Slovenská zváračská spoločnosť spolu s partnermi

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ZBORNÍK
44. medzinárodná konferencia
ZVÁRANIE 2016

BOOK

44. International Conference WELDING 2016

09. – 11. november 2016

Tatranská Lomnica, Vysoké Tatry, Slovenská republika

November 09 – 11, 2016, Tatranská Lomnica, High Tatras, Slovak Republic

Názov: **CD Zborník prednášok z 44. medzinárodnej konferencie ZVÁRANIE 2016**

Vydal: **Slovenská zváračská spoločnosť**
člen Zväzu slovenských vedeckotechnických spoločností – ZSVTS
člen Medzinárodného zváračského inštitútu – IIW (International Institute of Welding)
člen Slovenského plynárenského a naftového zväzu – SNPZ

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815 94 Bratislava
Slovenská republika

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web: www.szswelding.sk

Publikácia je vydaná v rámci osláv Týždňa vedy a techniky na Slovensku 2016

Pre internú potrebu Slovenskej zváračskej spoločnosti.

Zostavil: Ing. Helena RADIČOVÁ, PhD.

Tlač: Slovenská zváračská spoločnosť

Vydanie: Prvé, november 2016

Rozsah: 291 strán
Zborník prednášok ZVÁRANIE 2016 + samostatné príspevky na CD

Všetky príspevky sú recenzované. Akceptované príspevky sú publikované v recenzovanom zborníku z konferencie vydanom na CD-ROM.

Náklad: 250 ks

ISBN: 978 - 80 - 89296 - 19 – 4
EAN: 9788089296194 čiarový kód

Za jazykovú a obsahovú stránku príspevkov zodpovedajú autori.

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Tatranská Lomnica, 09.–11. november 2016
ABSTRAKT / ABSTRACT

Stanovenie zvárateľnosti a výber optimálnej technológie zvárania rúrky vyrobenej z Cr-Mn vysokopevnej ocele

Estimate of weldability and selection of optimal welding technology for the cover of a tube girder made of the Cr-Mn high strength steel

Vukić LAZIĆ[1], Dušan ARSIĆ[2], Ružica R. NIKOLIĆ[3], Srbislav ALEKSANDROVIĆ[4] Milan DJORDJEVIĆ[5], Branislav HADZIMA[6]

Abstrakt
V článku je prezentovaný základný postup a technológia zvárania rúrky. Spoj je tvorený rúrkou z Cr-Mn vysokopevnej ocele, ktorá je zváraná po celom obvode vo forme V drážky. Pred stanovením technológie zvárania bolo vyhodnotené chemické zloženie a mechanické vlastnosti základného materiálu. Následne bola určená zvárateľnosť základného materiálu, ktorá ukázala, že základný materiál je podmienečne zvárateľný s použitím predohrevu. Technológia zvárania bola zvolená na základe vopred stanovených parametrov a následne boli určené postupy zvárania a typ prídavného materiálu. Predpísaná technológia zvárania bola použitá pri výrobe skúšobných vzoriek a na nich bola technológia overená meraním tvrdosti a vyhodnotením mikroštruktúry jednotlivých častí zvarového spoja. Analýza nameraných výsledkov potvrdila, že technológia zvárania bola vhodná a môže byť aplikovaná na reálne súčasti.

Abstract
The basic procedure and welding technology for the cover of the tube girder is presented in this paper. The cover is made of the Cr-Mn high strength steel and it has to be welded over the whole perimeter in the V groove. Prior to prescribing the welding technology, the check of the base metal chemical composition and the mechanical properties was conducted. Then the estimate of weldability of the base metal was done what showed that that this steel was conditionally weldable with application of preheating. The welding technology was then prescribed, based on the previously determined parameters, and the welding procedure and filler metals were selected. The prescribed technology was executed on the selected samples and for its verification the hardness and the microstructure of the welded joint zones were determined. Analysis of experimental results has confirmed that the welding technology was appropriate and that it could be applied to the real part.

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1. Introduction

The procedure for determining which technology should be used for welding the cover of the tube made of the C-Mn high strength steel is presented in this paper. The welded tube is a part of the assembly of the large hadron collider (LHC) of the largest accelerator made under the auspices of CERN. According to Figure 1 the tube and the cover should be welded over the whole perimeter (Figure 1a) with previously prepared groove (detail "A" in Figure 1b).

