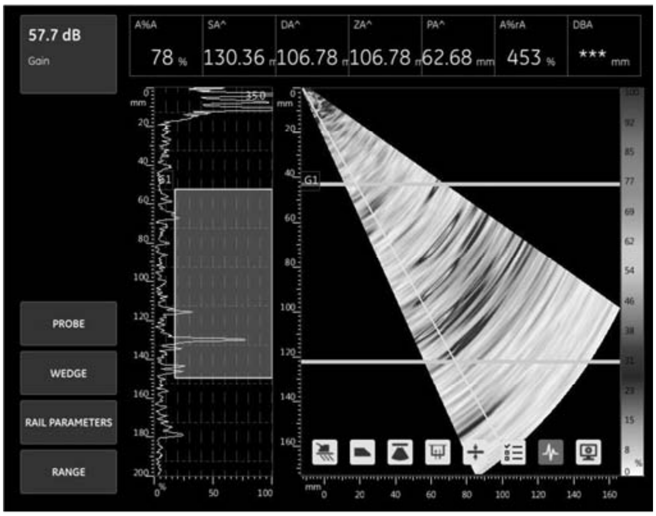
Slika 8. *Prikaz odjeka od referentnog reflektora SDH1 (PA-2M8E1P)*

Figure 8. *View of the echo from the reference reflector SDH1 (PA-2M8E1P)*



Slika 9. *Prikaz odjeka od referentnog reflektora SDH2 (PA-2M8E1P)*

Figure 9. *View of the echo from the reference reflector SDH2 (PA-2M8E1P)*



Slika 10. *Prikaz odjeka od referentnog reflektora SDH3 (PA-2M8E1P)*

Figure 10. *View of the echo from the reference reflector SDH3 (PA-2M8E1P)*

1.2. Zaključak provjere podešavanja osjetljivosti na referentnom etalonu

Podešavanje osjetljivosti primjenom konvencionalnog ultrazvučnog sustava (dvije ultrazvučne sonde) provedeno je prema beskonačnom reflektoru na etalonu V2 – R50 i V1-R100 te je konstruirana DGS krivulja na promjeru Ø 1,5 mm. S ciljem provjere podešenosti osjetljivosti konstruirana je krivulja prema bočnom provrtu SDH2. Usporedbom amplitudnih odziva nisu uočene značajne razlike u procjeni veličine reflektora (ERS).

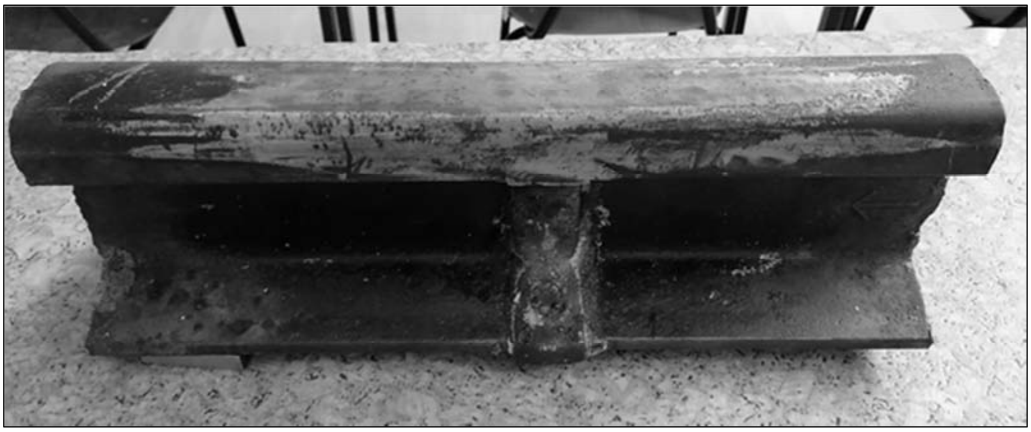
Prema dobivenim rezultatima i odjecima na A prikazu uređaja može se zaključiti da su rezultati ostvareni sa sondom SWB 45-2 za ovu vrstu tračnice i referentnih reflektora bolji u odnosu na rezultate ostvarene sa sondom MWB 45-2 kako je prikazano u Tabeli 2 [2].

Podešavanje osjetljivosti PAUT sustava provedeno je prema bočnim provrtima na referentnom uzorku SDH1, SDH2 i SDH3. U svrhu boljeg podešavanja osjetljivosti korištena je funkcija TCG-a (Time Corrected Gain), te je dobivena ujednačena osjetljivost uzimajući u obzir poziciju reflektora u vratu tračnice (Slika 8, Slika 9 i Slika 10) [1].

2. Referentni uzorak s nepravilnostima u vratu tračnice

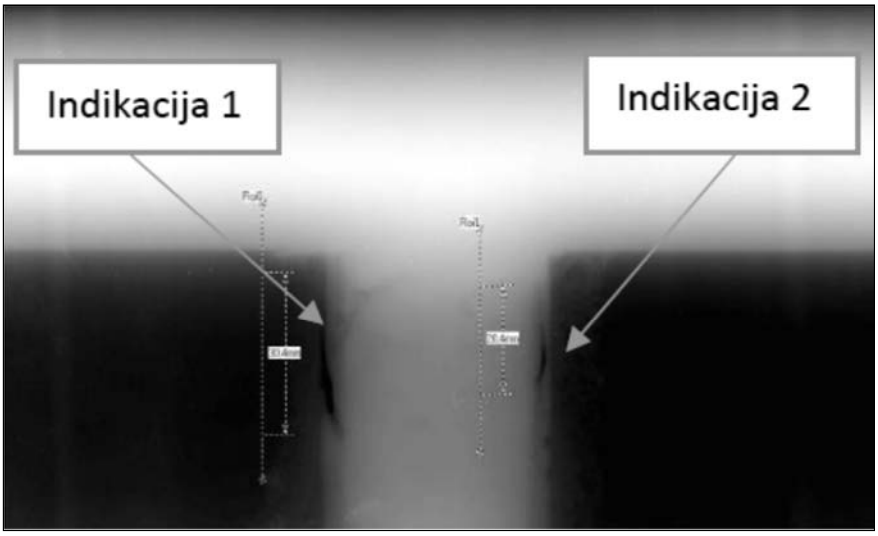
Referenti uzorak aluminotermijski zavarenih tračnica (Slika 11) ima više vrsti nepravilnosti u vratu tračnica, te je prethodno ultrazvučnom ispitivanju provedeno računalno radiografsko ispitivanje – cRT s ciljem točnijeg određivanja vrste nepravilnosti (Tabela 3).

