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FEATURES OF FORMING JOINTS USING SOLDER 18XFC DURING INDUCTION PRESSURE WELDING OF K76F STEEL

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Abstract. *The process of pressure induction welding with the use of activating substances occurs when the welding edges are heated to a plastic state by heat from eddy currents and complete melting of the activating substance previously introduced into the joint.The process of induction pressure welding itself was developed at the E. O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine mainly for pipes and pipe fittings. A significant contribution to the development of induction pressure welding was made by V. K. Lebedev, O. S. Pismennyi, V. D. Tabelev, M. E. Shinlov [1]. The application of induction pressure welding to solid products such as rods or parts with a developed cross-sectional area has not been fully researched. At the same time, the main task of improving the pressure induction welding process is to create the necessary uniform heating in the weld seam and in the spike zone in the 'inductor-product' system, and to obtain a joint which is formed in the solid phase, with common grains and minimal the possible seam thickness, after performing the deposition. Minimal residues of the reaction products of the activating substance during the welding process must be squeezed out of the cross-section of the weld when deposited in the grid and peripheral areas.The use of 18XFC solder as an activating substance during the butt-pressure induction welding process was tested on model samples. The chemical composition of this solder was studied. The main technological factors of the process of induction butt welding of model samples were determined, as well as the mechanical parameters of the resulting welded joints, and metallographic studies of the metal of the welded joint were carried out. It was established that solder residues in the form of eutectics were not detected in the obtained welded joints of the model samples. However, according to the results of metallographic studies, no hardening structures were found in the weld.*

Key words: *induction pressure welding, induction heating, activating substances, 18XFC solder, welded joint, model samples.*

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1. INTRODUCTION

In the E. O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine, as part of research aimed at developing technologies for welding steels in the solid phase, induction pressure welding was tested on model samples [2] with a diameter of 6 mm made of K76F rail steel using the developed methods [2, 3, 4, 5, 6, 7].

The relevant task is to determine the effect of induction pressure welding with the use of activating substances on the structure formation and properties of the welded joint. Research into induction pressure welding technologies for metals, including dissimilar metals, with subsequent heat treatment of welded joints, is being conducted in many scientific laboratories [8, 9, 10, 11]. The main factors influencing the formation and obtaining of welded joints in induction pressure welding with the use of activating substances are the distribution of the temperature field in the welded joint zone and electromagnetic parameters, the type of activating substances, and their thermochemical action under the thermo-deformation conditions of welded joint formation. Nowadays in Ukraine, welding the same structural elements of welded structures in the solid phase is seen as a promising area of research, but with the difference that the structural elements themselves are made by different manufacturers from related steel grades using different technological processes. In this case, there may be slight deviations in the geometric dimensions and cross-sectional areas of the structural elements. Such features affect the weldability and parameters of the process in different ways. Examples of such welded structure elements are reinforcing bars and pipes from different manufacturers. An important problem may be obtaining high-quality welded butt joints between railway rails from different manufacturers.

The objective of this paper is to determine the influence of one of the components of the activating agent, namely 18XFC solder, on the formation of welded joints in carbon steels during induction pressure welding. For this purpose, butt welding was performed on model samples with a diameter of 6 mm made of K76F rail steel. The resulting welded joints became the subject of the study.

The solder selection (taking into account its characteristics) and its testing in the welding of carbon steels is based on the concept of introducing ferromagnetic impurities into the activating substance for more effective use of induction heating in conditions where welded capillary gaps are difficult to access, or using non-capillary gaps in the weld [6].

The principles of modelling induction pressure welding with the use of an activating substance were applied, based on the use of the physical laws of propagation of electromagnetic fields and currents induced in the inductor, and induced currents in the edges of the parts to be welded, when obtaining the required temperature field in the welded joint area. Samples of welded joints were obtained in accordance with the performance of induction pressure welding operations using an activating agent with 18XFC solder on model samples. Fig. 1 shows the process of induction pressure welding on model samples.

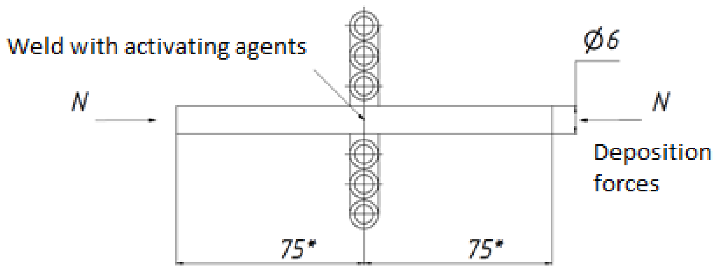


Figure 1. The process of induction pressure welding on model samples

Practical significance of the conducted research lies in obtaining welded joints when performing induction welding under pressure in the solid phase at the joint of carbon steels, in particular rail steel K76F, when testing the use of 18XFC solder as an activating agent component. From a physical point of view, surface activation consists in preparing this surface for atomic and molecular bonds with another surface by creating imperfections (defects) in the structure of the crystal lattice on the connecting (in our case) welding surface. The problem is the activation products and their removal from the joint area.

2. RESEARCH RESULTS

The 18XFC solder used is positioned as a solid copper-zinc-based solder with added silver for soldering alloyed and non-alloyed structural steels, as well as cemented, nitrided and galvanised steels in the form of hot-dip galvanised pipes and fittings, copper alloys with a melting point T_{melt} < 950°C, nickel, nickel alloys, and malleable cast iron.

It should also be noted that the use of 18XFC solder in the process of induction pressure welding is not widespread at all.

