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Improvement of the technology of resistance butt welding of rail strings for access railway lines

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Abstract. To ensure the quality of the welded rail joint, a study of the level of contamination with non-metallic inclusions of E76KhF rail steel (base metal and weld seam) was carried out. It was found that the predominant type of nonmetallic inclusions in welded joints in all studied samples are point oxides. It is shown that the modes of resistance butt welding do not affect the contamination of the samples.

1. Introduction

Welded joints are an integral part of a continuous welded rail and their quality depends not only on the welding modes [1-6]. Studies of the effect of welding modes with subsequent isothermal time of samples from rail steel, produced by passing alternating electric current pulses after welding, on the quality indicators of the welded joint showed that the obtained welded joints have low plastic properties, regardless of the presence of hardened structures in the seam metal and heat-affected zone [5,6]. It is most likely that the decrease in plastic properties in this case occurs due to discontinuities in the metal of the welded joint, in particular, oxide non-metallic inclusions. As it is known, flash butt welding of rails is performed in air, while the role of shielding gases is played by intensely emitted vapors of oxides and the metal being welded, formed in the joint.

Apparently, as a result of insufficient gas shielding, the formation of non-metallic inclusions is possible, which in the course of further welding operations must be squeezed out into weld burr during upsetting and removed together with the burr. According to the data of [8], the formation of nonmetallic inclusions in the weld is possible when they are present in the welded rail metal, and in steels contaminated with impurities, the probability of the formation of defects along the welding line is higher than in pure steels. This is due to the fact that segregation of base metal impurities occurs in the liquid metal layer on the surface of the ends.

Due to the uneven squeezing out of liquid metal in the process of deformation of the ends, in some areas, for example, in the deepest craters, an accumulation of liquid metal and, accordingly, non-metallic inclusions occurs. Such areas have reduced mechanical properties. In addition, in a number of cases, nonmetallic inclusions observed in fractures along the welding line, which are usually taken as welding defects, are in fact defects of the base metal. It should be noted that one of the main reasons for the decommissioning of rails is the accumulation of nonmetallic inclusions in the welded joint zone [9], and the nonmetallic inclusions themselves can be formed both during steel production (during smelting, out-of-furnace processing, steel casting), and directly when welding rails in a string. Therefore, the issues of the formation of non-metallic inclusions and their transformation during steelmaking and welding of rails are given great attention [10, 11].

2. Methods of the study

A study of the transformation of non-metallic inclusions formed during electric contact welding of rail steel was carried out. For welding we used samples of steel grade E76KhF (table 1) cut from the rail head with a section of 10 mm × 30 mm and a length of 90 mm. Continuous flash butt welding was carried out on MS – 20.08 machine according to the following mode: U2 = 5.76 V, I2 = 11.7 kA, Vfl = 1 mm/s, Δfl = 10 mm, where U2 is the secondary voltage; I2 – secondary current; Δfl – flash-off length; Δup – upsetting allowance; Vfl – flashing rate.

Table 1. Chemical composition of rail stee samples.

Sample No.	Mass fraction of elements, %								
	C	Mn	Cr	Si	V	Al	P	S	Cu
0	0.74	0.84	0.37	0.26	0.04	0.002	0.009	0.010	0.10
1	0.76	0.77	0.37	0.53	0.04	0.003	0.010	0.009	0.08
2	0.76	0.77	0.36	0.53	0.04	0.003	0.010	0.007	0.08
3	0.76	0.77	0.37	0.53	0.04	0.003	0.010	0.009	0.08
4	0.76	0.77	0.37	0.53	0.04	0.003	0.010	0.009	0.08
5	0.76	0.77	0.36	0.53	0.04	0.003	0.010	0.007	0.08
6	0.76	0.77	0.36	0.53	0.04	0.003	0.010	0.007	0.08
7	0.77	0.80	0.38	0.56	0.04	0.002	0.008	0.006	0.10
8	0.74	0.79	0.38	0.55	0.06	0.002	0.009	0.005	0.11
9	0.77	0.80	0.38	0.56	0.04	0.002	0.008	0.006	0.10

Welding of samples 1 – 9 was carried out with the supply of additional heat at the time of cooling by passing an alternating electric current through the welded joint according to the specified modes, sample 0 was obtained without additional passing of current after resistance butt welding by continuous flashing. The modes are shown in table 2.

