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DEVELOPMENT OF THE ZINC COATING PIPE CONNECTION TECHNOLOGY WITH ARC SOLDERING METHOD USING

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Обґрунтовано застосування методу дугового паяння для з'єднання труб з низьколегованої сталі та захисним цинковим покриттям діаметром 150 мм та товщиною стінки 3,2 мм, як альтернативи дуговому зварюванню, без пошкодження покриття в місці з'єднання. За результатами досліджень встановлено, що з'єднання виконані дуговим паянням з використанням присадкового дроту CuAl8, володіють достатньою міцністю та корозійною стійкістю швів

Ключові слова: з'єднання, дугове паяння, цинкові покриття, мікроструктура, мікротвердість, дифузійна зона, метал шва, зона термічного впливу, міцність з'єднання

Обосновано применение способа дуговой пайки для соединения труб из низколегированной стали с защитным цинковым покрытием диаметром 150 мм и толщиной стенки 3,2 мм как альтернативы дуговой сварке, без повреждения покрытия в месте соединения. По результатам исследований установлено, что соединения, выполненные дуговой пайкой, с использованием присадочной проволоки CuAl8 обладают достаточной прочностью и коррозионной стойкостью швов

Ключевые слова: соединения, дуговая пайка, цинковые покрытия, микроструктура, микротвёрдость, диффузионная зона, метал шва, зона термического влияния, прочность соединения

1. Introduction

The pipes with protective coating are widely used to lay pipelines for water, steam, oil products transportation. As usual, the pipes which inner diameters are below 150 mm are used.

Applying a thin layer of metal protective coating is the most reliable way of pipes corrosion protection and operation period increasing. Among well-known metal coating, zinc is the most widespread for steel pipes protection. Its electro-negative potential is higher than iron potential. Besides, zinc dissolves slower due to electrochemical reactions. Also, zinc coating is more efficient because of low costs and safer for the environment.

Consumable electrode for electric arc welding is most often applied to join zinc-coated pipes. Although in this case application of traditional electric arc welding ways makes considerable difficulties caused by intensive zinc evaporation that leads to pores creation in the welded joint and zinc coating destruction nearby the joint area. This fact needs additional measures of corrosion protection of the joint and the defective area.

Electric arc welding of pipes with zinc coating can be replaced by MIG soldering. It is based on low heat applying to base metal of pipe and welding consumables melting [1].

Investigation and application of MIG soldering for zinc-coated pipes junction without layer destroying allows to extend the field of galvanized pipe using in different areas and to prolong operation period.

2. Analysis of published data and problem statement

According to the State Standard DSTU B V.2.6-193:2013, anticorrosive zinc coating is applied on metal construction in two ways depending on corrosive medium, such as hot-dip galvanizing which allows to get layer thickness of 60–100 microns and metal powder spraying which allows to get layer thickness of 120–150 microns.

Zinc melting starts at 420 °C. If the temperature is 906 °C, the intensive boiling and evaporation begin. These facts cause certain difficulties during junction of zinc-coated construction by electric arc welding. Evaporation of zinc and its oxides puts obstacles in the way of arc stability and causes defects in the welded joints such as pores, shrinkage cracks. Effect of zinc vapor on arc stability can be decreased with the correct choice of welding torch slope angle [2] or arc left way moving [3].

But the most radical way to reduce zinc vaporization is arc heat power decreasing. This way can be realized with MIG arc welding.

Due to low melding temperature of welding consumables (from 900 °C to 1100 °C), the base metal isn't fused because the temperature of steel melting is higher (from 1300 °C to 1500 °C). That's why the zinc coating destruction area is smaller than during arc welding. According to the investigation [4], the zinc coating destruction area received by the arc welding is 24 mm and the same area received by MIG soldering is 1–3 mm.

MIG soldering is accompanied by less vapor of harmful compound ZnO in the welding spray as compared with arc MIG/MAG welding [5].

Nowadays getting high-quality galvanized steel junctions by arc soldering can be reached for steel plate thickness of which is below 1.5 mm. In [6], solder joints of low carbon steel plates TRIP 1.5 mm thick which was made with wire $CuAl_8$ with a high level of micro hardness and strength have been investigated. The level of mechanical characteristics of such joints and, accordingly, their microstructure parameters are controlled in a wide range by efficient choice of MIG soldering modes. It is confirmed by the investigation [7] that was obtained for plates 0.8–1.0 mm thick made with wire CuSi3 using the gas medium of different composition. It is found for soldered galvanized steel plates 1–2 mm thick [8] that heat effect increasing leads to intensification of diffusion processes and, as a result, diffusion area growth. The width of this area is the main parameter of strength evaluation. Similar patterns occur during bilateral arc soldering of dissimilar materials, for example, aluminum alloy and stainless steel, but the maximum thickness of plates isn't more than 2 mm [9].