Dobiveni odzivi od nepravilnosti primjenom UT i PAUT ultrazvučnog ispitivanja usporedit će se s onima dobivenim primjenom računalne radiografije.



Slika 11. *Referentni uzorak tračnice*

Figure 11. *Rail reference sample*



Slika 12. *Radiogram referentong uzorka tračnice s prikazanim vrijednostima parametara nepravilnosti*

Figure 12. *Radiogram of the rail reference sample with the irregularity parameter values shown*

Tabela 3. *Korištena oprema i ispitni parametri cRT sistema*

Table 3. *Used equipment and test parameters of the cRT system*

Metoda	Oprema	Ispitni parametri
cRT	rendgenski uređaj – Balteau 300d	veličina fokusa: 2x2,5 mm FF: 700 mm, napon: 175 kV struja: 4 mA vrijeme ekspozicije: 2,5 min
	skener – VMI 5100	napon lasera: 15 V napon fotomultiplikatora: 5,25 V rezolucija skeniranja: 50 µm
	slikovna ploča	kodak industrex flex Blue 10 x 12”

Pogreške u aluminotermijskim zavarenim spojevima tračnica

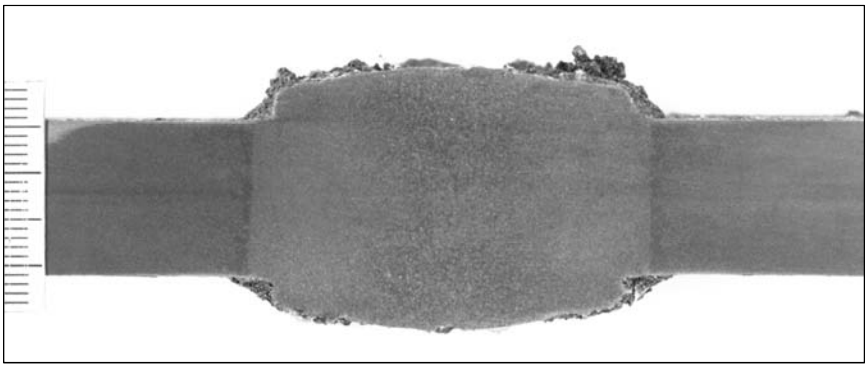
Od nepravilnosti se pri aluminotermijskom zavarivanju najčešće pojavljuju:

- Pukotine; pukotine nastaju kao posljedica vlačnih naprezanja prilikom hlađenja. To je posebno naglašeno u području metala zavara pri solidifikaciji i situaciji niskih okolišnih temperatura.

- Porozitet i plinski uključci; najčešće nastaju kao posljedica vlage u području spoja koja može doći iz nečistoća i masnoće te kondenzata u kalupu. Također, ako je dodatni materijal (porcija) kontaminiran u metalu zavara je česta pojava pora.
- Šupljine; nastaju kod skrućivanja rastaljenog materijala u kalupu posebno kada nema dovoljno dodatnog materijala (neodgovarajuća porcija ili istjecanje kroz neodgovarajuće postavljeni, zabrtvljeni ili puknuti kalup.). Prilikom solidifikacije dolazi do smanjenja volumena (fenomen skupljanja zavara) pa ako prilikom zavarivanja nije postignuto dovoljno miješanje veća je i vjerojatnost pojave šupljina.

- Naljepljivanje; nastaje kao posljedica nedovoljnog predgrijavanja osnovnog materijala ili neprilagođavanja tehnologiji niskim temperaturama okoliša. Iz tog razloga se striktno traži ovisno o gradaciji čelika postizanje i držanje temperature predgrijavanja kako bi se postiglo dobro miješanje sa stranicama žlijeba tj. osnovnim materijalom tračnice.

- Uključci; u metalu zavara mogu se pojaviti i nemetalni uključci nastali iz kontaminiranog praška u porciji ili npr. oksidni uključci nastali kao rezultat loše pripreme spojne površine te neodgovarajuće kvalitete rezanja plinskim plamenom. Također, mogu ostati i uključci od pijeska za brtvljenje.
- Nepravilna geometrija zavara na stopi, vratu i kruni tračnice; nastaju zbog lošeg postavljanja ili krive geometrije kalupa. Pri ovome je svakako važna uvježbanost i vještina operatera koji postavljaju kalup.



Slika 13. *Prikaz makrostrukutre u vratu tračnice bez nepravilnosti*

Figure 13. *View of the macrostructure in the neck of the rail without irregularities*

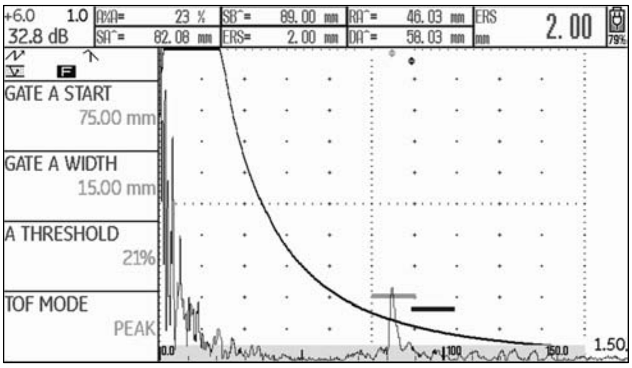
Na slici 12. vidljiva je šupljina uz područje intenzivnog nepovezivanja rastaljenog metala i stijenke tračnice. Uzrok predmetnoj nepravilnosti može se tražiti u neodgovarajućem toku rastaljenog metala u kalup pri čemu je došlo do turbulencije taline i neravnomjernog skrućivanja. Dodatno, ako stijenka tračnice nije dovoljno predgrijana ne dolazi do dovoljnog miješanja. Iz ove situacije dodatno se naglašava važnost adekvatne pripreme i predgrijavanja stijenke te savjesnosti i uvježbanosti operatera.