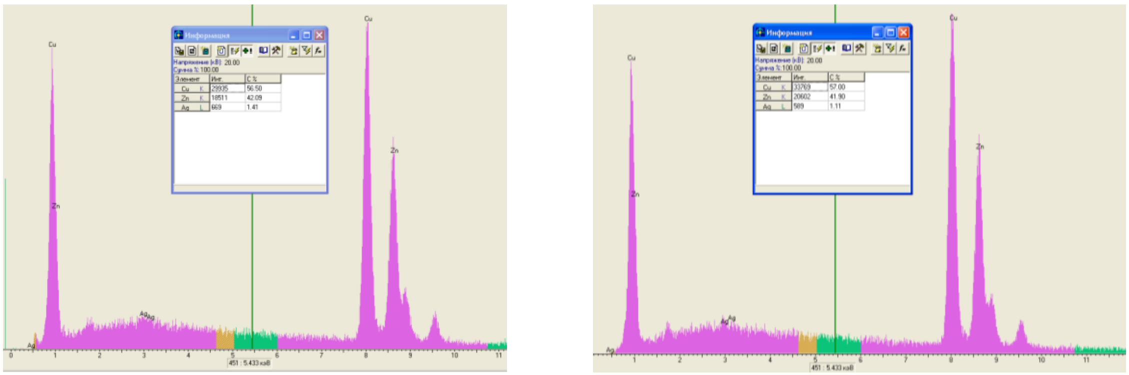
The technical specifications provided by the manufacturer Castolin Eutectic indicate a melting temperature range during soldering of (870...895)°C, and taking into account the soldering strength specified by the manufacturer (520...540) MPa, studies were conducted to test the application of 18XFC solder in the conditions of induction pressure welding.

The used solder 18XFC is not a low-temperature one. In addition, its characteristics are similar to those of the well-known PAN-3 solder in terms of physical properties, but not in terms of chemical composition, which has been tested in the process of induction pressure welding at the E.O. Paton Electric Welding Institute on some steel grades [7].

Technical characteristics of 18XFC solder [12]: – chemical composition: Cu, Zn, Ag; – melting temperature range: 870–895°C; – operating temperature: 895°C; – tensile strength: 520–540 MPa; – soldering type: capillary, brazing; – density: 8300 kg/m^3. Country of manufacture: France, manufacturer: Castolin Eutectic.

18XFC solder is supplied in the form of rods – individual electrodes with a diameter of 2 mm and a length of 50 mm.

A spectral analysis of the chemical composition of 18XFC solder was carried out. Fig. 2 shows the chemical composition of the solder based on two measurements. Thus, the copper content was 56.5–57.0% Cu, zinc – 41.90–42.09% Zn, silver – 1.11–1.41% Ag.



a b

Figure 2. Chemical composition of solder 18XFC:
(*a*) – measurement 1; (*b*) – measurement 2

Before using the 18XFC solder, it was ground to a powdery texture (Fig. 3).

Figure 3. Solder powder 18XFC (Sizes of powder parts from 0.1...0.5 mm)

The activating agent consisted of powdered solder 18XFC, flux PV209 (GOST 32178-78. High-temperature fluoroborate and boron-halogen soldering fluxes. Technical conditions), and Nairit adhesive was used as a binding agent for the components of the activating agent (Technical conditions TU U 24.6-30440956-003-2002. Polychloroprene (Baypren/Neoprene) universal water-resistant adhesive. Ukraine). The chemical composition of K76F rail steel before welding and after induction pressure welding using an activating agent based on 18XFC propane and inclusions in the welded joint area is shown in Table 1.

Table 1

Chemical composition of K76F rail steel and welded joint obtained using 18XFC solder as anactivating agent and inclusions in the welded joint area

Test materials	Composition of elements, %														Notes
	Fe	C	Si	Mn	S	P	Cr	Ni	Cu	V	Mo	Al	Zn	Ag	
18XFC									56.50				42.09	1.41	Measurement 1
									57.00				41.90	1.11	Measurement 2
K76F rail steel for welding	97.737	0.8	0.32	0.96	0.010	0.01	0.03	0.04	0.033	0.051	0.008	0.001			
Metal of the welded joint area, Fig. 12 a	97.06		1.19	0.72			1.03								Welded joint obtained
Weld line, Fig. 12 b	97.55		0.86	0.61			0.98								Weld thickness 400…485 μm
Inclusion No. 1, Fig. 13 a	88.33		0.95	5.02	4.32		1.4								Inclusion diameter D⌀incl < 0.5 μm
Inclusion No. 2, Fig. 13 b	55.19		2.60	1.65	0.3		0.89					39.37			Inclusion diameter D⌀incl < 0.5 μm
Inclusion No. 3, Fig. 13 c	29.50		1.12	10.31	0.51		1.24					57.33			Inclusion diameter Φ⌀incl < 0.5 μm
Inclusion No. 4, Fig. 13 d	81.90		0.97	8.34	6.17		1.49					1.13			Inclusion diameter Φ⌀incl < 0.5 μm
Inclusion No. 5, Fig. 13 e	69.18		0.94	14.89	11.95		1.55					1.50			Inclusion diameter Φ⌀incl < 0.5 μm

A series of experiments with the use of an activating agent was conducted on laboratory equipment using physical modelling of the induction pressure welding process which included 18XFC solder, on samples with a diameter of 6 mm made of K76F rail steel. [13–17]. Welded joints were obtained from rail steel. In addition, three measurements were taken to obtain the average values of the mechanical parameters of welded joints during induction pressure welding.

Table 2

Parameters of the induction pressure welding process and obtained research results.