That's why the issue of the day is investigation of MIG soldering of steel plates which thickness above 2 mm. It forms starting conditions for MIG brazed junctions application for pipe construction design and maintenance.

3. The purpose and objectives of research

The aim of this research was to establish the fact that MIG-soldering is indeed a relevant alternative for galvanized pipes welding with preserving the protective zinc coating for their connection.

The aim has to be achieved by solving the following tasks:

– to study the connections microstructure made by arc welding and MIG-soldering, such as the availability and characteristics of the properties changes in the weld metal, heat affected zone and fusion line;

– to investigate the angle bevel edges impact to the arc soldered joints properties;

– to determine the obtained joins mechanical properties via micro hardness measurements results.

4. Materials, equipment and research methods

The pipe specimens with nominal diameter of 150 mm, wall thickness of 3.2 mm were used for researching. They were made of 16GS steel and protective zinc coating has been applied to the surface with hot galvanizing method using.

Arc welding and soldering was performed with additive wires of brands SV-08G2S, $CuSi_3$ and $CuAl_8$ using. The chemical composition and mechanical properties of the additive materials are shown in Table 1.

Table 1

The chemical composition and mechanical properties of the additive materials

Wire brand	C, %	Cu, %	Mn, %	Si, %	Al, %	Ni, %	Cr, %	Ultimate tensile stress, MPa	Relative elongation δ, %	Toughness KCV, J/sm^2
SV–08G2S (GOST 2246-76)	0,08	–	2,0	0,8	–	0,2	0,2	550	30	70
CuSi3 (ISO 24373)	–	rest of all	0,8	2,9	–	–	–	350	40	60
CuAl8 (ISO 24373)	–	rest of all	0,2	–	8,0	0,3	–	430	40	100

The mix of Ar(82 %) + CO_2(18 %) gases was used as a protective environment during arc welding. Clear argon was used for protection during arc soldering because using of the mix argon with active gases during arc soldering leads to layer destruction zone growing [10].

Welding equipment was compiled for welding and soldering of selected pipe specimens. It consists of the welding semiautomatic device TPS-270i produced by known Austrian company FRONIUS, the welding rotator and the tripod for burner fixing (Fig. 1).

Fig. 1. Welding equipment that was used during researches: 1 — welding semiautomatic device FRONIUS TPS—270i; 2 — welding rotator; 3 — tripod for burner fixing

Mode parameters of arc welding and soldering are shown in Table 2.

Templets have been cut from the welded and soldered joints for further microstructural studies.

The chemical etching was used for microstructure revealing of the zinc-coated steel pipes specimens. Weak alcohol solutions or weak water solutions of acids are generally used for etching because they provide low-speed etching. If the thin film of the deformed metal is formed on the microsection surface as a result of grinding and polishing, the etching is going slow because of bad etching of the surface film. The reagent acts slowly at first and afterwards the etching intensity is becoming faster as the removal of the film. Repeated polishing and etching facilitates obtaining high-quality microsections.

Prepared metallographic specimen surfaces were subjected to etching with 5 % alcoholic solution of the picric acid for detection of the microstructure. This solution is recommended for etching of the carbon and alloy steels. It provides uniform etching, reveals the structure with fine details, doesn't pollute the ferrite by etching products. It reveals the carbides and perlite very well.

The reagent has been poured in the porcelain cup for etching of the received arc soldered joints. Prepared microsections have been placed by polished and cleaned surface into the reagent for a few seconds. It is known, that duration of the specimen holding in the reagent has to be different for different types of microstructures. In this case, pearlite microstructures were etched readily, while ferrite microstructures were etched more slowly. The microsections were cleaned by strong water jet during 1–2 seconds after etching and then immersed in pure alcohol. Further, the microsections were dried by wipes and examined under the microscope for determination of the surface etching completeness. If the image was not clear, the etching process has been reiterated again.

The modern digital technologies using allows to decrease considerably the metallographic research complexity and to increase the evaluation objectivity.

The digital photo and video cameras are used for registration of the microstructure photos which are received by metallographic microscopes. Further, the photos have to be entered into PC for next processing using special analyzer software.

The microscope MMO-1600AT has been used for receiving and registering the microstructure photos in combining with the KMM-5 digital camera.

