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ON THE PROBLEM OF HEAT TREATMENT OF WELDED JOINTS OF RAILWAY RAILS

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The peculiarities of design of inductors with magnetic cores, used in a portable module for heat treatment of railway rail welded joints, produced by flash-butt welding, are presented. It is shown that the shape of the inductive wire of inductors, the location of magnetic cores relative to the rail and the technology of induction heating by currents of 2.4 kHz frequency provide a uniform distribution of temperature field in a welded joint, low temperature drop between the surface and deep layers of the rail, and also a decrease in the heating time. As a result of heat treatment of welded joints of rails R65 of steel K76F and rails UIC 60 of steel 900A in a portable module of the E.O. Paton Electric Welding Institute (PWI), the microstructure of metal of welded joints changes significantly, the hardness HRC is uniformly distributed over the width of HAZ, the deviation of hardness HRC from the level of base metal decreases. 7 Ref., 2 Tables, 6 Figures.

Keywords: *rails, welded joints, heat treatment, inductors, microstructure, hardness distribution*

During heat treatment (HT) of welded joints of railway rails, made by flash-butt welding, the technology of induction heating of welded joints by high-frequency currents is applied, followed by quenching of running surface of the rail head by a compressed air. The HT technology should provide structural zonal homogeneity of welded joints, leveling metal hardness and elimination of unfavorable diagram of inner residual stresses [1, 2]. For HT of rail welded joints in the workshop and track conditions in the machines of type UIN-001 of different modification [3], the current frequency of 8.0–16.0 kHz of the induction heating source was used. The heating of welded joints of rails of type R65 to the temperature of 850–950 °C from welding heat is performed in the period of 240 s. The machines are considered to be resource-saving from the point of view of power of the induction heating source [4]. The portable module of the machines UIN-001, designed for carrying out HT in the track conditions, does not require special drives and mechanisms for its arrangement to the site of welded joint and moving along the rail [5].

However, the arrangement of inductive wires of inductors along the rail in the machines UIN-001 leads to unjustified increase in the width of heat-affected zone (HAZ), and therefore, to the increase in heating time of welded joints. A long heating time at HT of rail joints in the conditions of rail welding enterprises slows down the production rate of rail sections.

To reduce the heating time of welded joints and to decrease the temperature drop between the surface and deep layers of the rail, it is rational to reduce the current frequency. At the PWI, the model of a portable module for HT of welded joints of railway rails by currents of 2.4 kHz was tested. A distinctive feature of a portable module is the use of inductors with magnetic cores. The inductive wire of the inductor is oriented across the rail, it reproduces the bending of its surface and is made with an increased air gap above the web and tongues of the rail. The width of the inductive wire exceeds the width of the HAZ of welded joints. The magnetic cores are installed above the running surface of the head, side edges of the head, the web and the lower surface of the rail flange [6, 7]. Thus, the complex shape of the rail surface is taken into account, the magnetic coupling of the inductor-part system is improved and the necessary power distribution among the elements of the rail is achieved. A part of the power transferred to the head and to the flange is increased as compared to the web, and it decreases into the rail tongues, preventing their overheating.

In the present work the results of testing the portable module at HT of welded joints of rails R65 of steel K76F and rails UIC60 of steel 900A are presented. The quality of HT was determined on the basis of the results of metallographic examinations of butt joints after welding and after HT. The heating of joints was carried out at the power of induction heating source being 90 kW. The initial temperature of joints was 20 °C. The heating time of welded butt joints was 180 s, which is much shorter than the time, accepted in the machines of UIN-001 type. During this period, the temperature in the plane of a butt joint reached the following values: on the surface of the running head it is 900–920 °C; at a depth of 24 mm from the running surface of the head it is 850 °C; at the center of the web it is 870 °C; at a depth of 12 mm from the bottom of the flange it is 840 °C. The time for heating the running surface of the head up to the temperature of magnetic transformations was 50 s. After HT, the welded joints were cooled in calm air.

