New technology of rails welding

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Abstract. Today, in the manufacture of long-length rail strings, the obligatory heat treatment is provided after the flash butt welding operation. The basis for this operation is the unsatisfactory mechanical properties of the rail joints immediately after welding. Welding heat cycles at pulsed reflow do not always allow a welded joint with a sufficient level of ductility to be obtained. In this case, the induction heat treatment used at rail welding enterprises in Russia increases the length of the heat-affected zone, which adversely affects the wear resistance of the rails during operation. This paper presents studies in industrial conditions that were previously conducted in laboratory conditions. Studies show the possibility of obtaining the necessary mechanical properties by controlling welding heat cycles without the use of induction heat treatment.

1. Introduction

Welded joints of rail strings after electric contact welding are necessarily subjected to heat treatment at induction plants. At present, the installations UIN-001-100/RT-S and UIN-001-100/RT-P (hereinafter UIN) manufactured by “Magnit M” LLC are used in the Russian Federation. Previously, heat treatment was performed by installation ITT3-250/2.4 with a power source of 250 kW, the power source of the UIN units is 100 kW at the same heating rate of the welded rail joint. The most significant change is the replacement of the air-water mixture used as a quenching medium in the ITT3-250/2.4 units with compressed air in the new generation units. The use of compressed air provided better heat treatment of welded joints, which is especially relevant in connection with the expansion of the use of alloyed steels on domestic railways, including alloyed with chromium. For these steels, quenching cooling with an air-water mixture contributes to the formation of structures with the presence of martensite, which sharply reduces the resistance of rails to fatigue and brittle fracture of rail steel [1].

With all the positive effects of heat treatment [1] using a quenching medium in the form of compressed air, modern induction plants have a number of disadvantages that are associated with:

- the emergence of new heat-affected zones during local heating of welded joints in the conditions of heat treatment,
- unilateral cooling only from the head side, which leads to the deterioration in the straightness of the welded joints after cooling,
- insufficient heating depth of welded joints during heat treatment.

Local heat treatment of the welded joint leads to an increase and the appearance of new heat-affected zones compared to zones in contact welding of rails without heat treatment. An increase in the linear magnitude of the zones after heat treatment in the rail head at a distance of about 40-47 mm
from the welded joint and in its base at a distance of 70-75 mm leads to a decrease in the mechanical properties of the welded joint.

Shlatter company [2] proposed a solution to this problem using the butt welding process by flashing the rails on the equipment: the GAA 100 stationary rail welding machine. The process is divided into three stages. The first stage is the heating of the welded surfaces, the second stage is the actual welding, the third stage is the cooling of the welded joint. The first stage of heating, in turn, is divided into three stages: 1- “deliberate flashing”, 2- “pre-heating” and 3- “flashing”. The second stage of the actual welding is upsetting. During the last third stage after welding, heat treatment is applied similar to preheating to reduce the cooling rate after welding – an electric current is transmitted through the welded joint in several pulses. These current pulses are intended only to reduce the cooling rate and to eliminate the formation of quenching structures in the weld metal.

An alternative way to solve the problem, developed at SibSIU and protected by a patent of the Russian Federation, which after upsetting and cooling the welded joint at the moment the required temperature is supposed to maintain the set temperature by passing alternating electric current pulses through the welded joint. The holding temperature is selected based on obtaining a finer-grained structure of the weld metal. The exposure time is determined by the incubation period of the required structure formation and is regulated by the number of current pulses [3].

2. Materials and methods of research
The study of the influence of welding conditions with subsequent isothermal exposure of rail steel samples, produced by passing alternating electric current pulses after welding, on the weld joint quality parameters was carried out on a butt welding machine MSP-6301 in the conditions of the rail welding company LLC “RSP-M” (RSP-29). For the study the samples of full-profile rails of R65 type of DT350 category with 600 mm long were cut out. The rails were welded according to a given mode (table 1).

