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WELDING TEHNOLOGY FOR STEEL P460NL2

TEHNOLOGIJA ZAVARIVANJA ČELIKA P460NL2

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Ključne reči: P460NL2, MAG, EPP, tvrdoća, NACE MR0103, MR0175

Abstract

This paper presents the development of welding technology for P460NL2 steel with a thickness of 30 mm. The technology was developed for the purpose of producing housings in which the device PIG-Pipeline Inspection/Intervention Gauge intended for testing and maintenance of pipelines is installed. In this particular case, the housings were intended for cleaning pipelines for the transport of acid-aggressive gases. The material was selected in accordance with NACE MR0175/ISO 15156 and ASME BPVC IKS standards. The welding technology is made for butt joint, root pass with GMAW, and other layers filled with SAW. Preheating and heat treatment after welding were performed to restore the structure. Standard tests are conducted such as: metallography, hardness test, tensile test and toughness, and the results are presented and commented in this paper. In conclusion, the welding technology gives satisfactory results, but, in terms of meeting the specifics of the NACE MR0103 and MR0175 standards, it shows increased hardness in the transition zone, in the HAZ.

Rezime

U ovom radu je prikazan razvoj tehnologije zavarivanja čelika P460NL2 debeljine 30 mm. Tehnologija je razvijena u svrhu proizvodnje kućišta u kojima se postavlja uređaj PIG-Pipeline Inspection/Intervention Gauge namenjen za ispitivanje i održavanje cevovoda. U konkretnom slučaju, kućišta su bile predviđena za čišćenje cevovoda za transport kiselo-agresivnih gasova. Materijal je odabran u skladu sa standardima NACE MR0175/ISO 15156 i ASME BPVC IKS. Tehnologija zavarivanja je izrađena za sučeoni spoj, korenskim prelazom sa GMAW-om, a ispunjena sa EPP-om. Za povrat strukture izvršeno je predgrevanje i termička obrada nakon zavarivanja. U radu su prikazani rezultati sprovedenih standardnih ispitivanja: metalografije, tvrdoće, zatezanja i žilavosti. Zaključno, tehnologija zavarivanja daje zadovoljavajuće rezultate, ali, u smislu ispunjavanja specifičnosti standarda NACE MR0103 i MR0175, pokazuje povećanu tvrdoću u prelaznoj zoni, u ZUT-u.

1. Introduction

The housings for test and cleaning devices „PIG“ are used in environment of H_2S which is hydrogen promoter, thus later induction of hydrogen in the metal is supported. Therefore the high values of hardness after welding pose a problem. As it is known, high hardness is always associated with increased risk of cold crack failure [1, 2]. The construction of the housings should comply with the relevant NACE standards.

The adsorption and absorption of harmful amounts of hydrogen atoms in the steel after welding can be expected, when promoters such as H_2S acidic water solutions (pH <3) or clean active surfaces, support hydrogen absorption. Absorbed corrosive hydrogen can cause cracks even without external loads. Therefore, the problem with the high values of hardness is doubling dangerous. First, due to the fact that the high values of hardness depend on the wrong heat input, which already supports the absorption of carbon and hydrogen when welding, and as a result of the environment in which the material is used. Reducing sulphur content can be used in the fight against hydrogen induced cracks (HIC) [3, 4].

Adequate welding conditions should limit the absorption of hydrogen and allow its effusion. However, the optimization should include: 2

- Preparation of the welding environment, taking into account the thickness of the elements,
- Preheating,
- Type of welding and type of welded joint,
- Selection of suitable additional materials for welding and shielding gases,
- Welding mode, selection of optimal welding parameters,
- Heat treatment, annealing after welding.

Formulas for determining the equivalent carbon [5] content are used as a starting point to assess the sensitivity to the appearance of cracks and to optimize the preparations of the welding itself, but also to calculate the preheating temperature. There are numerous formulas for determining the equivalent carbon content, whereby the influence - the share of the content of individual alloying elements is taken into account differently. It is necessary to go into it in detail, because the hardness also encourages the appearance of cracks and needs to be analyzed, and if conclusions can be drawn and which welding parameters should be taken into account, due to the danger of the appearance of cracks based on the formulas for determination of equivalent carbon content.

2. Properties of fine-grain steel P460NL2

The chemical composition and mechanical properties of the steel P460NL2 are given in Table 1 and 2 according to DIN EN 10028-3.

Table 1. *Chemical composition in (% wt.) of P460NL2 steel*

Tabela 1. *Hemijski sastav u (% tež.) čelika P460NL2*

C max	Si max	Mn	P max	S max	Al min	N max	Cr max	Cu max	Mo max	Nb max	Ni max	Ti max	V max
0.20	0.60	1.1÷1.7	0.02	0.01	0.020	0.025	0.3	0.7	0.1	0.05	0.80	0.03	0.20

Table 2. *Mechanical properties of P460NL2 steel at room temperature*

Tabela 2. *Mehanička svojstva čelika P460NL2 na sobnoj temperaturi*

t (mm)	R_{eHmin} (N/mm^2)	R_m (N/mm^2)	A_{min} (%)
16 < t ≤ 40	445	570 ÷ 720	17

Steel P460NL2 is developed on the basis of normalized constructive S460N steel [6]. By reducing carbon content, effective methods are used to increase strength and reduce grain size such as micro alloying and additional thermo-mechanical processing. The result is a particularly fin -grained structure, which further enhances the tensile strength and improves the impact toughness at the same time. Furthermore, steel is easier to transform through a fine -grained structure, thereby significantly reducing the danger of increasing the hardness in the transitional zone of the welded joint. Further improvements, especially strength features (ReH and Rm), can be achieved through special thermal processing.

Particularly favourable values for impact toughness are achieved down to -40°C (ML1, QL1), -50°C (NL1, NL2, ML2) and -60°C (QL2). This is group of steels for low temperature application where P460NL2 belongs [7].

3. Weldability of P460NL2

The formula for calculating the equivalent carbon content CET [8] was formulated in 1991 by Uwer and Höhne and is currently the most comprehensive formula for calculating the equivalent carbon content for cold cracking prevention.

$$CET = C + \frac{Mn + Mo}{10} + \frac{Cr + Cu}{20} + \frac{Ni}{40} (\%) \qquad (1)$$

Weldability of steel is good or satisfactory when CE ≤ 0.4%. The CET value of the test series is found at 0.33255%. This means that the steel has good weldability.

