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Investigation of macro and micro structures of compounds of high-strength rails implemented by contact butt welding using burning-off

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Abstract. Investigations of the structural components of rail joints, obtained by contact butt welding using burning-off, which are revealed on the surface of kinks after the destruction of the compounds during static bending tests and after destruction in operating conditions, were carried out. Analysis of the microstructure and chemical heterogeneity of the fracture surface was carried out with the help of a scanning electron microscope JEOL JIB-Z4500, equipped with an attachment for energy-dispersive analysis. The analysis showed that the main structural defects were poor penetration and inclusions of iron-manganese silicates that significantly reduced the parameters for mechanical tests of welded joints. Their presence in welded joints is unacceptable. Clusters of inclusions of aluminosilicates, so-called matte spots, and oxide films of a more complex composition are formed in the compound on the basis of non-uniformly distributed nonmetallic inclusions of the metal of the rail.

1. Introduction
In the technical complex of the rail transport operations of Russia, a continuous welded rail represents a complexly expensive construction, for the maintenance and operation of which large economic, technical and human resources are expended. The number of highly defective welded joints of rails, detected in operation by means of defect detection, increases every year [1]. Also, the number of rail fractures in the area of welded joints due to welding defects is increasing annually. A pronounced increase in the number of fractures due to welding defects has been observed in recent years with the use of rails from modern steel grades for a continuous welded rail. New rail steels are distinguished by greater purity in nonmetallic inclusions and in the content of a number of impurities of alloying elements for improving the physico-mechanical properties regulated by GOST R-51685-2013 [2]. Therefore, during the welding of such production rails, there is a tendency to form nonmetallic inclusions in the seam, predominantly alumina-calcium ones, and to heat slightly the metal in the weld zone after welding. This leads to the fact that during the contact welding of such rails, more concentrated heating of metal and a high initial upset rate (minimum is about 35-40 mm/s [3]) are required. The most widely used

method for welding rails is the electrocontact method (ECM), which is used in more than 95% of cases. Only the ECM is used in rail transport of the Russian Federation. About 600 thousand rail joints at rail welding enterprises (RWE) and up to 50 thousand rail joints using track self-propelled rail-welding vehicles (TSRV) are annually executed by this method. The most complicated and loaded sections of a rail are welded joints. When welding a rail, areas adjacent to the joint are inevitably exposed to temperature effects, which affects the structure of the metal, and these effects affect different parts of the rail differently [1,2]. Investigation of the complex of strength and working properties of welded joints of rails of new steel grades showed that the current welding technology – continuous burning-off of rails – in most cases does not provide the required level of structural strength and leads to the formation of welding defects in weld joint metal [4]. This leads to a reduction in the service life of the welded rail and to the corresponding repair costs. Only in 2012, the Russian Railways spent about 10 billion rubles on the replacement of defected welded joints of rails in road conditions. The purpose of this work is to study defects in the welded joint of high-strength rails obtained by contact butt welding using burning-off.

2. Materials and methods of research

To study the quality of the welded joint, it is necessary to conduct a selective test of the properties in the welded joint and the heat-affected zone. For this, it is necessary to cut samples from these zones to conduct metallographic studies and carry out tensile and impact strength tests.

The rail is a fairly simple spatial structure consisting of three main parts: the head, neck and sole. If we measure hardness by a portable device in Figure 1, then we will not be able to qualitatively assess changes in the structure of the metal of the rail welding joint.

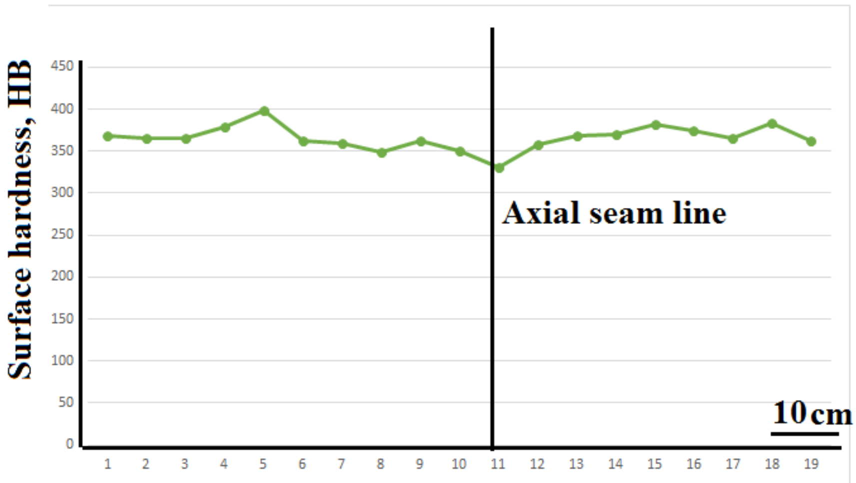

Figure 1. Measurement of hardness on the surface of the rail portable device.

