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INFLUENCE OF ACTIVATORS ON THE QUALITY OF SPIRALLY-WELDED PIPES, PRODUCED WITH APLICATION OF HIGH-FREQUENCY WELDING

V.V. POLUKHIN, A.S. PROKOFIEV, D.V. ROMASHKO, S.V. RYMAR and **R.S. GUBATYUK**
E.O. Paton Electric Welding Institute of the NAS of Ukraine
11 Kazimir Malevich Str., 03150, Kyiv, Ukraine. E-mail: office@paton.kiev.ua

The paper deals with development of the high-frequency welding technology in manufacture of thin-walled spirally-welded pipes by adding activators to the weld zone and applying the pressure to improve the strength characteristics of welded joint metal. Investigations are based on scientific principles of theoretical fundamentals of welding, materials science and problems of metal strength. A specifics of the welding technology considered is the fact that during heating of edges to be joined by high frequency currents the activators, having lower melting temperatures, transition to the liquid state, bind surface contaminations and transport them to the surface at pressure applying. Edges of the cleaned metal are joined as a result of running of diffusion processes at temperatures close to base metal melting temperatures. In principle, the process of joining at the final stage proceeds with the weld metal being in the solid phase. The obtained weld width does not exceed 4–8 μm. Weld metal consists of the base metal being welded, enriched in activator elements. Near-weld zone structure is close to that of the base metal. Thin-walled spirally-welded pipes can be produced with a high quality of welded joint at a high welding speed. 21 Ref., 3 Tables, 5 Figures.

Keywords: *thin-walled spirally-welded pipes, welding, high-frequency current, pressure application, activators*

In modern conditions of the pipe market development, the production of thin-walled spirally-welded pipes [1–3], in which the ratio of the diameter D to the wall thickness S (D/S) is 80/1 and higher, is remained actual. As a rule, the wall thickness of such pipes is determined by the thickness of the strip, from which such pipes are manufactured.

Thin-walled spirally-welded pipes are distinguished by a number of positive features. One of them is a high material utilization factor due to the reduced wall thickness and a large value of D/S ratio. The other one is a highly efficient and economical way of their production. In high-frequency electric pipe-welded mills, designed at the E.O. Paton Electric Welding Institute, the manufacture of thin-walled spirally-welded pipes is performed per a single pass. The mills provide a wide regulation of the D/S ratio by changing the diameter of the produced pipes, maintaining the wall thickness of the pipe S constant. This makes it possible to manufacture pipes of a wide range. The mill is small-sized and assembled according to the block scheme, with the possibility of its arrangement at a small production site or in the body of a trailer, railway platform, barge, which makes the equipment mobile.

In terms of energy costs per a running meter of a weld, the method of high-frequency welding in the manufacture of thin-walled spirally-welded pipes is the most economical and highly-efficient.

The advantages of thin-walled spirally-welded pipes can also include the possibility of applying protective coatings on them, including nonmetallic ones, in the form of enamel, glass, synthetic and composite materials, both inside and outside the pipe. In the case of polyethylene coating, the pipes are similar in appearance to plastic pipes, but they are significantly stronger than the latter ones. At the same time, traditional welding technologies are applicable during assembly of pipes into pipelines and installation of flanges ones.

Thin-walled spirally-welded pipes are widespread in the manufacture of air ducts, ventilation systems, pneumatic systems, different product pipelines, including those for bulk materials, as well as in fire extinguishing systems. Such pipes can be used in the manufacture of fire extinguishers, containers for paint industry, in the manufacture of cylinders, tubes, receivers and other similar products.

A spirally-welded thin-walled pipe is a pipe manufactured using complex forming and electric welding of sheet rolled metal, which is strip in this case. The basis of the technology of production of spirally-welded pipe consists in producing a weld along a cylindrical spiral along the pipe surface. The use of high-frequency currents can significantly increase the pipe manufacturing speed, however, it is necessary to provide the complexly deforming formation and rotational translational movement of a workpiece welded. To formation both welded billet as well as weld are subjected.

The spiral weld in such a pipe simultaneously combines the properties of a circumferential and longitudinal weld. Since the weld is produced along a cylindrical spiral, in spirally-welded pipes a favourable uniform distribution of loads to the weld is observed, and the weld metal is partially relieved from radial stresses [4] due to the fact that welds are located at an angle to the forming cylindrical surface of a pipe.