The occurrence of cold cracks in welded joints is not limited to the chemical composition of the base material and the weld metal, among other things it is largely determined by:

- thickness d (mm),

- the hydrogen content in the weld metal HD (ml/g),

- heat input into the material during welding Q (J/mm),

- the magnitude and distribution of residual stresses in the welded joint.

Very important influence on the structure in HAZ of weld has its chemical composition, the virgin microstructure and the cooling time in the temperature interval when the austenite unstable, which is between 800-500°C [9]. The cooling time is determined by the physical properties of the steel, the thermal conductivity and specific heat, the thickness of the base metal, the type of joint and the welding parameters. Lowering the base metal temperature along the groove edge, accelerates the cooling of the HAZ and shortens $t_{8/5}$. Therefore, in the HAZ, the possibility to form structures that are prone to martensite increases and capturing gases inside metal weld and HAZ.

4. Determination of welding technology

Determination of welding technology, especially pre-heating temperature, inter-pass temperature, cooling time $t_{8/5}$ which have significant impact on the microstructure are determined according to EN 1011-2, guidelines for arc welding of ferritic steels [10,11].

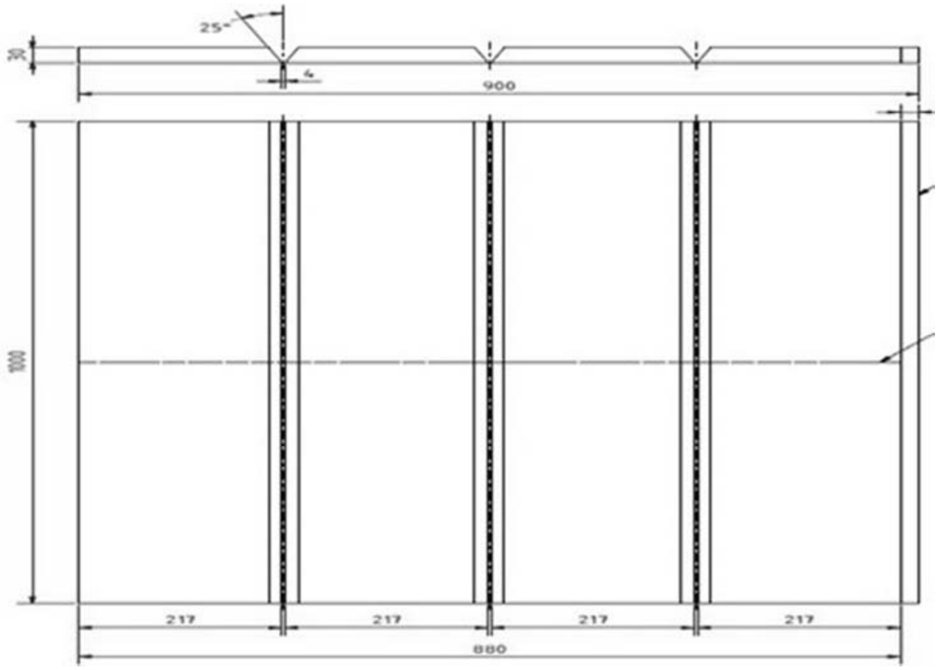


Figure 1. *Test plates and joint preparation*

Slika 1. *Ispitne ploče i priprema spoja*

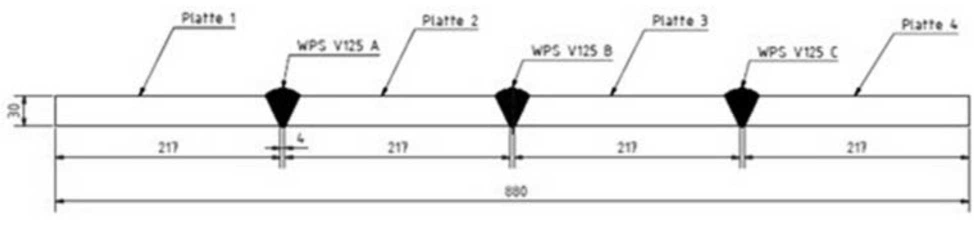
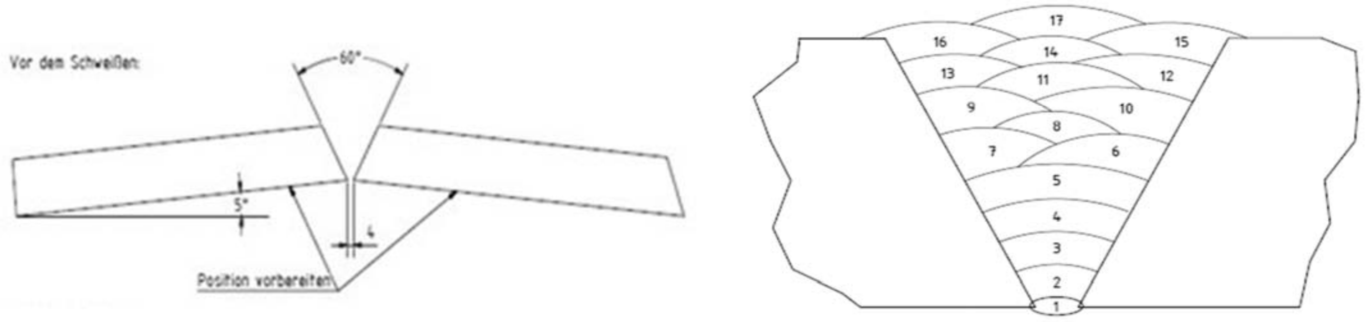


Figure 2. *Butt weld test joints*

Slika 2. *Ispitni spojevi sučeonog zavarivanja*



a) b)

Figure 3. *a) predeformation angle of 5°; b) welding sequence 1-3 with GMAW, 4-17 with SAW*

Slika 3. *a) ugao preddeformacije od 5°; b) sekvence zavarivanja 1-3 sa MAG, 4-17 sa EPP*