Welding of rails DT350 for the continuous welded rail are performed at rail welding plants (in the permanent study area) by contact butt-type machines such as MCP-6301 and K-1000. Rails are cut onto the samples by a "wet method" on a Discotom-10 cut-off machine with special cooling (see Figure 2 and Figure 3).

The microstructure was monitored on sections in accordance with GOST R 51685-2013 [2]. Studies were carried out with the help of an optical microscope MET-2 with an increase from 50 to 1000 times. For the analysis, a scanning electron microscope JEOL JIB-Z4500 was used.

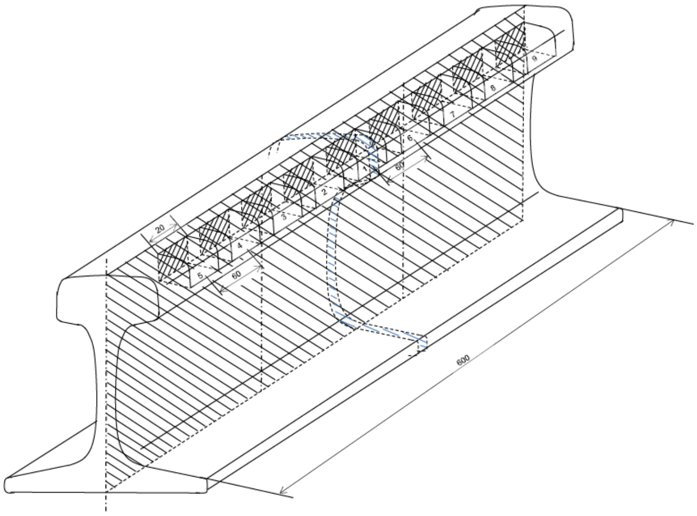

Figure 2. The scheme for cutting out samples for research of the macro and microstructure of the weld and heat affected zones.