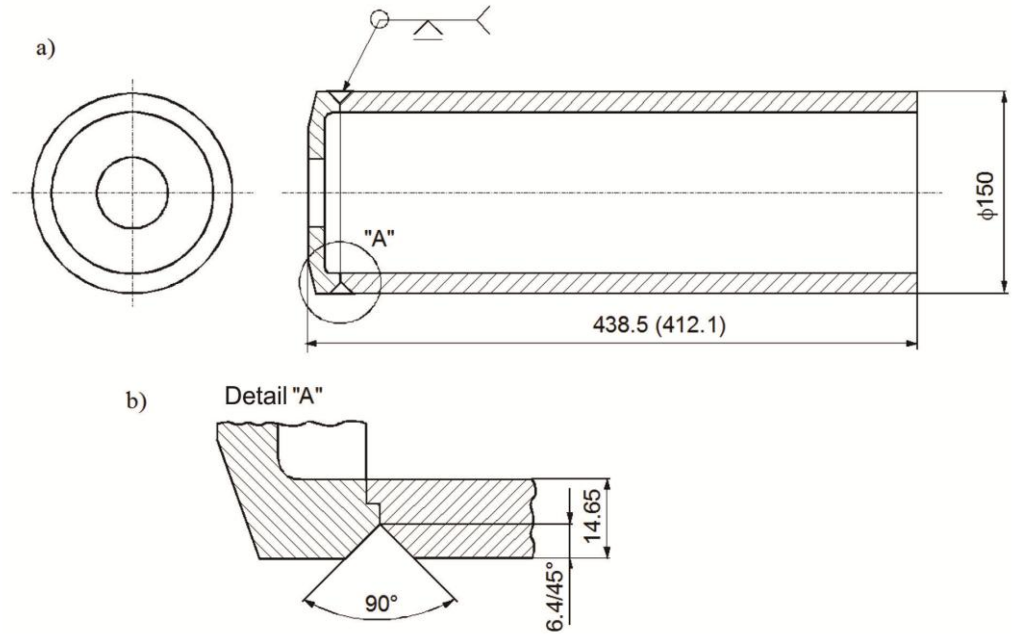


Fig. 1 *Welding of the tube and its cover (a) and appearance of the groove (b)*

2. Base metals' weldability and tendency towards creating cracks

Prior to selecting the welding process, technology and eventual heat treatment (before or after the welding), it is necessary to estimate the weldability of the base metal. The chemical composition and the mechanical properties of steel L355 (EN) i.e. St 52.0 (DIN), obtained from the manufacturer and by the chemical analysis are presented in Table 1 [1, 2]. This is the fine-grained C-Mn high strength steel of the ferrite-pearlite structure.

Tab. 1 *Chemical composition and mechanical properties of HSS L355 (St 52.0)*

Chemical composition, %									
	C	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Cu**	**Al**
Catalogue	0.14-0.20	0.40-0.55	1.2-1.5	≤0.040	≤0.04	≤0.30	≤0.30	≤0.03	-
Analyzed	0.17	0.45	1.33	0.008	0.009	-	-	-	0.028

Mechanical properties			
	R_{eH}**, MPa**	R_m**, MPa**	A_5**, %**
Catalogue	min 355	500-650	min 21
Analyzed	377	577	30.8

2.1 Weldability estimate according to chemically equivalent carbon

For this type of steels the chemically equivalent carbon (CE) is calculated from the expression [3-5]:

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}, \ \% \ . \tag{1}$$

Steels with value of CE > 0.45 % are considered as conditionally weldable (the application of the prior and post welding heat treatments is necessary – preheating and tempering), while the steels with value of CE ≤ 0.45% are considered as well weldable. The obtained value of chemically equivalent carbon was CE = 0.392 %, (i.e. < 0.45 %), so this steel is considered as well weldable. However, due to high responsibility of the welded assembly, the checking of this steel's tendency towards creation of the hot and cold cracks had to be performed.

