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Repairing Crumpling and Wear Defects of Rails in the Zone of Electrocontact Welded Joints by Electric Arc Surfacing

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***Abstract*—The actual problem is the outage of rails in the continuous path made by electric contact welding. Among the main causes of the outages are defects of contact-fatigue origin, buckling, wear, and thermomechanical damage. A possibility to use electric arc surfacing to repair defective rails is analyzed.**

***Keywords*— defects of crumpling and wear of rail connections, electric arc welding, metallographic studies**

I. INTRODUCTION

The Russian Railways comprise over 92 thousand km of operating continuous rail tracks, which have about 10 million welded rail joints [1]. The method of welding most widely used is electrocontact welding [2,3]. Improper heat treatment after welding results in the appearance of areas, where the metal hardness is reduced in the welded joint zone [4-6]. During operation, considerable deformations and temperatures occur in surface layers of the rails in the zone of the welded joint that lead to changes in the structure and properties of the metal and reduce the contact strength and wear resistance of the rails [7–10]. As a result, wear and crumpling occurs, as well as large areas of reduced hardness are formed up to 200 mm. Last year, 19 thousand crumples have been registered on the roads. This is twice as much as one year before. Over the last five years, the fraction of wear and crumpling in the total number of track defects has increased by 70%. Accordingly, the number of rail breaks in the area of welds increases [1]. This determines the importance of developing the methods of repairing damaged rails and improving their operational properties [11,12]. One of the ways of repairing is electric arc surfacing [13-17]. In order to develop technologies to repair crumple and wear defects of rails in the zone of an electric-contact welded joint, studies were carried out that were performed using electric arc surfacing with one and two layers.

II. RESEARCH

The research used decommissioned rails. The total tonnage of traffic was from 510 to 580 million tons gross. The metal structures in the welded joint zone and in the heat affected zone (HAZ) were analyzed before and after the surfacing, and differences between them were also identified. The hardness of the rail metal was measured at the joint, HAZ of the weld metal, its uniform distribution and the absence of jumps were monitored.

Defective specimens cut from the active path were examined. The defective area was polished with grinding wheels before the surfacing. The absence of surface defects was monitored by liquid-penetrant (color) test. The surfacing was performed with PUNAR device with Megatronic FOCUS power supply. The self-shielded cored wire OK Tubrodur 15.43 with a diameter of 1.6 mm was used. Before surfacing it was heated at a temperature of 400–450ºC.

Metallographic studies and measurements of the welded joint hardness were carried out on samples cut from three contact-welded rails. Two of them were repaired by surfacing. The cutting scheme for metallographic samples is shown in Fig. 1. The analysis was conducted: i) with a longitudinal sample cut from a contact-welded rail section; ii) with one longitudinal sample and with two transverse samples, which were cut from a contact-welded rail section repaired by surfacing in one and two layers.

For macro analysis, a stereoscopic microscope MBS-1 was used. Etching of the samples was performed with a 25% aqueous solution of nitric acid. Etching of samples for microanalysis was carried out with a 4% nitric acid with alcohol. Microscopic examination was performed using an Axiovert 40 MAT optical microscope at ×100 and ×500 magnifications. The metal hardness of the rails was measured with the TIMEGROUPINS hardness meter, HVS-10 model. The step was 2.0 mm and the load was 10 kg (HV10).

