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# DOUBLE HEAT TREATMENT OF WELDED BUTT JOINTS OF RAILWAY RAILS

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The paper presents the results of heat treatment of butt welded joints of R65 rails from K76F steel, produced by flash-butt welding. It is shown that after pre-annealing of butt welded joints with further accelerated heating up to the temperature of heat treatment and quenching of the rail rolling surface by compressed air, the microstructure of butt welded joint metal changes, grain size is considerably refined, hardness along the HAZ width is increased, and deviation of metal hardness along the joint line from base metal level becomes smaller. 12 Ref., 1 Table, 5 Figures.

*Keywords:* *rails, welded butt joints, heat treatment, microstructure, hardness*

Butt welded joints of railway rails should have a high complex of mechanical properties that is due to significant axial loads and freight train speeds. This is related, mainly, to high strength of the metal of butt welded joints which forms to a sufficient depth of the working part of the head, in combination with the high ductility and toughness of the web and foot metal. Welded joints of the rails made by flash-butt welding are subjected to heat treatment (HT). HT impact is aimed at achievement of structural zonal homogeneity in the HAZ and elimination of unfavourable diagram of the internal residual stresses [1, 2]. Modern technology and equipment for HT performance include heating of the butt joints to the temperature of 850–950 °C by high-frequency currents and surface quenching of the head by compressed air [3, 4]. However, the technology of such single HT of butt joints of rails from low-alloyed steel does not allow fully obtaining the complex of high mechanical properties. In this connection, it is necessary to search for new components of HT technology.

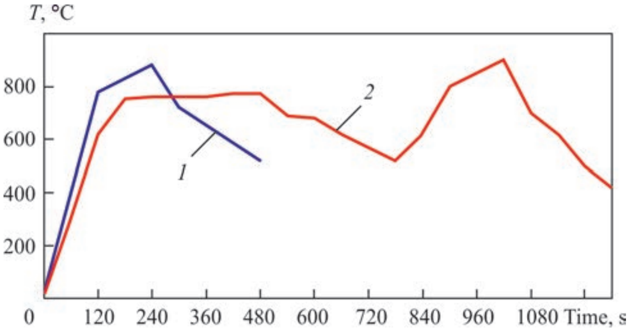


**Figure 1.** Time dependencies of the head heating temperature at the depth of 25 mm from the rolling surface at single (*1*) and double (*2*) HT



It is known that after quenching of steel with the initial fine-grained structure, it has higher wear resistance and contact-fatigue strength [5–7]. Annealing belongs to widely accepted technological operations, applied to form a fine-grained structure of a lower hardness, high ductility and toughness. It is rational to use the properties of pre-annealing as a component of the technology of HT of rail butt welded joints. In this case, the technology of such double HT will include pre-annealing, further accelerated heating up to HT temperature and surface hardening of the rail head in the butt joint.

This work gives the results of studying the impact of double HT on the properties of welded butt joints of R65 rails from K76F steel. Microstructure and hardness of butt joint metal along the HAZ width in the rail head, web and foot was analyzed. Properties of butt joints after welding, after single and double HT were compared. The model of PWI portable module was used to perform HT of welded butt joints [8, 9]. The butt joints were heated by inductors with magnet cores [10–12]. Current frequency was 2.4 Hz. HAZ width in the butt joints after single and double HT was greater than in the butt joints after welding. This is due to the features of the portable module structure.

Comparisons of heating modes and properties of butt welded joints given in the work predominantly concern the rail head at 25 mm depth from the rolling surface. This allowed ignoring the impact of quench cooling. At single HT of butt welded joints the rate of head heating at such a depth up to the temperature of magnetic transformation point was equal to 6.5 °C/s (Figure 1). The heating rate after the metal has lost its magnetic properties decreased to 1 °C/s. HT temperature at the end of heating reached 890–900 °C. Total heating time was 240 s. At the moment heating was stopped, the temperature gradient between the head