2.2 Parametric equations for tendency towards creation of cold cracks

For estimates of the C-Mn steel's tendency towards creation of cold cracks (when the yield strength is between 272 and 870 *MPa*), one applies equations that take into account the *chemical composition* of the base metal and the *content of the diffused hydrogen*, as well as the *stiffness* and the *thickness* of the welded joint. According to [6], the following equations should be applied:

$$P_{hp} = P_{CM} + \frac{K}{40000} + 0.015 \cdot \log\frac{H}{2.77}, \ for \ \mathrm{K} \le 1300, \tag{2}$$

$$P_{hp} = P_{CM} + \frac{K}{40000} + 0.075 \cdot \log\frac{H}{2.77}, \ for \ \mathrm{K} > 1300, \tag{3}$$

$$P_{CM} = C + \frac{Si}{30} + \frac{Mn + Cu + Cr}{5} + \frac{Ni}{60} + \frac{Mo + V}{15} + 5 \cdot B, \tag{4}$$

where:

$K = 70 \cdot s$ – is the stiffness factor of the but joints; s, *mm*, is the welded material thickness and H, $cm^3/100\ g$, is the content of the diffused hydrogen in the weld metal. The welded joint, for which the obtained value of P_{hp} is ≤ 0.24, is considered as resistant to cold cracks, while for the values of $P_{hp} > 0.24$ the preheating is necessary to temperature of:

$$T_p = 1600 \cdot P_{hp} - 308, \ ^\circ\mathrm{C}. \tag{5}$$

Under the assumption that the welding would be done in the protective gas atmosphere (80% Ar + 20% CO_2), with the dry and clean wire, value $H = 3$ *ml/100 g* was adopted. The maximum thickness of the welded part is $s = 14.65$ *mm*. According to those assumptions, the following values were obtained:

$K = 1025.25 < 1300$, $P_{CM} = 0.2515$, $P_{hp} = 0.278$, namely $\boldsymbol{T_p} = \mathbf{136\ ^\circ C}$.

Analogously to formula for the chemically equivalent carbon, Prochazka et al. [6] proposed that the indicator of tendency of the low alloyed steels towards creation of cold cracks during the welding should be calculated as:

$$P_C = P_{CM} + \frac{s}{600} + \frac{H}{60} \qquad (6)$$

where:

$$P_{CM} = C + \frac{V}{10} + \frac{Mo}{15} + \frac{Mn + Cu + Cr}{20} + \frac{Ni}{60} + 5 \cdot B \,. \qquad (7)$$

If the value of P_C is obtained to be $0.25 < P_C < 0.40$, at the medium input heat, then the preheating is necessary, at temperature:

$$T_p = 1440 \cdot P_C - 392 \text{, ºC.} \qquad (8)$$

With the same input parameters as for the previous formula, the following values were obtained:

P_{CM} = 0.2365, P_C = 0.3109, namely $\boldsymbol{T_p}$ **= 56ºC**.

The preheating temperature, for the conditionally weldable steels, could be also calculated according to expression, proposed by Seferian [7]:

$$T_p = 350 \cdot \sqrt{[C] - 0.25} \text{, ºC} \qquad (9)$$

$$[C] = [C]_h + [C]_s = [C]_h (1 + 0.005 \cdot s) \qquad (10)$$

$$[C]_h = C + \frac{Mn + Cr}{9} + \frac{Ni}{18} + \frac{7 \cdot Mo}{90} \,. \qquad (11)$$

With the same input data as before the following values were obtained:

$[C]_h$ = 0.317, $[C]$ = 0.34, namely $\boldsymbol{T_p}$ **= 105 ºC**.

However, taking into account that the first – root pass is the most important for obtaining the favorable welded joint, somewhat higher preheating temperature, $\boldsymbol{T_{pmax}}$ **= 150 ºC**, was adopted for the test welding.
So the conclusion is that this steel is <u>*resistant to cold cracks*</u>, with application of preheating.

2.3 Parametric equations for tendency towards creation of hot cracks

According to [8], tendency towards creation of hot cracks can be estimated according to the modified equivalent carbon:

$$CE_m = C + 2 \cdot S + \frac{Si - 0.4}{10} + \frac{Mn - 0.8}{12} + \frac{Ni}{12} + \frac{Cu}{15} + \frac{Cr - 0.8}{15} \text{, \%.} \qquad (12)$$

Steels that have the value CE_m > 0.45% are prone to create the hot cracks and vice versa.