The tests were performed on three welds (Fig.2). Certain parameters of the welding mode are identical in the three welded samples, in the three WPSs:

- thickness of the basic welded materials 30 (mm),
- type of weld BW,
- welding position horizontal PA,
- width of the weld groove 4 (mm),
- bevel angle of the groove 50°,
- preheating temperature 120 °C,
- interpass temperature 220 °C,
- $t_{8/5}$ is adopted 25 sec.,
- number of layers during welding 17,
- root and layers 2 and 3, made with GMAW,
- filling layers from 4 to 17, made with SAW,
- filler metal for GMAW, wire: G50 6 M Z3Ni1 / G46 4 C Z3Ni1 (Union K52 Ni),
- shielding gas for GMAW: M21 ($ArCO_2$-18),
- GMAW wire diameter: Ø 1.0 (mm),
- filler metal for SAW, wire: EN ISO 14171-A/ SZ 2 Ni1Mo (Union S 2 NiMo1),
- shielding powder for SAW: SZ 2 Ni1Mo (UV 418 TT),
- diameter of SAW wire: Ø 4.0 (mm).

After welding, the elements should be wrapped in mineral wool, in order to reduce the cooling speed.

During the GMAW welding of the first three layers, the root layer is performed with a short arc, and the filling of the second and third layer is performed with a spray arc.

Values for the variable parameters of the welding mode, such as:

- welding current,
- welding voltage,
- wire feed speed,
- welding speed,

are determined experientially and with the help of a graphical selector guide table.

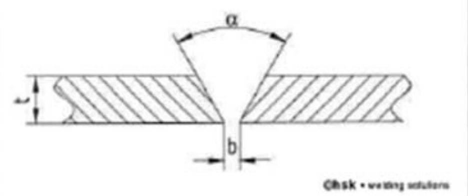
Tables 3, 4 and 5 show some of the WPSs according to which the three experimental welds were performed, namely: WPS V125 A, WPS V125 B and WPS V125 C.

Ort:	Kehl - Marlen	Prüfer oder Prüfstelle:		
WPQR-Nr.:	V125 A	Art der Vorbereitung und Reinigung:	Autogen Brennschneiden / Beschleifen	
Schweißer- qualifikation:	EN 287-1; Bediener nach EN 1418	Bearbeitung der Wurzellage:	Schleifen	
Schweißprozess:	(MAG), (UP)	Spezifikation Grundwerkstoff(e):		Gruppennr. ISO 15608:
Nahtart:	Stumpfnaht	1) [1.8918] P460NL2		1.3
Kunde:	Masterarbeit	2) [1.8918] P460NL2		1.3
Auftrags-Nr.:	28491	Werkstoffdicke:	30 mm	
Zeichnungs-Nr.:	28941_Masterarbeit Schweißen	Außendurchmesser:		
Teile-Nr.:	1, 2	Schweißposition:	PA	

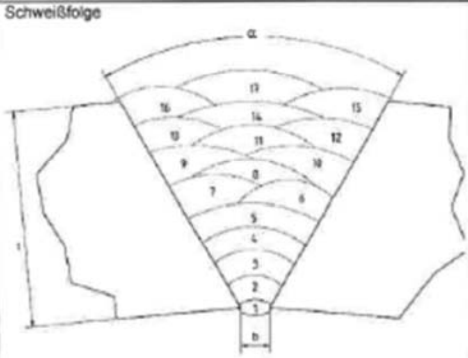
Maße:

α = 50 °
b = 4 mm
t = 30 mm

Gestaltung der Verbindung



Schweißfolge



Bemerkung:

Einzelheiten für das Schweißen

	Schweißlage	Prozess	Ø Schweiß-zusatz [mm]	Strom	Spannung [V]	Stromart / Polung	Draht-vorschub-geschw.	Schweiß-geschwindig-keit [cm/min]	Wärme-einbringung [kJ/mm]
A)	Wurzellage	135	1,0	88-90 A	17-19	= / +	3,5 m/min	15-18	0,399 - 0,547
B)	Fülllage 2	135	1,0	165 - 180 A	20-22	= / +	7,4 m/min	??????	
C)	Fülllage 3	135	1,0	240 - 250 A	24-26	= / +	13,5 m/min	36	0,768 - 0,867
D)	Fülllage 4	135	1,0	245 - 255 A	24-26	= / +	13,6 m/min	30	0,941 - 1,061
E)	Füll/Decklage 4-17	121	4,0	550-650 A	29 -31	= / +	1.3 m/min	38 -48	1,994 - 3,182

Schweißzusatz / Schweißpulver — Sondervorschriften für Trocknung

	Bezeichnung	Markenname	Hersteller	Zeit [h]	Temperatur [°C]
A)	G 50 6 M Z3Ni1 / G46 4 C Z3Ni1	Union K52 Ni	Böhler (t-put)		
B)	G 50 6 M Z3Ni1 / G46 4 C Z3Ni1	Union K52 Ni	Böhler (t-put)		
C)	G 50 6 M Z3Ni1 / G46 4 C Z3Ni1	Union K52 Ni	Böhler (t-put)		
D)	G 50 6 M Z3Ni1 / G46 4 C Z3Ni1	Union K52 Ni	Böhler (t-put)		
E)	S 50 6 FB SZ	Union S 2 NiMo 1/UV 418 TT	Böhler (t-put)	2	300 - 350

Schutzgas

	Typ	Markenname	Hersteller	Durchfluss [l/min]	Vorström- zeit [s]	Nachström-zeit [s]
A)	Schweißen: M21-ArC-18	ARCAL 5	Air Liquide	15		
B)	Schweißen: M21-ArC-18	ARCAL 5	Air Liquide	15		
C)	Schweißen: M21-ArC-18	ARCAL 5	Air Liquide	15		
D)	Schweißen: M21-ArC-18	ARCAL 5	Air Liquide	15		

Weitere Informationen

	Parameter / Wert
A)	Gaskappengröße: 15 Werkstoffübergang: Kurzlichtbogen Kontaktrohrabstand: 8 - 12 mm
B)	Gaskappengröße: 15 Werkstoffübergang: Mischlichtbogen Kontaktrohrabstand: 8 - 12 mm
C)	Gaskappengröße: 15 Werkstoffübergang: Mischlichtbogen Kontaktrohrabstand: 8 - 12 mm
D)	Gaskappengröße: 15 Werkstoffübergang: Mischlichtbogen Kontaktrohrabstand: 8 - 12 mm
E)	Kontaktrohrabstand: 18 - 22 mm