3. Rezultat ispitivanja referentnog uzorka tračnice

Tabela 4. *Rezultati ispitivanja referentnog uzorka tračnice*

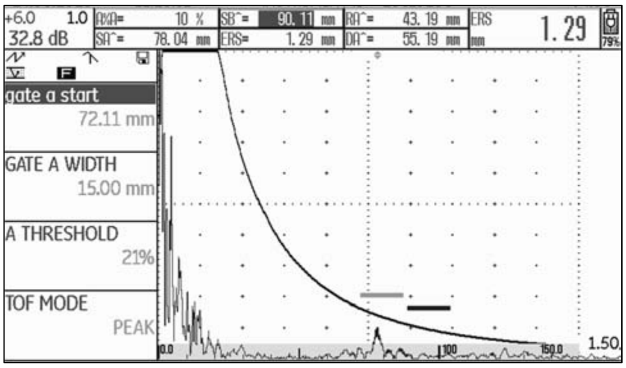
Table 4. *Test results of the rail reference sample*

Sustav	Reflektor	Prikaz reflektora na radnom etalonu		Procjena veličine (ERS)		Procjena duljine
		MWB 45 - 2	SWB 45 - 2	MWB 45 - 2	SWB 45 – 2	-6 dB
UT	Nepravilnost 1	Slika 14	Slika 16	2.00	2,05	3-5 mm
	Nepravilnost 2	Slika 15	Slika 17	1.29	1.50	2-4 mm
		PA-2M8E1P				
PA-UT	Nepravilnost 1	Slika 18				21 mm
	Nepravilnost 2	Slika 19				12,6 mm



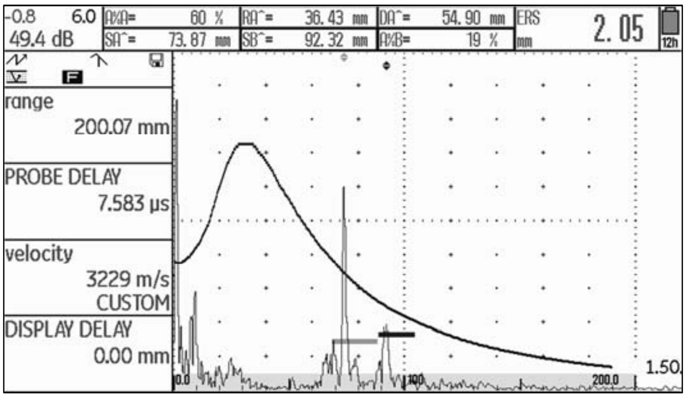
Slika 14. *Prikaz odjeka od indikacije 1 (MWB 45-2)*

Figure 14. *View of the echo from the indication 1 (MWB 45-2)*



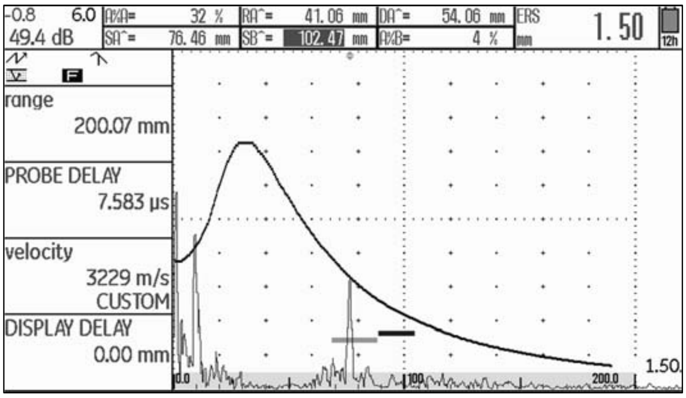
Slika 15. *Prikaz odjeka od indikacije 2 (MWB 45-2)*

Figure 15. *View of the echo from the indication 2 (MWB 45-2)*



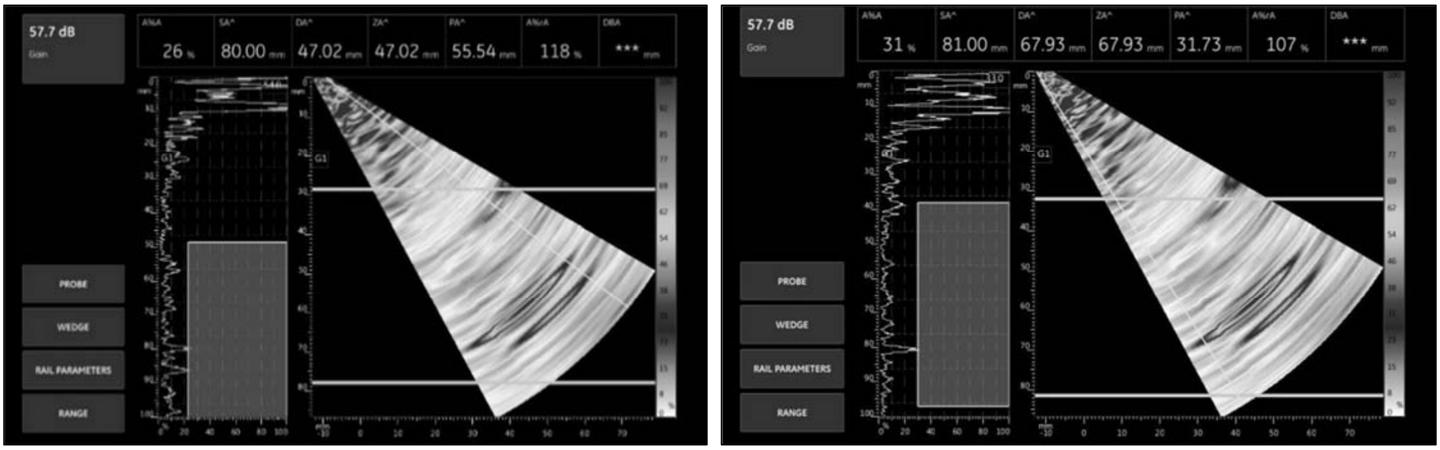
__Slika 16.__ Prikaz odjeka od indikacije 1 (SWB 45-2)