Ito and Bessyo [9] have derived the following expression for estimates of tendency for creating the hot cracks, he Hot Cracks Sensitivity factor – *H.C.S.*:

$$H.C.S. = \frac{C \cdot (S + P + \frac{Si}{25} + \frac{Ni}{100}) \cdot 10^3}{3 \cdot Mn + Cr + Mo + V}. \qquad (13)$$

The permissible value of the *H.C.S.* depends on the type of steel. Thus, for the carbon steels that are prone to creating the hot cracks the value should be *H.C.S.* > 4, while for the high strength steels it amounts to *H.C.S.* > 2 for thin sheets and *H.C.S.* > 1.6 for thick sheets.

According to expressions (12) and (13) the following values were obtained

CE_m = 0.237 < 0.45 and *H.C.S.* = 1.49 < 1.6,

which implies that the base metal St 52.0 is *resistant to hot cracks*.

3. Selection of the procedure and the technology of welding

The selected procedure was welding in the protective gas atmosphere (gas mixture 80% Ar + 20 % CO_2), on the semi-automatic programmed machine for the circular welding. To fix the cover to the tube, three fixture welds were executed at three points, at 120° distances, Figure 2. The fixing welding was done in the CO_2 protective atmosphere (CO_2 – GMAW) [10], with the wire of diameter 1.2 *mm* and current $I \approx 200$ *A*), while the length of welds was 20 *mm*. After the cooling to the room temperature, the beginnings and the ends of all the three welds were ground.

3.1 The calculated welding parameters

Technological parameters of welding in the protective gas atmosphere are given in Table 2.

Besides these parameters, one should also consider the length of the drawn wire, the position of the wire electrode with respect to the joining plane, the distance of the gas nozzle from the working piece surface, polarity of the wire electrode, welding position, variable inductance, etc.