Pendeln:	Strichraupe
Vorwärmtemperatur[°C]:	120
Zwischenlagentemperatur [°C]:	220
Verfahren	Glühen
Art der Erwärmung	Ofen
Aufheizrate	< 373 K/h
Haltetemperatur	621 +/- 5 °C
Haltezeit	40 min
Abkühlung	Ofen bis 200 ° C, ruhender Luft
Abkühlrate	< 124 K/h

Datum / Erstellt:	Datum / Geprüft:	Datum / Freigegeben:
08.04.2013 M.Blazeska Poser	08.04.2013 A. Schulz	
Unterschrift	Unterschrift	Unterschrift

Table 3. *WPS V125 A*

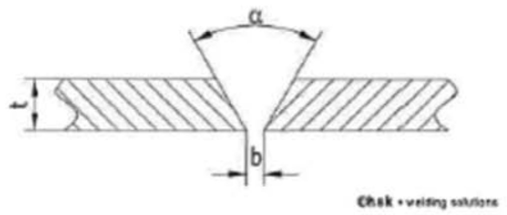
Tabela 3. WPS V 125 A

Ort:	Kehl - Marlen	Prüfer oder Prüfstelle:	
WPQR-Nr.:	V125 B-1	Art der Vorbereitung und Reinigung:	Autogen Brennschneiden / Beschliefen
Schweißer- qualifikation:	EN 287-1; Bediener nach EN 1418	Bearbeitung der Wurzellage:	Schleifen
Schweißprozess:	(MAG), (UP)	Spezifikation Grundwerkstoff(e):	Gruppennr. ISO 15608:
Nahtart:	Stumpfnaht	1) [1.8918] P460NL2	1.3
Kunde:	Masterarbeit	2) [1.8918] P460NL2	1.3
Auftrags-Nr.:	28491	Werkstoffdicke:	30 mm
Zeichnungs-Nr.:	28941_Masterarbeit Schweißen	Außendurchmesser:	
Teile-Nr.:	3, 4	Schweißposition:	PA

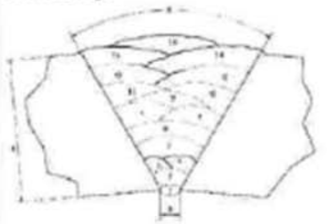
Maße:

α = 50 °
b = 4 mm
t = 30 mm

Gestaltung der Verbindung



Schweißfolge



Bemerkung:

Einzelheiten für das Schweißen

	Schweißlage	Prozess	Ø Schweiß-zusatz [mm]	Strom	Spannung [V]	Stromart / Polung	Draht-vorschub-geschw.	Schweiß-geschwindig-keit [cm/min]	Wärme-einbringung [kJ/mm]
A)	Wurzellage	135	1,0	84 - 92 A	16 - 17	= / +	3,8 m/min	18 (30)	0,215 - 0,417
B)	Fülllage 2	135	1,0	145 - 155 A	19 - 20	= / +	6, 8 m/min	30	0,441 - 0,496
C)	Fülllage 3	135	1,0	200 - 210 A	22 - 25	= / +	10,2 m/min	33	0,640 - 0,764
D)	Fülllage 4	135	1,0	200 - 210 A	22 - 25	= / +	9,8 m/min	33	0,640 - 0,764
E)	Füll/Decklage 5-16	121	4,0	500-600 A	29 - 31	= / +	1-1,1 m/min	[redacted]-45	1,933 - 3,189

Schweißzusatz / Schweißpulver — Sondervorschriften für Trocknung

	Bezeichnung	Markenname	Hersteller	Zeit [h]	Temperatur [°C]
A)	G 50 6 M Z3Ni1 / G46 4 C Z3Ni1	Union K52 Ni	Böhler (t-put)		
B)	G 50 6 M Z3Ni1 / G46 4 C Z3Ni1	Union K52 Ni	Böhler (t-put)		
C)	G 50 6 M Z3Ni1 / G46 4 C Z3Ni1	Union K52 Ni	Böhler		
D)	G 50 6 M Z3Ni1 / G46 4 C Z3Ni1	Union K52 Ni	Böhler		
E)	S 50 6 FB SZ	Union S 2 NiMo 1/UV 418 TT	Böhler (t-put)	2	300 - 350

Schutzgas

	Typ	Markenname	Hersteller	Durchfluss [l/min]	Vorström- zeit [s]	Nachström- zeit [s]
A)	Schweißen: M21-ArC-18	ARCAL 5	Air Liquide	15		
B)	Schweißen: M21-ArC-18	ARCAL 5	Air Liquide	15		
C)	Schweißen: M21-ArC-18	ARCAL 5	Air Liquide	15		
D)	Schweißen: M21-ArC-18	ARCAL 5	Air Liquide	15		

Weitere Informationen

	Parameter / Wert
A)	Gaskappengröße: 15 Werkstoffübergang: Kurzlichtbogen Kontaktrohrabstand: 8 - 12 mm
B)	Gaskappengröße: 15 Werkstoffübergang: Mischlichtbogen Kontaktrohrabstand: 8 - 12 mm
C)	Gaskappengröße: 15 Werkstoffübergang: Mischlichtbogen Kontaktrohrabstand: 8 - 12 mm
D)	Gaskappengröße: 15 Werkstoffübergang: Mischlichtbogen Kontaktrohrabstand: 8 - 12 mm
E)	Kontaktrohrabstand: 18 - 22 mm

Pendeln:	Strichraupe
Vorwärmtemperatur[°C]:	120
Zwischenlagentemperatur [°C]:	[redacted]180
Verfahren	Glühen
Art der Erwärmung	Ofen
Aufheizrate	< 373 K/h
Haltetemperatur	621 +/- 10 °C
Haltezeit	45 min
Abkühlung	Ofen bis 200 ° C, ruhender Luft
Abkühlrate	< 124 K/h

