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Gas Pipeline Welding Procedure Qualification – Standards and Tests

Kwalifikowanie technologii spawania gazociągów – normy i badania

Abstract: The article describes the so-called combined welding technologies, marked as method "A" – 141/135, method "B" – 141/111 and method "C" – 141/136. In each of the methods, the root run (root layer) was obtained using method 141, whereas the groove was filled using methods 135, 111 and 136. In respect of the welding technology qualification process, the key issue was connected with finding an appropriate range of values for a heat input to each run, aimed to prevent dangerously high grain growth in the HAZ. The results of welded joint tests were fully consistent with the PN-EN ISO 15614-1 and PN-EN 12732 standards as well as Annex 5 to PI-ID-I03.

Key words: welding, gas pipelines, natural gas, steel, NDT testing

Streszczenie: W artykule opisano tzw. kombinowane technologie spawania, które oznaczono jako: metoda „A" – 141/135, metoda „B" – 141/111, metoda „C" – 141/136. W każdej z metod warstwę przetopową wykonano metodą 141, a wypełnienie rowka metodą kolejno: 135, 111, 136. W kontekście procesu kwalifikowania technologii spawania, kluczowe było znalezienie odpowiedniego przedziału wartości ilości wprowadzonego ciepła spawania każdego ze ściegów, aby wskutek kumulacji ciepła spawania uniknąć niebezpiecznie wysokiego rozrostu ziarna w SWC. Otrzymane wyniki badań złączy spawanych są zgodne z wymaganiami norm PN-EN ISO 15614-1 oraz PN-EN 12732, a także załącznika nr 5 do PI-ID-I03.

Słowa kluczowe: spawanie, gazociągi, gaz ziemny, stal, badania NDT

1. Introduction

Recent years, despite an increase in the share of renewable sources in energy production, have seen an increased demand for supply of energy, natural gas and crude oil [1]. The most practical form of energy transfer is natural gas. Its numerous advantages have led to intensive gas engineering development. The primary components of natural gas are methane (up to 90 %) and ethane. Natural gas, being the basic fuel, is necessary for the development of a modern economy, hence its trouble-free transfer is of vital importance [2]. Ensuring the regularity and stability of fuel supplies is crucial for energy security, the efficient use of raw materials and environmental protection [3]. The construction of transmission networks, particularly gas pipelines, is a long-lasting process [1]. In addition, it is necessary to perform numerous tests to check the strength and quality of welded joints as these pipeline elements are most exposed to pressure loads [4].

Gas pipeline welding is possible using the following methods (in accordance with guidelines developed by GAZ-SYSTEM S.A.):

- process 111 – manual metal arc welding (MMAW),
- process 135 – gas metal arc welding (GMAW) – subtype: metal active gas welding (MAG),
- process 136 – flux-cored arc welding (FCAW),
- process 141 – gas tungsten arc welding (GTAW).

There is also the CRC Evans technology used for making circumferential (girth) joints of pipes (automatically by six welding heads located inside the pipe and four welding heads located outside) [5].

Contractors of welding works on gas pipelines are obliged to perform them in accordance with the requirements specified in the PN-EN 12732 standard [6] as well as with Annex 5 to PI-ID-103 (Fabrication of welded joints – requirements by the Operator of Transmission Gas Pipelines GAZ-SYSTEM S.A.) [5]. The preparation of welding procedure specification should be performed in accordance with the requirements contained in the PN-EN ISO 15609-1 [7], PN-EN 12732 [6] and PN-EN ISO 15614-1 standards [8].

2. Material, experiments and testing methods

2.1. Material

The tests involved tubes made of steel L485ME PSL2 (base material), the chemical composition of which is presented in Table 1 [9]. Steel L485ME PSL2 is characterised by high brittle cracking resistance. The steel was used to

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Table 1. Chemical composition of steel L485ME (wt %) [9]

C	Mn	Si	P	S	Cr	Ni	Cu
0.063	1.56	0.292	0.016	0.001	0.221	0.074	0.054
Mo	**V**	**Al**	**Nb**	**N**	**Ti**	**Ce [%]**	
0.114	0.004	0.037	0.066	0.006	0.019	0.18	

make joints subjected to welding technology-related tests. The test specimens were sampled from tubes having a diameter of 1016.0 mm and a wall thickness of 14.2 mm.