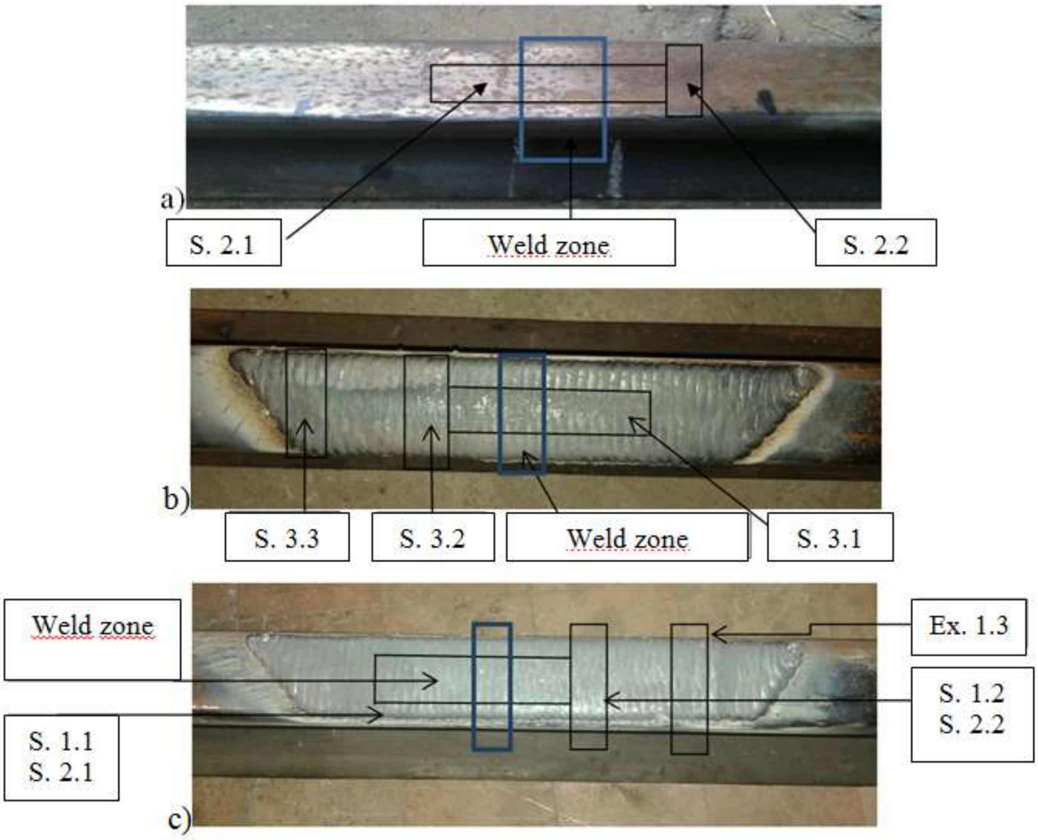

Fig. 1. Cutting scheme of samples extracted from contact-welded joint of rails: a) rail #1 without surfacing; b) rail #2 with single-layer surfacing; c) rail #3 with two-layers surfacing.

Macroanalysis of the sample cut from a contact-welded rail showed that the width of the weld was about 0.8 mm; the width of the heat-affected zone was 18.0 mm on each side. The width of the heat-affected zone from the heat-treatment after the contact welding was 100.0 mm, and its depth in the welded zone was 27.0 mm (Fig. 2). Operating cracks were found in the macrosection studied. On the rolling surface of the rail head there are chipped metal, as well as plastic deformation at the rolling surface formed during operation.

The study of macrosections showed that the thickness of the weld metal in one layer was 4.0 mm; the depth of the heat-affected zone was from 5.0 to 10.0 mm. The width of the HAZ of the weld was 17.0 mm at each side (Fig. 3). No macrodefects were found in the surfaced metal or the heat-affected zone.

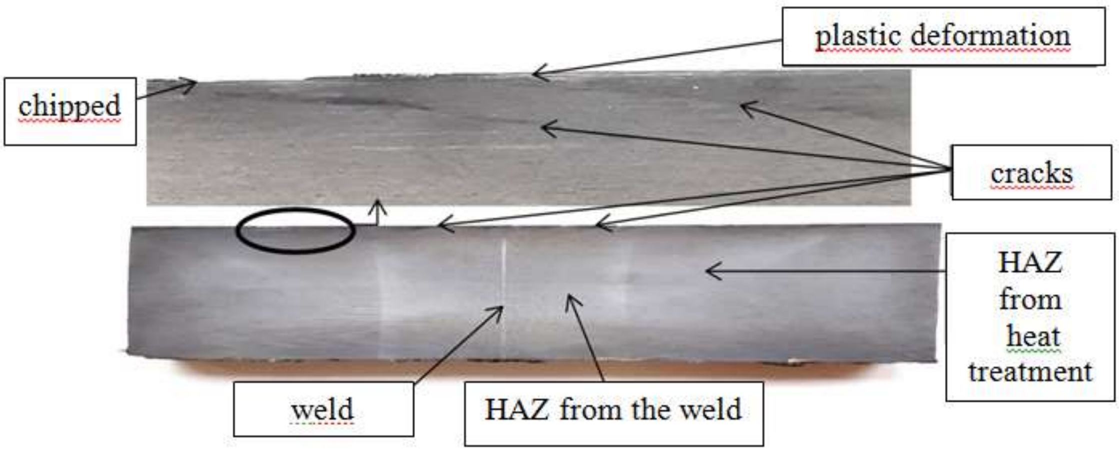

Fig. 2. Macrostructure of contact-welded joint of rails.

