Improvement of aluminothermic welding on the basis of the experimentally-theoretical research of welding seam cooling process

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Abstract. The distinctive features of welding rails in the aluminothermic way are considered. Defects appearing in the process of operation of welded rail seams are indicated. A computer simulation of the aluminothermic welded rail connection cooling process using the LVMFlow software package was carried out. Thermograms were obtained showing the temperature distribution over the cross-section of the rail during cooling. To confirm the results of computer simulation, we conducted field experiments, based on the results of which time-temperature dependences of cooling of the rolling surface of an aluminothermic welded seam were constructed. The time of the surface cooling of the welded seam after welding has been determined to reach a temperature of 600 °C, which is necessary for grinding.

1. Introduction

The railway track today has more than 10 million welded seams [1]. The safety of movement depends on the quality of the welded seams. Welded seams are obtained by contact and aluminothermic welding methods. Contact welding is the most common on the railway network, because this type of welding is carried out by special rail welding machines. In contrast to the contact method for welding rails, aluminothermic welding is carried out manually and the quality of the welded seams in most cases depends on the level of specialist’s training. However, the need for aluminothermic welding is growing, since this welding method is mobile and less expensive [1].

In recent years, there has been a trend towards the increase in the number of defective welded seams, as well as the number of seized highly defective rails (HDR) for welding (Fig. 1) [2]. The most common defects that arise during the operation of welded seams obtained by the aluminothermic welding method are fractures of welded seam and crushing of the rail head rolling surface in the weld.

Previous studies [3] have shown that the defect of the rail head crushing in the field of the weld during operation is associated, apparently, with a lower value of the weld hardness as compared to the hardness of the rail base metal. According to the measurements, the weld hardness is 220-245 HB, and the rail hardness is 340-360 HB. The cause of breaks in aluminothermic welded seams is an increased value of hardness at the border of the cast metal alloying and rail metal of about 380 HB. The increased value of hardness can be explained by the fact that at the fusion boundary of the cast metal and the rail metal, an increase in temperature occurs during welding, whereby the metal of the rail at the fusion interface heats up, the austenite grain grows and this coarse granulation persists, which leads to the increase of hardness and embrittlement.
Figure 1. The number of defective and highly defective rails (HDR) for welding in the period from 2012 to 2016

The literature review showed that the problem of the defect appearance and the disclosure of their occurrence causes in welded aluminothermic seams is topical. The paper [4] noted that the cause of surface defect appearance in aluminothermic welded seams is a violation of the casting mold installation technology. Investigations aimed at improving the mechanical properties of welded seams due to the doping of a thermite powder are reported in [5-7]. The articles contain the results of heat treatment effect study [8] and surface plastic deformation [9] on the structure and properties of welded rail seams. The results of simulating the loading process of aluminothermic welded seams of rails with imperfections and porosity defects are presented in [10, 11].

2. Statement of the problem
It is possible to influence the mechanical properties of the rolling surface of the aluminothermic welded rail connection either before welding by changing the chemical composition of the foundry termite powder or after welding by post-welding machining operations. Earlier, we carried out a complex of studies on the effect of grinding performed at different residual post-weld temperatures of welded seams on hardness and roughness [12]. It has been established that the grinding of welded seams immediately after welding at welding temperatures of 850, 800, 700 and 600 °C leads both to a decrease in hardness before and to an increase in hardness. It should be noted that for today in the normative documentation there is no information on the optimum temperature of welded rail connections grinding. In practice, grinding is carried out immediately after removing the grate from the rolling surface of the rail head. According to the results of the studies presented in [12], to ensure the hardness of the welded seam close to the hardness of the base metal 340-360 HB, grinding should be carried out at a residual post-weld temperature of a welded seam of the order of 600 °C. The task of this work is to determine the aluminothermic welded rail connection to a temperature of 600 °C after welding.