The study of E76KhF steel samples for non-metallic inclusions was carried out on OLYMPUS GX-51 metallographic microscope with a magnification of 100 times in accordance with GOST 1778-70.

The study of the level of contamination with nonmetallic inclusions was carried out on samples before welding, as well as after welding in the zone of the welded joint.

Table 2. Modes of contact heating of E76KhF steel samples.

Sample no.	Cooling time after upsetting, s	Heating time, s	Cooling time after heating, s	Number of heating pulses, s
1	30	0.6	15	4
2	30	0.6	15	2
3	30	0.6	10	4
4	30	0.6	10	2
5	25	0.6	15	4
6	25	0.6	15	2
7	25	0.6	10	4
8	25	0.6	10	2
9	27.5	0.6	12.5	3

3. Results and discussion

Figure 1 shows images of the types of non-metallic inclusions present in the base metal. Non-metallic inclusions in the weld zone are shown in figure 2.

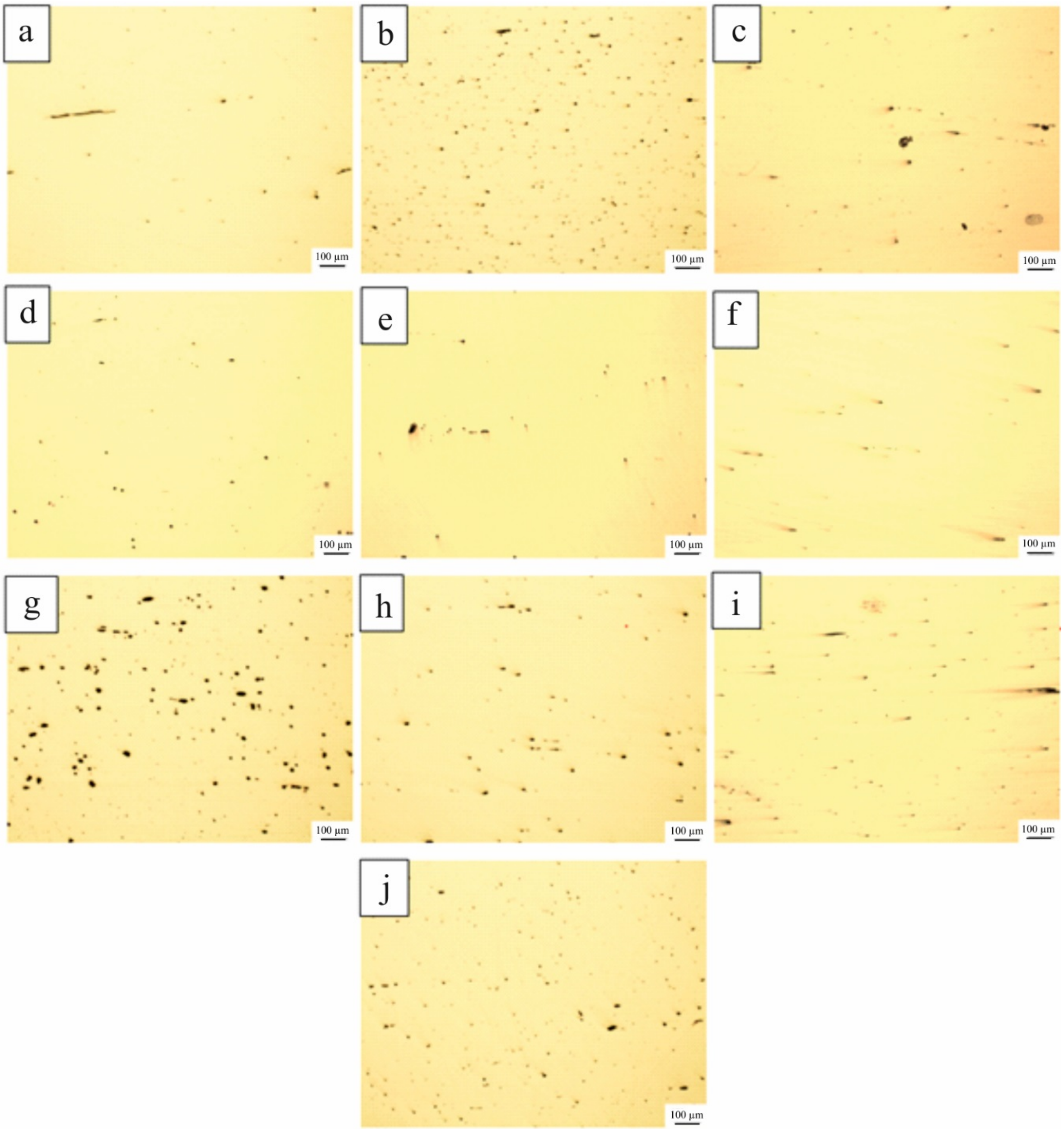

Figure 1. Non-metallic inclusions of the base metal: a – sample No. 0; b – sample No. 1; c – sample No. 2; d – sample No. 3; e – sample No. 4; f – sample No. 5; g – sample No. 6; h – sample No. 7; i – sample no. 8; j – sample No. 9.

The revealed non-metallic inclusions are typical for inclusions formed in the metal during the smelting of rail steel. The results of the contamination assessment with non-metallic inclusions in terms of the score and the average value of contamination of the zones are given in tables 3, 4.

The data given in table 3 indicate the presence in the base metal of non-metallic inclusions in the form of point oxides, silicates of plastic, non-deformable and brittle and line nitrides. The carried out investigations of the contamination of the samples showed that in the zone of the base metal non-metallic inclusions similar to those present in the zone of the welded seam were revealed. It was found that in the base metal, the highest level of contamination with non-metallic inclusions is observed in sample 6, and with a low level of contamination – in samples 5 and 8.