Metal grain size number along the joint line (JL) at 5–8 mm from the joint line (5–8 mm from JL) and in incomplete recrystallization zone (IRC)

| Rail element | Grain size number after welding | | | Grain size number after single HT | | | Grain size number after double HT | | | Base metal |
|---|---|---|---|---|---|---|---|---|---|---|
| | JL | 5–8 mm from JL | IRC zone | JL | 5–8 mm from JL | IRC zone | JL | 5–8 mm from JL | IRC zone | |
| Head (25 mm from the rolling surface) | 2–3 | 4–5 | 6–7 | 7–9 | 8–9 | 9 | 10 | 9–10 | 8–9 | 5–8 |
| Web (center) | 3 | 5 | 7 | 7–9 | 7–8 | 9 | 9–10 | 8–9 | 9 | 7–8 |
| Foot (10 mm from the base) | 3 | 5 | 7 | 8–9 | 8 | 10 | 9–10 | 10 | 10 | 5–6 |

rolling surface and layer at the depth of 25 mm was not more than 50 °C. At double HT the butt welded joints were heated to the temperature of 750 °C at the rate of 5 °C/s. The temperature was maintained for 300 s and the butt joints were cooled to the temperature of 510 °C in calm air. Then the butt joints were heated up to the temperature of 890–900 °C. Reheating time was equal to 230–240 s. At the moment of heating interruption, the temperature gradient between the head rolling surface and layer at 25 mm depth was less than 40 °C. Quenching of the head rolling surface was performed by forced blowing by compressed air. Quenching time was 240 s, and pressure in air feeding system was 0.5 MPa.

Longitudinal samples were used to study the structure of metal of butt welded joints of rails. Sample surface coincided with the rail axis of symmetry, included the HAZ and adjacent regions of base metal. The size of metal grain was determined by GOST 5639–82. For instance, in the rail head at 25 mm depth from the rolling surface, in the butt joints after welding the grain size number in decarbonized metal band along the joint line was 2–3 (Table). Metal structure is sorbite with narrow ferrite fringes along the large grain boundaries (Figure 2, *a*). At 5–8 mm distance from the joint line, the structure consists of sorbite with grain size number of 4–5 (Figure 2, *b*). In incomplete recrystallization (IRC) zone, at 18 mm distance from the joint line, the structure consists of fine sorbite with grain size number of 6–7. The base metal had regions with grain size number from 5–6 to 7–8. After single HT of the butt joints, the metal microstructure is much finer. Along the joint line in the sorbite structure the grain size number increased from 2–3 to 7–9 (Figure 2, *c*). At 5–8 mm distance from the joint line, in the structure of sorbite with troostite regions the grain size number increased from 4–5 up to 8–9 (Figure 2, *d*). In IRC zone at 28 mm distance from the joint line, grain size number is 9. At the distance of 18–20 mm from the joint line, where IRC zone was located after welding, grain size number increased up to 7–9. After double HT of butt joints, the grain became even finer. Along the joint line the grain is fine and uniform with fragmented ferrite boundaries