__Figure 16.__ View of the echo from the indication 1 (SWB 45-2)



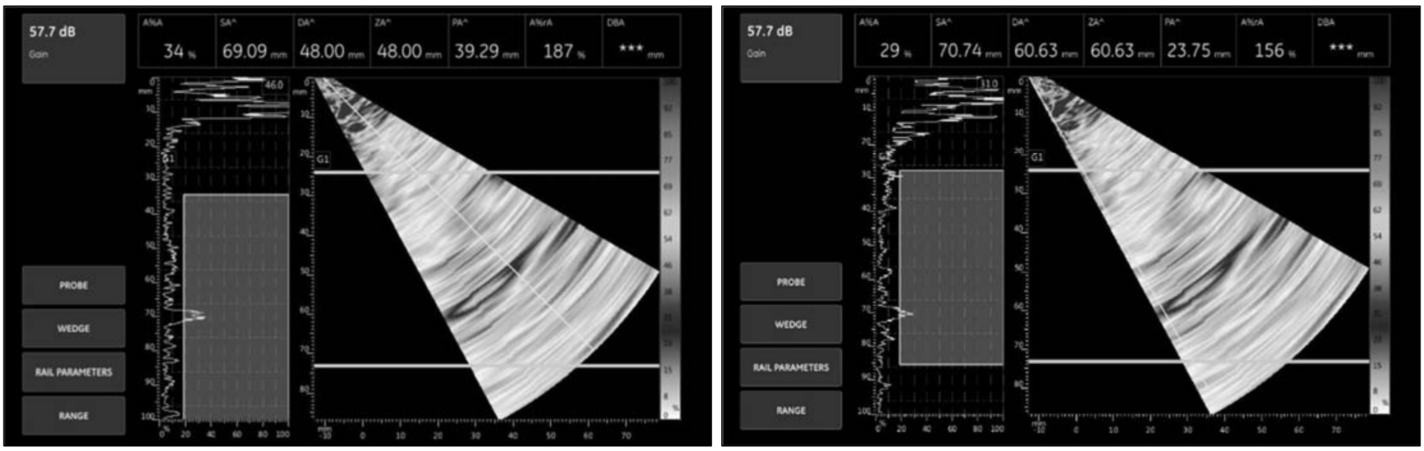
__Slika 17.__ Prikaz odjeka od indikacije 2 (SWB 45-2)

__Figure 17.__ View of the echo from the indication 2 (SWB 45-2)



__Slika 18.__ Prikaz odjeka od indikacije 1 (PA-2M8E1P)

__Figure 18.__ View of the echo from the indication 1 (PA-2M8E1P)



__Slika 19.__ Prikaz odjeka od indikacije 2 (PA-2M8E1P)

__Figure 19.__ View of the echo from the indication 2 (PA-2M8E1P)

4. Zaključak

Uslijed eksploatacije može doći do razvoja pukotina unutar zavara tračnice te je odabir odgovarajuće metode i tehnike provedbe nerazornog ispitivanja od velikog značaja.

S obzirom na ograničenja ultrazvučnih sustava prikazanih u ovom radu, rezultati ispitivanja ukazuju na prednost višepretvorničkog ultrazvučnog sustava (PAUT) u odnosu na konvencionalni sustav. Prednost spomenutog sustava posebno je vidljiv prilikom pronalaska nepovoljno orijentiranih indikacija u uskim dijelovima vrata tračnice. Prema ostvarenim rezultatima procjene veličine nepravilnosti kao i njezine uvjetne duljine primjenom konvencionalnog ultrazvučnog sustava može se zaključiti da se ne radi o značajnim nepravilnostima.

Prema spomenutom, zavareni spoj sukladno kriteriju prihvatljivosti može se ocijeniti kao prihvatljiv za daljnju uporabu u uvjetima eksploatacije. Međutim, rezultati ostvareni primjenom višepretvorničkog sustava jasno ukazuju suprotno.

4. Conclusion

As a result of exploitation, cracks may develop within the rail welds, and the selection of the appropriate method and technique for non-destructive testing is of great importance.

Considering the limitations of the ultrasound systems presented in this paper, the test results indicate the advantage of the multi-transducer ultrasound system (PAUT) compared to the conventional system. The advantage of the mentioned system is especially visible when finding unfavourable oriented indications in narrow parts of the rail neck. According to the obtained results of the assessment of the size of the irregularity as well as its conditional length using a conventional ultrasound system, it can be concluded that these are not significant irregularities.

According to the aforementioned, the welded joint in accordance with the acceptance criteria can be evaluated as acceptable for further use in the conditions of exploitation. However, the results obtained using the multi-converter system clearly indicates the opposite.

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[2] Jagodić N. (2022), Ispitivanje ultrazvukom aluminotermijskih zavarenih tračnica. Diplomski rad Zagreb: Sveučilište u Zagrebu, Fakultet strojarstva i brodogradnje

Međunarodna hibridna konferencija i izložba : “Napredak u zavarivanju i tehnologijama aditivne proizvodnje metala - WAAM -2024”

Međunarodna hibridna konferencija i izložba WAAM 2024 ima za cilj da poveže naučnike, inženjere i studente koji rade i koriste napredne tehnologije zavarivanja i aditivane proizvodnje metala (MAM) u svojim istraživačkim projektima i industrijskim aplikacijama. Međunarodni stručnjaci u ovim oblastima će predstaviti najnovije informacije i diskutovati o sadašnjim i budućim izazovima i inovativnim rešenjima za povećanje efikasnosti zavarivanja i tehnologija za proizvodnju metala AM i Wire Arc Additive Manufacturing (WAAM). Mesto održavanja konferencije je Istambul Gedik Universiti u Istambulu u Turskoj 21. i 22. Novembra 2024.

Međunarodna konferencija WAAM 2024 će pokriti sledeće teme:
- Napredne tehnologije elektrolučnog zavarivanja uključujući procese dvostrukog luka i tandema,
- Tehnologije i primene laserskog snopa i hibridnog zavarivanja,
- Zavarivanje elektronskim snopom primenom žice ili praškova,
- Tehnologije punjene žice i punjene bešavne žice i njihova upotreba,
- Zavarivanje svih legura metala, ispitivanje i analiza njihovih zavarenih spojeva,
- Industrijske primene, inspekcije i ispitivanja,
- Površinska modifikacija delova za aditivnu proizvodnju,
- Zavareni spojevi visoke čvrstoće i oklopnog čelika, njihova svojstva (uključujući balistička svojstva),
- Tehnologije podvodnog i mokrog zavarivanja i njihov potrošni materijal,
- Aspekti dizajna i simulacije materijala za aditivnu proizvodnju metalnih materijala (MAM),
- Ispitivanje MAM materijala, sprečavanje deformacija i zaostalih napona MAM delova,
- Aspekti otpornosti na zamor i žilavost loma MAM i bimetalnih WAAM delova,
- Programiranje i razvoj softvera u robotskim MAM i WAAM aplikacijama,
- Prediktivni teorijski i računarski pristupi za aditivnu proizvodnju,
- Ispitivanje, NDT metode i procena defekata MAM i VAAM delova,
- Razvoj na edukaciji-obuci-sertifikaciji zavarivanja i MAM & WAAM osoblja.