The microstructure has been photographed in layers, allocating the layers that accord to different zones of received arc soldering joints. The photography results at 100^x magnification have been saved in PC. The special software Image J 1.50 g was used to identify the microstructure morphological changes for further analysis.

Table 2

Mode parameters of arc welding and soldering

Joint type	Wire brand	Wire diameter, mm	Protective gas type	Layer	Arc voltage U, V	Welding current I_w, A	Welding speed V_w, sm/min	Wire feed speed $V_{w.f}$, m/min
without bevel edges	CuSi3	1,0	argon	1	22,1	147	45	9,0
with bevel edges	CuSi3	1,0	argon	1	18,8	100	45	5,3
				2	19,0	105	35	5,5
with bevel edges	CuAl8	1,2	argon	1	19,4	120	40	3,7
				2	19,9	140	40	4,4
with bevel edges	Sv08G2S	1,2	Ar 82 % CO_2 18 %	1	17,7	150	25	4,0
				2	19	160	28	4,0

5. Results and Discussion

Fig. 2, *a–d* shows different microstructure zones of arc soldering joints which have been received (100^x magnification).

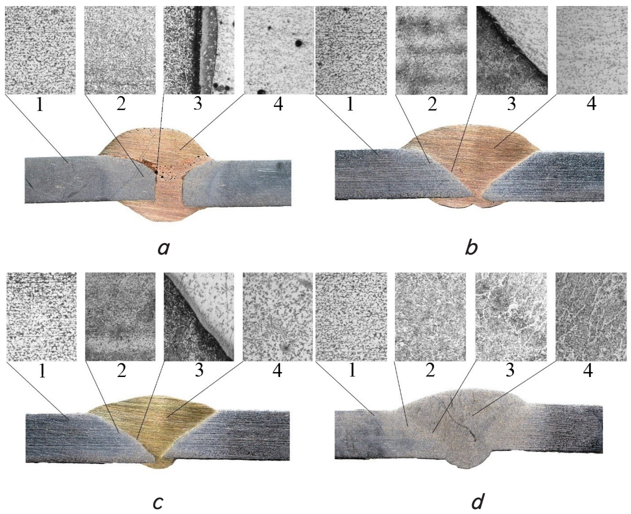

Fig. 2. Macrostructure (3^x) and microstructure (100^x) of joints: *a* — with straight edges using CuSi3 wire; *b* — with bevel edges using CuSi3 wire; *c* — with bevel edges using CuAl8 wire; *d* — with bevel edges using Sv-08G2S wire; *1* — base metal; *2* — heat affected zone; *3* — fusing line; *4* — weld metal

The microstructure of the arc soldering joint made of silicon bronze CuSi3 has been explored. The results show (Fig. 2, *a*, *b*) that expressed diffusion zone (width ~30 mkm) forms between the base and additive metal via making of the eutectic type mixture. The interaction character in close to equilibrium conditions shows that it consists of ferrite and Cu-based solid solution (ε-phase) eutectic mixture [11]. The intensive diffusion of the ferrite into the welded layer base is observed. Therefore, small dispersed phases (~1 mkm) exude in the microstructure of the soldered joint during its solidification. The form and distribution character of these phases indicates phases based on iron silicide [12]. They contribute to strengthening of the welded layer via blocking the deployment moving in accordance with the Orowan mechanism [13], and strength increasing via grain size pounding, and a Hall-Petch effect developing.

Presented character of strengthening is showing up more clearly during arc soldering with albronze wire (CuAl8) (Fig. 2, *c*) because the disperse inclusions in the weld joint are intermetallic phase Fe_xAl_y forms. They have high physical-mechanical features which are much higher than the silicon phases of ferrite [14], and have two times higher volume concentration in the weld joint metal that makes dispersive strengthening more effective [15]. The diffusion zone of those joints is characterized by a more disperse and uniform microstructure.

The weld joints are formed during arc soldering on the diffusion surface. The diffusion process depends on the thermal welding cycle and affects the joint mechanical properties. Measurements of the micro hardness distribution through joints cross-section from the centre (Fig. 3) have been done for the heat influence evaluation on the heat affected zone.