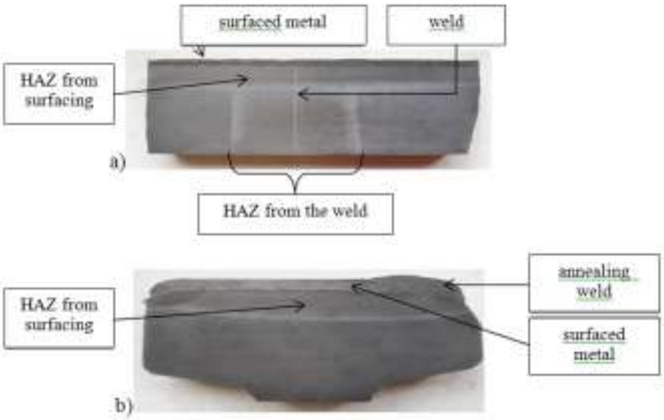

Fig. 3. Macrostructure of a welded rail joint after single-layer surfacing: a) longitudinal sample; b) transverse samples.

No regions of an increased hardness were detected in the heat-affected zone, but there was an increased value of hardness of 385HV_{10} in the surfaced metal. This point of hardness was located at the boundary of fusion of the surfaced metal with the main metal.

Microanalysis of rail samples with surfaced metal showed that the microstructure consisted of fine perlite, ferrite and bainite (Fig. 4). The hardness of the surfaced metal was 343–399 HV_{10}. Small bainite areas with a hardness of 399–401 HV_{10} were observed in the edge areas of surfacing at the metal fusion boundary and under the annealing weld.

III. TESTS

Static tests and fatigue tests were carried out for pilot samples of rails with defects repaired by electric arc surfacing and for non-repaired samples. Static tests were carried out on a PMM-500 press equipped with means for measuring load and deflection with the construction of a loading diagram.

Two pairs of samples were used in static bending tests (one pair was surfaced; the other was not surfaced) with a stretch of the rail head and foot (Fig. 5). The stretching zone of rail samples was set at a span of 1 m, the load was applied in the middle of the span in the center of the rail foot (head), fixed destructive load, P_{dest}, and deflection of samples, f. Table 1 presents the results.

Fatigue tests were carried out both for the pilot samples of rails with repaired defects and for the samples of rails without surfacing. The tests were carried out on a hydropulser IO-CD 200 PU equipped with measuring tools at an asymmetric cycle with a loading frequency of about 5 Hz.

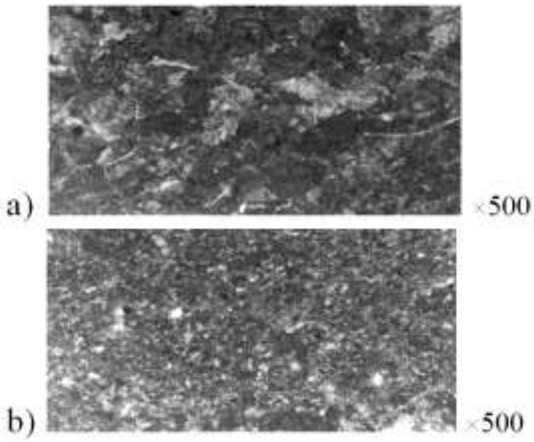

Fig. 4. Microstructure of the overheated region in the heat-affected zone: a) HAZ overheating site: thin-plate perlite, ferrite, fragments of ferritic net; b) HAZ overheating site under the annealing weld: thin-plate perlite and ferrite.

Fig. 5. Surfaced sample, load on the head. The breaking load 2260 kN (norm is 1500 kN), bending deflection 49.6 mm (norm is 30 mm).