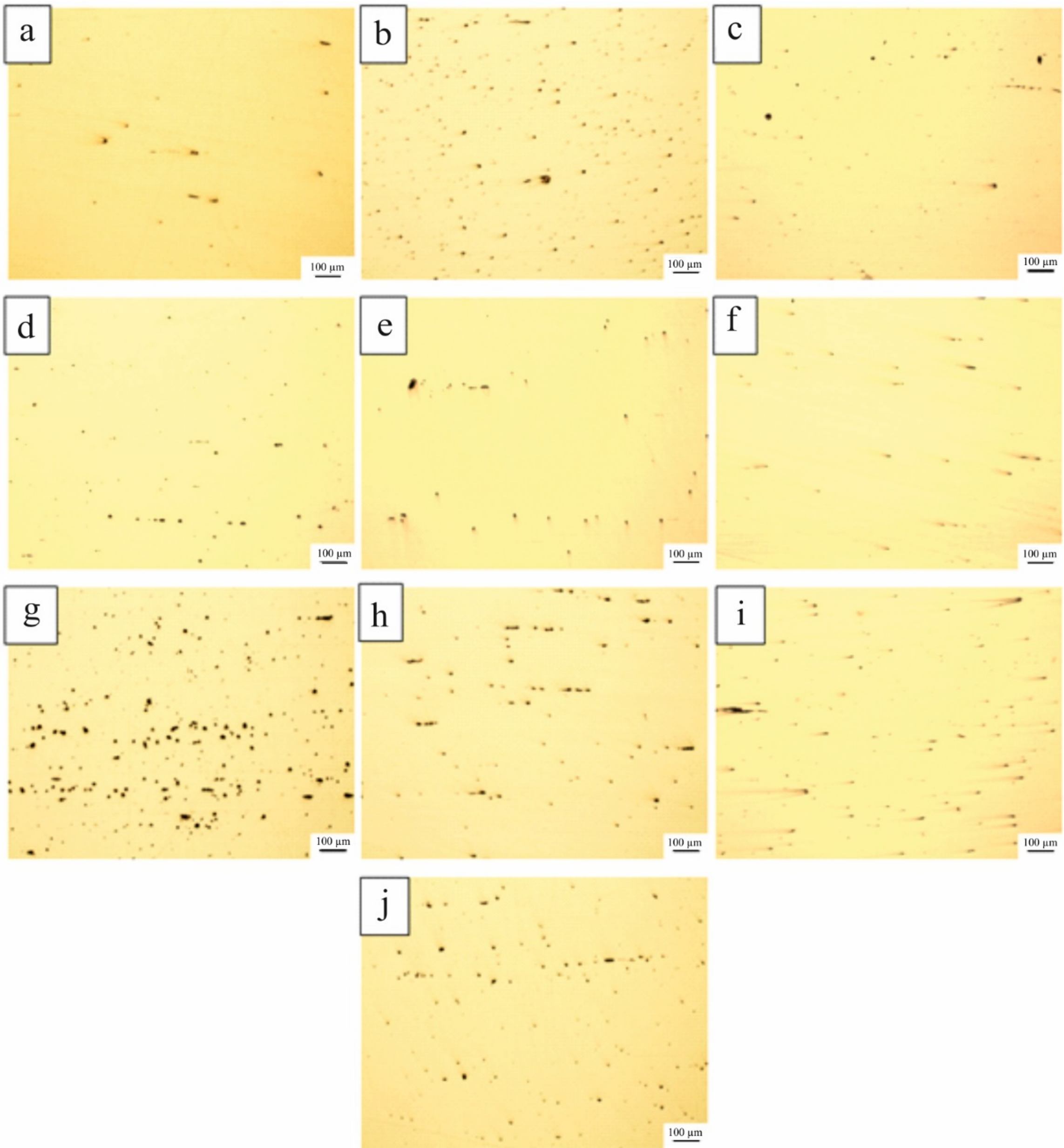

Figure 2. Nonmetallic inclusions of the welded seam of E76HF steel: a – sample No. 0; b – sample No. 1; c – sample No. 2; d – sample No. 3; e – sample No. 4; f – sample No. 5; g – sample No. 6; h – sample No. 7; i – sample no. 8; j – sample No. 9.

According to the results shown in table 4, it can be concluded that non-metallic inclusions in the form of point oxides prevail in the weld zone. In this area, contamination with lamellar, non-deformable and brittle silicates and row nitrides is observed. Among all samples, it was revealed that the most contaminated is sample 6, and samples 5 and 8 with a low level of non-metallic inclusions.

Thus, non-metallic inclusions located in the base metal, outside the weld zone, are typical for inclusions formed during smelting, and indicate the slag nature of their origin, and FBW did not affect the formation of new non-metallic inclusions during welding in the samples.

Table 3. Types of non-metallic inclusions of the base metal of steel E76KhF.

Sample No.	Types of nonmetallic inclusions by samples, points					
	Point oxides	Plastic silicates	Non-deformable silicates	Brittle silicates	String nitrides	Mean
0	1 (a)	3 (a)	–	–	2 (a)	1.2
1	1 (a)	4 (a)	5 (a)	–	–	2
2	1 (a)	4 (a)	5 (a)	–	–	2
3	1 (a)	–	–	3 (a)	2 (a)	1.2