Before welding, the tubes were subjected to Y-grove joint preparation performed at an angle restricted within the range of 50° to 60°, using a technological threshold restricted within the range of 0.5 mm to 1.0 mm; the gap between the elements to be welded was restricted within the range of 2.0 mm to 3.5 mm.

The filler metal was selected following the investor's recommendations, the regulations specified in Annex 5 to PI-ID-I03 [5] and the requirements contained in the PN-EN 12732 standard [6]. The filler metal should also be provided with conformity certificate 3.1 in accordance with the PN-EN 10204 standard [10].

Presented below are the filler metals used in the tests (selected in accordance with the above-presented requirements.

As regards process 141/135 (method "A"), the filler metal used in the root run was wire grade OK Tigrod 13.23 (in accordance with the PN-EN ISO 636-A standard, W23 Ni1 (ø 2.4 mm)), the filling process was performed using solid filler metal wire grade OK Autrod 13.23 (in accordance with the PN-EN ISO 14341-A standard, G 46 4 M21 3Ni (ø 1.2 mm)).

As regards process 141/111 (method "B"), the filler metal used in the root run was wire grade OK Tigrod 13.23 (in accordance with the PN-EN ISO 636-A standard, W23 Ni1 (ø 2.4 mm)), the filling process was performed using covered electrodes OK 53.70 (in accordance with the PN-EN ISO 2560-A standard, E 42 5 B12 H5 (ø 3.25 mm and 4.0 mm)).

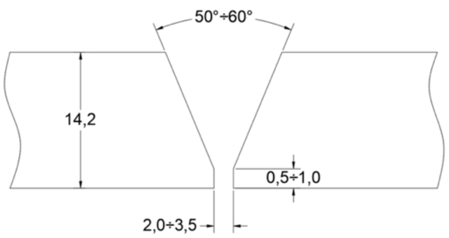
As regards process 141/136 (method "C") the filler metal used in the root run was wire grade OK Tigrod 13.23 (in accordance with the PN-EN ISO 636-A standard, W23 Ni1 (ø 2.4 mm)), the filling process was performed using flux-cored wire grade OK Tubrod 15.17 (in accordance with the PN-EN ISO 17632-A standard, T 46 4 1Ni P M21 2 H5 (ø 1.2 mm).

2.2. Joints

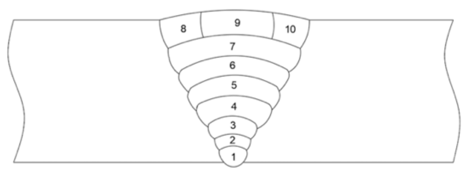
The welding of the test joints was performed on the basis of preliminary welding procedure specifications (pWPS) developed for methods "A", "B" and "C". The welded joints were made under installation conditions in a trench. In relation to the set of filler metals "A", the shielding gas selected in accordance with the PN-EN ISO 14175 standard for process 141 was gas I1 (fed at a flow rate of 12 l/min); the shielding gas selected for process 135 was gas M21 (fed at a flow rate of 15 l/min). In relation to the set of filler metals "B", the shielding gas selected in accordance with the PN-EN ISO 14175 standard for process 141 was gas I1 (fed at a flow rate of 12 l/min). In relation to the set of filler metals "C", the shielding gas selected in accordance with the PN-EN ISO 14175 standard for process 141 was gas I1 (fed at

Table 2. Welding conditions: method "A"

Joint preparation

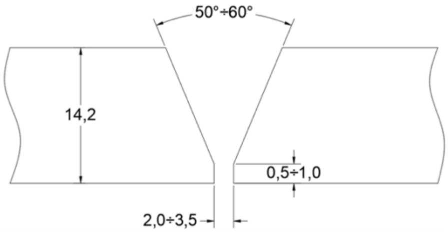
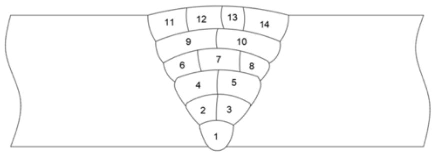