Table 4. *WPS V125 B*

Tabela 4. *WPS V125 B*

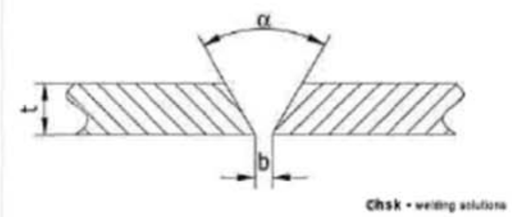
Ort:	Kehl - Marlen
WPQR-Nr.:	V125 B-1
Schweißer- qualifikation:	EN 287-1; Bediener nach EN 1418
Schweißprozess:	(MAG), (UP)
Nahtart:	Stumpfnaht
Kunde:	Masterarbeit
Auftrags-Nr.:	28491
Zeichnungs-Nr.:	28941_Masterarbeit Schweißen
Teile-Nr.:	2,3

Prüfer oder Prüfstelle:		
Art der Vorbereitung und Reinigung:	Autogen Brennschneiden / Beschliefen	
Bearbeitung der Wurzellage:	Schleifen	
Spezifikation Grundwerkstoff(e):		Gruppennr. ISO 15608:
1) [1.8918] P460NL2		1.3
2) [1.8918] P460NL2		1.3
Werkstoffdicke:	30 mm	
Außendurchmesser:		
Schweißposition:	PA	

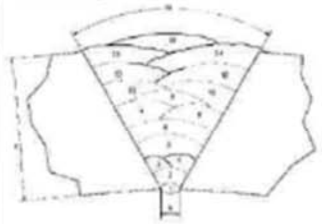
Maße:

α = 50 °
b = 4 mm
t = 30 mm

Gestaltung der Verbindung



Schweißfolge



Bemerkung:

Einzelheiten für das Schweißen

	Schweißlage	Prozess	Ø Schweiß-zusatz [mm]	Strom	Spannung [V]	Stromart / Polung	Draht-vorschub-geschw.	Schweiß-geschwindig-keit [cm/min]	Wärme-einbringung [kJ/mm]
A)	Wurzellage	135	1,0	86 - 90 A	17 - 18	= / +	3,7 -3,8 m/min	48	0,146 - 0,162
B)	Fülllage 2	135	1,0	180 - 190 A	22-23	= / +	8,9 - 9,0 m/min	25	0,760 - 0,839
C)	Fülllage 3	135	1,0	250-265 A	28 - 29	= / +	14,9 - 15 m/min	29	1,159 - 1,272
D)	Füll/Decklage 5-16	121	4,0	550 - 600 A	29-31	= / +	1-1,1 m/min	40-50	1,914 - 2,790

Schweißzusatz / Schweißpulver — Sondervorschriften für Trocknung

	Bezeichnung	Markenname	Hersteller	Zeit [h]	Temperatur [°C]
A)	G 50 6 M Z3Ni1 / G46 4 C Z3Ni1	Union K52 Ni	Böhler (t-put)		
B)	G 50 6 M Z3Ni1 / G46 4 C Z3Ni1	Union K52 Ni	Böhler (t-put)		
C)	G 50 6 M Z3Ni1 / G46 4 C Z3Ni1	Union K52 Ni	Böhler		
D)	S 50 6 FB SZ	Union S 2 NiMo 1/UV 418 TT	Böhler (t-put)	2	300 - 350

Schutzgas

	Typ	Markenname	Hersteller	Durchfluss [l/min]	Vorström- zeit [s]	Nachström-zeit [s]
A)	Schweißen: M21-ArC-18	ARCAL 5	Air Liquide	13		
B)	Schweißen: M21-ArC-18	ARCAL 5	Air Liquide	13		
C)	Schweißen: M21-ArC-18	ARCAL 5	Air Liquide	13		

Weitere Informationen

	Parameter / Wert
A)	Gaskappengröße: 15 Werkstoffübergang: Kurzlichtbogen Kontaktrohrabstand: 8 - 12 mm
B)	Gaskappengröße: 15 Werkstoffübergang: Mischlichtbogen Kontaktrohrabstand: 8 - 12 mm
C)	Gaskappengröße: 15 Werkstoffübergang: Mischlichtbogen Kontaktrohrabstand: 8 - 12 mm
D)	Kontaktrohrabstand: 18 - 22 mm

Pendeln:	Strichraupe
Vorwärmtemperatur[°C]:	120
Zwischenlagentemperatur [°C]:	~~220~~ 180
Verfahren	Glühen
Art der Erwärmung	Ofen
Aufheizrate	< 373 K/h
Haltetemperatur	621 +/- 10 °C
Haltezeit	45 min
Abkühlung	Ofen bis 200 ° C, ruhender Luft
Abkühlrate	< 124 K/h

Table 5. *WPS V125 C*

Tabela 5. *WPS V 125 C*

5. Post weld heat treatment

The welded samples, after the radiographic tests and determination of the quality of the weld, were subjected to additional heat treatment, annealing in order to reduce residual stresses from welding.

The heat treatment was carried out in a vacuum furnace, for duration of 11 hours and 44 minutes.

The annealing process is performed in accordance with the requirements of ASME VIII Div.1: heating rate from max. 100 °C/h (<373 K/h), up to an annealing temperature of 611 °C to 631 °C, with a holding time depending on the thickness of the base material, 1.0 min/mm, but not shorter than 45 min, by slow cooling in a furnace.

Pos. Item	Stück Qty.	Typ Type	Abmessung Dimension	Werkstoff Material	Schmelze Nr./ Probe Nr. Heat No./ Sample No.	Hersteller Manufacturer
1	4	Blech	30 x 217 x 1000	P460NL2/ P460NH	38313	Ilsenburger Grobblech (TÜV11)

Anforderungen / requirements: acc. to ASME VIII Div. 1

Glühobjekt / Object of Heat Treatment: Längsnaht Probenplatte / longitudinal weld test plate

Aufheizzeit / Time of heating on: ≤ 100 °C / h (< 373 K / h)

Glühtemperatur / Annealing temperature: 621 °C +/- 10 °C

Haltedauer / Holding time: 1,0 Min. / mm Wanddicke / mm wall thickness (45 min)

Abkühlung / Cooling: An ruhender Luft / by air in closed furnace

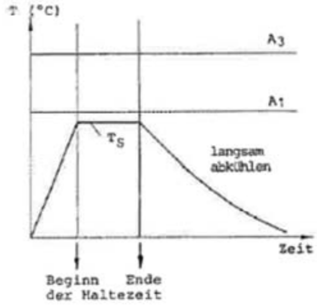


Figure 4. *PWHT parameters*

Slika 4. *Parametri termičke obrade posle zavarivanja*

6. Examination results

Tests on mechanical properties were performed on the welded samples: tensile tests, bending tests, impact toughness tests and hardness measurement. The tests are conducted in accordance with EN and DIN standards.

