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Calculation of optimal modes for electric-contact welding of rails of mine haulage tracks

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Abstract. The choice of thermal regime is based on the exclusion of formation of quenching structures (martensite and bainite), causing additional stresses and cracks which lead to the destruction of rails. After welded joint upset and cooling at the time of reaching the required temperature it is proposed to perform quasi-isothermal exposure by passing pulses of alternating current through the welded joint. The method for calculating the quasi-isothermal exposure is described that depends on the strength of the welding current and different rails section. It is suggested that after welding the rails during quenching, a quasi-isothermal holding is carried out in the temperature range of the formation of the fine-dispersed structure by passing pulses of alternating electric current through the welded joint maintaining this temperature until the end of the transformation. It is shown that the use of quasi-isothermal exposure at a chosen temperature of 600 – 650 °C makes it possible to obtain a finely dispersed structure of the welded seam of rails of mine haulage tracks without additional heat treatment.

1. Introduction

At present, the method of pulsed flash welding has become the most widespread in contact welding of rails. This method of contact welding is the most efficient and technological in comparison with continuous flash welding. During contact welding of rails, as well as during other types of welding, heating occurs and continuous cooling of metal in the heat-affected zone (HAZ). Depending on the steel chemical composition the technological process of welding is selected among the existing methods of welding: continuous or pulsed flash welding determining the linear value and temperature fields in the HAZ welded joint [1, 2]. The choice of thermal regime is based on the exclusion of formation of quenching structures (martensite and bainite) causing additional stresses and cracks which lead to rail destruction [3]. In connection with this [4, 5], the development of such regimes for rails made of chromium steel is of particular importance.

It is known that an increase in chromium content of steel causes a shift to the right of C-shaped curves of the beginning (H) and end (K) of austenite decay on the diagram of isothermal austenite decay (Figure 1) leading to a decrease in critical cooling rate at which austenite is transformed into martensite [6, 7]. At a rapid heating of the welded joint, which is provided by the method of pulsed flash welding and subsequent intensive cooling in the HAZ, a high-strength layer with a martensite structure is formed in the place of microvolumes with an increased content of chromium, nickel and carbon. Martensite sections [3] play the role of stress concentrators and lead to the formation of defects in welded joints (development of fatigue cracks in the head, neck and the base of the rail with a brittle fracture).



This problem in the process of track construction during rails welding is solved by mandatory heat treatment of the welded joint. Heat treatment is performed with induction units that increase the costs. This disadvantage in practice is suggested to be corrected by combining continuous and pulsed flash welding methods, changing the heating intensity during welding and controlling the cooling rate [4]. At the same time, partial usage of the method of continuous flash welding, can cause welding defects.

2. Results and discussion

This paper focuses on the alternative way of problem solution, allowing any of the discussed methods to be used. After welded joints upset and cooling at the time of reaching the required temperature it is proposed to perform quasi-isothermal exposure by passing pulses of alternating electric current through the welded joint. To avoid the formation of quenching structures the exposure temperature is selected based on the obtaining of a fine-grained structure of the weld metal (figure 1). The exposure time is determined by the incubation period of the formation of the required structure and is controlled by the number of current pulses.

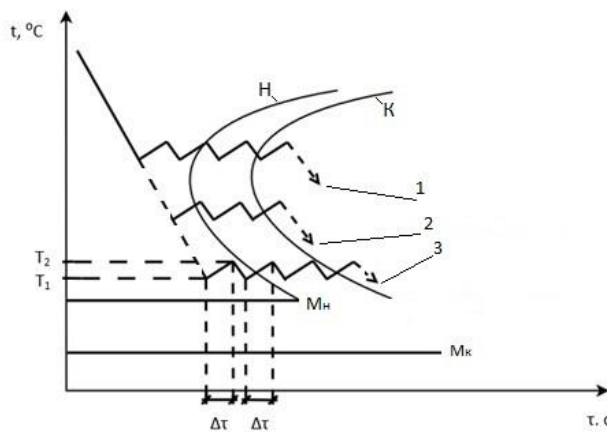


Figure 1. Scheme of isothermal austenite decay with different quasi-isothermal modes of samples exposure after welding for obtaining of perlite (1), sorbitol (2) or bainite (3) structures.

During the steel cooling in the austenite state (from high-temperatures range region), the austenite transformation occurs only after its supercooling below the eutectoid temperature $Ar_1 = 727^\circ\text{C}$, which is explained by the change in the free energy of alloys phases and structures upon heating and cooling. At low temperatures perlite has less amount of free energy as compared to austenite, so with steel supercooling the austenite transforms in a plate-like perlite (ferritic-cementite mixture). The greater the degree of austenite supercooling, the finer the ferritic-cementite mixture is. The resulting pearlite structures depend on temperature. With a small degree of austenite supercooling in the temperature range $727 - 650^\circ\text{C}$ perlite is obtained. With a greater degree of supercooling in the temperature

range of $650 - 600^\circ\text{C}$ sorbitol is formed after austenite transformation (a finer ferritic-cementite mixture is finer than perlite). At even higher degrees of supercooling in the temperature range $600 - 500^\circ\text{C}$, troostite (a finer plate ferritic-cementite mixture in comparison with sorbitol) is obtained [8].