Welding sequence



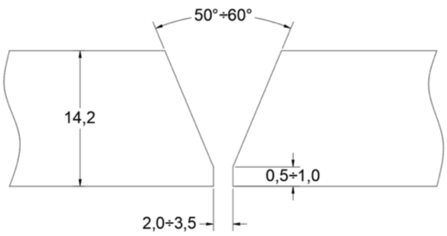
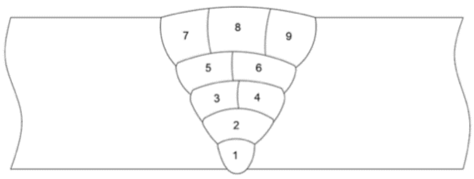
Run	Welding process	Filler metal size [mm]	Current [A]	Voltage [V]	Filler metal wire feed rate [m/min]	Welding rate [mm/s]	Type of current	Heat input [kJ/mm]
1	141	2.4	140-150	13-14	–	0.98-1.22	DC(-)	0.89-1.29
2	135	1.2	250-260	29-31	4.7-5.8	4.70-4.80	DC(+)	1.21-1.37
3	135	1.2	285-300	30-32	4.9-6.1	5.10-5.90	DC(+)	1.16-1.50
4	135	1.2	285-300	30-32	4.9-6.1	5.10-5.90	DC(+)	1.16-1.50
5	135	1.2	285-300	30-32	4.9-6.1	5.10-5.90	DC(+)	1.16-1.50
6	135	1.2	285-300	30-32	4.9-6.1	5.10-5.90	DC(+)	1.16-1.50
7	135	1.2	285-300	30-32	4.9-6.1	5.10-5.90	DC(+)	1.16-1.50
8	135	1.2	190-215	27-29	4.1-4.7	4.75-5.40	DC(+)	0.76-1.05
9	135	1.2	190-215	27-28	4.1-4.7	4.75-5.30	DC(+)	0.77-1.01
10	135	1.2	190-215	27-28	4.1-4.7	4.75-5.30	DC(+)	0.77-1.01

Table 3. Welding conditions: method "B"

Joint preparation	Welding sequence
	

Run	Welding process	Filler metal size [mm]	Current [A]	Voltage [V]	Filler metal wire feed rate [m/min]	Welding rate [mm/s]	Type of current	Heat input [kJ/mm]
1	141	2.4	140-150	13-14	–	0.98-1.22	DC(-)	0.90-1.29
2	111	3.25	120-130	12-13	–	1.83-2.00	DC(+)	0.58-0.74
3	111	3.25	120-130	12-13	–	1.83-2.00	DC(+)	0.58-0.74
4	111	3.25	120-130	12-13	–	1.83-2.00	DC(+)	0.58-0.74
5	111	3.25	120-130	12-13	–	1.83-2.00	DC(+)	0.58-0.74
6	111	4.00	150-160	15-17	–	2.15-2.80	DC(+)	0.64-1.01
7	111	4.00	150-160	15-17	–	2.15-2.80	DC(+)	0.64-1.01
8	111	4.00	150-160	15-17	–	2.15-2.80	DC(+)	0.64-1.01
9	111	4.00	150-160	15-17	–	2.15-2.80	DC(+)	0.64-1.01
10	111	4.00	150-160	15-17	–	2.15-2.80	DC(+)	0.64-1.01
11	111	4.00	140-150	14-16	–	2.05-2.40	DC(+)	0.65-0.94
12	111	4.00	140-150	14-16	–	2.05-2.40	DC(+)	0.65-0.94
13	111	4.00	140-150	14-16	–	2.05-2.40	DC(+)	0.65-0.94
14	111	4.00	140-150	14-16	–	2.05-2.40	DC(+)	0.65-0.94

Table 4. Welding conditions: method "C"