Parameter	
Sample material	High-carbon rail steel K76F (0.8% C)
1	2
Average length of the welded sample obtained $L_{2\ FINAL}$, mm	147
Sample diameter before welding, Φ20, mm	6
Sample cross-sectional area, S 2O, mm^2	28.274
Deposition rate, $\Delta\ l_2$, mm	3.2
Volume of deformed metal, $\Delta\ v_2$, mm^3	90.432
- $\Delta\ l_2/S_{\ 2O}$, mm^{-1} – ratio of the amount of deposition to the cross-sectional area, before welding a rod or pipe, or other welding workpiece	0.1132
bend radius f_2, mm based on 120 mm	6.75
bend angle α, ^{O}	6°

End of the table

1	2
Total welding time, t s	32
Ambient temperature, T ^{O}C	20
Initial sample temperature, T ^{O}C	20
Set heating temperature of the joint area, T ^{O} C	850–900
Supply current frequency, kHz	90…100
Inductor current, A	350…500
Three-turn radial inductor, R mm	27...27.5
Outer diameter of the inductor, $\Phi_{12,}$ mm	54..55
Inner diameter of the inductor, Φ_{11}, mm	10
Width of the inductor, H_1 mm	8
Distance between the turns of the inductor, Δ H_1 mm	2
Outer diameter of the inductor tube, Φ $_{1O,}$ mm	6

Note to Table 2: – The first digit (1) denotes lowercase indices that refer to the working heating element – the inductor.

- The first two digits (2) denote lowercase indices that refer to the product (welded sample).

The calculated deposition rates during induction pressure welding with the use of activating substances characterise the thermo-deformation processes, which consist of mutual counter-plastic deformation of the edges of the welding workpieces. They also characterise the formation of the welded joint.

The deposition indicators for induction pressure welding using activating substances in rods include:

- Δ l_2 mm is the deposition rate, i.e. the linear displacement of a rod, pipe or other welding workpiece along its main axis during the process of counter plastic deformation when performing induction pressure welding;
- Δ v_2 mm^3 = Δ $l_2 \times$ S $_{2O}$. – the volume of deformed metal displaced into the grid and peripheral area of the weld and round weld area after deposition during welding of a rod, pipe or other welding workpiece;
- $\Phi_{20.}$ mm is a diameter before welding a rod, pipe or other welding workpiece;
- $\Phi_{21.}$ mm is a diameter after deposition during welding of a rod or pipe, or other welding workpiece;
- S_{2O}. mm^2 is the cross-sectional area before welding a rod, pipe or other welding workpiece;
- S $_{21.}$ mm^2 is the cross-sectional area obtained after deposition during welding of a rod, pipe or other welding workpiece;
- Δ l_2/S $_{2O.}$ mm^{-1} is the ratio of the deposition value to the cross-sectional area, before welding a rod or pipe, or other welding workpiece;
- Δ l_2/S $_{21.}$ mm^{-1} is the ratio of the deposition value to the cross-sectional area obtained during induction pressure welding.

The specified deposition rates during induction pressure welding depend on the distribution of electromagnetic and thermal fields around the perimeter of the welded joint and the weld area, the uniformity of the volumetric heating of the welded joint, and the shape of the inductor.

Considering the technological features of induction pressure welding, namely the location of the inductor on the outside, i.e. the inductor covering the perimeter of the welded joint, it can be assumed that $\Phi_{21.}$ is the diameter after deposition during welding of a rod or pipe, or other welding workpiece, limited by the inner diameter of the inductor Φ_{11}. That is $\Phi_{21.} \approx \Phi_{11.}$ In this case $S_{21.}$ is the cross-sectional area obtained after deposition during welding of a rod or pipe, or other welding workpiece, is also limited by the internal cross-sectional area of the inductor: $S_{21.} \approx S_{11.}$

However, the ratio of the deposition amount to the cross-sectional area ($\Delta l_2/S_{2O.}$) and the ratio of the deposition amount to the cross-sectional area obtained during induction welding with a rod or pipe pressure or other welding workpiece ($\Delta l_2 / S_{21.}$) are fairly easy to measure on the resulting welded joint after welding on rods or pipes, or on other parts after welding, and are characteristic indicators of deposition.

It should also be noted that Δv_2 – the volume of metal displaced into the grate and peripheral area of the weld and the weld zone circle after deposition during welding of a rod or pipe or other welding workpiece – can take various forms. The shape of the grate and the appearance of the peripheral area of the weld and the weld zone (Fig. 4) depend on the shape of the inductor and the corresponding distribution of electromagnetic and thermal fields around the perimeter of the welded joint and the weld zone.

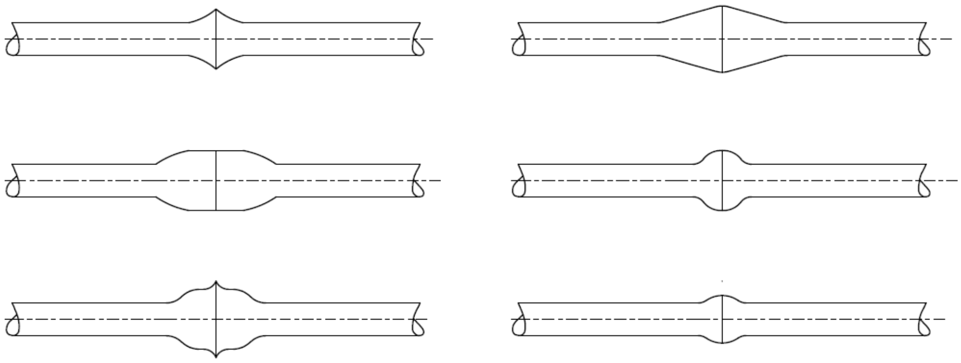


Figure 4. Different types of the peripheral part of the seam and the circle of the weld zone

Initial assessment tests of welded joints.

After welding, tests were carried out to determine the deflection f_2 in a special laboratory device, taking into account the similarity criteria. The deflection is almost $f_2 = 6.75$ mm (Fig. 5 a); Fig. 5 b); Fig. 5 c)). Previously, the volume of metal Δv_2 –, which was displaced into the grid and the peripheral area of the weld and the weld zone, was removed and cleaned after deposition to achieve the initial diameter of the sample, $\Phi_{2O.}$

Tests were also carried out to determine the angle of deflection α^O (Fig. 6).