Table 1. Grain number of metal of welded joints of rails R65 after welding and after HT

Rail element	Grain number after welding			Grain number after HT			Base metal
	Joint line	5 mm from the joint line	Zone of a partial recrystallization	Joint line	5 mm from the joint line	Zone of a partial recrystallization	
Head	2-3	4-5	6-7	7-8	6	7	7-8 (5-6)
Neck	3	5	7	7-8	6-7	7	6
Foot	3	5	7	7-8	6	7	5-6

The metallographic examinations of welded joints were carried out at a depth of 24 mm from the running surface of the head, in the center of the web and at a depth of 12 mm from the flange bottom. The microstructure of metal across the width of the HAZ and the distribution of the Rockwell integral hardness (*HRC*) were determined. The polished surfaces of the specimens for investigation coincided with the axis of symmetry of the rail transverse plane. Along the rail, the surface covered the base metal and the HAZ width. To reveal the microstructure, the method of chemical etching was used in a 4 % alcohol solution of nitric acid. The size of the metal grain was determined in accordance with GOST 5639–82. The integral hardness *HRC* was measured in the durometer TK-2M at a load of 150 kg.

As investigations showed, the microstructure of base metal of rails R65 represents sorbite. There are regions with a grain number of 5-6 and 7-8 (Table 1). After welding, the width of the HAZ of joints was 37–40 mm. The microstructure of the metal along the joint line (Figure 1, *a*) consists of sorbite and narrow fringings of ferrite along the grain boundaries. The grain is rather coarse, the grain size corresponds to the number 2-3 (Table 1). In the zone of a coarse grain, at a distance of 5 mm from the joint line (Figure 1, *b*), an almost pure sorbite structure with a grain number 4-5 occurs. In the zone of a partial recrystallization, at a distance of 18–20 mm from the joint line, a significant refinement of a sorbite grain to a number 6-7 is observed. After HT of welded joints the HAZ width was 55–60 mm. The microstructure of metal across the width of HAZ was noticeably refined. Along the joint line (Figure 1, *c*) it consists of separate precipitations of sorbite and ferrite. The amount of ferrite increased. The grain number is 7-8. At a distance of 5 mm from the joint line (Figure 1, *d*), the grain number is 6-7. The similar microstructure is at a distance of 18–20 mm from the joint line. The microstructure of metal in the zone of a partial recrystallization, at a distance of 30 mm from the joint line does not differ from the specimens after welding. The grain number is 7.

The diagrams shown in Figure 2 reflect the character of distribution of the integral hardness *HRC* along the rail after welding and after HT. In the joints after welding (Figure 2, *a*), the hardness along the joint line in the head is *HRC* 31, which is higher than the level of the base metal (*HRC* 27–28). In the web and in the flange the hardness along the joint line is *HRC* 26–28. In the rail head, at a distance of 4–6 mm from the joint line, the hardness increased to *HRC* 35. In the zone of a partial recrystallization, at a distance of 20 mm from the joint line, the hardness decreased to *HRC* 23–24. After HT of welded butt joints the change in the structure of metal led to change in hardness (Figure 2, *b*). Along the joint line it approached the level of base metal. In the head and web the hardness *HRC* is 26–28, in the flange it is *HRC* 25. The hardness in the zone of a coarse grain in the head is *HRC* 32–33. Further, up to the zone of a partial recrystallization, the hardness was stabilized up to the level of *HRC* 33, which is higher than the level of base metal. The hardness at a distance of 20 mm from the joint line changed from *HRC* 23–24 (after welding) to the level of *HRC* 33 (after HT). In the zone of a partial recrystallization, at a distance of 30–35 mm from the joint line, the hardness did not differ from butt joints after welding. A uniform distribution of the temperature field in the welded joints of rails should be noted. The level of hardness at the places of the head-to-web transition (at a depth of 40 mm from the head running surface) and web-to-flange transition (at a depth of 25 mm from the flange bottom surface), in the problem places for induction heating by high-frequency currents, corresponds to the hardness level in the head, in the web and in the flange of the rail.