Joint preparation	Welding sequence
	

Run	Proces spawania	Welding process [mm]	Current [A]	Voltage [V]	Filler metal wire feed rate [m/min]	Welding rate [mm/s]	Type of current	Heat input [kJ/mm]
1	141	2.4	140-150	12-14	–	0.98-1.22	DC(-)	0.83-1.29
2	136	1.2	210-220	27-28	3.2-4.1	3.30-5.60	DC(+)	0.81-1.49
3	136	1.2	250-260	28-29	3.8-5.3	4.25-6.20	DC(+)	0.90-1.42
4	136	1.2	250-260	28-29	3.8-5.3	4.25-6.20	DC(+)	0.90-1.42
5	136	1.2	250-260	28-29	3.8-5.3	4.25-6.20	DC(+)	0.90-1.42
6	136	1.2	200-210	28-29	3.1-4.0	3.60-5.35	DC(+)	1.12-1.35
7	136	1.2	200-210	27-28	3.1-4.0	3.60-5.30	DC(+)	0.82-1.30
8	136	1.2	190-215	27-28	2.8-3.8	3.45-5.40	DC(+)	0.76-1.40
9	136	1.2	190-215	27-28	2.8-3.8	3.45-5.40	DC(+)	0.76-1.40

a flow rate of 12 l/min); the shielding gas selected for process 136 was gas M21 (fed at a flow rate of 20 l/min).

The welding conditions are presented on (Tables 2-4).

2.3. Testing methodology

Within the assessment of the quality of welded joints, test specimens representing each method (“A”, “B” and “C”) were subjected to tests, the scope of which was based on instructions contained in the PN-EN ISO 15614-1 standard [8].

The tests included two groups, i.e. non-destructive and destructive tests. The non-destructive tests (NDT) included visual tests (VT) (performed in accordance with the PN-EN ISO 17637:2017-02 standard [11]), magnetic particle tests (MT) (performed in accordance with the PN-EN ISO 17638:2017-01 standard [12]) and radiographic tests (RT) (performed in accordance with the PN-EN ISO 176361-1:2013-06 standard [13]). In turn, the destructive tests included the bend test (performed in accordance with the PN-EN ISO 5173:2010/A1:2012 standard [14]), tensile test (performed in accordance with the PN-EN ISO 4136:2013-05 standard [15]), impact strength test (performed in accordance with the PN-EN ISO 9016:2013-05 standard [16]), hardness test (performed in accordance with the PN-EN ISO 9015-1:2011 standard [17]) and macroscopic test (performed in accordance with the PN-EN ISO 17639:2022-07 standard [18]).

The hardness measurements were performed in accordance with the schematic diagram presented in Figure 1.

The specimens used in the tensile and bend tests were made in accordance with the PN-EN ISO 4136:2013-05 and PN-EN ISO 5173:2010/A1:2012 standards.

The macroscopic tests involved the cross-section in relation to the longitudinal axis of the weld. The specimens were subjected to grinding with abrasive paper and etching with Adler’s reagent. The tests revealed the proper placement of the runs and the absence of any internal imperfections. Figures 2, 3 and 4 present the macroscopic photographs of the joints.

3. Test results and discussion

The test results are presented in Tables 5-8 and Figures 2-6.

The macrostructural photographs of the test joints (Fig. 2, 3 and 4) revealed the banded structure in the base material and welding sequence. It was also possible to observe the clearly visible fusion line, heat affected zone (HAZ) and root layer.

The diagrams below present hardness distribution values measured on the weld face and root side (Fig. 5 and Fig. 6).