At the E.O. Paton Electric Welding Institute, a high-efficient technology of the high-frequency welding for the manufacture of thin-walled spirally-welded pipes of low-carbon and low-alloy steels was developed. This is a high-frequency welding at pressure with flashing, without flashing and with melting [1–3, 5]. Also, at the E.O. Paton Electric Welding Institute a method of induction press welding with the use of activators in the weld zone and subsequent plastic deformation of the joint zone was developed [1, 2, 6, 7–16]. In 2006, this process of joining metals was introduced into the State Standard of Ukraine [17] under the term braze welding.

The use of activators in the weld zone during their melting allows activating the joining surfaces of the base metal, partially alloying the edges of the metal to be joined, protecting the welding zone from the effects of the atmosphere, reducing the temperature of the welding process. In this case, the formation of the welded joint itself occurs in a solid phase without melting the base metal. The temperature of the process of induction press welding at pressure with use of activators in the weld zone is determined by the melting temperature of the activators, which is lower than the base metal melting temperature. The use of pressure and the subsequent plastic deformation of welded joint allow accelerating the counter diffusion processes in the weld zone, increasing the area of the surface joined in the weld, which contributes to removal of activation products from the weld zone in the form of a thin liquid interlayer, washing the base metal edges, and which is an undesirable component in the formed weld. Thus, the joint forms a refined base metal, which is in the solid state and has a temperature, being somewhat higher than the point A_{c3} of the steel state diagram.

The work is devoted to development of high-frequency welding technology in the manufacture of thin-walled spirally-welded pipes by applying pressure to the edges welded and, which is innovative, by introducing activators into the weld zone for increase in its strength characteristics. This direction of work is associated with the growing use of foreign low-alloyed and corrosion-resistant steels in the manufacture of spirally-welded thin-walled pipes and solves the problem of improving the quality of welded joints while using high-frequency welding.

The basic technological parameters of the process of welding of specimens of thin-walled spirally-welded pipe are welding speed, and accordingly, the upsetting rate associated with it. Also, the basic parameters are the electrical parameters: output voltage and welding current of the high-frequency power source. They determine the heating temperature of the edges welded at the point of their convergence and plastic properties of the weld metal, depending on the grade of metal. An important parameter is the initial value of edges overlapping.

The simultaneous favourable combination of basic parameters of high-frequency welding in the production of specimens of thin-walled spirally-welded pipes allows producing a high-quality welded joint. At the same time, due to the complex process of forming a spirally-welded pipe from a strip and at the same time performing upsetting with a high-frequency welding, where, in addition to the counter deformation of welded edges, their unrolling and decrease in the overlapping thickness to the thickness of the initial material (strip) occurs, the weld from the overlapped one transforms into a bevel butt one.

During the weld formation in producing of specimens of thin-walled spirally-welded pipes, at the point of convergence of edges welded, the concentration of heating, as well as heating of the activators located in the weld zone occurs. As a result of concentrated heating, a transition of activator to the liquid phase, washing and activation of base metal edges welded, being in the solid-plastic state, occurs. At the same time, the processes of mutual diffusion of the activator in the liquid phase into the base metal and vice versa occur. Applying pressure to the edges welded in the form of upsetting intensifies these processes in the weld, and also leads to almost complete removal of reaction products of the activator into the flash and its subsequent crystallization outside the weld.

As a result of upsetting, a plastic deformation of edges welded and a partial squeezing out of plastic metal from the weld zone in the form of flash to the peripheral colder regions of the weld both inside and also outside the pipe with its flattening–out over the pipe surface occur.

The research work was performed in the special equipment S-460, designed at the E.O. Paton Electric Welding Institute, which was previously delivered to the pipe plants and used in the manufacture of thin-walled spirally-welded pipes from low-carbon

Table 1. Chemical composition of used steels

Chemical composition [4]	Steel grade			
	St3sp	08kp	S355	12Kh18N10T
C	0.14–0.22	0.05–0.12	0.15–0.2	≤0.12
Cr	≤0.3	≤0.1	≤0.3	17–19
Fe	97	98	96	67
Mn	0.4–0.65	0.25–0.5	1.15–1.6	≤2
Ni	≤0.3	≤0.3	≤0.3	9–11
P	≤0.04	≤0.035	≤0.03	≤0.035
S	≤0.05	≤0.04	≤0.035	≤0.02
Si	0.15–0.3	≤0.3	0.4–0.6	≤0.8
N	≤0.008	–	0.008	–
Cu	≤0.3	≤0.3	≤0.3	≤0.3
As	≤0.08	≤0.08	≤0.08	–
Al	–	–	0.02–0.05	–
V	–	–	≤0.12	–
Ti	–	–	–	0.4–0.8