In order to judge about the degree of austenite supercooling, the procedure for calculating the cooling of the welded joint was used [9]. It was assumed that with the upset ($t = t_w$), the heated metal of each rod is removed at length d . In this case, for the initial temperature distribution at the cooling stage ($t > t_w$) we take the known solution $T(x, t_w)$ at the end of the heating. Placing the beginning of the X-axis in the center of the weld we obtain,

$$T_{(x,t)} = \frac{1}{2} \cdot (T_b - T_0) \cdot \exp\left(-\frac{v \cdot d}{a} - \frac{x^2}{4 \cdot a \cdot (t - t_w)}\right) \cdot \left[\exp\left(\frac{[2 \cdot v \cdot (t - t_w) - x]^2}{4 \cdot a \cdot (t - t_w)}\right) \times \right. \\ \left. \Phi^*\left(\frac{2 \cdot v \cdot (t - t_w) - x}{\sqrt{4 \cdot a \cdot (t - t_w)}}\right) + \exp\left(\frac{[2 \cdot v \cdot (t - t_w) + x]^2}{4 \cdot a \cdot (t - t_w)}\right) \cdot \Phi^*\left(\frac{2 \cdot v \cdot (t - t_w) + x}{\sqrt{4 \cdot a \cdot (t - t_w)}}\right) \right]; \quad (1)$$

$$\Phi^*(u) = 1 - \frac{2}{\sqrt{\pi}} \int_0^u \exp(x^{-2}) dx, \quad (2)$$

where $T(x, t)$ is the function of temperature dependence on time and distance from the center of the weld, °C; x is the distance from the heat source, mm; v – flash rate, mm/s; d is the value of the upset, mm; t – total welding and cooling time, s; t_w is the welding time, s; λ – thermal conductivity, J/(cm·s·°C); T_b is the temperature of the liquid metal in the spark gap, °C; T_0 is the ambient temperature, °C; a is the coefficient of temperature conductivity, cm²/s; $\Phi^*(u)$ is the error function.

The heating time was calculated from the data of [10, 11]. The amount of heat required to heat the sample from T_1 to T_2 was calculated by the formula:

$$Q = mc(T_2 - T_1), \quad (3)$$

where Q is the amount of heat, J; m is the mass of the heated volume of metal, kg; c – specific heat capacity of metal, J/(kg °C); T_1 – initial temperature of metal, °C; T_2 – final temperature of metal, °C.

The heating of the samples is described by the Joule-Lenz law:

$$Q = I^2 R \Delta\tau, \quad (4)$$

where I is the current passing through the sample A; R is the resistance of metal sample, Ohm; $\Delta\tau$ – current transit time, s.

Using formulas (3) and (4), the necessary time was determined for heating the sample from temperature T_1 to T_2 at a given current I :

$$I^2 R \Delta\tau = mc(T_2 - T_1); \quad (5)$$

$$\Delta\tau = \frac{mc(T_2 - T_1)}{I^2 R}. \quad (6)$$

The mass of the heated volume of metal was calculated by the formula:

$$m = Sl\rho, \quad (7)$$

where S – the cross-sectional area of the sample (rail), mm²; l is the distance between the electrodes of the welding machine, mm; ρ is the density of steel, kg/mm³.

The resistance of the heated section was calculated by the formula:

$$R = \rho_e \frac{l}{S}, \quad (8)$$

where ρ_e is the electrical resistivity of steel, Ohm·mm²/mm.

Quasi-isothermal exposure can be carried out by passing pulses of alternating electric current through a welded joint from the welding machine which performs the welding of the product.

Based on the set parameters: $T_1 = 600$ °C; $T_2 = 650$ °C; $c = 565$ J/(kg·°C); $l = 200$ mm; $\rho = 7.85 \cdot 10^{-6}$ kg/mm³; $\rho_e = 0.25$ Ohm·mm²/m to calculate the required heating time for a welded joint of different cross-section at a temperature of 600 – 650 °C the calculation of the heating time at different current strengths using the above formulas was carried out and a nomograph was constructed (figure2).

To calculate the cooling after heating, provided that the temperature was distributed evenly to a certain extent over the sample, Newton's heat transfer law was used:

$$\frac{dQ}{d\tau} = \alpha A(T_0 - T), \quad (9)$$

where α is the heat transfer coefficient, $W/(mm^2 \cdot ^\circ C)$; A is the surface area of the body through which heat is transferred, mm^2 ; T – body temperature, $^\circ C$; T_0 is the ambient temperature, $^\circ C$.