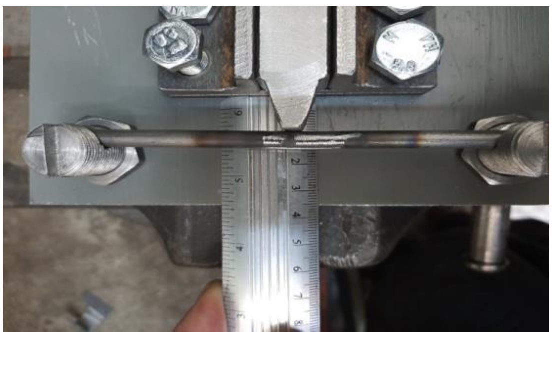


Figure 5 a) Determination of the bending (initial position of the sample)

Figure 5 b) Determination of the bending (intermediate position of the sample)

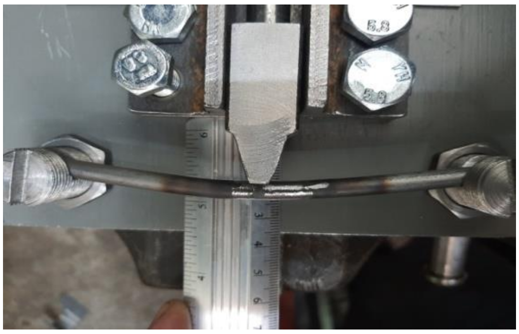


Figure 5 c) Determination of the bending (final position of the sample)

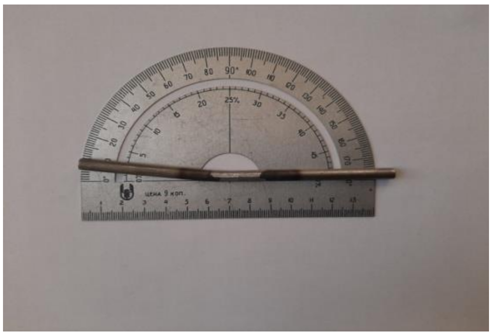


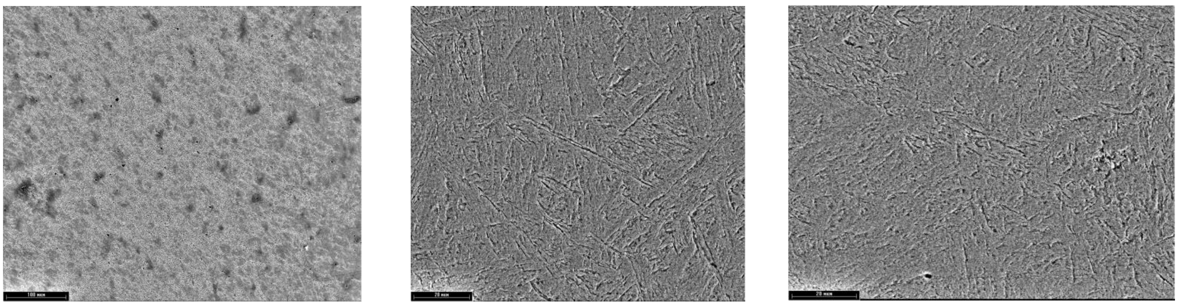
Figure 6. Determination of the bending angle α^{O} (Intermediate position, after reaching plastic deformation)

Metallographic studies of the welded joints obtained.

To study the effect of using 18XFC solder as part of the activating agent on K76F rail steel (P65 type rails) during induction pressure welding, metallographic studies of a welded joint sample were carried out. To reveal the microstructure, the sample was chemically etched in a 4% alcohol solution of nitric acid (nitral). The study and microphotography of the obtained microstructures were performed on a NEOPHOT-32 microscope with an OLYMPUS photo attachment and on a JSM-840 scanning microscope (JEOL, Japan) with a Micro Capture image capture system and an advanced Link 860/500 micro X-ray spectrometry system with Magallanes 2.2 software (Ukraine). The Vickers hardness across the joint area was measured using a LECO M-400 hardness tester at a load of 100 grams at a distance between punctures of 100 μm to 500 μm.

Microstructure of the base metal. The grain size in the base metal corresponds to grade 9...11 on the main scale of GOST 5639-82 (Fig. 7, a). The microstructure of the base metal is sorbitic (Fig. 7, b) and/or even troostitic (Fig. 7, c). The hardness of the base metal according to Vickers HV0.1 is 2800–3200 MPa.

