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DEVELOPMENT OF THE TECHNOLOGY OF SEMI-AUTOMATIC ARC WELDING FOR THE CONDITIONS OF OVERHAUL AND RECONSTRUCTION OF THE LINEAR PART OF THE MAIN GAS PIPELINES OF UKRAINE

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More than 37 thou km of gas pipelines were laid through the territory of Ukraine. Their safe operation is based on proper technical maintenance and timely repair or reconstruction. At present manual arc welding is the main welding method used during performance of repair. Its low productivity necessitates shortening the duration of welding operations with simultaneous improvement of their quality. The objective of the work was development of the main principles and technology of semi-automatic arc welding of position circumferential butt joints of pipes of up to 1420 mm diameter inclusive that will enable shortening the time of welding operations performance, with the corresponding acceleration of laying of the restored sections of the main gas pipelines and simultaneous improvement of welded joint quality. Welding was performed by gas-shielded flux-cored wire OK Tubrod 15.19 of 1.2 mm diameter in Ar + CO_2 atmosphere and self-shielded flux-cored wire Coreshield 8 of 1.6 mm diameter. Analysis of the obtained results shows that the site of sample destruction is located in the base metal in all the cases. Such results indicate that the welded joint strength is higher than that of the base metal for these combinations of welding consumables and shielding gas. With the proper welding practices and strict adherence to the welding mode, butt joints of pipe steels comply with the normative documents, and flux-cored wire OK Tubrod 15.19 can be recommended for welding pipe steels of strength class K-60, while self-shielded flux-cored wire Coreshield 8 can be used for welding pipe steels of strength class K-52. 15 Ref., 6 Tables.

Keywords: *main gas pipeline, semi-automatic arc welding, circumferential butt joint, flux-cored wire*

Pipeline network of Ukraine is characterized by considerable length (up to 37 thou km), large pipe diameters (up to 1420 mm inclusive), high working pressure (up to 7.4 MPa) and considerable service life (25 years and more). The latter circumstance makes stringent requirements of the linear part of the main gas pipelines in terms of ensuring the operational reliability and industrial safety [1, 2]. Safe operation of the main gas pipelines is based on proper engineering maintenance and timely repair or reconstruction [3, 4]. Repair performance envisages taking a package of technological measures, which are aimed at restoration of the main parameters and characteristics of the linear part of the main gas pipelines (LPMGP) up to design values [5–7].

Experience of repair operations in the main pipelines shows that manual arc welding is the most widely accepted method of their performance [8]. Practical experience shows that it takes a welders team of two workers not less than 5 h to weld just one circumferential position butt joint on a 1420 mm pipeline at wall thickness of 16 mm. That is why there is the need for shortening the duration of welding operations with simultaneous improvement of their quality.

For economic conditions of Ukraine, solution of this problem is seen in the application of mechanized arc welding as a sufficiently simple and progressive method, on the one hand, and a comparatively inexpensive one, on the other. Application of solid wires allows increasing the productivity of welding operations by not less than 1.5–2.0 times, depending on the wire diameter. It is clear that increase of the diameter requires increase of the welding parameters for a stable running of the process of metal transfer into the weld pool. However, in welding in the modes, ensuring short-circuiting transfer of liquid metal into the pool, welding consumable consumption rises 1.5–3.0 times, as a result of spattering of liquid metal drops [9]. This results in greater time consumption, because of the need for additional cleaning of the welding zone from spatter [10]. Therefore, in order to keep a balance between welding productivity and welded joint quality, application of solid wires of up to 1.2 mm is acceptable in mechanized gas-shielded welding [11].

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Table 1. Modes of mechanized welding in different positions

Layer	Welding consumable	V_w, m/min	I_w, A	U, V
Downhand position, 1G				
Root	Sv-08G2S	4.0	135	19.2
Filling	OK 15.19	9.4	207	28.4
	Coreshield 8	2.5	188	21
Facing	OK 15.19	9.4	210	28.2
	Coreshield 8	2.5	191	22
Vertical position, 3G				
Root	Sv-08G2S	2.8	103	18.8
Filling	OK 15.19	7.5	192	22.6
	Coreshield 8	2.5	202	23
Facing	OK 15.19	7.5	198	22.4
	Coreshield 8	2.5	214	24.2
Overhead position, 4G				
Root	Sv-08G2S	2.9	115	16
Filling	OK 15.19	8.0	185	26.3
	Coreshield 8	2.3	200	23.5
Facing	OK 15.19	7.5	180	26.0
	Coreshield 8	2.3	210	23

Rutile-type flux-cored wires for mechanized gas-shielded welding have quite significant advantages over solid wires, due to reduction of spattering and time required for scraping the deposited metal, 30–50 % increase of welding process productivity, ability to increase weld ductility by special alloying of the material [12]. The main advantage of self-shielded wires is believed to be the need for shielding gas application during welding. This feature enhances the mobility, facilitates operation performance under the field conditions, and eliminates the need for application of tents for protection from the wind. Unfortunately, the enterprises of SC «Ukrtransgas» now do not have any experience of application of these modern welding consumables.