Table 6. *Results of tensile test of welded joint at 20°C according to EN ISO 6892 A4 and DIN EN ISO 4136*

Tabela 6. *Rezultati ispitivanja zatezanjem zavarenog spoja na 20°C prema EN ISO 6892 A4 i DIN EN ISO 4136*

WPS	Sample No.	Dimensions			Force	Tensile strength	Location of failure
		a mm	b mm	S_0 mm^2	F_m kN	R_m MPa	
A	1	24.90	25.08	624.49	364	583	BM
A	2	24.83	25.10	623.23	364	584	BM
B	1	24.90	25.08	624.49	363	581	BM
B	2	24.85	25.06	622.74	361	580	BM
C	1	24.83	25.06	622.24	361	580	BM
C	2	24.89	25.04	623.25	363	582	BM

Table 7. *Results of tensile test of all metal weld at 20°C according to EN ISO 6892 A4 and DIN EN ISO 5178*

Tabela 7. *Rezultati ispitivanja zatezanjm svih metalnih šavova na 20°C prema EN ISO 6892 A4 i DIN EN ISO 5178*

WPS	Dimensions			Force	Yield stress	Force	Tensile strength	Elongation
	d_0 mm	S_0 mm^2	l_0 mm	$F_{eH}/F_{0,2}$ N	$R_{eH}/R_{0,2}$ MPa	F_m N	R_m MPa	A_5 %
A	9.98	78.23	50	40390	516	46220	591	28.8
B	9.98	78.23	50	42540	544	47895	612	36.6
C	9.97	78.07	50	42540	545	47882	613	38.0

The bending test was performed according to DIN EN ISO 7438 and DIN EN ISO 5173 standards. 4 samples of the three welded joints were tested, with a cylindrical pusher with Ø 48 mm. The samples were placed on supports at a distance of 75 mm. All 12 test samples are bent to an angle of 180° without the appearance of cracks.

The toughness test was performed according to DIN EN ISO 148-1 and DIN EN ISO 9016 standards, according to the Charpy method with a V groove at -50°C.

For each WPS, tests were carried out in two series, on three test samples. In the first series, the groove is in the weld metal, and in the second series, the groove is in the HAZ. The results of the impact toughness are given in table 8.

Table 8. *Results from Charpy toughness*

Tabela 8. *Rezultati ispitivanja energije udara po Charpi ju*

Samples	Groove location	WPS A KV_2 (J)	WPS B KV_2 (J)	WPS C KV_2 (J)
1	WM	110	122	96
2	WM	158	104	164
3	WM	131	96	91
Average		**133**	**107**	**117**
4	HAZ	76	98	100
5	HAZ	80	104	96
6	HAZ	41	78	76
Average		**66**	**93**	**91**

The results of the measured Vickers hardness of the welded samples are shown in tables and with macroscopic images of the welded samples with marked measurement points on the weld and HAZ. The values which are higher than the requirements (248HV) set by NACE MR0103 and MR0175 for the maximum allowable values in the weld metal and HAZ are marked with red colour in the macroscopic image.

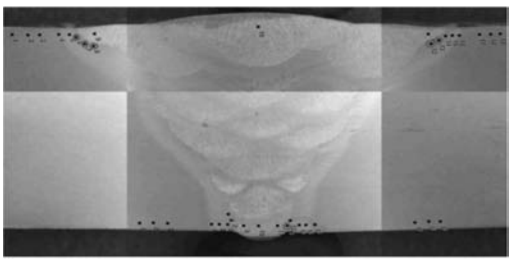


Figure 5. *Weld sample WPS V125A*

Slika 5. *Zavareni uzorak WPS V125A*

Table 9. *HV values-WPS V125A top layer*

Tabela 9. *HV vrednosti-WPS V125A gornji sloj*

Table 10. *HV values-WPS V125A bottom layer*

Tabela 10. *HV vrednosti-WPS V125A donji sloj*

Measuring point	Location	Hardness HV10	Measuring point	Location	Hardness HV10
1	Base Metal	173	1	OM	174
2	Base Metal	174	2	OM	172
3	Base Metal	176	3	OM	175
4	HAZ	186	4	3BT	192
5	HAZ	237	5	3BT	211
6	HAZ	257x	6	3BT	243
7	HAZ	250x	7	3BT	222
8	HAZ	256x	8	3BT	215
9	Weld Metal	217	9	M3	191
10	Weld Metal	210	10	M3	197
11	Weld Metal	238	11	M3	190
12	HAZ	269x	12	3BT	247
13	HAZ	262x	13	3BT	258x
14	HAZ	248	14	3BT	215
15	HAZ	203	15	3BT	194
16	HAZ	178	16	3BT	172
17	Base Metal	173	17	OM	172
18	Base Metal	173	18	OM	174
19	Base Metal	169	19	OM	172