After HT of welded joints, the deviation of hardness *HRC* from the level of the base metal decreased

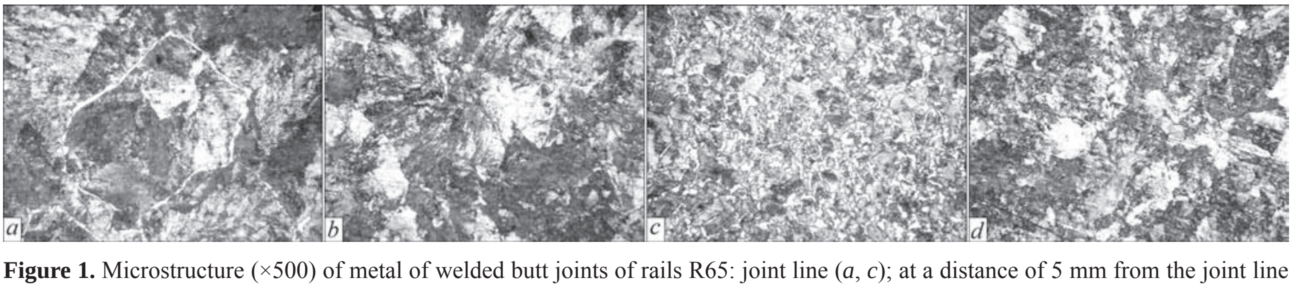

Figure 1. Microstructure (×500) of metal of welded butt joints of rails R65: joint line (*a*, *c*); at a distance of 5 mm from the joint line (*b*, *d*); after welding (*a*, *b*); after HT (*c*, *d*)

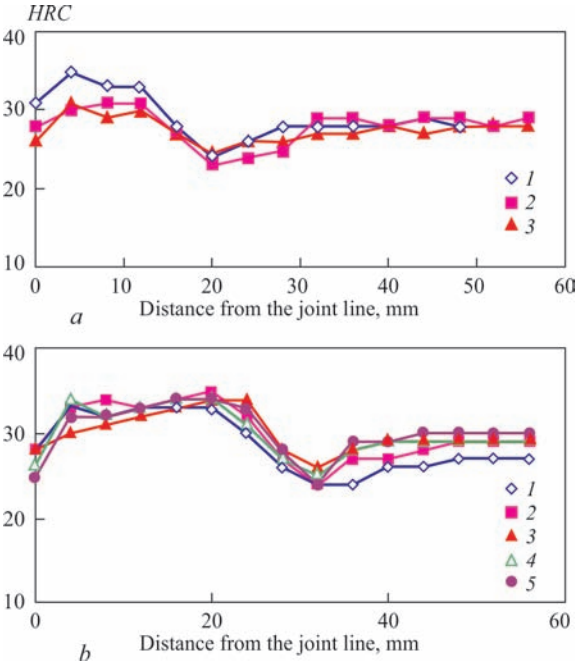

Figure 2. Distribution of hardness *HRC* across the HAZ width of welded butt joints of the rails R65: *a* — after welding (*1* — head; *2* — web; *3* — flange); *b* — after HT (*1* — center of the head; *2* — head-to-web transition; *3* — center of the web; *4* — neck-to-flange transition; *5* — center of the flange

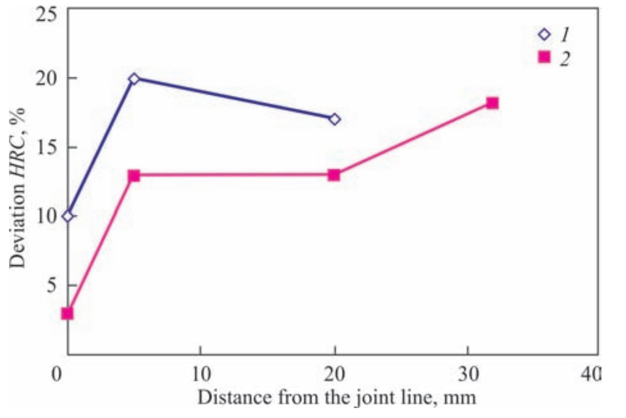

Figure 3. Deviation of hardness *HRC* in the head of the welded butt joints of the rails R65 from the level of the base metal after welding (*1*) and after HT (*2*)

(Figure 3). In particular, along the joint line in the rail head, the deviation of hardness decreased from 10 % (after welding) to 3 % (after HT), in the zone from 5 to 20 mm to the joint line — from 20 to 13 %. In the zone of a partial recrystallization, the hardness deviation is 17 % (after welding) and 18 % (after HT).