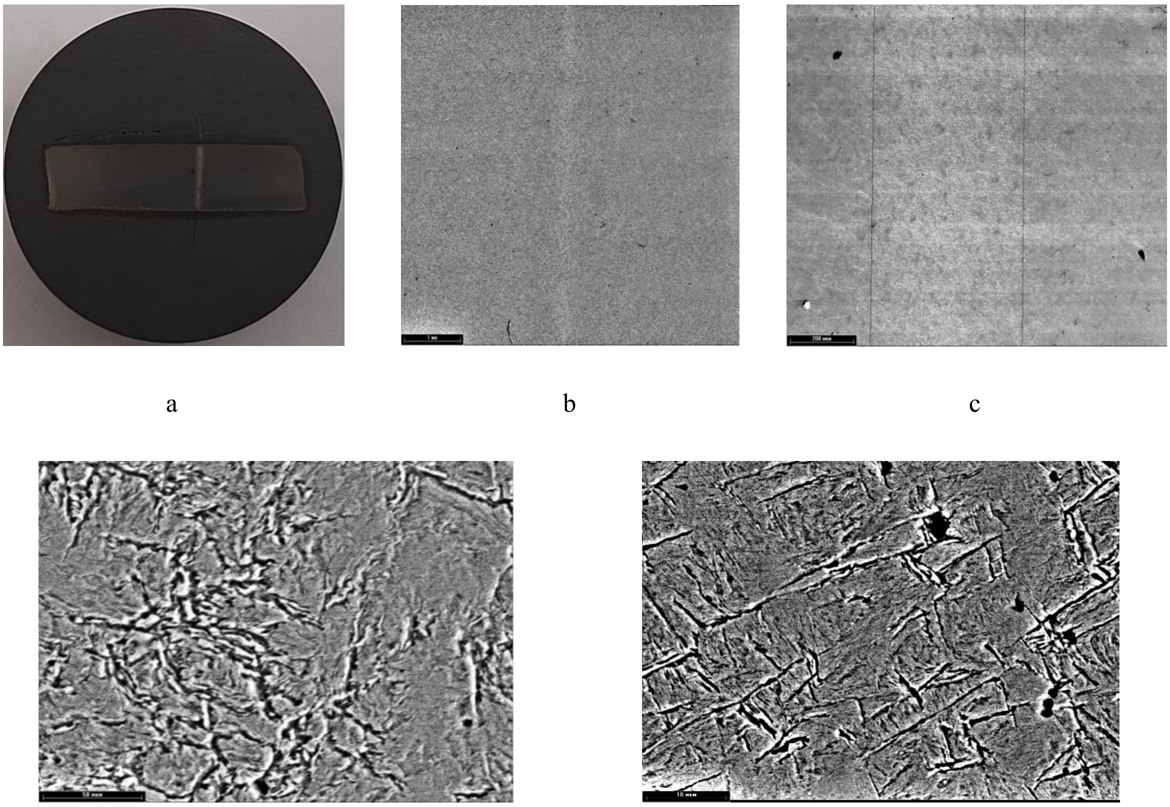
The microstructure of the sample in the welded joint area in the 'light band' section, which is a welded joint, is predominantly sorbite with martensite inclusions. The size of the sorbite grains is 10–15 μm. The hardness of the sorbite component HV0.1 is in the range of 2850–3300 MPa. The hardness of individual martensite grains reaches 6340–6810 MPa. Non-metallic inclusions in the weld are mainly manganese sulphides (MnS) and aluminium oxides (Al2O3). No hardening structures were found. In the near-weld zone on both sides of the weld, there are individual inclusions of the powdered activating agent used, which includes 18XFC solder. There is no solder in eutectic form. No cracks form in the weld or the near-weld zone of the welded joint.



a b c

Figure 7. Microstructure of rail steel K76F before welding:
(a) – magnification x200; (b) and (c) – magnification x2000

Fig. 8, a shows a fragment of a welded joint (vertical light stripe), Fig. 8, b and *c* show magnifications of x20 and x100, respectively, and Fig. 8, d and e show a magnification of x2000. The joint width is 400–485 μm.

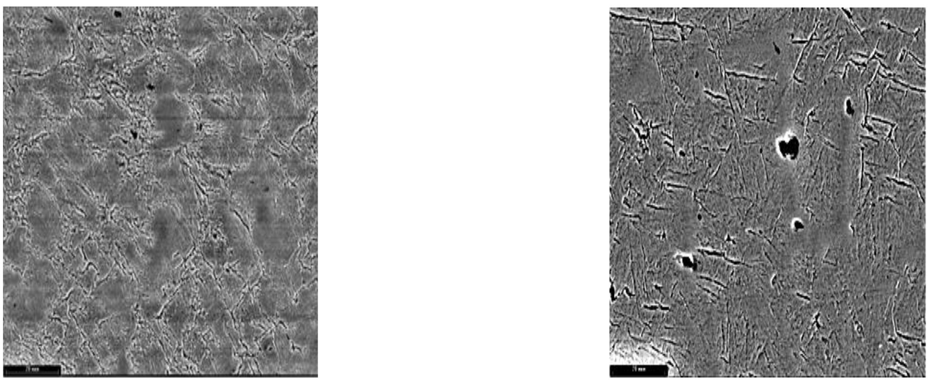


a b c

d e

Figure 8. A sample of a welded joint: (*a*) – fragment of a weld (vertical light strip); (*b*) – magnification x20; (c) – magnification x100 (limited by vertical lines); (d), (e) – magnification x2000

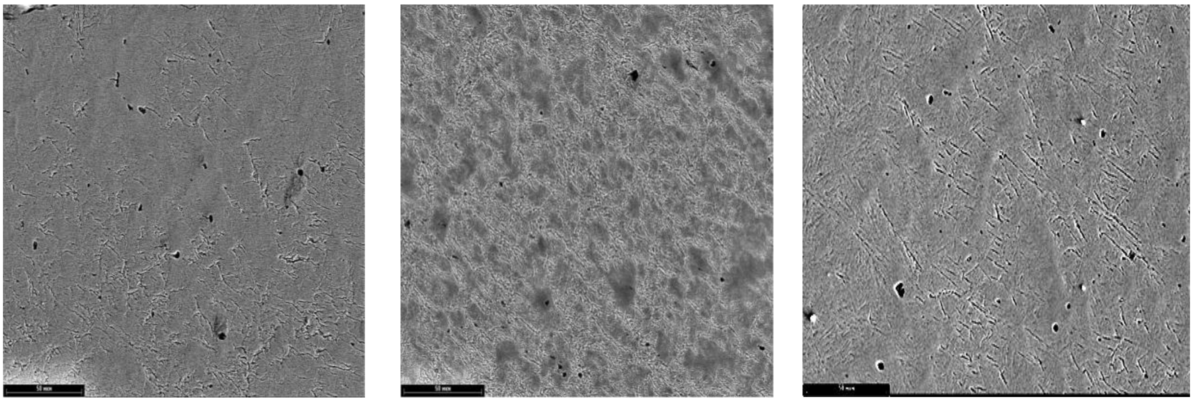
The microstructure of the sample was also studied in three areas (Fig. 9): in the upper, middle and lower parts of the welded joint at a magnification of x1000. The microstructure varies along the height of the weld.



a b

Figure 9. Changes in the microstructure in the weld joint: (a) – the upper part of the weld; (b) – middle part. Magnification x1000

Non-metallic inclusions and/or pores were found in the weld, which were observed in all parts of the welded joint that were studied (Fig. 10).