and low-alloyed steels at the application of high-frequency currents. For heating the edges converging in a spiral, a high-frequency welding generator VChS-160/044 with a power of 160 kW and a frequency of 440 kHz with contact current supply to the edges welded is used. The main processes of high-frequency welding under pressure in the manufacture of test specimens of spirally-welded pipes of the diameters D = 98, 108 and 152 mm were carried out on low-carbon steels of grade St3sp(killed) (S = 1.0 mm thickness) and 08kp(rimmed) of S = 1.0 and 1.3 mm thicknesses, low-alloyed steel S355 (analogue of steel 17G1S) with S = 2.0 mm thickness and corrosion-resistant steel of grade 12Kh18N10T (S = 0.8 and 1.0 mm thicknesses). The chemical composition of the applied steels is given in Table 1.

Figure 1 shows the scheme of the formation of joining of spirally-welded pipe edges during high-frequency pressure welding and the use of activators: *a* — beginning of the joint formation, *1* — preliminary applied activator on the metal edges to be joined (overlapped joint); *b* — process of upsetting in the form of unrolling the overlapped joint with activator in the weld zone immediately after heating by high-frequency currents, *2* — activator on the metal edges to be joined; *c* — formed bevel-butt joint of edges, *3* — metal with an activator, squeezed out from the weld, unrolled over the pipe surface; *4* — formed weld (with probable inclusions of activator of 0–50 μm thickness).

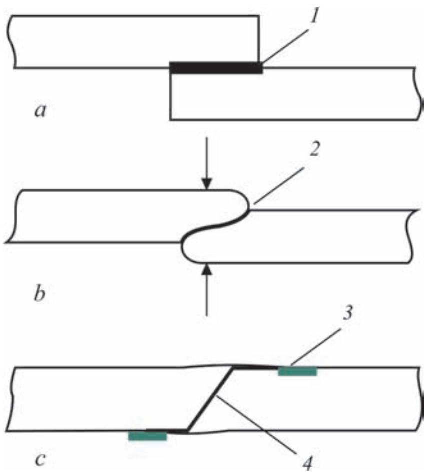

Figure 1. Scheme of forming joint of edges of a spirally-welded pipe (see the description of *a*–*c* in the text)

In producing test specimens of spirally-welded pipes of the mentioned steels, the activators were used, representing a powder mixture of flux PV-201 or PV-209 and a copper-nickel brazing alloy PAN-3 (PD58G32N8S) (Cu — base 58, Mn — 32, Ni — 8, Si — up to 1.5 %) [18], which was applied by spraying on a thin layer of raw adhesive, with which the welded edges were preliminary greased.

To fix the powdered mixture of the flux and the activator on the welded edges, cyanoacrylate adhesives and BF glue, containing phenol formaldehyde resin and polyvinyl acetal or polyvinyl butyral were used. These adhesives did not leave any undesirable impurities during the welding process.

For test specimens of spirally-welded pipes made of corrosion-resistant steel of grade 12Kh18N10T with a thickness S = 0.8 and 1.0 mm, the activators were used, representing a powder mixture of flux PV-201 or PV-209 and a powdered brazing alloy VPr-1 (Cu — the base of 65.7–70.8 %, Ni — 27–30, Si — 1.5–2.0, Fe — 0.1–1.5, B — 0.1–0.3, impurities — 0.5) [18, 19] or self-fluxing boron-silicon brazing alloy PG-Zh14 (Fe — base of 43 %, Ni — 37, C — 1.4, Cr — 14, B — 2.2, Si — 2.5, hardness *HRC* is 38–45) [20].

It was established that activating powder mixture of components should contain one part of the flux and seven-ten parts of brazing alloy during spraying a powdered mixture of 0.05–0.15 mm thickness.