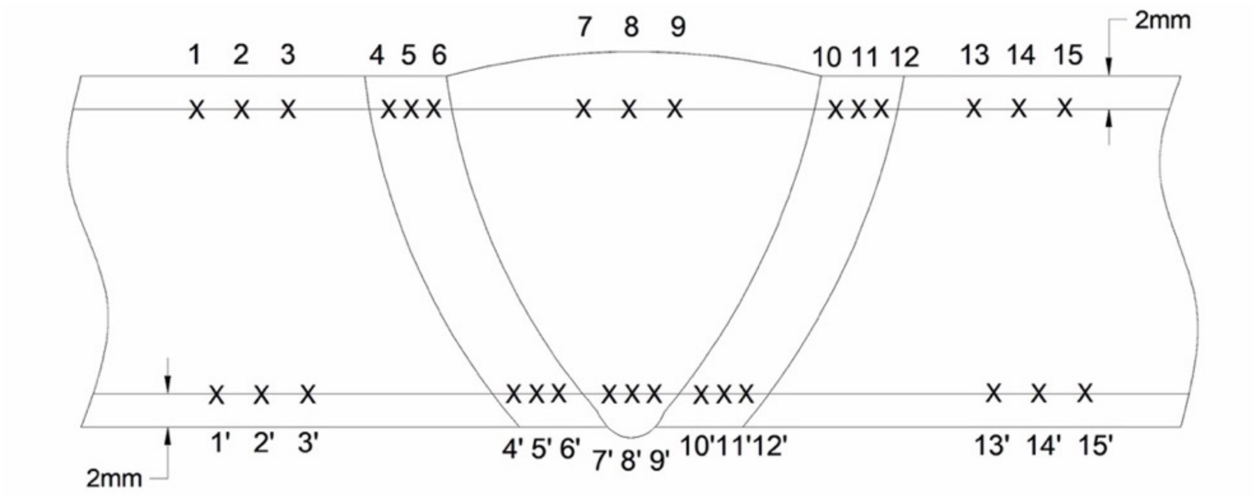
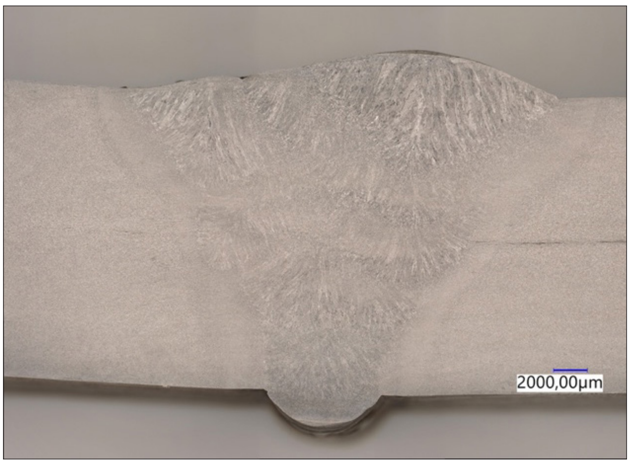
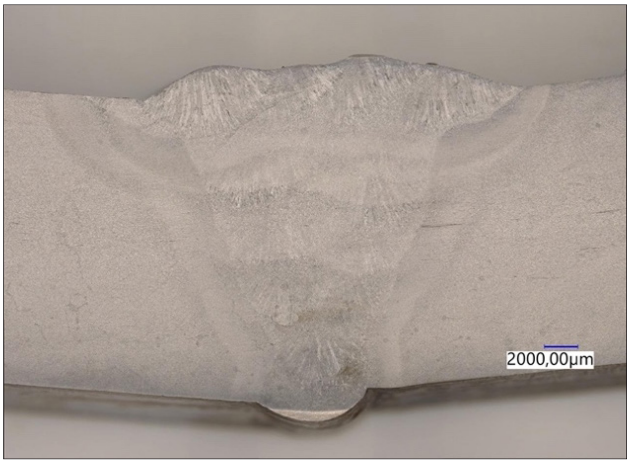


Fig. 1. Arrangement of hardness measurement points in cross-section on the weld face and weld root

Rys. 2. Makrostruktura złącza (metoda „A”)



Rys. 3. Makrostruktura złącza (metoda „B”)



Rys. 4. Makrostruktura złącza (metoda „C")

It was possible to observe the tempering effect of subsequent runs. The distribution of hardness was characterised by smaller differences in values between segments (Fig. 6).