The objective of the work as a whole was development of the main principles and technology of semi-automatic arc welding of circumferential position butt joints of up to 1420 mm pipes inclusive, that will enable reducing the time of welding operation performance with the respective acceleration of laying of the restored sections of the main gas pipelines with simultaneous improvement of welded joint quality.

In order to study the mechanical properties and impact toughness of butt welds, samples were welded in different positions with edge beveling by 30° to each side. Welding was performed using Evomig 500 semi-automatic machine in the downhand position with gas-shielded flux-cored wire OK Tubrod 15.19 of 1.2 mm diameter in Ar + CO_2 atmosphere and with self-shielded wire Coreshield 8 of 1.6 mm diameter. In both the cases, Sv08G2S wire of 1.2 mm diameter was used for root layer welding with Ar + CO_2 shielding.

Table 3. Tensile testing of Mi-18 samples

Welding consumable	Position	Strength limit σ_t, MPa	Sample destruction site
OK 15.19	Downhand, 1G	575.3	Base metal
Coreshield 8		504.1	Same
OK 15.19	Vertical 3G	579.1	»
Coreshield 8		505.2	»
OK 15.19	Overhead, 4G	570.9	»
Coreshield 8		503.3	»

In the first case, X70 steel plates of thickness t = = 16 mm were used as the base metal. Welding was performed in four layers: root, two filling and facing layer. In the second case, 09G2S steel 12 mm thick was selected as the material for welding. Welding was performed in five layers: root, three filling and facing layer. All the layers were made in one pass with transverse oscillations of the electrode (except for the root layer). Welding modes and chemical composition of the materials are given in Tables 1 and 2.

After welding, Mi-18 samples were cut out across the weld, which were tested by static tension. Test results are given in Table 3.

Analysis of the obtained results shows that the site of sample fracture is located in the base metal in all the cases. Such results indicate that the welded joint strength is higher than that of the base metal for these combinations of welding consumables and shielding gas. Therefore, further laboratory studies were aimed at determination of mechanical characteristics and impact toughness of the weld metal. During the experiment, performance of each subsequent pass was started at the moment, when the base metal temperature was 120–150 °C in the specified points at cooling. Results of weld metal testing are given in Tables 4 and 5.

Comparison of the obtained test results shows that the yield and strength limits of the metal of welds, made by gas-shielded wire OK 15.19 in different positions, are on the level of normative values of the base metal of pipes of K60 strength class. Ductility characteristic (δ_5) of the base metal is also higher than

Table 2. Chemical composition of materials, wt.%

Material	C	Si	Mn	Cr	Ni	Nb	Ti	Al	Mo	V	Cu	S	P
Sv-08G2S	0.09	0.065	1.65	–	–	–	–	–	–	–	–	–	–
OK 15.19	0.05	0.4	1.3	–	1.0	–	–	–	–	–	–	–	–
Coreshield 8	0.19	0.14	0.5	0.1	0.25	0.01	–	0.43	0.03	0.02	0.1	0.02	0.02
X70	0.08	0.26	1.60	0.03	0.03	0.062	0.002	–	–	–	–	0.006	0.022
09G2S	0.09	0.63	1.51	0.06	–	–	–	–	–	–	–	0.035	–

Table 4. Mechanical characteristics of weld metal

Welding consumable	σ_y, MPa	σ_t, MPa	δ_5, %	ψ, %
Downhand position, 1G				
OK 15.19	467–491 479	598–603 600.5	28.0	73.0
Coreshield 8	382.2–374 378.1	532.1–533 532.0	27.0	70.0
Vertical position, 3G				
OK 15.19	567–571 569	669–679 674	24.0	69.0
Coreshield 8	327.8–389.7 358.7	503.0–518.5 510.7	31.0	69.8
Overhead position, 4G				
OK 15.19	534–541 537.5	648–653 650.5	25.0	68.0
Coreshield 8	354.0–384.0 369	514.0–517.0 515.5	26.4	70.4