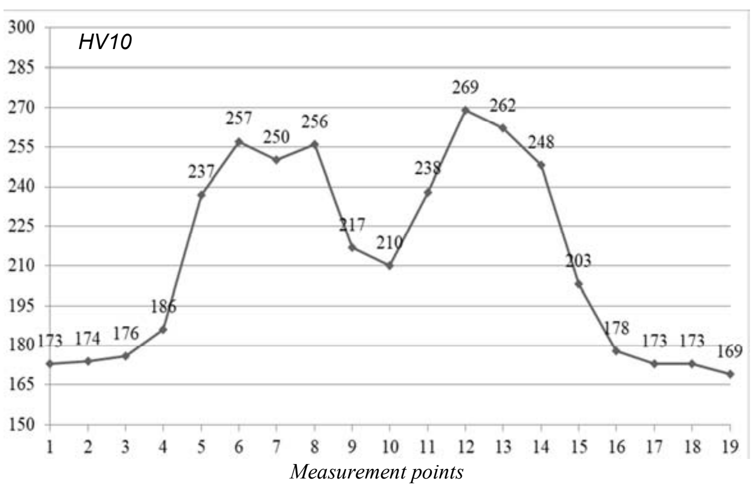


Figure 6. *Diagram for HV-WPS V125A top layer*

Slika 6. *Dijagram za gornji sloj HV-WPS V125A*

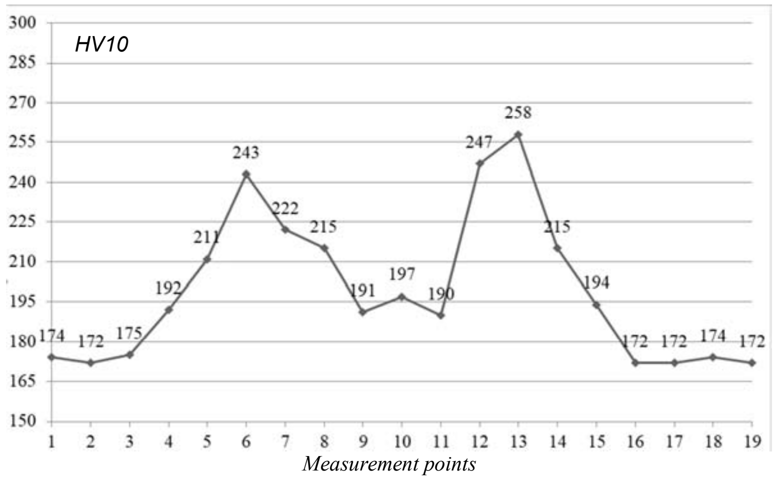


Figure 7. *Diagram for HV-WPS V125A bottom layer*

Slika 7. *Dijagram za donji sloj HV-WPS V125A*

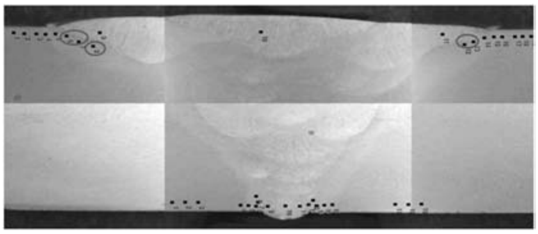


Figure 8. *Weld sample WPS V125B*

Slika 8. *Zavareni uzorak WPS V125B*

Table 11. *HV values-WPS V125B top layer*

Tabela 11. *HV vrednosti-WPS V125B gornji slo*

Table 12. *HV values-WPS V125B bottom layer*

Tabela 12. *HV vrednosti-WPS V125B donji sloj*

Measuring point	Location	Hardness HV10	Measuring point	Location	Hardness HV10
1	Base Metal	169	1	Base Metal	175
2	Base Metal	171	2	Base Metal	179
3	Base Metal	170	3	Base Metal	178
4	HAZ	185	4	HAZ	180
5	HAZ	241	5	HAZ	195
6	HAZ	259x	6	HAZ	219
7	HAZ	259x	7	HAZ	218
8	HAZ	255x	8	HAZ	202
9	Metal Weld	237	9	Metal Weld	196
10	Metal Weld	206	10	Metal Weld	192
11	Metal Weld	217	11	Metal Weld	192
12	HAZ	258x	12	HAZ	213
13	HAZ	253x	13	HAZ	202
14	HAZ	241	14	HAZ	196
15	HAZ	191	15	HAZ	184
16	HAZ	173	16	HAZ	183
17	Base Metal	175	17	Base Metal	178
18	Base Metal	175	18	Base Metal	178
19	Base Metal	177	19	Base Metal	176

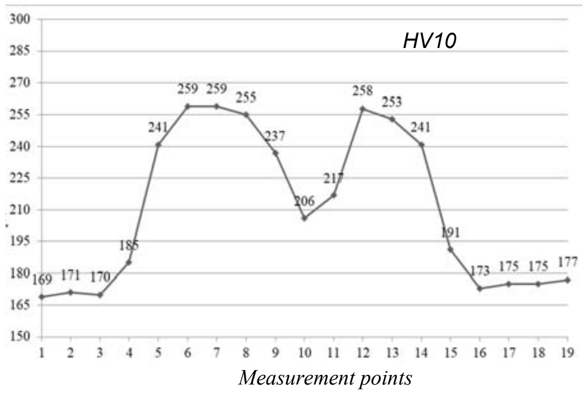


Figure 9. Diagram for HV-WPS V125B top layer

Slika 9. Dijagram za gornji sloj HV-WPS V125B

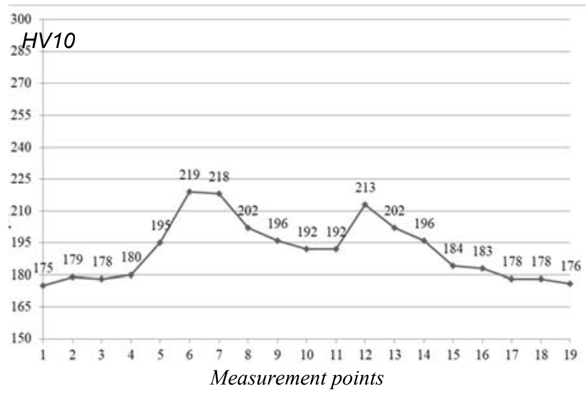


Figure 10. Diagram for HV-WPS V125B bottom layer

Slika 10. Dijagram za donji sloj HV-WPS V125B

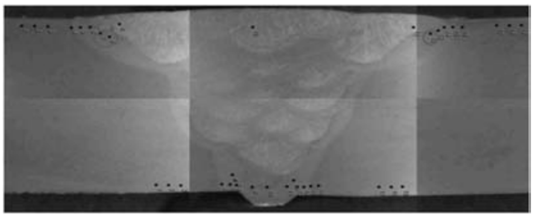


Figure 11. Weld sample WPS V125C

Slika 11. Zavareni uzorak WPS V125C

Table 13. HV values-WPS V125C top layer

Tabela 13. HV vrednosti-WPS V125C gornji sloj

Measuring point	Location	Hardness HV10
1	Base Metal	171
2	Base Metal	172
3	Base Metal	174
4	HAZ	184
5	HAZ	224
6	HAZ	269 x
7	HAZ	264 x
8	HAZ	263 x
9	Metal Weld	241
10	Metal Weld	211
11	Metal Weld	239
12	HAZ	255 x
13	HAZ	248
14	HAZ	243
15	HAZ	195
16	HAZ	173
17	Base Metal	170
18	Base Metal	171
19	Base Metal	170