Table 2. Dependence of bending angle and width of heat-affected zone on welding speed applying pressure and activators at different anode voltage

Number	Parameters				
	Overlapping, mm	Welding speed, m/min	Bending angle		Width of heat-affected zone, mm
			I variant	II variant	
Anode voltage 4.0 kV					
1	2.0	10	100	60	12
2		15	110	100	10
3		20	180	140	7
4	3.0	10	180	150	13
5		15	180	180	11
6		20	180	180	9
7	4.0	10	180	180	14
8		15	180	150	12
9		20	180	140	11
Anode voltage 5.0 kV					
10	2.0	15	20	10	10
11		20	70	50	10
12		25	90	40	9
13	3.0	15	180	150	11
14		20	180	180	10
15		25	180	180	9
16	4.0	15	180	180	12
17		20	180	150	11
18		25	160	140	10
Anode voltage 6.0 kV					
19	2.0	15	50	30	10
20		20	90	80	9
21		25	120	100	8
22	3.0	15	160	120	10
23		20	180	180	9
24		25	180	180	8
25	4.0	15	180	180	12
26		20	180	180	10
27		25	160	140	9

Figure 2 shows the stages of forming a bevel-butt joint on the specimens of thin-walled spirally-welded pipes. The process of upsetting was carried out in the form of unrolling the overlapped joint immediately after its heating with high-frequency currents applied to the welded edges with an activator. Figure 2, *a* shows a cross-section of bevel-butt weld at initial stage of its formation.

Figure 2, *b* shows the outer surface of a specimen of thin-walled spirally-welded pipe with a formed weld (top view) after the upsetting of the overlapped joint edges. A metal is visible, squeezed out from the weld, which is unrolled over the surface of the pipe and a squeezed out activator in the form of a thin film with the products of its reaction removed from the weld zone. Figure 2, *c* shows a formed cross-section of a bevel-butt at the final stage, in which the thickness S_{st} is somewhat larger than or equal to the thickness of the strip of the pipe: $S_{st} \geq S$.

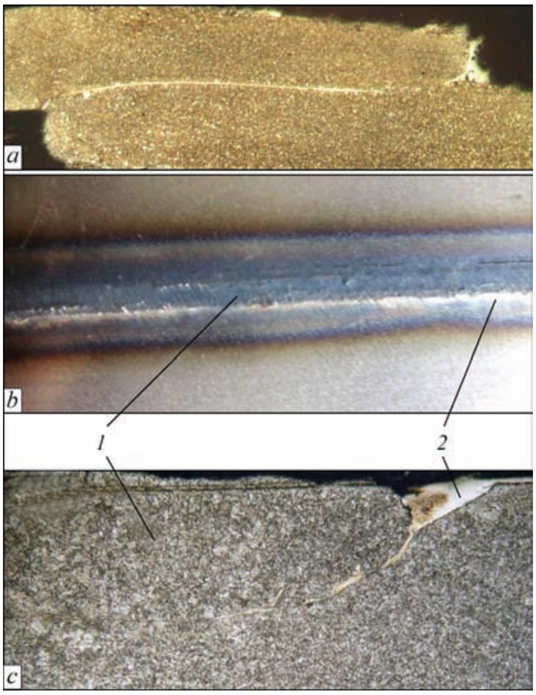

Figure 2. Stages of forming bevel-butt weld on specimens of thin-walled spirally-welded pipes: *a* — cross-section of the weld at the initial stage of its formation; *b* — appearance of the formed welded joint (top view); *c* — cross-section of the formed bevel-butt weld at the final stage; *1* — metal squeezed out from the weld, unrolled over the pipe surface; *2* — activator squeezed out from the weld

Producing welds on specimens of thin-walled spiral welded pipes was carried out in the experimental installation of the E.O. Paton Electric Welding Institute at the speeds of strip movement being 15, 20 and 25 m/min, at the corresponding values of power from the applied high-frequency generator, being 50, 80 and 110 kW. The length of region of welded edges heating (distance from the place of contact of the current supply of the welding high-frequency generator at the edges welded of the formed spirally-welded pipe billet to the place of point of convergence of edges and their entering the forming rolls) was 35–50 mm. The width of the zone of fixation of traces of the applied activator on the surface of specimens of thin-walled spirally-welded pipes reached 15 mm. The value of edges overlapping was selected at the level of 0.25–2.5 mm from thickness S of the applied strip, but did not exceed 4.5 mm for the thickness of the strip S = 2 mm at the diameter of the pipe D = 152 mm, which allowed producing a reliable welded joint and supporting a stable mode of forming specimens of thin-walled spirally welded pipes. At the same time, after the upsetting by unrolling the thickness of the weld wall S_{st} in the specimens of thin-walled spirally-welded pipes, almost reached the thickness of the applied strip S.

Figure 3. Specimens with weld fragments after mechanical rupture tests. Type of specimens is 8 according to GOST 6996–66

The quality of the weld of experimental thin-walled spirally-welded pipes produced with the use of activators was estimated from the results of mechanical tests of specimens, cut out from these pipes, by such parameters as bending angle and tensile strength. The heat-affected zone was determined by the change in colour and structural analysis of the weld metal and near-weld zone. The presence of scratches was detected visually.