Table 5. Impact toughness (*KCV*) of weld metal

Welding consumable	Impact toughness *a*, J/cm^2 at temperature, °C		
	+20	–20	–40
Downhand position, 1G			
OK 15.19	137–173 164	126–160 139	98–101 98
Coreshield 8	122.3–151.5 137.3	70.2–135 124.6	64.2–84.3 73.5
Vertical position, 3G			
OK 15.19	109–154 134	99–111 104	82–99 88
Coreshield 8	127–152 139	90.3–115 99.6	54.2–58.4 56.1
Overhead position, 4G			
OK 15.19	109–152 136	116–143 132	67–99 79
Coreshield 8	124–143 134.3	87.1–89.2 87.4	48.4–52.0 50.6

the minimum required one — $\delta_5 \geq 24$ %. One can see that the values of mechanical characteristics are practically the same in welding in the downhand, vertical and overhead positions. At application of self-shielded wire Coreshield 8 the yield and strength limits of the weld metal are on the level of the normative values of the base metal of pipes of K50–K52 strength class. Ductility is higher than the minimum required one — $\delta_5 \geq 20$ %. Impact toughness results are high even at testing temperature of –40 °C of the Charpy samples.

In order to evaluate the limit ductility of the weld metal, testing of standard samples for static bending was performed. These tests allow assessment of the ability of the welded joints to withstand the specified plastic deformation, the magnitude of which is determined by the bend angle. For circumferential butt joints of pipelines, this angle should be less than 120°. In all the variants of the combinations of the positions of welds and electrode wires, the bend angle was equal to 180°.

Table 6. Nitrogen [N] and oxygen [O] content in the deposited metal, %

Welding consumable	[N], %	[O], %
OK 15.19	0.0079	0.0428
Coreshield 8	0.0433	0.063

Analysis of the obtained results shows that with the proper welding practices and selected welding modes, the butt joints meet the normative requirements.

It is known that in gas-shielded welding of low-carbon and low-alloyed steels, such accompanying elements as nitrogen and oxygen are impurities [13, 14]. Under certain conditions, they can influence the lowering of welded joint ductility. Therefore, investigations were conducted with determination of the impact of shielding gases on the content of these elements in the weld metal. Investigation results are given in Table 6.

Obtained data show that a higher nitrogen content is recorded in welding with self-shielded wire Coreshield 8. There may be several reasons for this, namely higher voltage; poor gas shielding of the deposited metal from air. In self-shielded wires of carbonate-fluorite type, the gas shielding of the metal occurs due to carbonate decomposition. The quantity of nitrogen in the weld metal depends on the welding mode. It rises with increase of arc voltage. With greater length of the arc gap during the wire melting, the evolving gas can be insufficient to press the air away from the molten metal surface, partial pressure of nitrogen in the arc zone increases and its quantity in the metal becomes greater [15]. Increase of welding current will intensify the carbonate decomposition, but at the same time it will increase the nitrogen content in the deposited metal [11]. A more detailed answer can be given at thorough and directed performance of further experiments.

Conclusions

1. Conducted investigations showed that the welded joints produced on X70 steel with application of gas-shielded wire OK Tubrod 15.19 in Ar + CO_2 mixture ensure mechanical characteristics of welded joint strength on the level of σ_t = 574–580 MPa, while mechanical characteristics of the weld metal in different positions are σ_t = 600–670 MPa.

Charpy impact toughness of weld metal is equal to 79–98 J/cm^2 for –40 °C temperature. Ductile characteristics of the weld metal are δ_5 = 28% that is higher than those specified for X70 steel ($\delta_5 \geq 23$ %). Thus, summing up the resultant technological indices, as well as the obtained mechanical properties in welding X70 steel with gas-shielded wire OK Tubrod 15.19

in Ar + CO_2 mixture we can say that welding of pipe steels of strength class K-60 (σ_t = 588 MPa) is permissible.

2. Obtained results of testing samples welded with self-shielded wire Coreshield 8 shows that strength (σ_t = 515 MPa) and yield (σ_y = 369 MPa) of the weld metal are on the level of normative values for base metal of pipes from steels of K-50–K-52 strength class. Charpy impact toughness of weld metal at testing temperature of –40° is equal to 56–73 J/cm^2.

3. Analysis of the obtained results shows that with proper welding practices and strict adherence to the welding mode butt joints of pipe steels correspond to the normative documents.

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