TABLE I. STATIC TEST RESULTS

Parameter	Without surfacing		Surfaced	
	Head up, #10	***Head down, #18***	***Head up, #9***	***Head down, #13***
P_{dest} (metric ton)	184	125	186	130
f (mm)	46	18	50	18

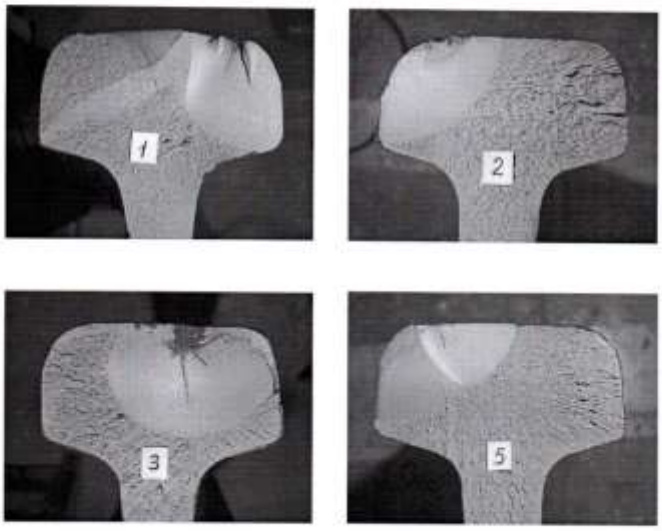

Fig. 6. Samples subjected to fatigue tests.

Two groups of rails were subjected to the tests: group 1—the rails without surfacing (#14, 15, 16, 17, и 19), and group 2—the rails surfaced at the wear sites (#1, 2, 3, 4 and 5) (Fig. 6). The stretching zone of the rail samples was set at a span of 1 m; the load was applied in the middle of the span at the center of the rail foot. The loads, at which the samples of the rails of both groups were tested, were chosen to obtain an even distribution of durability within the test base of $N_0 = 2\times10^6$ cycles. The endurance limits with probabilities of non-destruction $\alpha = 0.5$ and $\alpha = 0.95$ were evaluated by means of mathematical processing of the results of tests using a statistical-probabilistic method. The regimes of variable loading of the samples in the tests were monitored by means of a load-measuring device of the testing machine.

The analysis of the rail samples shows that most of them collapsed in the welded joint zone, samples 1 and 2 of the group 1 rails (without surfacing) started destructing from 150 to 220 mm from the welded joint that is associated with greatest damage to the rolling surface heads in these zones.

IV. Results

The study of the contact-welded rail template without surfacing showed that i) at the rolling surface of the rail head and in the weld zone there are plastic deformation of the structure of the weld metal, cracks and chips formed during operation; ii) increased hardness at the rolling surface is caused by plastic deformation; iii) quenching structures in the weld zone are not detected.

The structure of the weld metal and the HAZ is generally favorable on the rails repaired with surfacing. However, there are areas of increased hardness and areas with the bainite structure at the fusion boundaries of the weld metal that indicate a high cooling rate in these zones. The surfacing technology needs to be adjusted by applying tempering to reduce the cooling rate of metal in the zone of surfacing.

According to the criteria of static strength (breaking loading and deflection of samples), the pilot rail samples repaired with electric arc surfacing and the non-repaired rail samples are at the same level. The results of static tests of the pilot samples are positive.

Fatigue tests showed that the conditional endurance limit for the pilot repaired samples was $\sigma_{0.1}$ = 282 MPa (40 metric tons). It was not possible to find this limit for the samples of rails without surfacing, because none of them passed the tests even at low loads.

To determine the effectiveness of the technology developed, operational tests of the rails restored by electric arc surfacing were carried out. There were no defects on the rolling surface of the repaired joints. High hardness values were not found, the hardness of the surfaced layer is 328HB. The operational tests confirm the viability of this technology to extend the operation of the rails.

V. Conclusion

Laboratory and operational tests have shown that surfacing does not affect adversely the structure, the properties of rail metal, the weld or HAZ. Static tests of the pilot samples of repaired rails were carried out according to the criteria of static strength. The pilot samples with repaired defects of collapse and wear of the rail head in the weld zone by electric arc surfacing (surfaced) and the rail samples without repairing the head profile (not surfaced) are at the same level. Fatigue tests showed a positive effect from surfacing at the wear points in the welded joint. The conditional endurance limit of rail samples with repaired wrinkling and wear of the rail head was $\sigma_{0.1}$ = 282 MPa (40 metric tons). A positive result shows the feasibility of using electric arc surfacing to repair crumpling and wear defects of the rails in the zone of the electric contact weld.

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