Table 14. HV values-WPS V125C bottom layer

Tabela 14. HV vrednosti-WPS V125C donji sloj

Measuring point	Location	Hardness HV10
1	Base Metal	174
2	Base Metal	176
3	Base Metal	177
4	HAZ	190
5	HAZ	197
6	HAZ	225
7	HAZ	217
8	HAZ	204
9	Metal Weld	182
10	Metal Weld	160
11	Metal Weld	178
12	HAZ	211
13	HAZ	220
14	HAZ	190
15	HAZ	178
16	HAZ	178
17	Base Metal	173
18	Base Metal	174
19	Base Metal	173

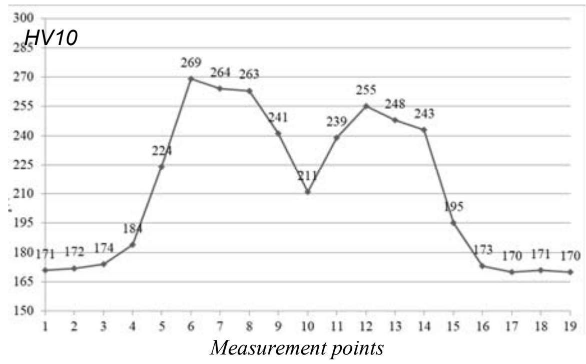


Figure 12. *Diagram for HV-WPS V125C top layer*

Slika 12. *Dijagram za gornji sloj HV-WPS V125C*

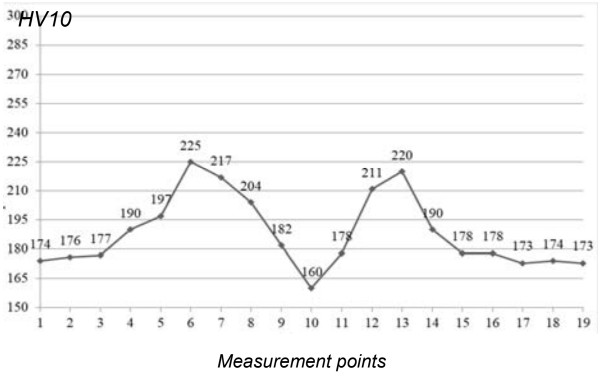


Figure 13. *Diagram for HV-WPS V125C bottom layer*

Slika 13. *Dijagram za donji sloj HV-WPS V125C*

7. Conclusion

In general, the results obtained from the tests of the welded samples are within permissible limits and are satisfactory. The maximal measured hardness is below the allowable value given in EN ISO 15614-1:2004+A2:2012.

Specifically speaking, considering standards NACE MR0103 and MR0175, some of the measured hardness values are higher than the max. value of 248 HV set in the standards. From this point of view, the welded joint and the prescribed welding technology does not meet the initial requirement. The requirements are partially met.

Although the highest measured hardness in the top layer of the weld is 269HV and is slightly higher than 248HV, given the importance of the welded housing for „PIG“ device and the hostile working environment inside (H_2S), the request for reliability in terms of cold cracks, especially hydrogen induced cracks is very important. Thus, NACE MR0103 and MR0175 need to be fully met.

From the analysis, it can be concluded that the increased hardness occurs dominantly near the surface layers of the joint, which is due to the

7. Zaključak

Generalno, dobijeni rezultati ispitivanja zavarenih uzoraka su u dozvoljenim granicama i zadovoljavajući su. Maksimalna izmerena tvrdoća je ispod dozvoljene vrednosti date u EN ISO 15614-1:2004+A2:2012.

Konkretno, s obzirom na standarde NACE MR0103 i MR0175, neke od izmerenih vrednosti tvrdoće su veće od maksimalnih vrednost od 248 HV prema standardima. Sa ove tačke gledišta, zavareni spoj i propisana tehnologija zavarivanja ne ispunjavaju početni zahtev. Uslovi su samo delimično ispunjeni.

Iako je najveća izmerena tvrdoća u gornjem sloju šava 269HV i nešto je veća od 248HV, s obzirom na značaj zavarenog kućišta za „PIG“ uređaj i agresivno radno okruženje u njemu (H_2S), veoma su važni zahtevi za pouzdanost u odnosu na pojavu hladnih prslina, posebno prslina izazvanih vodonikom. Prema tome NACE MR0103 i MR0175 moraju biti u potpunosti ispunjeni.

Iz analize se može zaključiti da se povećana tvrdoća javlja prvenstveno u blizini površinskih slojeva zavarenog spoja, što je posledica povećane brzine hlađenja spoja u odnosu na koren žleba. Na increased cooling rate of the joint towards the ends of the groove. At these end welds, the cooling time between 800 and 500°C is greater, relative to the grove centre. Highest hardness is measured in HAZ, in the coarse zones of end runs.

Finally, welding technology can be improved to be fully satisfactory, if the critical cooling time is corrected, by shortening the $t_{8/5}$ of the end layers of the welded joint through a lower heat input, thus avoiding increasing the width of the microstructure with coarse grain size.

ovim mestima zavarenih spojeva, vreme hlađenja između 800 i 500°C je veće u odnosu na centar žljeba. Najveća tvrdoća je izmerena u ZUTu, u grubozrnim zonama završnih prolaza pri zavarivanju.

Konačno, tehnologija zavarivanja se može poboljšati tako da bude u potpunosti zadovoljavajuća, ako se koriguje kritično vreme hlađenja, skraćivanjem vremena $t_{8/5}$ završnih prolaza zavarenog spoja kroz manji unos toplote, čime se izbegava povećanje širine grubozrne mikrostrukture.

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