Since $Q = CT$, where C is the heat capacity of the body, the differential equation can be written as:

$$\frac{dT}{d\tau} = \frac{\alpha A}{c}(T_0 - T) \quad (10)$$

The solution of this equation has the form:

$$T(\tau) = T_0 + (T_2 - T_0)e^{-\left(\frac{\alpha A}{c}\tau\right)}, \quad (11)$$

where T_2 is the body temperature after heating, $^\circ C$.

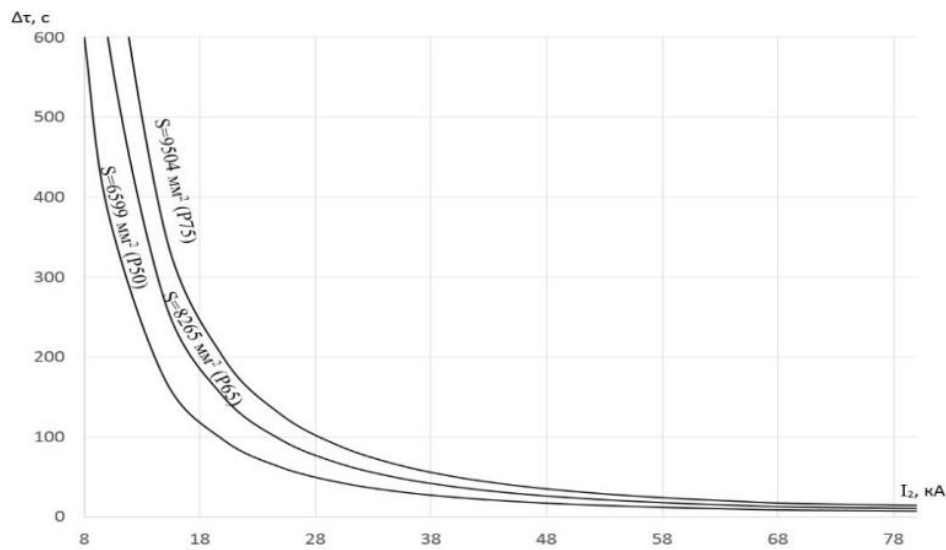


Figure 2. Dependence of heating time $\Delta\tau$ ($T_1 - T_2$) on the current across the secondary winding of transformer at different cross-sectional areas S of the heated samples.

When calculating the quasi-isothermal exposure for 3 pulses each 0.5 seconds long at $\alpha = 100$ $W/(m^2 \cdot ^\circ C)$; $c = 266.76$ $J/^\circ C$; $A = 300$ mm^2 ; $T_2 = 650$ $^\circ C$; $T_0 = 20$ $^\circ C$; $l = 200$ mm ; $I = 11700$ A , we plotted the exposure curves (figure 3).

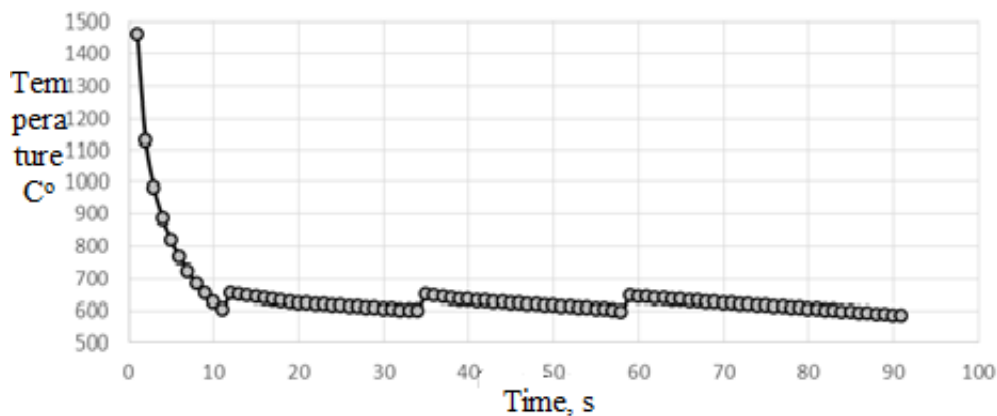


Figure 3. Calculated graph of quasi-isothermal exposure.

The obtained results of calculations formed the basis for the development of a new technology for welding rails without the use of post-welding heat treatment, which is very important for mines characterized by increased combustion hazard.

3. Conclusions

1. The calculation and construction of a nomograph for determining the necessary heating time for a welded joint of rails of different cross-sections depending on the welding current strength was carried out.

2. After welding the rails during cooling it is proposed to conduct a quasi-isothermal exposure in the temperature range of the formation of a finely dispersed structure by passing pulses of alternating electric current through a welded joint maintaining this temperature until the end of the transformation.

3. It is shown that the use of quasi-isothermal exposure at a temperature from 600 to 650 °C makes it possible to obtain a finely dispersed structure of the welded seam of rails of mine haulage tracks without additional heat treatment.

4. References

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