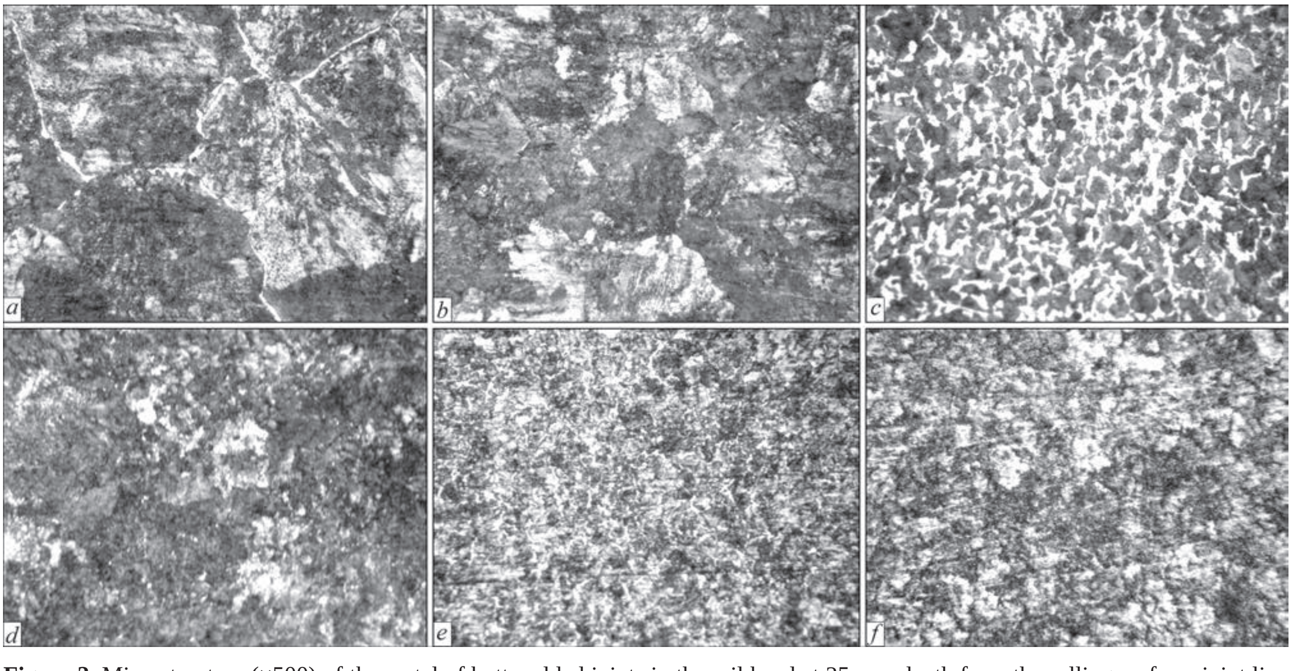


**Figure 2.** Microstructure (×500) of the metal of butt welded joints in the rail head at 25 mm depth from the rolling surface: joint line (*a*, *c*, *e*); 5–8 mm from the joint line (*b*, *d*, *f*), as-welded (*a*, *b*); after single HT (*c*, *d*); after double HT (*e*, *f*)

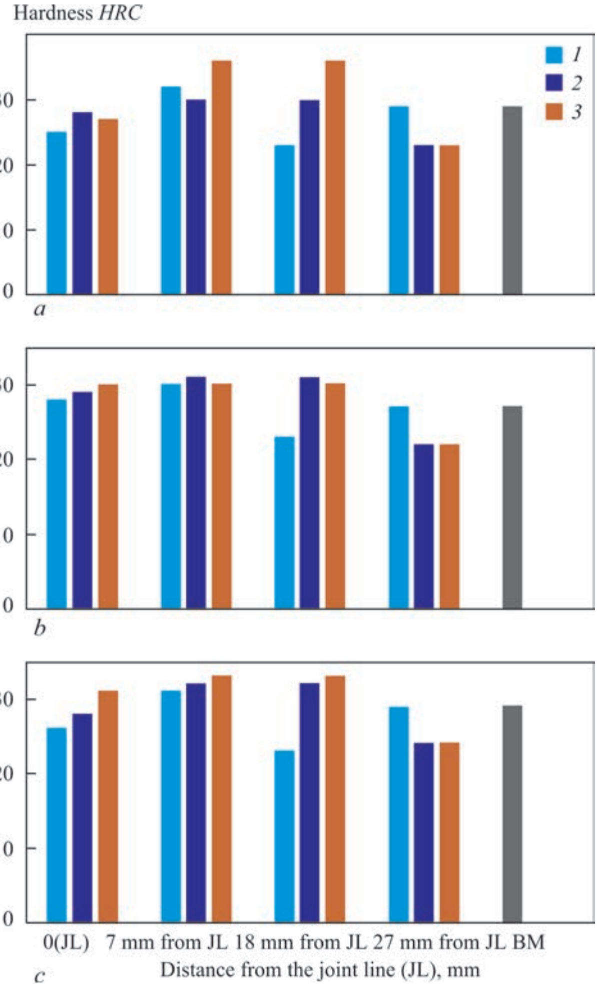


**Figure 3.** Distribution of *HRC* hardness along the HAZ width of butt welded joints of rails in the head at 25 mm depth from the rolling surface (*a*); in the web center (*b*) and in the foot at 10 mm distance from the base (*c*), after single HT (*2*) and after double HT (*3*)

(Figure 2, *e*), the grain size number increased to 10. At 5–8 mm distance from the joint line, the structure is fine uniform sorbite (Figure 2, *f*). Grain size is 9–10.

Integral hardness *HRC* of the metal of butt welded joints was measured in TK-2M hardness meter at 150 kg load. As shown in Figure 3, the hardness along the joint line (JL) in butt joints after welding was *HRC* 25 at 25 mm depth from the rolling surface, in the web center it was *HRC* 28, and at 10 mm distance from the foot base it was *HRC* 26. At 7 mm distance from the joint line (7 mm from JL) hardness in the head and foot was *HRC* 31–32, and in the web it was *HRC* 30. Metal in IRC zone at 18 mm distance from the joint line (18 mm from JL) had low hardness of *HRC* 22–23. After single HT, hardness along the joint line increased to *HRC* 28 in the head, in the web to *HRC* 29 and in the foot to *HRC* 28. After double HT, hardness along the joint line was equal to *HRC* 27, it increased to *HRC* 30 in the web, and to *HRC* 31 in the foot. From the joint line to IRC zone hardness in the head increased to *HRC* 36, and in the foot to *HRC* 33. In IRC zone at 27 mm distance from the joint line, hardness was *HRC* 22–24. Such a distribution of hardness by the HAZ width is also characteristic for regions of the head transition to the web, and of the web to the foot. Hardness distribution in the zone of quench cooling was somewhat different (Figure 4). After double HT, the hardness at 5 mm depth from the head rolling surface and 7 mm distance from the joint line increased to *HRC* 40. This is more than in the initial rails, where hardness is *HRC* 37–38.