It was established that the electrical properties of high-frequency welding have a significant effect on the weld quality. To produce specimens of thin-walled spirally-welded pipes at different speeds of the strip movement of 15, 20 and 25 m/min, the values of the anode voltage at the generator tube were changed, affecting the electrical power supplied to the weld zone.

The specimens with weld fragments for mechanical tests were obtained. The test results are given in Table 2.

Table 3 shows the data of the results of mechanical rupture tests of specimens with fragments of a weld of thin-walled spirally-welded pipes of diameter D = = 108 mm and wall thickness S = 1.3 mm, made of steel 08kp.

Figure 3 presents specimens with fragments of weld after conducting mechanical rupture tests. The specimens is the type 8 according to GOST 6996–66. Ultimate rupture strength is 370–380 MPa. The fracture of specimens occurs on the base metal. At 20 °C the tensile strength σ_t for heat-treated steel 08kp, is 310–440 MPa. The presented data testify of a high strength of the welded joint produced in a spirally-welded pipe, which is achieved also due to the thermomechanical hardening of the weld as a result of subsequent upsetting in the form of rolling-out overlapped joint of welded edges with applied activator in the weld zone.

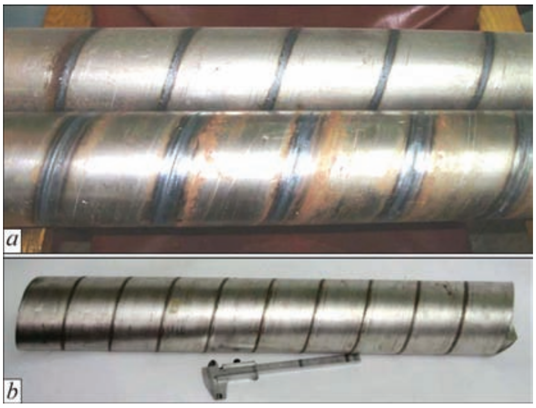

Figure 4. Specimens of thin-walled spirally-welded pipes with welds made applying pressure: *a* — at the top a pipe of steel 08kp, below — S355; *b* — 12Kh18N10T

Table 3. Dependence of rupture strength of specimens of welds of spirally-welded pipes of 108×1.0 mm on welding speed applying pressure and activators and overlapping values at different anode voltage and length of heating zone 35/50 mm

Number	Overlapping, mm	Welding speed, m/min	Rupture strength, MPa
Anode voltage 4.0 kV			
1	2.0	10	40
2		15	90
3		20	340
4	3.0	10	360
5		15	380
6		20	380
7	4.0	10	350
8		15	380
9		20	380
Anode voltage 5.0 kV			
10	2.0	20	60
11		25	140
12		30	340
13	3.0	20	350
14		25	355
15		30	345
16	4.0	20	363
17		25	370
18		30	370
Anode voltage 6.0 kV			
19	2.0	15	60
20		20	250
21		25	265
22	3.0	15	330
23		20	370
24		25	370
25	4.0	15	370
26		20	370
27		25	370

In the upper part of Figure 4, *a* the specimen of thin-walled spirally-welded pipe of diameter D = = 108 mm and wall thickness S = 1.0 mm is shown, made of steel 08kp with a narrow heat-affected zone, in the lower part — a specimen of thin-walled spirally-welded pipe of diameter D = 108 mm and wall thickness S = 2.0 mm of steel S355 with a wide heat-affected zone. For the specimen of steel S355, an activator was used in the form of a mixture of brazing alloy PAN-3 and flux PV-201. The difference in the width of the heat-affected zone is determined by a combination of parameters, such as the speed of welding, the amount of power introduced into the weld, the chemical composition of steel.

Figure 4, *b* shows the specimen of thin-walled spirally-welded pipe of diameter D = 98 mm and wall thickness S = 0.8 mm of steel 12Kh18N10T. While producing this specimen, an activator was used in the form of self-fluxing brazing alloy PG-Zh14. Despite of a rather narrow heat-affected zone, to produce long quality welded joints of specimens of thin-walled spirally-welded pipes of corrosion-resistant steels, it is further necessary to provide a reliable protection of the weld zone with shielding gases from environment effect in the used experimental installation. For the time being, the produced weld is visually different from the base metal: corrosion resistant steel 12Kh18N10T.