3. Simulation results
Experimental studies and computer modeling were carried out to determine the holding time of the welded seam. Computer simulation was carried out using the software product LVMFlow, in which, based on the finite element method, it is possible to determine the temperature value at any point of the model and construct a temperature field in the selected section of the calculated region. In accordance with the existing technological process for the production of aluminothermic welded rail
seam [13], after the completion of the thermite reaction and filling the mold with liquid metal, the mold is first held for 8-10 minutes, and then removed and started to perform mechanical processing. Therefore, for modeling using the program "KOMPAS-3D" two three-dimensional models were created. Model No. 1 consisting of two rails, a welded seam, a mold, gates and a profitable part is designed to simulate the process of cooling the weld metal from the metal pouring into the mold until the mold and excess metal are removed (Figure 1). Model No. 2 consisting of two rails and a welded seam allows measuring the change in the temperature of the metal without a mold (Fig. 2).

![Figure 2. Three-dimensional models of LVMFlow](image)

High accuracy of computations during modeling was provided due to the small size of the cells of the difference grid equal to 1 mm. Initial installations for modeling the cooling process of a welded seam with a mold (Model No. 1): steel grade - E76; the material of the form is quartz sand; the temperature of the filled metal is 2500 °C; The temperature of the rails and mold is 850 °C. Initial data for modeling the cooling of the rail seam without a mold (Model No. 2): steel grade - E76; the temperature of the weld metal is 1500 °C; the temperature of the connected rails is 1200 °C. The temperature of the weld metal was determined at certain points that were installed on the models in the cross section of the rail and along its length. The simulation results are shown in Fig. 3.

![Figure 3. Results of simulating the temperature distribution of the aluminothermic welded rail connection in the process of cooling after welding](image)
At the first stage of the simulation, the change in the temperature of the welded seam metal was estimated from the moment when molten metal was poured into the mold before the operations for removing the shape and excess metal (Fig. 3, a). The second stage consisted in determining the temperature of the welded seam metal during the post-welding treatment of the welded seam rail head (Figure 3, b).

4. Results of field experiments

After the simulation, a series of full-scale experiments was carried out to measure the surface temperature of the rolling aluminothermic welded rail seam and determine the holding time to reach a temperature of 600 °C during cooling after welding the rails. The experimental conditions (steel grade, mold material, cast metal temperature, rails and mold temperature) are similar to those in the simulation. Measurements the surface temperature of the rolling aluminothermic welded seam were carried out with a pyrometer. In contrast to the simulation, the measuring the surface temperature of the rolling rail head was carried out only after the mold was removed, because the casting mold does not have access to the rolling surface. The results of the experiments are presented in the table.

5. Discussion of results

The results obtained in the course of the experiments and modeling are presented in the form of temperature-time dependences (Fig. 4). It should be noted that the results obtained during the experiment are consistent with the results of the simulation. The greatest drop in temperature is noted in 2 cases: when the metal is poured into the welding mold (the beginning of the crystallization of the metal) and when the welding mold is removed in the weld region.

![Graph](image)

Figure 4. Temperature-time dependence upon cooling of the rolling surface of an aluminothermite welded rail connection after welding
The decrease in temperature at the end of the pouring metal into the welding mold from 2500 to 1800 °C is explained by the intense heat removal to the welded rails, which is confirmed by the thermograms in Fig. 3. When removing the casting mold, there is also a significant drop in the temperature of the metal from 1600 to 900 °C, which is associated with a decrease in the volume of the casting.

As noted earlier, grinding to increase the hardness of the rolling surface of aluminothermic welded seam should be carried out at a residual post weld temperature of welded seam of about 600 °C. It can be seen from the graph that this temperature is reached after 1200-1300 s after pouring the metal into the welding mold.

6. Conclusions and inclusion

Experimental and theoretical studies of the cooling process of the aluminothermite welded rail seam after welding have been carried out. The results of the investigation of the temperature field distribution arising during the welding of rails in an aluminothermic way, carried out using the computer simulation of the molding processes of LVMFlow, are presented. As a result of the simulation, thermograms were obtained showing the distribution of heat in the region of the rail seam in the process of its cooling. The results of computer simulation are confirmed by the results of field experiments. The time for holding the weld seam in the mold after the welding of the rails for grinding at the metal temperature of the weld head of the welded seam 600 °C is determined. The results of experimental and theoretical investigation of the process of cooling the welded seam in aluminum thermit welding make it possible to develop a number of measures for perfecting the organization of aluminothermic welding technology.

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