Dodatne informacije mogu se naći na adresi: WAAM2024.gedik.edu.tr

Međunarodni sajam industrije zavarivanja Weld Tech

Vrednost poljske industrije zavarivanja stalno raste. Otvara se za nova rešenja i dobitke zahvaljujući automatizaciji, robotizaciji i inovacijama u optimizaciji procesa. Tokom međunarodnog sajma za industriju zavarivanja Weld Tech, koji će se održati od 3. do 5. septembra 2024. godine, moći ćete da pogledate ove i druge trendove, kao i savremene tehnologije koje određuju pravac razvoja sektora. Varsav Expo će ponovo postati mesto gde inovacije ispunjavaju potrebe kupaca. Mesto održavanja Varšava, Poljska. Više informacija na web adresi: https://weldexpopoland.com/en

Konferencija o zavarivanju elektronskim snopom

7. Međunarodna konferencija o zavarivanju elektronskim snopom, IEBW 2024. Ovaj događaj, koji su sponzorisali Američko društvo za zavarivanje (AWS), Nemačko društvo za zavarivanje (DVS) i Međunarodni institut za zavarivanje (IIW), održaće se u FABTECH-u, 15-16. oktobra 2024. u Orlandu, FL.

Konferencija se održava svake dve godine, naizmenično između SAD i Nemačke. IEBW će okupiti naučnike i inženjere iz industrije, akademske zajednice i istraživačkih laboratorija širom sveta kako bi razgovarali o trenutnim i budućim trendovima u zavarivanju elektronskim snopom. Za više informacija kontaktaktirati: sbeller@avs.org.

14. Međunarodni kongres i izložba primenjene fizike i nauke o materijalima (APMAS)

14. Međunarodni kongres i izložba primenjene fizike i nauke o materijalima (APMAS)“ će se održati od 8. do 14. oktobra 2024. godine u Convention Centre u Liberty Hotels Lykia /Oludeniz u Muğla, Turska.
APMAS 2024 namerava da bude globalni forum za istraživače i inženjere koji će predstaviti i diskutovati o najnovijim inovacijama i novim tehnikama u tehnologiji materijala. Pored naučnih seminara, biće dostupan širok spektar društvenih programa uključujući krstarenja brodom i posete istorijskim mestima. Više informacija na web adresi: www.apmascongress.org.

Dragan Mitić [1], Mladen Mitić [1], Goran Sofronić [2], Davor Gruber [3]

EXPERIENCES IN WELDING THE TURKISH STREAM GAS PIPELINE AND INTERCONNECTOR SERBIA - BULGARIA

ISKUSTVA U ZAVARIVANJU GASOVODA „TURSKI TOK“ I INTERCONECTOR SRBIJA – BUGARSKA

Professional paper / Stručni rad

Paper received / Rad primljen:

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Paper accepted / Rad prihvaćen:

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Keywords: centralizer device for connecting and centering pipes on the gas pipeline, STT device for MAG welding, FCAW-S - filled self-shielding welding wire.

Ključne reči: centralizer uređaj za povezivanje i centriranje cevi na gasovodu, STT uređaj za zavarivanje MAG postupkom, FCAW-S -punjena samozaštitna žica za zavarivanje.

Abstract

The gas pipeline "Turski Tok" was built in the period from 2019 to 2021 with a total length of 403 km (Zaječar-Horgoš). The pipeline has a capacity of up to 15 billion cubic meters, a diameter of 1219 mm and its thickness is 14.27 mm. The steel L485MEPSL2 was used for production. The Serbia-Bulgaria interconnector is 109 km long (Niš-Sofia), with a capacity of 1.8 billion cubic meters of gas, a diameter of 711 mm and the thickness is 8.7 mm. Steel X52 was used for its construction.

Different procedures were used for welding:

- Welding E-111 (cellulose and basic coating).
- MAG 135 with welding of the root of the welded joint with a semi-automatic device STT, and filling with an automatic procedure with two devices.
- Welding with the MAG process of the root of the welded joint on the inside, using the internal centralizer, and on the outside with the automatic MAG process with two devices.
- Welding from the outside with automatic MAG process with two devices, Self-Shielded Flux Cored Arc Welding wire FCAW-114 using an internal centralizer with a copper ring.

The paper presents experiences with gas pipeline welding, with a critical review of selected solutions and suggestions for optimizing welding technology.

Rezime

Gasovod „Turski tok“ je izgrađen u periodu 2019. do 2021. godine u ukupnoj dužini od 403km (Zaječar-Horgoš). Cevovod je kapaciteta do 15 milijardi kubnih metara, prečnika 1219mm i debljine 14,27mm. Za izradu je korišćen čelik L485MEPSL2. Interkonektor Srbija-Bugarska je dužine 109 km (Niš-Sofija), kapaciteta 1.8 milijardi kubnih metara gasa, prečnika 711mm i debljine 8,7mm. Za izradu je korišćen čelik X52.

Za zavarivanje su korišćeni različiti postupci:

- Zavarivanja E-111(celulozna i bazična obloga);
- MAG 135 sa zavarivanjem korena zavarenog spoja poluautomatskim uređajem STT, a ispuna automatskim postupkom sa dva uređaja;
- Zavarivanje MAG postupkom korena zavarenog spoja unutrašnje strane, pomoću unutrašnjeg centralizera, a sa spoljašnje strane automatskim MAG postupkom sa dva uređaja;
- Zavarivanje sa spoljne strane automatskim MAG postupkom sa dva uređaja, samozaštitnom žicom FCAW-114 pomoću unutrašnjeg centralizera sa bakarnim prstenom.

U radu su predstavljena iskustva sa zavarivanjem gasovoda, sa kritičkim osvrtom na izabrana rešenja i predlozima za optimizaciju tehnologije zavarivanja.

The paper was published in its original form in the Proceedings of the International scientific and professional conference: Welding connecting - "Welding and welded structures 2023" held in Sarajevo, BiH, from October 25 to 27, 2023

1. Introduction

With accelerated industry development and the increased foreign investments in new factories development, the demand of energy sources has increased, as well. Since the end of ninetees Serbia has not constructed a single pipeline of regional character, and not to talk about the pipeline inter-connecting the countries. An additional problem is gas supply, coming from the direction of Hungary only and interruption of this pipeline would be a great problem for Serbia. Based on these reasons, as well as on geopolitical situation, the works on the gas pipeline - Turkish stream, from the border with Bulgaria to the border with Hungary, started in 2019.

The gas pipeline Turkish stream was constructed in the period from 2019 to 2021, in the total length of 403 km (Vrška Čuka - Horgoš). The capacity of the pipeline is up to 15 billion cubic meters of gas, the diameter is 1219 mm and the thickness is 14,27mm. The steel L485ME X70 PSL2 was used in construction.

After two years, further diversification of gas supply was continued, in the way that in 2023 the construction of Interconnector Serbia – Bugarska started, the total length of which was 109 km, capacity 1.8 billion cubic meters of gas, diameter - 711mm and the pipe wall thickness – 8.7mm. Steel pipes X52 were used for fabrication of gas pipeline.