4	2 (a)	2 (a)	1 (a)	–	–	1
5	1 (a)	2 (a)	1 (a)	–	–	0.8
6	4 (a)	4 (б)	–	2(a)	2 (a)	2.4
7	2 (a)	–	–	1 (a)	2 (a)	1
8	1 (a)	2 (б)	–	–	–	0.6
9	1 (a)	–	–	1 (a)	3 (a)	1

Table 4. Types of non-metallic inclusions in the welded seam of E76KhF steel.

Sample No.	Types of nonmetallic inclusions by samples, score					
	Point oxides	Plastic silicates	Non-deformable silicates	Brittle silicates	String nitrides	Mean
0	1 (a)	3 (a)	–	–	2 (a)	1.2
1	1 (a)	4 (a)	5 (a)	–	–	2
2	1 (a)	4 (a)	5 (a)	–	–	2
3	1 (a)	–	–	3 (a)	2 (a)	1.2
4	2 (a)	2 (a)	1 (a)	–	–	1
5	1 (a)	2 (a)	1 (a)	–	–	0.8
6	4 (a)	4 (б)	–	2(a)	2 (a)	2.4
7	2 (a)	–	–	1 (a)	2 (a)	1
8	1 (a)	2 (б)	–	–	–	0.6
9	1 (a)	–	–	1 (a)	3 (a)	1

4. Conclusion

The study of nonmetallic inclusions of samples in the base metal and in the zone of the weld seam showed that the modes of resistance butt welding by continuous flashing did not affect the contamination of the samples. Based on the data obtained on the contamination with nonmetallic inclusions in accordance with GOST 1778-70, it was found that the predominant type of nonmetallic inclusions in welded joints in all studied samples are point oxides. Non-metallic inclusions revealed in the studied samples are typical of inclusions formed during the smelting of rail steel.

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