In the rails of UIC60 type of steel 900 A, the microstructure of base metal is sorbite with a grain number 5-6 (Table 2). The changes in grain number were not revealed. After welding, the width of the HAZ of butt joints was 40–42 mm. The microstructure of the metal in the joint line (Figure 4, *a*) consists of a mixture of sorbite-like and lamellar pearlite. The thin interlayers of ferrite along the grain boundaries, as well as separate areas of ferrite component are revealed. The grain number is 2-3. At a distance of 5 mm from the joint line (Figure 4, *b*), in the zone of a coarse grain, the microstructure of the metal in the head and in the flange is sorbite, in the web it is sorbite and sorbite-like pearlite. The grain number is 4-5. In the zone of a partial recrystallization, at a distance of 18–20 mm from the joint line, a significant refining of sorbite structure in the head to the number 7-8, in the web the refining of sorbite-like pearlite to number 9-10 are observed. After HT of rail welded joints, the width of the HAZ in the head and in the flange is 64 mm and in the web it is 58 mm. The microstructure of metal along the joint line (Figure 4, *c*) represents a fine-grained sorbite structure with precipitations of ferrite component along the grain boundaries. In the flange there are noticeably less ferrite precipitations than in the head and web of the rail. The grain number is 8. At a distance of 5 mm from the joint line (Figure 4, *d*) the grain number is 6-7. In the zone of a partial recrystallization, at a distance of 32 mm from the joint line, the microstructure is insignificantly different from that of the rails R65 after HT. The grain number is 7-8.

The hardness of the base metal of rails UIC60 in the head is *HRC* 35, in the web and flange it is *HRC* 30. After welding, the investigated joints differed by a sharp decrease in hardness *HRC* along the joint line (Figures 5, 6) from the level of the base metal, in the head to *HRC* 13, in the flange to *HRC* 15. In the zone of a coarse grain, at a distance of 5 mm from the joint line, the hardness was at the level of the base metal. In the zone of a partial recrystallization, located at a distance of 18–22 mm from the joint line, the hardness in the head is *HRC* 26, in the web and flange is *HRC* 23–25. After HT of welded joints, the deviation of hardness decreased. Along the joint line in the rail head the hardness is *HRC* 24, in the flange it is *HRC* 24. At a distance of 4–6 mm from the joint line and up to the zone of a partial recrystallization, the hardness in the head is *HRC* 34–35, which cor-

Table 2. Grain number of metal of welded joints of rails UIC60 after welding and after HT

Rail element	Grain number after welding			Grain number after HT			Base metal
	Joint line	5 mm from the joint line	Zone a partial recrystallization	Joint line	5 mm from the joint line	Zone a partial recrystallization	
Head	2-3	4-5	7-8	8	6-7	7	5-6
Neck	3-4	5	9-10	8	7	7-8	5-6
Foot	3-4	4-5	9-10	8	6	7-8	5-6

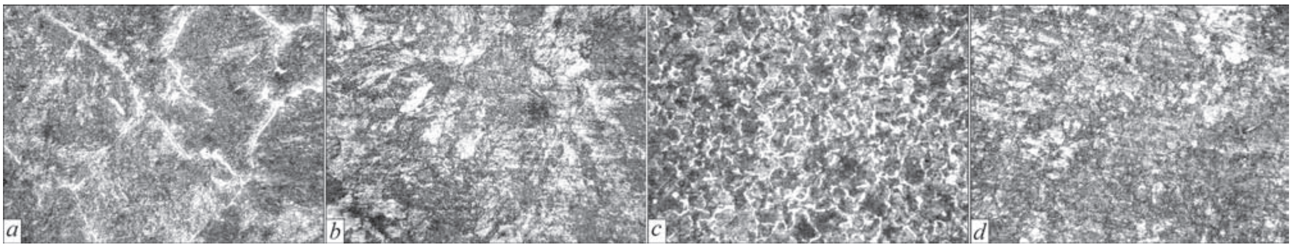

Figure 4. Microstructure (×500) of metal of welded joints of rails UIC60: joint line (*a*, *c*); at a distance of 5 mm from the joint line (*b*, *d*); after welding (*a*, *b*); after HT (*c*, *d*)