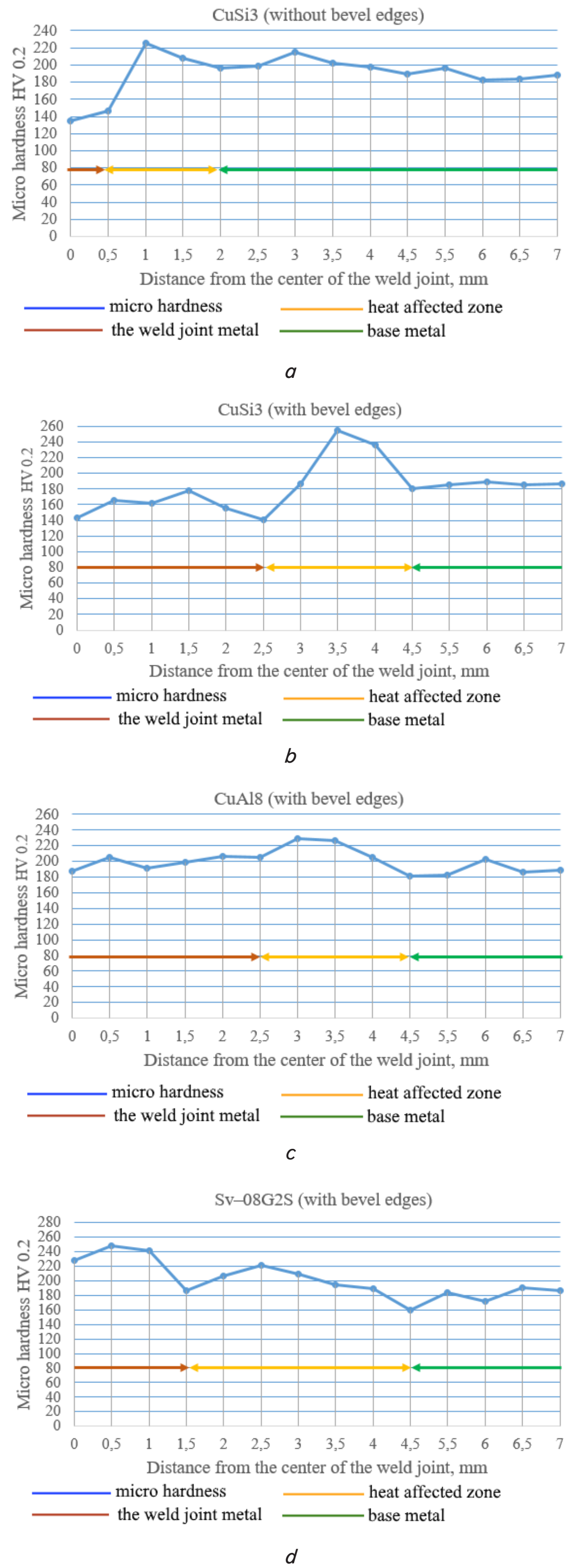

Fig. 3. Diagrams of the micro hardness distribution through joints cross-section from the centre: *a* — joint without bevel edges with using CuSi3 wire; *b* — bevel edges joint with using $CuSi_3$ wire; *c* — bevel edges joint with using CuAl8 wire; *d* — bevel edges joint with using Sv—08G2S wire

If the micro hardness of the arc soldering joints made of CuSi3 and CuAl8 wires is compared with the same one for the joints made of Sv-08G2S wire, the hardness increasing along the heat affected zone for all specimens is observed. The heat impact was the least for the bevel edges arc soldering using Sv-08G2S (Fig. 3, *b*), so a higher hardness caused by the least heat affecting is observed in the heat affected zone. It leads to the fast cooling and growth of the grain. The curves of the micro hardness distribution show decreasing of the heat affected zone size during arc soldering.

The weld joint metal hardness with using CuSi3 wire is much lower than basic metal hardness, so it indicates its low hardness. The features of the weld joint hardness with using CuAl8 wire are the same as for basic metal in contradistinction to using additive material which is CuSi3. The strength of this joint is almost same as for basic metal.

The research has shown that the arc soldering method can be used for zinc-coated pipes joining not only for thin sheet constructions joining. But it is known, that products are transported by pipelines under working pressure of up to 10 MPa. So, the research of the arc soldering joint mechanical properties and calculation and exploration of theirs stress-strained state has to be made. It can be a promising direction of future research.

6. Conclusions

1. The arc soldering joints are formed due to diffusion layer between the joint and the base metal. The strength of joints depends on the size of this layer. The arc soldering joints, which are made of the CuAl8 copper-based wire, have a good strength because the disperse inclusions of the joint have the intermetallic phases form. The physical and mechanical features of these phases are much higher than silicide phases of iron.

2. The edges preparation type significantly affects the arc soldered joints. The weld joints with bevel edges have higher strength than with straight edges because the contact area of the weld metal with the base metal is increasing so as the sectional area too.

3. The arc soldering joint metal, which is produced of the $CuAl_8$ copper wire, has micro hardness approximately similar to the base metal. It indicates a good strength of this joint.

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