| Sec. No. | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| S, mm   | 2   | 4   | 3   | 2.5 | 2.5 | 2   | 1.5 | 1.5 | 1.5 | 1.5 |
| U, %    | 75  | 70  | 55  | 60  | 60  | 65  | 70  | 88  | 88  | 98  |
| Vu, mm/s| 0.6 | 1.3 | 0.8 | 1   | 1.1 | 1.2 | 0.7 | 0.9 | 1.1 | 1.2 |
| Vd, mm/s| 0.5 | 0.6 | 0.5 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 |     |
| Icor, A | 200 | 300 | 200 | 200 | 250 | 250 | 250 | 300 | 400 | 500 |
| Ist, A  | 300 | 450 | 350 | 350 | 400 | 400 | 460 | 500 | 600 | 700 |
| Irev, A | 400 | 500 | 400 | 400 | 450 | 450 | 550 | 600 | 700 | 800 |
| Isc, A  | 1200| 1200| 1200| 1200| 1200| 1200| 1200| 1200| 1200| 1200|

Sups = 14 mm – upsetting path;
Vups = 100 mm/s – upsetting rate;
Si = 6 mm – upsetting under current.

The welding mode mainly consists in controlling the flashing during butt welding, which is carried out by adjusting the set flashing speed depending on the current value of the current. This is done by changing the settings of the beginning of the speed corrections (correction current Icor), the current Ist, which stops the supply, and the current Irev, which gives the command for reverse.

For this, the programmable values of the speed and reflow current, which implement feedback Icor, Ist, Irev, are selected so that the actual average value of the current on the waveform is 2 times less than the short circuit current. This corresponds to the maximum electric power developed in contact between the melted ends of the workpieces. Inadmissible current deviations in the form of spasmodic changes in its magnitude are eliminated due to high-speed feedback. The same feedback stabilizes the current value of the welding current.

To obtain information about the heat effect on the metal structure, the temperature measurements in the heat-affected zone during welding were performed using the HotFind-D thermal imager. The
HotFind-D thermal imager allows you to measure temperatures up to 1500°C. The thermal imager is equipped with an uncooled microbolometric matrix in the focal plane of the lens with a resolution of 160×120 pixels. The video image of thermograms is transmitted to a PC using a video capture board of an analog signal in NTSC format with a frequency of 60 Hz. The thermal imager was mounted on a tripod at a distance of 1 meter from the welded joint of the rails.

To search for optimal isothermal exposure conditions in the first series of experiments, a full factorial experiment \( N = 2^k \) was carried out (table 2). The studied parameters were: \( X_1 \) – cooling time after upsetting (characterized by the cooling rate (degree of austenite overcooling) and the temperature \( T_1 \) to which cooling occurs); \( X_2 \) – heating time (characterized by temperature \( T_2 \), to which heating occurs); \( X_3 \) – cooling time after heating (characterized by the temperature \( T_1 \) to which cooling occurs); \( X_4 \) is the number of heating pulses (characterized by the incubation period of austenite into perlite transformation).

The exposure time (\( X_1 \)) must be selected so that the weld joint cools down to the temperature at which the required weld metal structure is formed. The current transmission pulses were set at a certain interval. The pulse duration (\( X_2 \)) is determined by the temperature of the welded joint, which should not rise above the temperatures required for the formation of the necessary structure. The duration of the interval (\( X_3 \)) is selected so that the temperature of the weld joint does not fall below the temperature values at which the necessary structure of the weld metal is formed. The number of pulses (\( X_4 \)) sets the time during which the average temperature of the weld joint is maintained, which is necessary for the formation of the required structure during welding.

### Table 2. Matrix of experiment planning \( N = 2 \cdot 3^k \)

| Sample No. | \( X_1 \), s | \( X_2 \), s | \( X_3 \), s |
|------------|-------------|-------------|-------------|
| 1          | 60          | 2           | 30          |
| 2          | 160         | 2           | 30          |
| 3          | 60          | 6           | 30          |
| 4          | 160         | 6           | 30          |
| 5          | 60          | 2           | 15          |
| 6          | 160         | 2           | 15          |
| 7          | 60          | 6           | 15          |
| 8          | 160         | 6           | 15          |

For comparison, the sample No. 0 was also welded without isothermal exposure.
The number of pulses (\( X_4 \)), to reduce the number of experiments, was set equal to 4 in all modes of isothermal exposure.

