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Development of technology for manufacturing rail strings for railway access roads to mines

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Abstract. The technology of contact-butt welding of rail strings was developed. The effects of welding modes with subsequent isothermal exposure of samples made from rail steel were studied. The optimal isothermal exposure rate was selected. Tests of welded joints for static three-point bending were carried out.

1. Introduction

Currently, the electrocontact method of welding rails by the electric contact method is most widely used. It is believed that this method is the most economical and technological in comparison with flash welding. During the direct-energy welding of rails, as well as during welding by other methods, heating and continuous cooling of the metal occur in the HAZ. Depending on the chemical composition of the steel, the welding technology is selected using existing reflow methods: continuous or flash welding, determining the linear value and temperature fields in the HAZ of the welded joint [1, 2]. The choice of thermal conditions is based on the exclusion of the formation of quenching structures (martensite and bainite) causing additional stresses and cracks, which lead to the destruction of the rails [3]. Thus, the development of such welding modes for high-speed railways made of chromium steel is of particular importance [4].

Welded joints of rail strings after welding, necessarily subjected to heat treatment on induction installations UIN-001-100/RT-S and UIN-001-100/RT-P (hereinafter UIN), produced by the company CLL "Magnit M".

Previously, installations ITT3-250/2.4 with a 250 kW power source were used for heat treatment, the power source of UIN installations is 100 kW at the same heating rate of the rail welded joint. The most significant change is the replacement of the air-water mixture used as a quenching medium at ITT3-250/2.4 installations by compressed air in the new-generation installations. The use of compressed air proved to be a better heat treatment of welded joints, which is particularly relevant in connection with the expansion of the use of alloyed steels, including steels alloyed with chromium, on domestic railways. For these steels, quenching cooling with an air-water mixture contributes to the formation of structures with martensite, which sharply reduces the resistance of rails to fatigue and brittle destruction of rail steel [5].

With all the positive effects of heat treatment with the use of quenching medium in the form of compressed air, modern induction plants have a number of disadvantages, which are related to: the emergence of new heat-affected zones during local heating of welded joints during heat treatment,

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unilateral cooling only from the head, which leads to deterioration of straightness of welded joints after cooling, insufficient depth of heating of welded joints during heat treatment.

Local heat treatment of the welded joint leads to an increase and the generation of new heataffected zones compared to the zones observed in the process of welding rails by contact method without heat treatment. The increase in the linear size 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 bottom at a distance of 70-75 mm leads to a decrease in the mechanical properties of the welded joint [5].

Shlatter proposed a solution to this problem using the process of flash butt welding by flashing the rails on the equipment: a stationary rail welding machine GAA 100. The process is divided into three stages. The first stage is the heating of the surfaces being welded, 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 - "intentional flashing", 2 - "pre-heating" and 3 - "flashing". The second stage of actual welding is flash upset welding. During the last third stage after welding, heat treatment is applied like preheating to reduce the cooling rate after welding – several pulses of electric current is passed through the welded joint. These current pulses are needed only to reduce the cooling rate and eliminate the formation of quenching structures in the weld metal [6].

The alternative method to solve the problem, developed in SibSIU and protected by the patent of the Russian Federation, is supposed to maintain the desired temperature by passing alternating electric current pulses through the welded joint after its upsetting and cooling at the moment when the required temperature is reached. The soaking temperature is selected on the basis of obtaining a more fine structure of the weld metal. The soaking time is determined by the incubation period of the formation of the necessary structure and is governed by the number of current pulses [7].

2. Results and discussion

The study of the influence of welding modes, which are followed by isothermal exposure of samples from rail steel produced by passing alternating electric current pulses, on the quality indicators of a welded joint was carried out on a MSR-6301 butt welding machine at the LLC "RSP-M" rail welding enterprise (RSP- 29). Samples 600 mm long were cut for the study from full-profile rails of P65 type of DT350 category. Welding of rails was carried out according to the given mode (table 1).

Table 1. Welding mode of rails R65.										
Section 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
V _v , mm/s	0.6	1.3	0.8	1	1.1	1.2	0.7	0.9	1.1	1.2
V _n , mm/s	0.5	0.6	0.5	0.4	0.4	0.5	0.4	0.3	0.2	
I _{cor} , A	200	300	200	200	250	250	250	300	400	500
I _{stop} , A	300	450	350	350	400	400	460	500	600	700
I _{rev} , A	400	500	400	400	450	450	550	600	700	800
I _{sc} , A	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200

S_{up}.=14 mm – upsetting path;

 $V_{up.}^{ap} = 100 \text{ mm/s} - \text{upsetting rate;}$

 $S_i = 6 \text{ mm} - \text{upsetting path under current.}$

The welding mode mainly consists in the control of flashing during resistance butt welding, which is carried out by adjusting the set flashing rate depending on the actual value of the current. This is done by changing the settings of the beginning of the speed correction (correction current I_{cor}), the current Istop stopping the feed, and the current Irev giving the command for reverse. For this, programmable values of the rate and current of flashing, implementing feedback I_{co}r, I_{ston}, I_{rev}, are selected so that the actual average current value on the oscillogram is 2 times less than the short circuit current. This corresponds to the maximum electrical power developed in the contact between the

melted ends of the blanks. Unacceptable current deviations in the form of abrupt changes in its magnitude are excluded due to high-speed feedback. The same feedback stabilizes the actual value of the welding current.