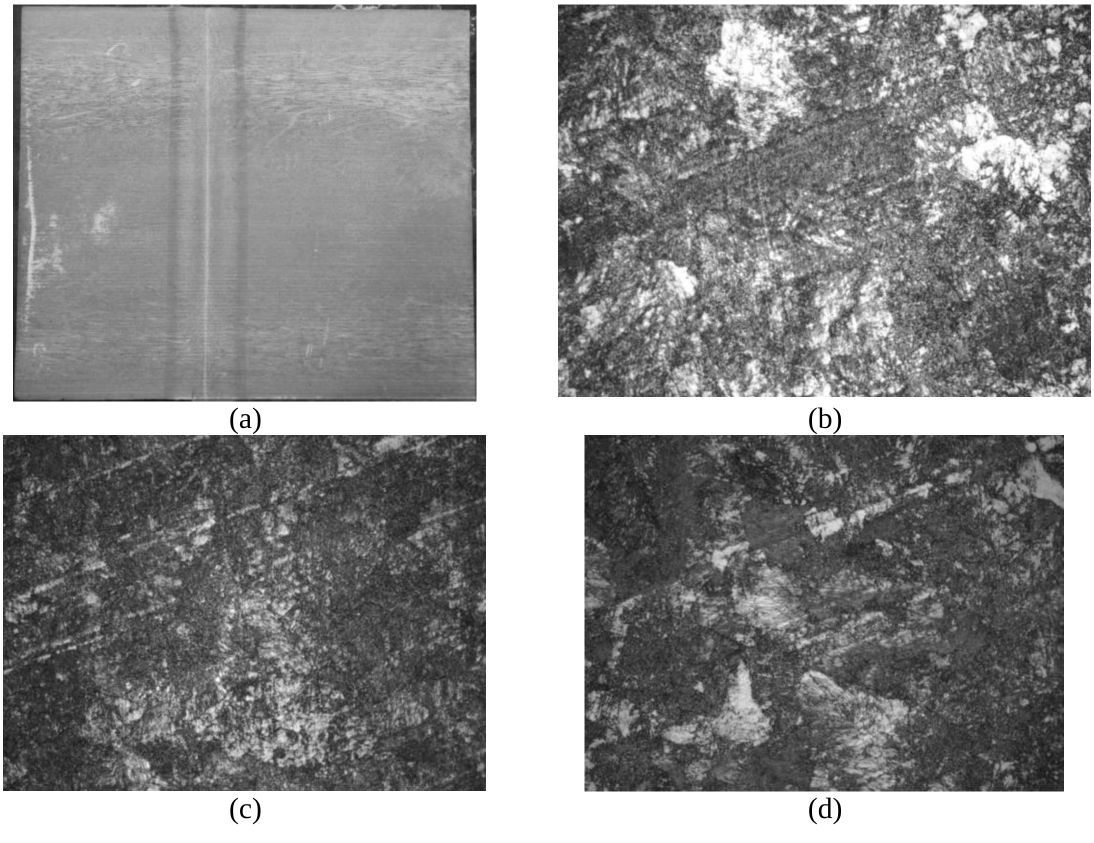

Figure 3. The macro and microstructure of the weld and heat affected zones; (a) weld macrostructure (hot etching), $\times 10$; (b), (c), (d) microstructures in the cutting section, $\times 500$.

3. Research results and discussion

The technological process of welding rails by electrocontact method is usually divided into several stages [3,4]: I – burning-off, II – burning-off, III – forcing, IV – upsetting, V – burr removal. The first step is to heat the contact surfaces. The task of the second stage is to achieve a uniform melting (of a liquid metal layer) at the ends of the rails. The third stage, the forcing, is the accelerated movement of the moving frame, which provides the best protection of the spark gap. At the fourth stage, sediment, the ends quickly approach each other with great effort. At the same time, the liquid metal with oxide films is squeezed out from the joint to the outside and forms a burr during solidification, which is removed when being hot at the fifth stage (burr removal). Each stage is characterized by welding modes: current strength I, A; voltage U, V; the amount of movement of the movable frame S, mm; system pressure P, Pa; the speed of movement of the movable frame V, mm/s; duration of stage T, s. The study of rail joints and optimization of welding regimes is an extremely important problem, the solution of which will not only improve the economic performance of railways, but also ensure a higher level of transport safety. To study the rail joint, we developed a sample preparation method (Figure 3).

The microstructure of the metal of welded joints of rails executed in optimum mode represents sorbitic perlite (Figure 2b, 2c, 2d). A band of about 200-250 μm in width with a hypocutcctoid ferrite precipitation along the boundaries of primary austenite grains, whose size by ASTM corresponds to a score of 2-3 is observed by means of the joint line. Depending on the gradient of the temperature field during the welding, the amount of the hypocutcctoid ferrite may vary. With optimal rigid regimes, characterized by a high gradient of the temperature field, thickness of the ferrite rim is minimal, and it can be interrupted. Such compounds have the highest plastic properties. The microstructure of the base metal of the rail is sorbitol-pearlitic. In the base metal there are numerous sulphides (Fe, Mn) S in the form of chains of small globules and lenticular inclusions, elongated along the rolling direction. There were also isolated and randomly scattered larger sulphides with irregular forms. Lenticular sulfides are known to be enriched in iron, more ductile and a product of hot deformation during rolling. Investigation of the factographies of fracture of rail joints, welded in optimum mode, showed that it has a crystalline structure.

The surface of the fracture mainly consists of the cleavage facets with a crooked pattern and tongues, crests of detachment. On the surface of the fracture there are refractory inclusions of titanium carbonitrides, calcium aluminates, manganese oxysulfides. The size of these nonmetallic inclusions does not exceed a dozen micrometers. The presence of such inclusions makes a fracture relief. Defects that have a significant effect on the strength properties of compounds are manifested as a violation of the homogeneity of the crystal structure of the fracture. One of such defects is poor penetration. During contact butt welding by burning-off, poor penetration is formed under conditions where the metal of the end butt of rail, before the precipitate, is in a solid or solid-liquid state. On the fracture, it looks like a flat, shiny area. Another type of defects is spots with undeveloped relief, within which shiny and dull places are combined. Analysis of the microstructure of the fracture surface showed that the shiny places represent a layer of ferromanganese silicates. Dull places, adjacent to the monolithic layer, are the place of accumulation of particles of ferromanganese silicates. Defects that in regulatory documents are defined as “dull” or “gray” spots are of particular interest. On the surface of the fracture, they are observed as areas of dark color with undeveloped relief. These defects are most often encountered during tests of welded joints of various metals, made by contact butt-welding using burning-off [3-8]. Table 1 shows the results of X-ray microanalysis of the area of metal shown in Figure 4.