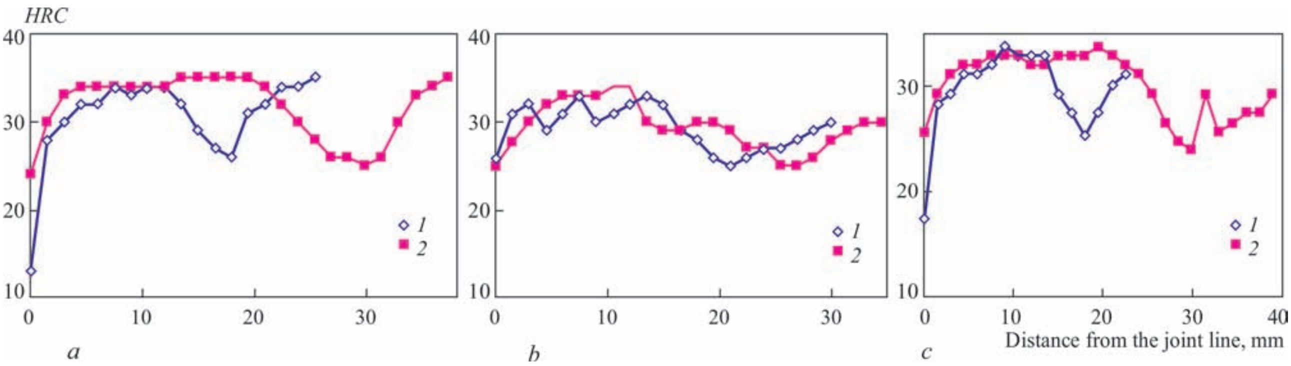

Figure 5. Distribution of hardness along the width of HAZ of welded joints of rails UIC60 in the head (*a*), in the web (*b*) and in the flange (*c*); after welding (*1*) and after HT (*2*)

responds to the level of base metal. At a distance of 18–22 mm from the joint line (zone of a partial recrystallization after welding), the hardness in the head increased to the level of base metal. In the zone of a partial recrystallization, the decrease in hardness did not differ from that of joints after welding.

In the rail head, the deviation in the hardness *HRC* from the level of base metal (Figure 6) decreased from 63 % (after welding) to 30 % (after HT). In the zone of a coarse grain, at a distance of up to 30 mm from the joint line, the hardness deviation decreased from 8 to 3 %. In the zone of a partial recrystallization, the deviation of the hardness *HRC* is 25 % after welding and after HT.

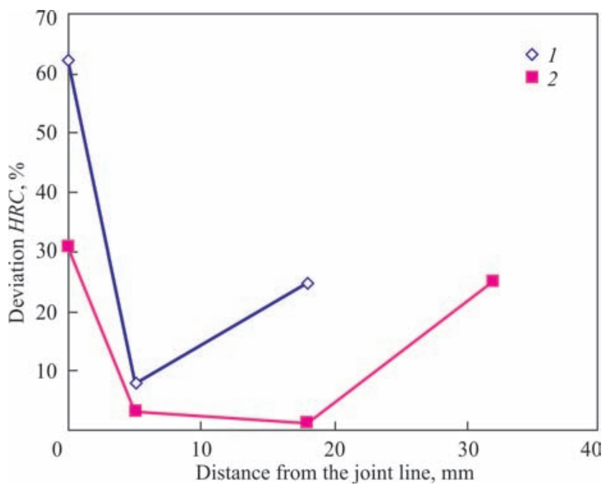

Figure 6. Deviation of hardness *HRC* in the head of the rails UIC60 after welding (*1*) and after HT (*2*)

Conclusions

1. In the portable module of PWI for HT of welded joints of railway rails, the use of inductors with magnetic cores and technology of induction heating by currents of 2.4 kHz frequency provides a uniform distribution of the temperature field in welded joints, a low temperature drop between the surface and deep layers of the rail, as well as shortening in heating time.

2. As a result of HT of welded joints of rails R65 of steel K76F and rails UIC 60 of steel 900A in the portable module of PWI, the microstructure of metal of the welded joints is significantly changed, the hardness *HRC* is uniformly distributed over the width of the HAZ, the deviation of the hardness *HRC* from the level of base metal is decreased.

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