Temperature measurements in the heat-affected zone during welding were performed using HotFind-D thermal imager to obtain information on the thermal effect on the metal structure. Thermal Imager HotFind-D allows temperatures up to 1500°C to be measured. The imager is equipped with an uncooled microbolometric matrix in the focal plane of the lens with a resolution of 160×120 pixels. Transmission of video images of thermograms to a PC is performed using an analog video capture card in NTSC format with a frequency of 60 Hz. The imager was mounted on a tripod at a distance of 1 meter from the welded joint of the rails. A full factorial experiment N = 2k was performed (table 2) to find the optimal isothermal regimes in the first series of experiments. The investigated parameters were: X_1 – cooling time after setting (characterized by the cooling rate (degree of austenite supercooling) and temperature T1, to which cooling occurs); X_2 – heating time (characterized by the temperature T₂, to which the heating occurs); X_3 – cooling time after heating (characterized by the incubation period for the conversion of austenite to perlite).

The duration of exposure (X_1) must be chosen so that the welded joint is cooled to the temperature at which the required structure of the weld metal 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 values of temperatures required for the formation of the required structure. The duration of the interval (X_3) is chosen so that the temperature of the welded joint does not fall below the temperatures at which the required structure of the weld metal is formed. The number of pulses (X_4) sets the time during which the average temperature of the welded joint is maintained, which is necessary for the formation of the required structure during welding.

Sample No.		Values of factors	
Sample No	X1, 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

Table 2. Matrix of experiment planning $N = 2 \cdot 3k$.

For comparison the welding of sample No. 0 was also performed – without isothermal exposure. To reduce the number of experiments the number of pulses (X_4) was set equal to 4 in all modes of isothermal exposure.

For comparison, sample No. 0 was also welded – without isothermal exposure.

The number of pulses (X_4) was set equal to 4 in all modes of isothermal exposure to reduce the number of experiments. Control of isothermal exposure after welding is performed using a personal computer by changing the program of an industrial controller SIMATIC S7–300. Using the software Simatic Step 7 a program was written that allows the modes of isothermal exposure to be controlled.

Timers were used to set the required time parameters (figure 1a). To turn on the welding transformer, a trigger was used to which the inputs S and R are connected in series and in parallel with the contacts that are activated by timers (figure 1b).



Figure 1. The program responsible for isothermal exposure.

Subsequently, heat-treated joints were tested for three-point static bending according to the RZD Standards 1.08.002-2009 "Railway rails welded by the electric contact method". Tests on static bending was performed on a press of the type PMS-320. Control samples were tested after welding and burring without additional processing of the joints. When testing 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 the distance between the supports of 1 m. Testing of the control sample was produced with the application of the load on the head (figure 2). The results of the test are the values of the force arising from the bending of P_{bend} , kN and the values of the deflection boom f_{defl} , mm at which the control sample is destroyed, or the maximum values of these indicators, if the specimen was not destroyed during the tests. Table 3 shows the test results.



Figure 2. Test scheme for static transverse bending.

Sampla No	Values of factors				
Sample No.	P _{bend} , kN	f _{defl} , 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			

Table 3. Results of tests on static three-point bending.

As a result of the experiment, samples 3 ($P_{bend} = 2364 \text{ kN}$, $f_{defl} = 35.4 \text{ mm}$) and 8 ($P_{bend} = 2244 \text{ kN}$, $f_{defl} = 31.2 \text{ mm}$) have test indicators higher than ($P_{bend} = 2000 \text{ kN}$, $f_{defl} = 27 \text{ mm}$) requirements of RZD standards 1.08.002-2009. According to the data, regression models were obtained for the output parameters of the bending and deflection forces: $P_{bend} = 1926.5 - 2.05 \text{ X}_1 + 64.38 \text{ X}_2 + 3.2 \text{ X}_3$; $R_2 = 0.61$, $f_{defl} = 15.72 - 0.04 \text{ X}_1 + 2.37 \text{ X}_2 + 0.07 \text{ X}_3$; $R_2 = 0.51$.

At the same time, having considered the cooling process (figure 4 and 5) of the best results, we can conclude that the formation of favorable mechanical properties of the welded joint occurred to some extent due to the slowing down of the cooling rate, because the isothermal exposure modes were not fully implemented.



Figure 3. Cooling plot after sample welding 9 (1 - the center of the seam, 2 - 20 mm from the center of the seam, 3 - 28 mm from the center of the seam).



Figure 4. Cooling diagram after welding of sample 10 (1 – the center of the seam, 2 – 20 mm from the center of the seam, 3 – 28 mm from the center of the seam).

To confirm the results, the second series of experiments was carried out in which welding was repeated using the best test results, and an isothermal exposure mode was selected that fully satisfies

the temperature conditions. Modes and results of the repeated series of experiments are provided in table 4.

Samples No.		Values of factors	Results of the s	Results of the static bend test		
	X ₁ , s	X ₂ , s	X3, s	P _{bend} , kN	f _{defl} , mm	
9 (8) *	160	6	15	1962	21.5	
10 (3) *	60	6	30	2276	34.2	
11	200	4	10	2493	40.2	

Table 4. The results of the second series of experiments.

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

out of brackets is the serial number of the sample, in brackets the number of the repeated one

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 makes the difference, since this sample was first welded after a long equipment downtime. One of the factors that influenced the instability is insufficient heating of the hydraulic fluid, which directly affects the parameters of the welding process (the speed of movable frame during flashing and upsetting).

3. Conclusion

By conducting experiments the optimum welding modes were selected with subsequent isothermal exposure. Welded joints providing the required mechanical properties were obtained. The experiments made it possible to develop the method of resistance butt welding protected by the patent of the Russian Federation [8], which allows a welded joint of products, made from rail steel with the required and superior technical requirements of RZD standards 1.08.002-2009 in regards to mechanical properties of welded joints of the R65 rail type DT350, to be obtained.

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