The above-presented test results satisfied the requirements of the PN-EN ISO 15614-1 and PN-EN 12732 standards as well as those of Annex 5 to PI-ID-I03. In the light of present standards and regulations, research on welding technologies is extremely important to achieve such important goals in welding engineering as high quality and safety in the complex process of gas pipeline construction as they enable the verification of newly developed welding technologies for satisfying the requirements concerning the quality and mechanical properties of joints. The above-presented test results revealed the high quality of butt welded joints of line pipes (of gas pipelines). The test butt welded joints made using each of the combined

Table 5. Results of visual tests (VT), magnetic particle tests (MT) and radiographic tests (RT) in relation to all the welding methods ("A", "B" and "C")

Welding method	Type of test	Required level	Identified imperfection/ level of imperfection	Assessment result	Remarks
A, B, C	Visual tests	B	not revealed	positive	×
	Magnetic particle tests	1(2x)	not revealed	positive	×
	Radiographic tests	B	**A** – not revealed **B** – gas pore 2011 **C** – not revealed	positive	×

× assessment in accordance with the PN-EN ISO 15614-1 standard

Table 6. Tensile test results in relation to all the welding methods ("A", "B" and "C")

Welding method	Type of test	Required level $R_{m\,min}$ [N/mm^2]	Result R_m [N/mm^2]			Rupture	Assessment result
			A	B	C		
A, B, C	Tensile test	659	683.692	668.671	687.694	outside the weld	positive

Table 7. Bend test results in relation to all the welding methods ("A", "B" and "C")

Welding method	Type of test	Area subjected to the test	Bend angle	Surface assessment result	Assessment result
A, B, C	Bend test*)	weld face – 2 specimens (for each method)	180°	lack of imperfections	positive
	Bend test*)	weld root – 2 specimens (for each method)	180°	lack of imperfections	positive

*) – bending pin diameter ≤ 4d (d – specimen thickness) (in accordance with the PN-EN ISO 5173:2010/A1:2012 standard) → 50 mm

Table 8. Impact strength test results in relation to all the welding methods ("A", "B" and "C")

Welding method	Test area – *V*-notch location	Acceptable min. value *KV* [J]	Test temperature [°C]	Value *KV* [J]		
				A	B	C
A, B, C	Weld – VWT	27	-30	35, 41, 38	32, 38, 29	38, 32, 34
	HAZ – VHT	27	-30	176, 168, 174	167, 173, 158	172, 184, 169
	Weld – VWT	40	0	69, 71, 61	58, 62, 53	56, 61, 73
	HAZ – VHT	40	0	221, 224, 218	209, 218, 211	206, 228, 197