Figure 5, *a* shows microsection of the weld of the specimen of a spirally-welded pipe of diameter D = = 108 mm and wall thickness S = 1.3 mm of steel 08kp, produced in the process of high-frequency welding using activators: brazing alloy PAN-3, flux PV-201. The weld in the form of a thin residual interlayer of crystallized activator, formed under upsetting pressure and was not completely squeezed out from the joint zone, is clearly visible. The width of the weld (interlayer) does not exceed 4–8 μm. At the same time, the chemical composition of the formed weld is enriched with elements of base metal being welded, applied activator, and, partially with the products of surface activation. The structure of metal in the near-weld zone, close to weld, approaches the structure of the base metal.

Figure 5, *b* shows microsection of the steel 12Kh18N10T weld, produced in the process of high-frequency welding using an activator — self-fluxing brazing alloy PG-Zh14 without shielding gases. In the place of edges joining, an activator is seen, filling the microscopic nonuniformities of the joint surfaces. The width of the weld is about 1 μm. The chemical composition of the formed weld is enriched with elements of the welded base metal, however, here there is also a visual difference of the produced weld metal from the base metal.

It is assumed that to produce a stable welded joint of corrosion-resistant and alloyed steels in high-frequency welding as-applied to the production of spiral welds of pipes, it is necessary to protect the zone of the joint formation by neutral gases or to increase the welding speed for the contact between the molten and not yet crystallized activators with the atmosphere of air, which is minimum in time. This is the task of further investigations.

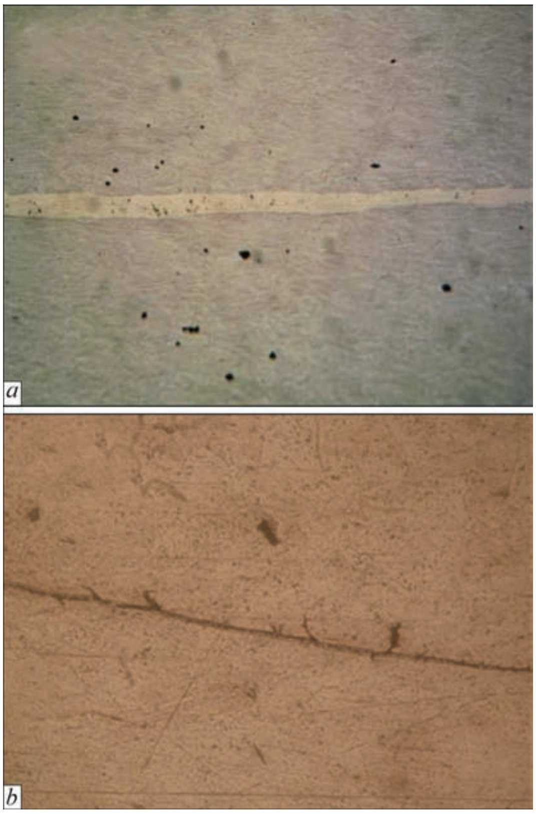

Figure 5. Microsections (×500) of specimens of welds of spirally-welded pipes made applying pressure and activators: *a* — pipe weld of steel 08kp; *b* — 12Kh18N10T

An increase in the welding speed is possible due to an increase in the introduced power of high-frequency generator, which will have a positive effect on the economic indicators of the welding process.

The further investigations should be continued to search the optimal control of the welding process [21] and modernize the equipment, especially in searching a way to protect the zone of welding from weather influence in case of using corrosion-resistant and alloyed steels. However, it is already obvious that this process can become promising in the manufacture of high-quality and inexpensive thin-walled spirally-welded pipes, including the subsequent deposition of protective coatings on them.

Conclusions

1. The use of high-frequency welding provides a possibility of producing thin-walled spirally-welded pipes of a wide range of diameters, which is relevant for different fields of industry.

2. In case of high-frequency welding of spirally-welded pipes with the application of pressure and the use of activators, the latter provide the binding of surface contaminants and their escape beyond the borders of section welded while applying pressure. As a result, the edges of the purified metal are joined at the temperatures close to the melting temperatures of

the base metal, at the development of diffusion processes in the metal, and at the final stage the process of joining occurs in the solid phase of the base metal.

3. The prospects for the application of high-frequency welding technology in the production of thin-walled spirally-welded pipes consist in producing high-quality welds. One of the ways of development is adding activators into the weld zone, which allows producing quality welded joints of low-carbon and low-alloy steels.

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