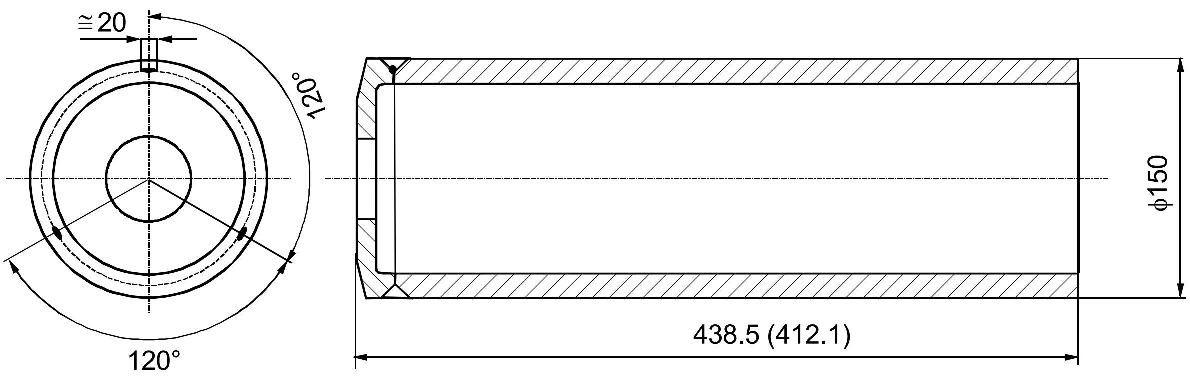


Fig. 2 *Schematic presentation of the fixing-welding*

Tab. 2 Technological parameters of welding

1	Grove area	$A_z = 2 \cdot P_\Delta = 2 \cdot \frac{6.4 \cdot 6.4}{2} = 40.96\ mm^2$
2	Weld area	$A_w \approx 1.2 \cdot A_z = 1.3 \cdot 40.96 = 53.248\ mm^2$
3	Area of a single weld	$A_{sw} \approx 25\ mm^2$
4	Weld's mass per unit length	$M = \rho \cdot A_z \cdot L = 7.85 \frac{g}{cm^3} \cdot 0.25 cm^2 \cdot 1 cm = 1.9625 g$
5	Deposited material mass per time unit	$m_{1.6} = 0.64 + 0.55 \cdot M - 0.055 \cdot M^2 \approx 1.51 g/s$
6	Welding speed	$v_w = \frac{m \cdot 6000}{A_z \cdot \rho} = \frac{1.51 \cdot 6000}{25 \cdot 7.85} = 46\ cm/min = 0.768\ cm/min$
7	Wire melting rate	$v_m = \frac{0.012732 \cdot A_z \cdot v_z}{d^2} = \frac{0.012732 \cdot 25 \cdot 46}{1.6^2} = 5.7\ m/min$
8	Welding current intensity	$I_{1.6} = 378 \cdot \log v_t + 26 = 378 \cdot \log 5.7 + 26 \approx 312\ A$
9	Working voltage	$U = 14 + 0.05 \cdot I = 14 + 0.05 \cdot 312 \approx 30\ V$
10	Welding input heat	$q_l = \frac{U \cdot I}{v_z} \cdot \eta = \frac{30 \cdot 312}{0.768} \cdot 0.85 = 10359\ J/cm$
11	Welding depth	$\delta = 0.3 \cdot r = 0.3 \cdot 0.00537 \cdot \sqrt{q_l} = 0.3 \cdot 0.00537 \cdot \sqrt{10539} = 1.64\ mm$
12	Protective gas type	mixture (80% Ar + 20% CO_2)
13	Protective gas flow rate	$q \approx 20\ l/min$

3.2 Selection of the filler metal

The copper plated steel wire VAC 60, Ø = 1.6 *mm* (SRPS C.H3 Č3203; DIN 8559/94 SG-2-CY 4233; AWS A5.-18-79 ER 70S-6) was used as the filler metal, which is aimed for welding in the protective gas atmosphere. According to the manufacturer's recommendations, this wire is adequate for welding of the non-alloyed and low-alloyed structural steels with strength up to R_m = 590 *MPa*, boiler thin sheets, ship thin sheets etc. Mechanical properties of the pure weld metal and the chemical composition of the wire are given in Tables 3 and 4, respectively.

Tab. 3 Mechanical properties of the pure weld

Yield stress $R_{p0.2}$, *MPa*	Tensile strength R_m, *MPa*	Elongation A_5, %	Toughness (- 40 °C) ISO-V, *J*
410-490	510-590	22-30	> 47

Tab. 4 Chemical composition of the wire

C	Si	Mn	P	S
0.08	0.90	1.50	<0.025	<0.025

Welding current: DC (E+)

3.3 Control of samples before and after the welding

Prior to commencing the welding, both the test and the real one, the circular radial deviation of each working piece was controlled (Figure 3a). This deviation was within the range 0.1 to 0.2 *mm*, what was considered as acceptable.