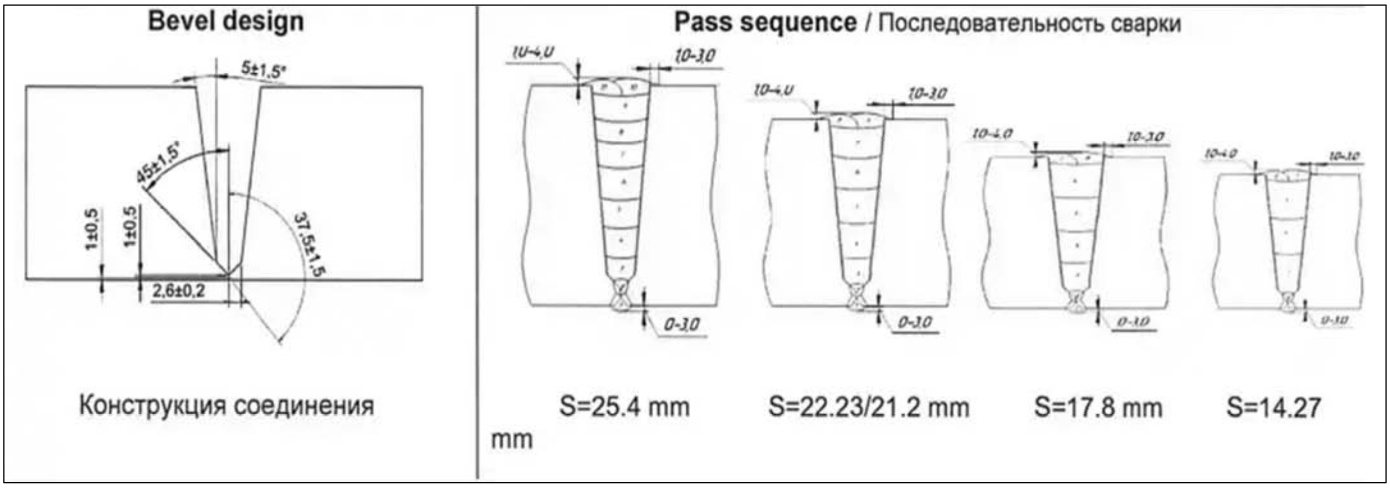

Figure 1. *Pipe ends preparation with IDC for automatic welding*

Slika 1. *- Priprema krajeva cevi kod IDC-a za automatsko zavarivanje*

2. Welding processes used in the pipeline Turkish stream

Since two contractors were engaged in this pipeline construction, there was the difference in welding technologies, SAIPEM was welding from external side only, while IDC had the welding devices CRC-EVANS, by means of which they were welding the weld root from the interior side, while the hot pass, the filler welds and final weld were done from the external side.

On the internal centralizer, IDC had 4 heads, which were welding the weld root from the internal pipe side. Both contractors were using automatic MAG welding process, in that, Saipema weld root was being welded in the way that the internal centralizer had a copper ring on it, which enabled gaining of a quality root weld.

For welding connections – assemby welds, both contractors used the same preparation of the pipe ends, but different welding technology.

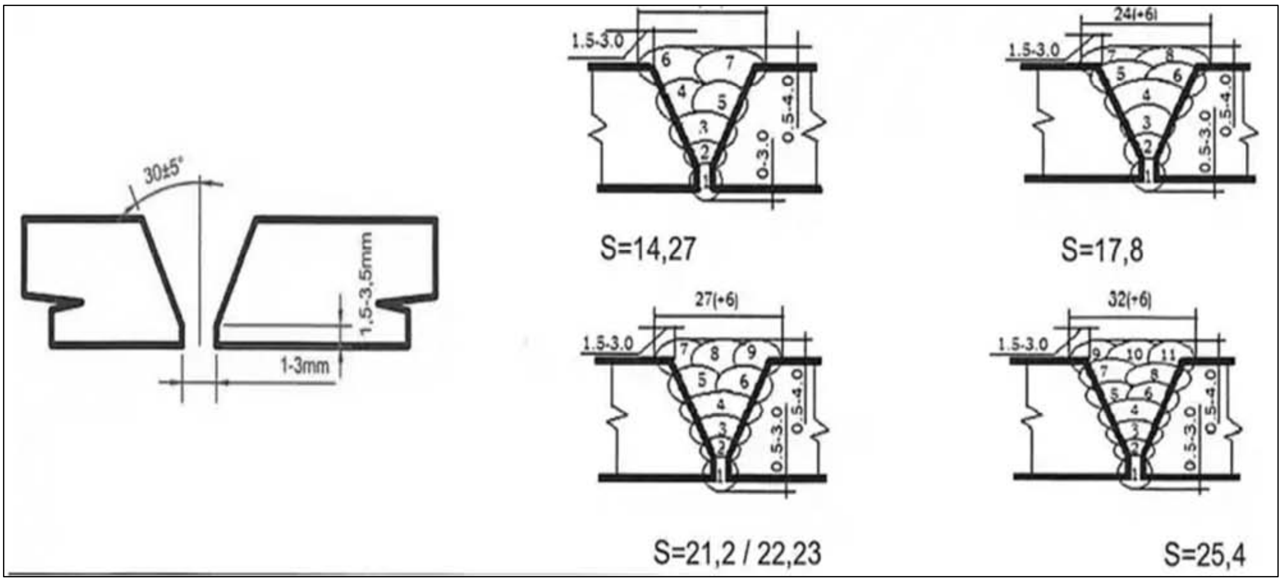

***Figure 2.** Pipe ends preparation for E process with IDC and Saipema, respectively*

***Slika 2.** Priprema krajeva cevi kod IDC-a i Saipema za E postupak*

Filler metal for pipe interior side welding - welding pass of IDC was wire Thyssen TS-6 ER70S-G Ø 0.9mm, while the wire, used for hot pass welding, filler weld and final weld was Ø1,0mm K-600 EN-ISO 14341-A G 46 2 C1 4Si1 [1]. The following devices were used for root weld: IWM+Lincoln Idealarc DC400/Lincoln V350, while the automatic welding machine Evans P600/P625+Fronius TPS 3200 were used for other welds.Welding position PJ, from top to bottom DC+.

Preheating temperature was 120°C, and the inter-layer temperature was 250°C. Preheating was performed by an induction device PIH120, and the inter-layer preheating was done by two gas burners. Shielding gas was EN ISO 14175 M21.