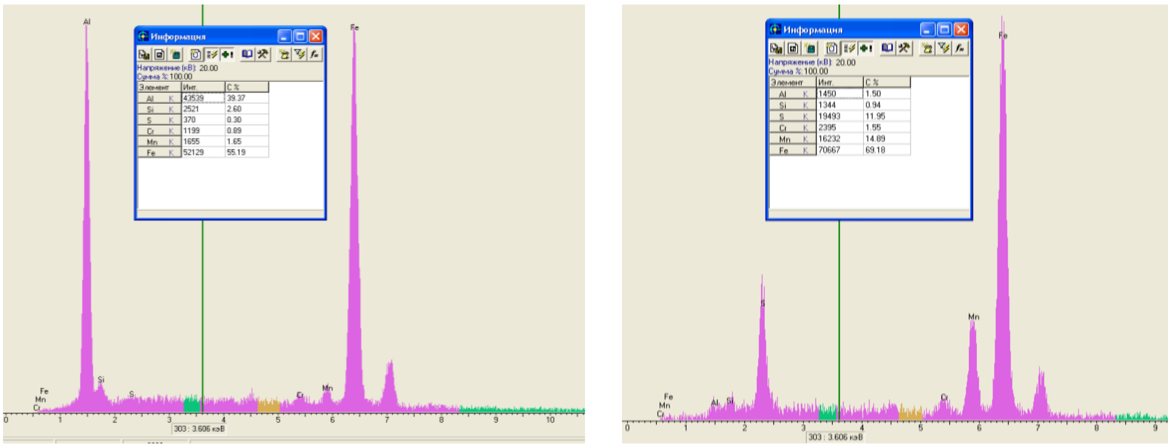


a b c

Figure 10. Non-metallic inclusions and/or pores in the weld. Magnification x500

Non-metallic inclusions in welded joints are mainly aluminium oxides Al_2O_3 and manganese sulphides MnS (Fig. 11). An increased aluminium content indicates the presence of Al_2O_3, while an increased sulphur and manganese content indicates the presence of a manganese sulphide-based compound.

No cracks form in the welded joint or around the weld area.

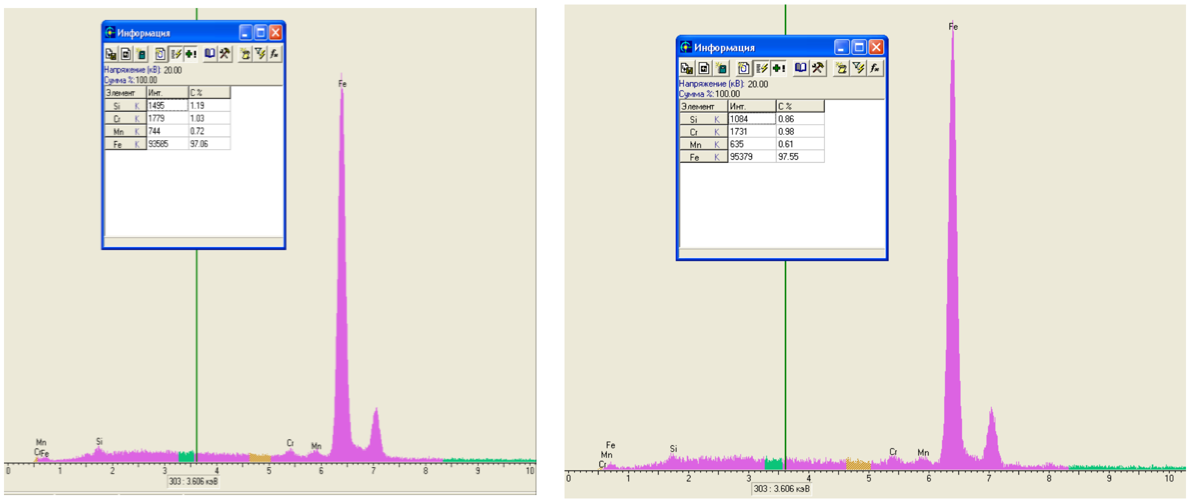


a b

Figure 11. Chemical composition of impregnation-inclusion
in the zone of the welded joint

After welding, the chemical composition of the metal in the welded joints of the model samples was analysed.

The measurement of the chemical composition of the base metal near the fusion line in the welded joint is shown in Fig. 12 *a*. The amount of iron is Fe = 97.06%, which coincides with the base metal of the rail before welding. The chemical composition of the fusion line is shown in Fig. 12, *b,* where iron is Fe = 97.55%. Therefore, iron is the basis of the welded joint obtained.



a b

Figure 12. Chemical composition of the metal in the zone of the welded joint:
(*a*) – base metal near the fusion line; (*b*) – weld lines

Analysis of the welded joint obtained using 18XFC solder as an activating agent and inclusions in the welded joint area.

Fig. 8 c shows a sample of a welded joint with a fragment of a welded joint with a vertical light strip (limited by vertical lines, magnification x100).

We believe that the nature of the light strip lies in a sharp decrease in the carbon content in the welded joint during the induction pressure welding process.

Based on the data in Table 1, there is no carbon content along the fusion line.

We assume that the sharp decrease in carbon in the welded joint area and its absence along the fusion line is due to the action of thermochemical and electrochemical factors of the induction pressure welding process.