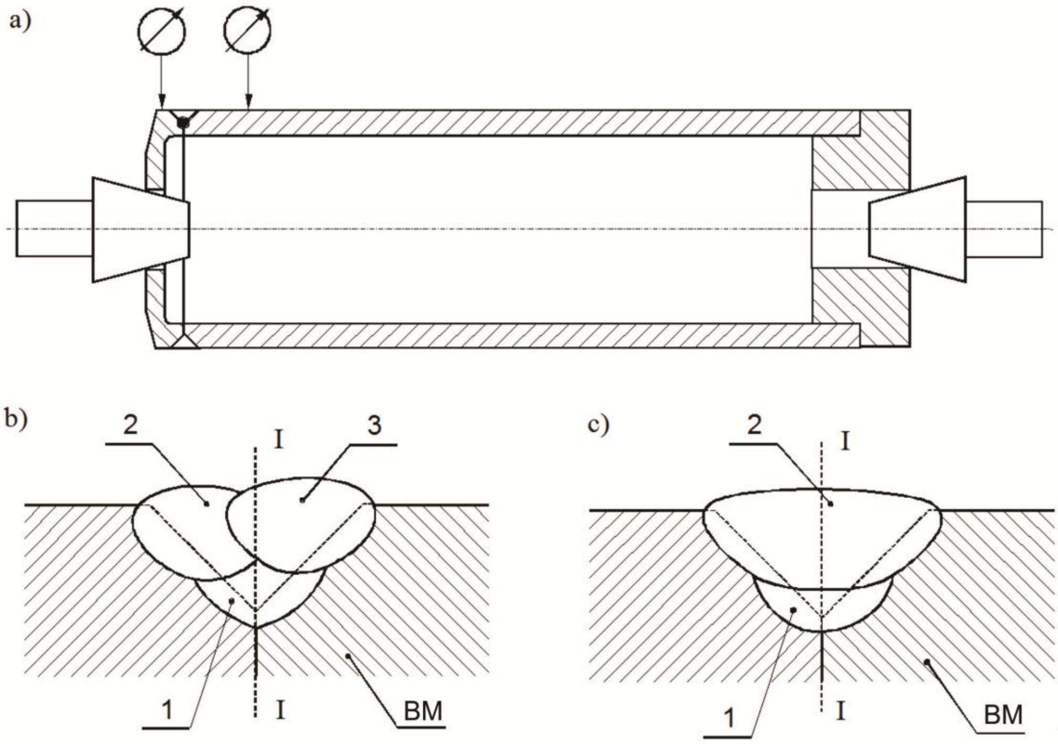


Fig. 3 *Schematic presentation of the circular deviation control (a); of the three-pass welding (b) and the two-layer welding (c).*

In addition, before the welding the fixed pieces were degreased by washing with an appropriate detergent and then dried.

To be sure that the optimal welding technology was selected, numerous test welds were executed with the calculated welding parameters, in conditions with the preheating (T_p = 120 ºC) and without the preheating, with three (Fig. 3b) and two passes (Fig. 3c).

The metallographic samples were prepared by grinding from the tested welded pieces, which served for measuring the micro hardness (HV1) and for reading the micro structure of the welded joint different zones.

4. Results and discussion

Results of the hardness measurements of the welded joint individual zones and the corresponding micro structures are shown in Table 5.

Hardness distribution and appearance of micro structures for the two-layer and three-pass welding are presented in Figures 4 and 5, respectively (hardness measurement direction is the I-I direction shown in Figures 3b and 3c).

Tab. 5 *Measured hardness and microstructures of the welded joint individual zones*

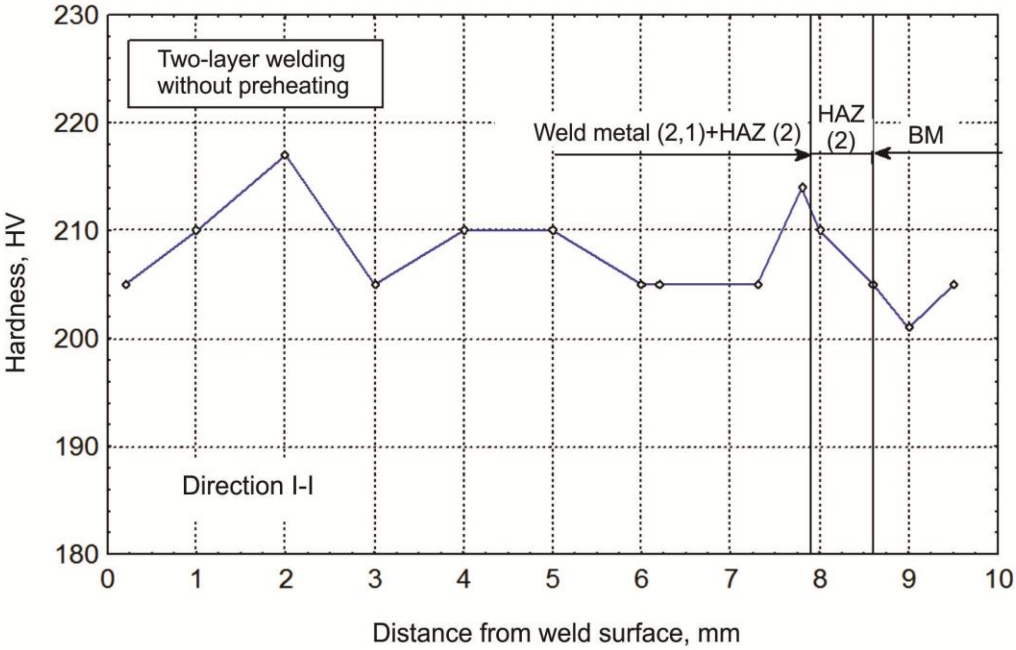
Number of layers/passes	Preheating temperature °C	**Maximal and minimal hardness (HV1) and Determined microstructure**		
		Weld metal	**$HAZ_{3,2,1}$ and $HAZ_{2,1}$**	**BM**
3 passes	$T_p \approx 150$ °C	221-251 HV1 Fine grained Widmannstetten	210-227 HV1 Interphase + tempered martensite	201-210 HV1 Lamellar pearlite-ferrite
2 layers	$T_p \approx 20$ °C	205-217 HV1 Fine grained Widmannstetten	205-214 HV1 Interphase + tempered martensite	201-210 HV1 Lamellar pearlite-ferrite
3 passes	$T_p \approx 20$ °C	201-234 HV1 Fine grained Widmannstetten	219-229 HV1 Interphase + tempered martensite	201-210 HV1 Lamellar pearlite-ferrite