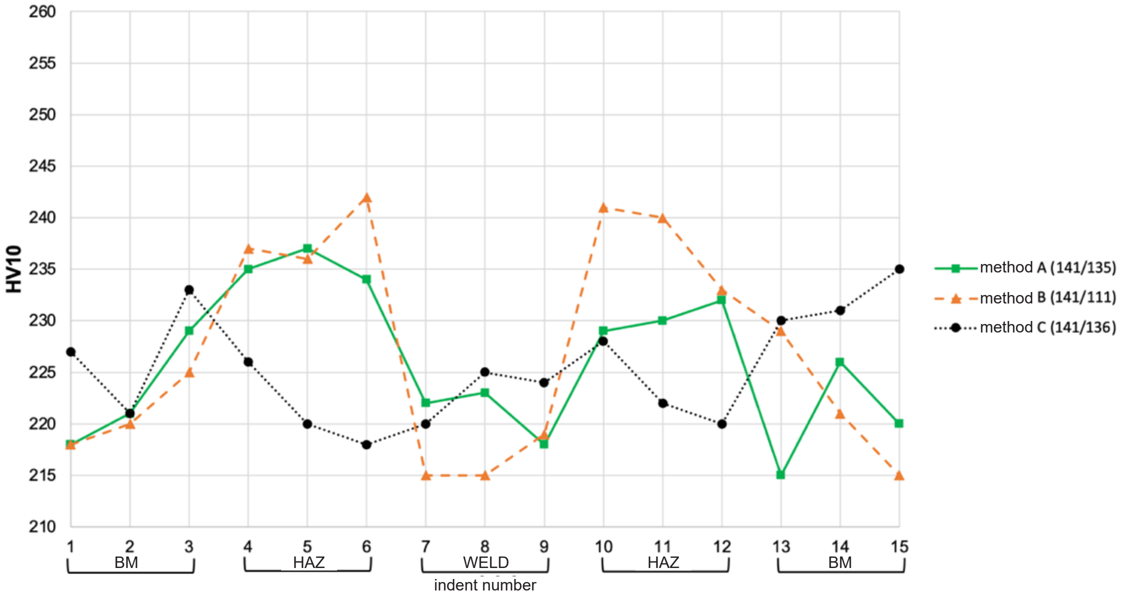


Fig. 5. Hardness distribution in the cross-section of the joint (as a function of indent number – a test performed on the weld face side)

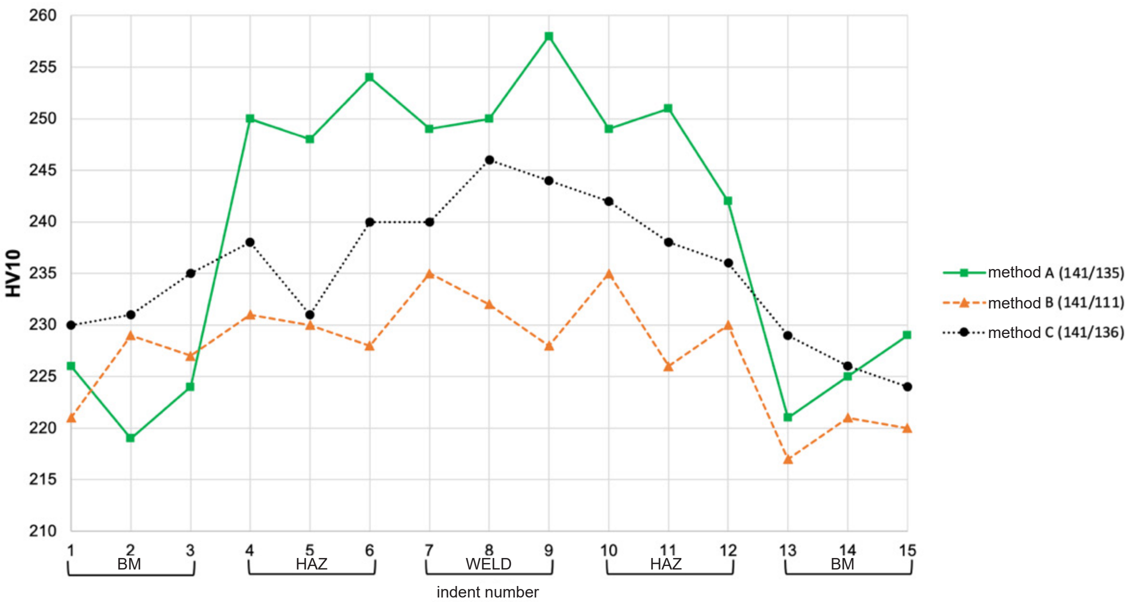


Fig. 6. Hardness distribution in the cross-section of the joint (as a function of indent number – a test performed on the weld root side)

methods presented in the article fully satisfied related requirements and criteria.

4. Conclusions

- Both the destructive and non-destructive test results confirmed the high quality of the test joints; the lack of cracks during the bend test and the location of rupture in the base material during the static tensile test revealed that the mechanical properties of the weld were superior to those of the base material).
- Hardness measurement results concerning the test joints revealed that the welding technologies used in the tests enabled the obtainment of appropriate hardness.
- Toughness results concerning the weld and that of the HAZ satisfied related normative requirements and confirmed the high quality of the joints.
- Macroscopic tests confirmed the proper adjustment of welding parameters, revealing the absence of cracks and the proper shape of the joints.
- Welding procedure qualification in accordance with related standards fully confirmed the applicability of the welding methods in the construction of gas pipelines in the field.

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