Depending on what was welded, the welding current strength ranged from 180-220A at root pass, 220-300A at hot pass, 160-220A at filler welds and from 110-150A at the final pass. The voltage ranged from 18V at root pass up to 26V at final pass.

The welding speed at root pass was 60cm/min and up to 35cm/min at the final pass, in that, pulsation was included in filler weld and final weld, and its value was variable, depending on the pipe wall thickness, that is, on the weld width.

***Figure 3.** Internal centralizer IDC*

***Slika 3.** Unutrašnji centralizer IDC*

For such welding technology, it is anticipated that there is no clearance between the pipes, and the allowed deviation is 0.5mm, but for not more than 100mm. The time that may elapse between the root weld and hot pass welding, may not be longer than 5min.

When welding connections and at spots where the terrain configuration was not easily accessible, the E welding process was used, with the basic coating, namely, the root pass was done by EN ISO 2560-A E 42 5B 12 45 OK 53.70, and other welds were done by means of an electrode EN ISO 2560-A E 50 4 Y B 42 H5 OK 74.70 Ø3,2mm.

The welding current ranged from 90-110A at root pass, 100-120A at hot pass, 110-130A at filler welds and 110-120A at final pass. The voltage ranged from 19V for root pass, up to 24V for the final pass.

Figure 4. *An Operator monitors the welding head operation in MAG process*

Slika 4. *Operater prati rad glave za zavarivanje MAG postupkom*

The welding technology of the second Contractor of works – Saipem differed in terms of the filler materials selection, for mechanized MAG process, in the way implying the electrode wire 14341-A G4Si1 OK Autrod 12.66 Ø1.0mm [2].

For the assembly welds and for weld repairs, there was used E process, namely, for root pass, an electrode with a cellulose coating EN ISO 2560-A E 38 3 C 21 Bohler FOX CEL Ø3,2 mm [3]. The other welds were done with an electrode with basic coating EN ISO 18275-A E 56 6NiMo B 4 2 H5, of Ø3.2 and 4.0mm diameter. Welding position PH, from the bottom to the top, unlike the mechanized MAG welding process.

Welding parameters for mechanized MAG process are, as follows:

The strength of the current, depending on the pass, ranged from 200-260A at root pass, 180-240A at the hot pass, 180-240A for filler weld, and 120-180A for final weld. The voltage of the arc from 22 to 26V, in that, pulsation was used for other passes, except the root pass, and the frequency ranged from 80 to 160 No/min.

The welding speed ranged from 90cm/min for root pass, from 50cm/min for hot pass and filler welds and around 30cm/min for the final weld.

Welding parameters for E process are, as follows:

The strength of the current, depending on the pass, was around 100A at the root pass, 100-120A at the hot pass, 160-180A for filler welds, and 110-130A for the final weld. Arc voltage from 18 to 24V.

Welding speed ranged from 10cm/min for the root pass, around 12-14cm/min for filler welds, and around 10cm/min for the final weld.

Welding position PH, shielding gas, gases mixture 30% Ar and 70% CO_2. As in the case of the first Contractor, the time between the root pass and the hot pass may have not exceeded 5 min.

3. Welding processes used in the pipeline Interconnector Serbia - Bulgaria

In this gas pipeline, the welding was also performed by two contractors, KONVAR Serbia and HABAU Austria-Romania. The welding technogy with both contractors was similar, that is, the root pass was performed by MAG process 135, by solid wire Ø1.0mm, position PJ, and the filler weld was welded by MAG -136 process, by filled wire Ø1.2mm, position PH. The difference was only in the welding equipment, with Habau – it was STT - Lincoln Electric, while in Konvar it was LSC Fronius for the root pass welding. Welding of the hot pass, filler weld and final weld were performed by automatic devices Piper plus, with Habau, and Proteus devices, with Konvar.

Figure 5. *Welding on the route*

Slika 5. *Zavarivanje na trasi*

This welding technology was used for overhead welding in the route, the welding parameters were similar, and the selection of the filler material was different. For welding of the root pass Konvar used Bohler EMK6 EN ISO 14341-A G 42 4 M21 3 Si [3], while Habau used Supramig Ultra EN ISO 14341-A G50 5 M 4 Si1.

For welds of the hot pass, filling and final pass, Konvar used the filled electrode wire Bohler Diamond Sparks 52RC EN ISO 17632-A T 46 4 P M21 H5, while Habau used Fluxofil MHD EN ISO 17632-A T 46 3 PM 1 1 H5 [4].

Root pass welding parameters: current strength 90-120A, voltage 15-17V, welding speed 18cm/min, hot pass and filler welds: current strength 160-175A, voltage 22-25V, welding speed 17-19cm/min. Final weld: current strength 170-190A, voltage 23-25V, welding speed 16-18cm/min with pulsation.

Connection welds, repair of welded joints, as well as the sections of the route in inaccessible mountain conditions were being welded by E process, by means of cellulose coated electrode. The welding technology with both contractors was the same, as well as the selection of additional material. For the root pass the electrode used was the one with a cellulose coating Bohler Fox Cel Ø3,2mm, EN ISO 2560-A E 38 3 C21, and for filler welds and final weld it was Bohler Fox Cel Mo Ø3,2 ili 4,0mm, EN ISO 2560-A E 42 3 Mo C 25.

Welding parameters: root pass – current strength 80-90A, voltage 22-23V, welding speed 8 to 10cm/min; hot pass and filler welds - current strength 95-105A, voltage 23-24V, welding speed 10-12cm/min and the final weld - current strength 100-110A, voltage 25-26V, welding speed 10cm/min.

Self-shielded wire was not used for welding in these two gas pipelines, although the welding process is much simpler, but the aforementioned processes. For this process it is necessary to have the internal centralizer with a copper ring, which Saipem possessed and to have special guns for self-shielded wire.

Figure 6. *Automatic welding device with self-shielding wire*

Slika 6. *Uređaj za automatsko zavarivanje samozaštitnom žicom*

4. Conclusion

Based on the experiences gained in these two gas pipelines, as well as the gas pipeline, constructed by the end of the last century, it may be said that each technology has its advantages and shortcomings.

While at E-process welding by means of an electrode with cellulose coating all failures in preparation of a joint may be corrected by a skillful welder, the problem is productivity, because with pipe wall thickness of 8.7mm and diameter of 711mm, one welder may weld 1 to 2 welds during the day.

This process is unavoidable when performing welding connections and when welding in not easily accessible terrains. MAG welding process when the centralizer does not have the copper ring, requires programmes for weld root welding and sensitivity to the occurrence of porosity, particularly if the gas pipeline passes near big watercourses.