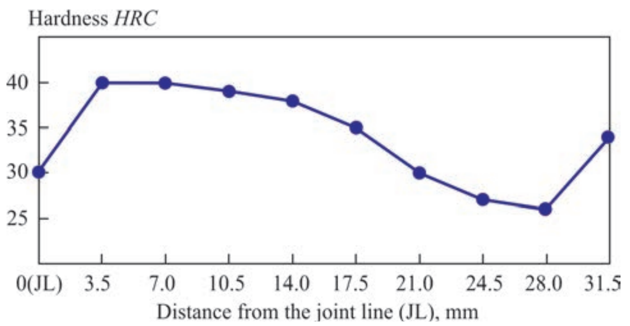


**Figure 4.** Distribution of *HRC* hardness along the HAZ width of rail butt welded joints in the zone of quench cooling at 5 mm depth from the head rolling surface after double HT

Histograms given in Figure 5 characterize the deviation of *HRC* hardness along the width of the HAZ of rail butt joints relative to the hardness of base metal of the respective rail elements. In the butt joints after welding the hardness in the head along the joint line (JL) is smaller than that of the base metal by 14 %, at the distance of 7 mm from the joint line it is higher by 10 %, and in IRC zone it is by 21% smaller. In the web center hardness along the joint line is higher by 3 %, in IRC zone it is lower by 15 %. Significant deviation of hardness is characteristic for the rail foot. Here, hardness lowering reached 10 % along the joint line and 18 % in IRC zone. After single HT, it can be noted that hardness along the joint line and at 7 mm distance from the joint line in the rail head and foot became close to that of the base metal. In particular, hardness deviation along the joint line is not more

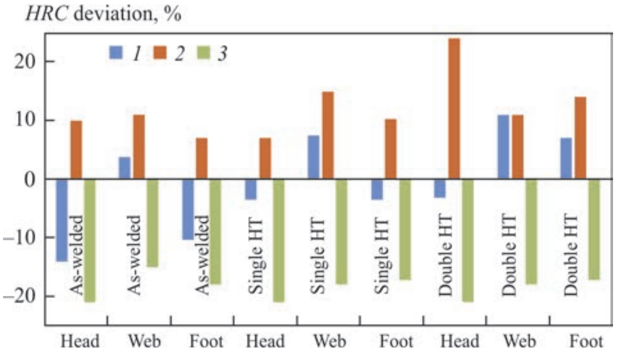


**Figure 5.** Deviation of *HRC* hardness of rail butt welded joints from base metal hardness along the joint line (JL) (*1*), at 7 mm distance from the joint line (7 mm from JL) (*2*) and in incomplete recrystallization zone (IRC) (*3*) after welding, after single HT and after double HT

than 3 %. It is indicative of the mechanical properties of butt welded joints becoming closer to base metal level. In the butt joints after double HT the hardness in the head along the joint line also decreased by 3 % from the base metal level, and in the web and foot it increased by 11 and 7 % respectively. At 7 mm distance from the joint line, the hardness increased considerably, by 24 % in the head and by 14 % in the foot.

**Conclusions**

1. Single HT of welded butt joints of R65 rails from K76F steel, after accelerated heating to the temperature of 890–900 °C, and quenching of the rolling surface in the butt joint zone, results in the mechanical properties of the welded butt joints becoming close to the level of the rail base metal.

2. Double HT of butt welded joints of rails which includes pre-annealing at the temperature of 750 °C, its further accelerated heating up to the temperature of 890–900 °C and quenching of the rail rolling surface in the butt joint zone, led to a change of the metal microstructure, grain refinement to size number 8–10 along the entire HAZ width. Hardness in the head along the joint line became close to base metal level and increased in the web and foot. Hardness along the HAZ width became much higher in the direction from the joint line to incomplete recrystallization zone.

3. Hardness in the zone of quench cooling of the head after double HT and quenching of the rolling surface was higher than the initial rail hardness.

4. Impact of single and double HT on the structure and hardness of butt welded joints of rails, made by flash-butt welding, allows recommending application of such technologies to increase the reliability of butt joints, particularly under hard operating conditions of the rail track.

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