The isothermal exposure control after welding is performed using a personal computer, changing the program of the industrial controller SIMATIC S7-300. Using the Simatic Step 7 software, a program was written to control isothermal time modes. Timers were used to set the necessary time parameters (figure 1a). To activate the welding transformer, a trigger was used, to the inputs S and R of which the contacts, activated by timers, are connected in series (figure 1b). Subsequently, the heat-treated joints were tested for a three-point static bend according to STO RZD 1.08.002-2009 “Railway rails, welded by electric contact method”. Static bending tests were carried out on the press of PMS-320 type. The control samples were tested after welding and removal of burr without additional processing joints. In tests for static transverse bending, the control sample had a length of at least 1200 mm with a welded joint in the middle.

The load was applied in the middle of the span of the control sample in the place of the welded joint with a distance between the supports of 1 m. The test of the control sample was performed with the application of a load on the head (figure 2). The test results are the values of the force arising during bending \( P_{\text{bend}} \), kN and the values of the deflection \( f_{\text{def}} \), mm at which the control sample is destroyed, or the maximum values of these indicators if the sample did not break during the test.
3. Results and discussion
As a result of the experiment, samples 3 (P\text{bend} = 2364 kN, f\text{def} = 35.4 mm) and 8 (P\text{bend} = 2244 kN, f\text{def} = 31.2 mm) have higher test values (P\text{bend} = 2000 kN, f\text{def} = 27 mm) than the requirements of STO RZD 1.08.002-2009. According to the data, the regression models were obtained for the output force parameters of bending and deflection: P\text{bend} = 1926.5 – 2.05 X_1 + 64.38 X_2 + 3.2 X_3; R^2 = 0.61, f\text{def} = 15.72 – 0.04 X_1 + 2.37 X_2 + 0.07 X_3; R^2 = 0.51. Table 3 shows the test results.

### Table 3. Test results on static three-point bending.

| Sample No. | P\text{bend}, kN | f\text{def}, mm |
|------------|------------------|----------------|
| 1          | 2002             | 17.4           |
| 2          | 1882             | 17.9           |
| 3          | 2364             | 35.4           |
| 4          | 1970             | 20.1           |
| 5          | 2107             | 23.4           |
| 6          | 1616             | 11             |
| 7          | 2059             | 20.9           |
| 8          | 2244             | 31.2           |
| 0          | 2179             | 24.4           |
At the same time, having examined the cooling process (figures 3 and 4) of the best results, it can be concluded that the formation of favorable mechanical properties of the welded joint occurred to some extent due to a slowdown in the cooling rate, since the modes of isothermal exposure were not fully implemented.

![Figure 3](image1)

**Figure 3.** Pattern of cooling after welding of sample 9: 1 – the seam center, 2 – 20 mm from the seam center, 3 – 28 mm from the seam center.

![Figure 4](image2)

**Figure 4.** Pattern of cooling after welding of sample 10: 1 – the seam center, 2 – 20 mm from the seam center, 3 – 28 mm from the seam center.

To confirm the results, the second series of experiments was carried out. The welding was repeated in the modes that showed the best test results, and the isothermal holding mode was selected that fully satisfies the temperature conditions. The modes and results of the repeated series of experiments are given in table 4.

The results of the second series of experiments confirmed the reproducibility of parallel experiments. In the case of sample 9 (8), the instability of the rail welding machine played a role, since this sample was welded first after a long downtime of the equipment. One of the factors influencing instability is insufficient heating of the hydraulic fluid, which directly affects the parameters of the welding process (the movement speed of the movable bed during flashing and upsetting).
Table 4. The results of the second series of experiments.

| Sample No. | Factor values | Test results for static bend |
|------------|---------------|-----------------------------|
|            | $X_1, \text{s}$ | $X_2, \text{s}$ | $X_3, \text{s}$ | $P_{\text{bend}}, \text{kN}$ | $t_{\text{def}}, \text{mm}$ |
| 9 (8*)     | 160           | 6                          | 15                  | 1962                      | 21.5                     |
| 10 (3*)    | 60            | 6                          | 30                  | 2276                      | 34.2                     |
| 11         | 200           | 4                          | 10                  | 2493                      | 40.2                     |

*Indicates the number of the repeated sample.

The number of pulses ($X_4$), to reduce the number of experiments, was set equal to 4 in all modes of isothermal exposure.

4. Conclusion

Based on the conducted experiments a method of contact butt welding was developed and protected by the patent of the Russian Federation [4]. It makes possible to obtain a welded joint of products from rail steel with the necessary technical requirements of STO RZD 1.08.002-2009 surpassing the mechanical properties of welded joints of rails of P65 type of DT350 category.

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