Another problem, incurred here refers to pipe dimensions tolerances, because there are big differences in allowable deviation of pipe circumference, ovality and thickness of the pipe wall. This process is almost two and half times more productive, but it's shortcoming is in insufficient penetration, particularly if the pipe wall thicknesses exceeded 10mm. The welding process with self-shielding wire is the most productive from all the mentioned ones, there are no problems with seam porosity occurrence or insufficient penetration, both in the weld root, and the pipe walls. Possessing the internal centralizer with a copper ring always enables good penetration of weld root and overcoming all problems related to the pipe quality, allowable dimensional deviations. The shortcoming is high cost of self-shielded wire, compared to the price of other filler materials and poor selection of self-shielded wires for welding pipes made of better quality steels -X70.

4. Zaključak

Na osnovu iskustva sa ova dva gasovoda, kao i gasovoda, koji rađen krajem prošlog veka ,svaka tehnologija ima svoje prednosti i mane.

Dok kod zavarivanja E postupkom elektrodom sa celuloznom oblogom, sve greške u pripremi spoja , vešt zavarivač može da ispravi, problem je produktivnost, jer kod debljine zida cevi 8,7 mm i prečnika 711 mm, jedan zavarivač može da zavari 1 do 2 zavara u toku dana.

Ovaj postupak je neizbežan kod zavarivanja konekcija i zavarivanja na nepristupačnom terenu. Zavarivanje MAG postupkom ako centralizer ne poseduje bakarni prsten, zahteva posebne programe za zavarivanje korena vara i osetljivost na pojavu poroznosti, naročito ako gasovod prolazi blizu velikih vodotokova.

Problem koji se ovde još javlja, su tolerancije dimenzija cevi, jer imate velike razlike u dozvoljenom odstupanju obima cevi, ovalnosti i debljini zida cevi. Ovaj postupak ima skoro dva i po puta veću prodiktivnost, ali ima nedostatak u nedovoljnoj penetraciji, naročiti ako su debljine zida cevi veće od 10mm. Postpak zavarivanja samozaštitnom žicom je naj produktivniji od svih navedenih, nema problema sa pojavom poroznosti u šavu ili sa nedovoljnom penetracijom , kako u korenu vara, tako i na zidove cevi. Posedovanje unutrašnjeg centralizera sa bakarnim prstenom omogućava uvek dobar provar i sve probleme vezane za kvalitet cevi, koji se odnose na dozvoljena dimenzionalna odstupanja.

Nedostatak je visoka cena samozaštine žice u poređenju sa cenom ostalih dodatnih materijala i mali izbor samozaštitnih žica za zavarivanjr cevi od kvalitetnijih čelika X70.

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[4] https://www.lincolnelectric.com/en-GB/Products

ČASOPIS ZAVARIVANJE I ZAVARENE KONSTRUKCIJE
Cenovnik oglasnog prostora u četiri uzastopna broja 2024

	A4	2/2	1/1	1/2	1/4	1/8
	dimenzije (mm)	2 x 210 x 297	210 x 297	180 x 120	90 x 120	90 x 60
DIN	crno/beli	-	42 900	25 300	17 600	11 000
	kolor	115 500	82 500	-	-	-

- <u>U cene nije uračunat PDV 20%.</u>
- Objavljivanje oglasa u samo jednom broju iznosi 30% od datih cena.
- Reklamni tekstovi: 25 % od cene površine crno/belih oglasa.
- Dostava materijala:
  - za crno-beli film ili CD (Adobe Photoshop / CorelDRAW);
  - za kolor film ili CD (Adobe Photoshop / CorelDRAW);
  - izrada filma sa CD: 10 % od cene angažovanog prostora.
- Na web prezetaciji DUZS-a, (<u>www.duzs.org.rs</u>), na strani <u>Marketing</u>, objavljuje se pregled firmi-oglašivača sa podacima o glavnim grupama proizvoda/usluga i adresom web prezetacije. Svi posetioci naše web prezentacije mogu da posete i web prezentacije oglašivača, preko aktivnih linkova koji se nalaze na ovoj stranici!

WELDING & WELDED STRUCTURES, Quarterly review
Advertising prices for four successive numbers in 2024

	A4	2/2	1/1	1/2	1/4	1/8
	dimensions (mm)	2 x 210 x 297	210 x 297	180 x 120	90 x 120	90 x 60
EUR	black/white	-	924	480	372	264
	colour	2 880	1 848		-	-

- VAT 20% included.
- Advertising in one number only is 35% of the given prices.
- Commercial articles: 30 % of black/white advertising price.
- Print material:
  - for black/white CD (Adobe Photoshop / CorelDRAW)
  - for color CD (Adobe Photoshop / CorelDRAW).
- All the visitors of our web site may be linked to the advertisers' web site.

INDEKS OGLAŠIVAČA
ADVERTISERS INDEX

MESSER TEHNOGAS

REFIT INŽENJERING

YASKAWA SLOVENIJA

HONEX

ELIMP

NEMINIK

SIGMA LAB

EDC D.O.O. HRVATSKA

TMS CEE D.O.O BEOGRAD

1. **ČLANARINA DUZS za 2024. godinu** .... **3.500 dinara**

   Članovima DUZS **GRATIS** godišnje izdanje časopisa "ZAVARIVANJE I ZAVARENE KONSTRUKCIJE"

2. **ČASOPIS "ZAVARIVANJE I ZAVARENE KONSTRUKCIJE" - 2024. godina**
   u slobodnoj prodaji (u cene je uračunat PDV 10%):
   - cena pojedinačnog broja.. 825 dinara
   - godišnja pretplata za 1 komplet brojeva godišnjeg izdanja.. 2.500 dinara
3. **ČASOPIS - stari brojevi** (u cene je uračunat PDV 10%)

   a) u slobodnoj prodaji:
   - cena pojedinačnog broja za 2023. godinu .... 500 dinara
   - cena pojedinačnog broja za prethodne godine.. 250 dinara

   b) beneficirane cene za članove DUZS:
   - cena pojedinačnog broja za 2023. godinu (pouzećem ili preuzimanjem) .... 400 dinara
   - cena pojedinačnog broja za prethodne godine (pouzećem ili preuzimanjem) .... <u>Gratis</u>
4. **Knjiga Organizacija i ekonomika zavarivačkih radova –** autor: prof. dr Zoran Radojević (uračunat PDV 10%) .... 1.045 dinara
5. **Zbirke standarda OBEZBEĐENJE KVALITETA U ZAVARIVANJU, komplet 4 toma** 6.750 dinara