To obtain a high-quality welded joint, it is necessary to achieve uniform heating across the entire cross-section of the weld, in other words, across the entire joint plane. The use of an induction energy source allows this to be done faster than other energy sources and, most importantly, allows it to be done in the required location, which is the weld. However, it should be noted that the heating process starts from the ambient temperature, and in some places, including the welded joint, there are more or less intense heating points, where thermochemical processes occur more intensively. It takes time to achieve uniform heating across the entire cross-section of the welded joint. It is during this time that the thermochemical action of the activating substances in the form of a powder mixture takes place, which consists in a reaction with oxide films on the welding surface of the workpieces before deposition, with this temperature range being below the melting point of the solder. Next, the applied solder enters into the thermochemical processes, it is converted into a liquid phase and spreads over the welding surface of the workpieces, then uniform heating is achieved over the entire cross-sectional area of the welded joint, and only then is the deposition operation performed, which squeezes all the liquid low-melting phase into the peripheral zone of the joint – into the grid.

The effect of deposition during induction pressure welding also consists in changing the density of the metal of the workpieces that are subjected to welding both in the welded joint itself and in the weld zone. The structure of the metal itself also changes in these areas [18]. Changes in metal density also lead to changes in the density of dislocations, imperfections, and inhomogeneities (defects). The time required for deposition is rather short, and the effect of deformation rate on the formation of the welded joint is significant. We believe that during this time, thermochemical processes also occur, during which the interaction of elements takes place. Considering that at temperatures above 1000°C, carbon interacts with metals and forms carbides.

All types of carbon, when heated, restore metal oxides to form free metals (Zn, Cd, Cu, Pb, etc.) or carbides (Ca2C, Mo2C, ZnC2, WC, Ta, etc.):

Thus, the presence of a 'vertical light strip' (Fig. 8 a); Fig. 8 b); Fig. 8 c) in the area of the weld, which is a welded joint, indicates a sharp decrease in carbon content, i.e. a carbon-free state in the welded joint.

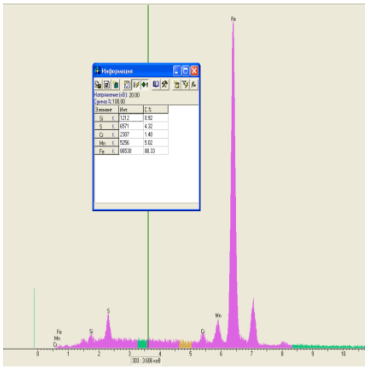
In addition to the above, electrochemical processes also occur. In this case, there is also an electrochemical effect on the surface of the edges of the parts to be welded from the side of the activating substance components. The process of achieving uniformity of the temperature field across the welded joint area occurs at the maximum values of the parameters of the induction system inductor – product, while the current induced by the electromagnetic field circulates in the welding gap in the environment of the molten base metal and the molten mixture of the activating substance, including the applied 18XFC solder, which forms the liquid phase, circulates. It is likely that during induction heating, a uniform distribution of temperatures (1000–200)°C is achieved and distributed in the plane of the welded joint, which are higher than the declared melting temperature of the 18XFC solder during soldering: (870...895)°C, which in turn also contributes to the intensification of electrochemical processes in the molten mixture of the activating agent.

As for Cr, it should be noted that the chromium content in the resulting welded joint, namely in the weld, increased significantly from 0.03% compared to its content in the base metal – the second line in Table 1 – to 0.98...1.0% in the welded joint.

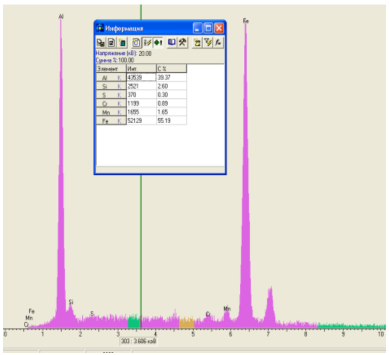
At that, taking into account the electrochemical series of metals activity and the location of the corresponding elements, namely Mn and Zn located to the left of Cr, in the volume of the molten mixture circulating in the welded joint under the action of the induced electromagnetic field, the reduction of Cr will proceed faster than Mn and Zn. However, if we refer to Table 1, the manganese Mn content in the welded joint decreased to (0.62...0.72)% compared to 0.96% in the base metal. As for Zn, it was not detected in the welded joint, although its content in (41.90...42.09)% is present in the composition of the 18XFC solder.

Considering that chromium alloys have a melting point (1350–1900)°C, or chromium in steel has a melting point of this steel, which starts at 1300°C, then, accordingly, its involvement in the thermochemical and electrochemical process of liquid phase formation is evident, but not as intense given its melting point.

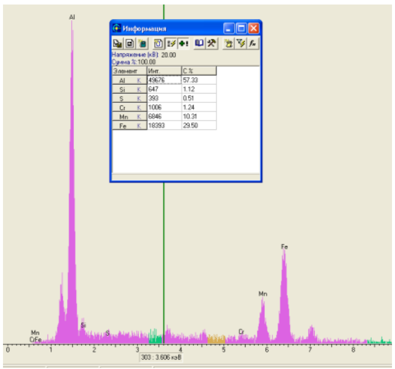
After deposition, the formation of the welded joint occurs in the *solid phase*, i.e. the connection is formed by the deep layers of the welded workpieces with a lower temperature of about (700)°C compared to the temperature (1000–1200)°C in the welded joint zone.