By analyzing the obtained results, one can conclude that no major differences were noticed of both values of measured hardness and red-off microstructures in individual zones of the welded joint, during the welding either with or without the preheating.

Welding of the cover to the tube with three passes without preheating was done primarily because of the large angle of the groove opening and necessary post treatment of the weld's face. The passes were executed immediately one after the other (Fig. 3b). The cover pass 2 tempers the root cover 1 and the cover pass 3 tempers the root pass 1 and partially the pass 2, as well, what produces significantly more favorable microstructure, avoids creation of the possible brittle phases and reduces the level of residual stresses. With this type of welding the necessary overfill of the welded joint was created, which is later removed by machining for the final ultrasonic control.

The energetic parameters (current I, voltage U and the welding velocity v_w), related to the welding input heat, were constantly monitored. The input heat was within limits q_l = 9500-10500 *J/cm*; it provides necessary welding penetration, favorable hardness and micro structure, as well as the adequate output mechanical properties of the welded joint.

Experimental investigations have confirmed that the base metal was the well weldable steel, thus either the previous or the additional heat treatment were not necessary.



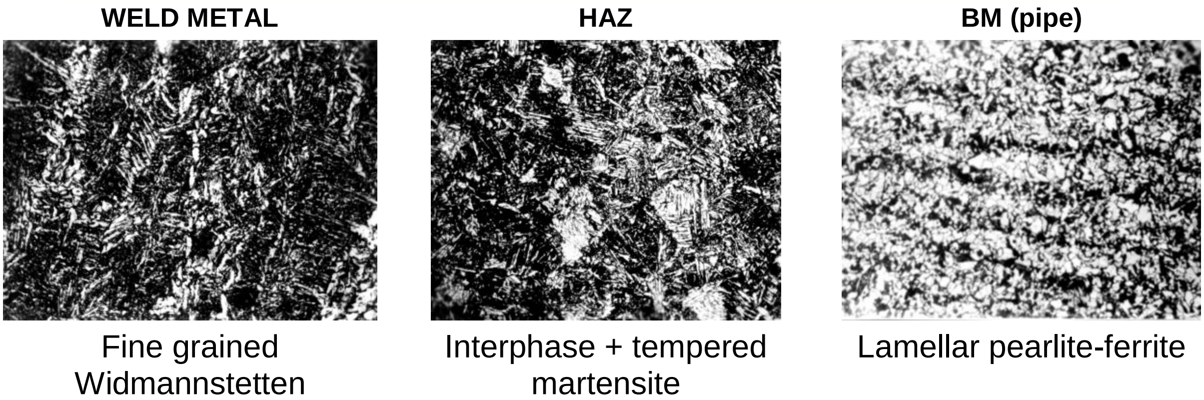


Fig. 4 *Hardness distribution and appearance of micro structures in the two-layer welding*

Besides the visual control and conducted metallographic tests, each welded joint on real parts was controlled by the ultrasonic defectoscopy in the laboratory, which was accredited for the non-destructive testing. In all the performed investigations, no flaws, external or internal, were noticed in the welded joints.

5. Conclusions

Based on the theoretical and experimental analysis of the base metal's weldability, adopted welding technology and control of the welded joints, the following conclusions were drawn:

- The base metal from the class of the high strength steel belongs to a group of the well weldable metals with mandatory application of preheating;
- This steel is not prone to creation of cracks and brittle phases during the welding by melting;

- Welding can be successfully executed in the protective gas atmosphere with the proposed technology;
- The three-pass welding is necessary due to structurally required type of groove (too large groove opening);
- Neither unfavorable structures nor the zones of increased hardness were noticed during the experimental investigations;
- Neither previous nor additional heat treatment were necessary.