Table 1. Results of X-ray microanalysis.

Spectrum	In stat.	Mass fraction of the element, weight%									Total
		C	O	Al	Si	P	Ca	Cr	Mn	Fe	
Spectrum1	Yes	7.28	6.96	0.58	0.57	0.41	0.29	3.33	0.78	79.80	100.00
Spectrum2	Yes	6.88			0.54			0.47	0.85	91.27	100.00
Spectrum3	Yes	6.61			0.54			0.44	0.83	91.57	100.00

A complex compound may be formed. It contains iron phosphide Fe_3P. Analyzed inclusions are close to spinels and silicates of the $xFeO_yMnO_zSiO_2$ type. During the study of a large number of defects, such as dull spots, in rail joints it was found that they significantly differ from the defects mentioned above not only by the composition of structural components, but also by a thickness that does not exceed 20 μm. On the one hand, small thickness makes it difficult to identify them using ultrasonic testing, and on the other hand, presence of such defects in welded joints of rails does not significantly affect the performance in field tests for static and impact bending.

In a plane perpendicular to the rail axis, it makes sense to divide the study area into equal segments with a certain pitch. After this division, each of the obtained samples remains too large for most methods of hardware research. The method of sample separation should take into account that different parts of the rail have a different shape and thickness, respectively, the samples are unevenly selected. For different studies it is necessary to choose different ways of cutting the rail into samples for research.

This method allows you to get the most relevant picture of the macro- and microstructure of the metal in different parts of the rail under study at different distances from the weld.

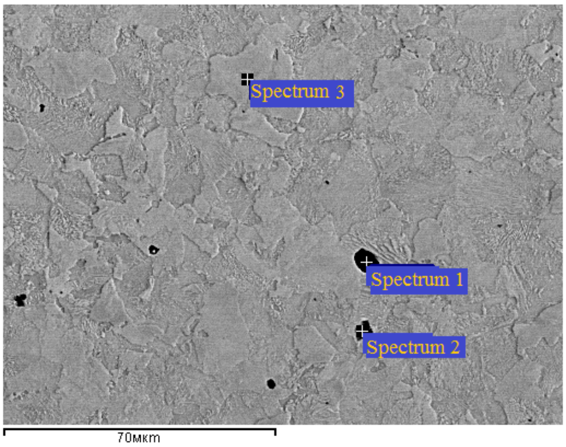

Figure 4. The sample after etching; locations of the microanalysis are indicated. The image in the backward shows electrons.

4. Conclusion

As a result of the conducted study, it was determined that the presence of nonmetallic inclusions in rail steel can significantly influence the formation of defects in the welding zone. The type and structure of defects are largely determined by the composition of nonmetallic inclusions of defects in welded joints of rails, obtained by contact welding by burning-off. It is shown that most defects are in the plane of the joint. According to the structure and the influence on mechanical properties, defects can be divided into groups. In the first group there are poor penetrations. The second group of defects consists of inclusions that are not squeezed out during precipitation of inclusions (such as ferromanganese silicates). The third group contains inclusions of manganese aluminosilicates that are also called dull spots. Defects of these groups significantly reduce the performance of mechanical tests. Their presence in welded joints influences their service life.

References

[1] Balanovsky A E, Shtayger M G, Kondratev V V, Huy Vu V, Karlina A I 2018 *IOP Conf. Ser.: Mater. Sci. and Eng.* **411** 012013

[2] GOST R 51685-2013 *Rails railway. General specifications* 2014 (Standartinform, Moscow)

[3] Kuchuk-Yatsenko S I 1976 *Contact butt welding by continuous melting* (Kyiv: Naukova Dumka) p 213

[4] Kenji Saita, Kenichi Karimine, Masaharu Ueda, Katsuya Iwano, Takeshi Yamamoto, Kiyoshi Hiroguchi *Nippon Steel & Sumitomo Metal Technical Report* **105** 84-92

[5] Mansouri H, Monshi A 2004 *Sci. and Technol. of Weld. and Joining* **9(3)** 237-246

[6] Fujii Mitsuru, Nakanowatari Hiroaki, Nariai Kiyoshi 2015 *Jfe technical report* **20** 159-163

[7] Shtayger M G, Balanovsky A E, Kondratev V V, Karlina A I, Govorkov A S 2018 *Adv. in Eng. Res. Conf. Proc.* 360-364
[8] Fedin V M, Borts A I 2009 *Metal Science and Heat Treatment* **51(11-12)** 544-552