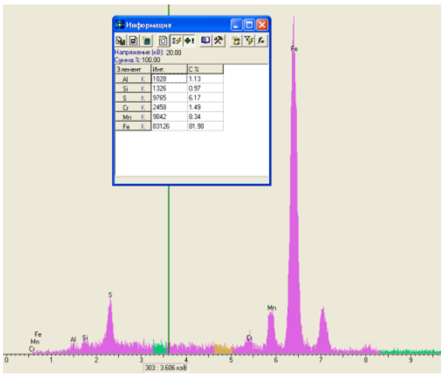
(a) – inclusion 1



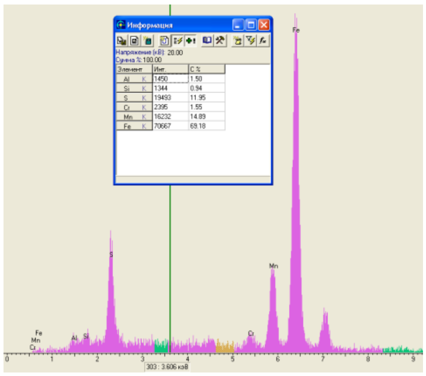
(b) – inclusion 2



(c) – inclusion 3



(d) – inclusion 4



(d) – inclusion 5

Figure 13. Chemical composition of inclusions in the seam line of the welded joint:
(a) – inclusion 1; (b) – inclusion 2; (*c*) – inclusion 3; (*c*) – inclusion 4; (e) – inclusion 5

It was interesting to investigate the chemical content of the inclusions. Figure 13 shows the chemical composition of the inclusions in the weld line of the welded joint. The iron content in inclusion 1 is Fe = 88.33%. Thus, iron is the basis of inclusion 1. The iron content in inclusion 2 is Fe = 55.19% (more than a half), and the aluminium content is Al = 39.37%, which indicates the presence of Al_2O_3 oxide in the inclusion. The iron content in inclusion 3 is Fe = 29.50% (less than half), while Al = 57.33%, i.e. Al_2O_3 oxide predominates in the inclusion. The iron content in inclusion 4 is Fe = 81.90% and it is the basis, but the presence of manganese Mn = 8.34% and sulphur S = 6.17% indicates the presence of manganese sulphide MnS. The chemical composition of inclusion 5 is similar to that of inclusion 4. The iron content in inclusion 5 is Fe = 69.18% (more than half), manganese Mn = 14.89% and sulphur S = 11.85%, which indicates a significant amount of manganese sulphide MnS in it.

As for the aluminium oxide content in the inclusions, we consider it to be introduced from the external environment during the process of grinding 18XFC solder to a powdery state or the induction pressure welding process, as it is not found in the initial components of the activating substance or in the composition of the samples subjected to welding.

The inclusions also always contain iron and compounds with chemical elements of activating substances. The inclusions do not affect the quality of the welded joint, as they are very small in size and few in number.

In order to further improve the strength and quality of welded joints when performing induction pressure butt welding of rail steel, it is necessary to conduct further research on larger diameters of model sample rods.

3. CONCLUSIONS

1. It was found that when studying the microstructure of a welded joint sample made by induction pressure welding on model samples with a diameter of 6 mm from K76F rail steel using activating substances based on 18XFC solder, the thickness of the welded joint is 400...485 μm. The diameters of the inclusions are less than 0.5 μm (Φ_{inc}l. < 0.5 μm).

2. It has been determined that the microstructure of the sample in the welded joint zone, made by induction pressure welding using activating substances based on 18XFC solder in the 'light band' area – the welded joint – is predominantly sorbite with martensite inclusions. The width of the weld is 400–485 μm.

3. The size of sorbite grains is 10–15 μm. The hardness of the sorbite component HV0.1 varies from 2850 MPa to 3300 MPa. The hardness of individual martensite grains reaches 6340–6810 MPa.

4. Non-metallic inclusions in the welded joint (junction zone) are mainly manganese sulphides MnS and aluminium oxides Al_2O_3. In the near-weld zone, on both sides of the welded joint, there are individual inclusions of the structure of the powdered activating agent used, which includes 18XFC solder.

5. No cracks form in the welded joint or in the near-weld zone. There is no eutectic solder in the sample. No hardening structures were found in the welded joint.

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ОСОБЛИВОСТІ ФОРМУВАННЯ З’ЄДНАНЬ ІЗ ЗАСТОСУВАННЯМ ПРИПОЮ 18ХГС ПРИ ІНДУКЦІЙНОМУ ЗВАРЮВАННІ ТИСКОМ СТАЛІ К76Ф

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Резюме. *Процес індукційного зварювання тиском із застосуванням активуючих речовин відбувається при нагрітих зварювальних крайках до пластичного стану теплом від вихрових струмів і повним розплавленням попередньо введеної в місце з’єднання активуючої речовини. Сам процес індукційного зварювання тиском розроблено у ІЕЗ ім. Є. О. Патона НАН України в основному для труб і трубної арматури. Значний внесок у розвиток індукційного зварювання тиском внесли В. К. Лебедев, О. С. Письменний, В. Д. Табелев М. Є. Шинлов. Застосування способу індукційного зварювання тиском на суцільних виробах таких як стрижні, або деталі із розвиненою площею поперечного перерізу є малодослідженим. При цьому основна задача вдосконалення процесу індукційного зварювання тиском полягає у створенні необхідного рівномірного нагріву в зварному шві та в колошовній зоні в системі «індуктор-виріб», та в отриманні з’єднання, яке формується у твердій фазі, зі спільними зернами та мінімально можливою товщиною шва, після виконання осадження. Мінімальні залишки продуктів реакції активуючої речовини у процесі зварювання повинні бути вичавлені з перерізу зварного шва при осадженні у грат та периферійні ділянки. Апробовано на модельних зразках застосування припою 18ХГС у складі активуючої речовини при виконанні процесу індукційного зварювання тиском у стик. Досліджено хімічний склад даного припою. Визначено основні технологічні чинники процесу індукційного зварювання тиском у стик модельних зразків, а також механічні показники отриманих зварних з’єднань, проведено металографічні дослідження металу зварного з’єднання. Встановлено, що залишків припою у вигляді евтектики в отриманих зварних з’єднаннях модельних зразків не виявлено. При цьому, за підсумками металографічних досліджень, у зварному шві гартівних структур також не виявлено.*

Ключові слова: *індукційне зварювання тиском, індукційне нагрівання, активуючі речовини, припій 18ХГС, зварний стик, модельні зразки.*

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