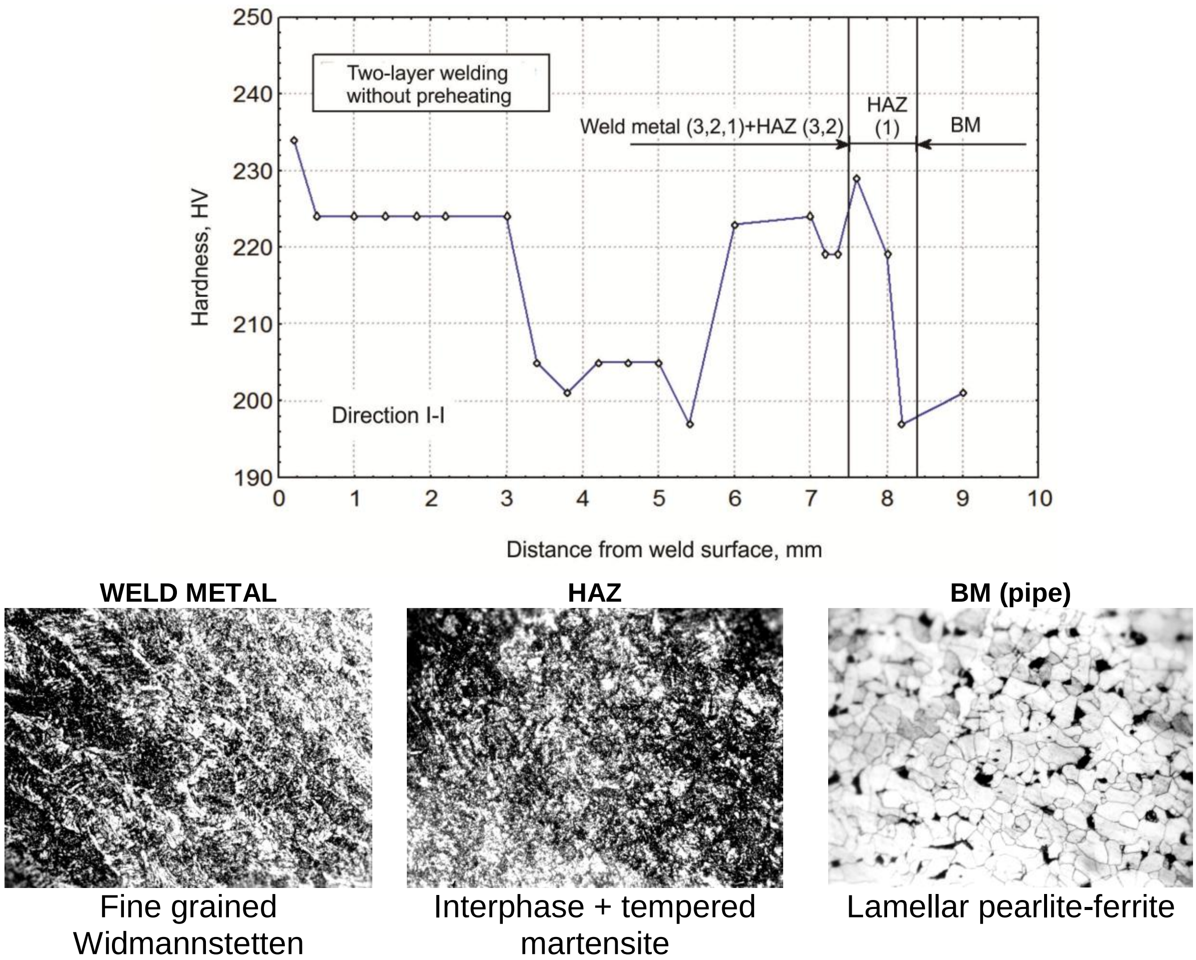


Fig. 5 *Hardness distribution and appearance of micro structures in the three-pass welding*

Acknowledgement

This research was partially financially supported by European regional development fund and Slovak state budget by the project "Research Centre of the University of Žilina" – ITMS 26220220183 and by the Ministry of Education, Science and Technological Development of Republic of Serbia through grants: ON174004, TR35024 and TR33015.

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