Analysis of rail welding methods for mine rail access with the use of modern technologies

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Abstract. Welded joint zones are weak sections of the railway track for all traffic cases (in the case of high-speed traffic and heavy traffic). In the paper advantages and disadvantages of the basic ways of rails welding, which are widely used today, are considered: electrocontact and aluminothermic. Carefully selected mode of differentially thermally strengthened rails string will allow the process of correction after heat treatment to be minimized and internal residual compressive stresses to be kept.
Particular attention should be paid to the method of rails welding, in which after rails welding during their cooling it is offered to perform quasi-isothermal exposure in the temperature range of fine structure formation by passing pulses of alternating electric current through the welded joint maintaining this temperature until the end of the transformation. The use of quasi-isothermal exposure at a temperature of 600 – 650 °C makes it possible to obtain a finely dispersed structure of the welded seam of rails without additional heat treatment.

1. Introduction

Rail access are an important part of industrial transport, which means a set of transport devices and facilities that serve the needs of an enterprise in the transportation of finished products, raw materials and semi-finished products. Also, the intensity of cargo flows puts forward new requirements to the upper structure of track, in particular, to the main element – rails. At present, both on the Russian railways and abroad the jointed construction of tracks is neglected.

One of the main drawbacks of the jointed track is the presence of a joint. The development of technologies that make it possible to provide a continuous welded railway track is an actual direction at present [1 - 6]. It should be taken into account that the operation of the railway access in the country takes place in difficult climatic and operational conditions. Thus, the use of modern technologies for construction and repair of access roads will increase the quality of the road.

2. Results and discussion

To the advantages of a continuous welded rails can be attributed [7, 8]:

- a 30-40% reduction in the costs spent on the current road maintenance and improvement of traffic safety, construction reliability;
- a 8-10% reduction in the main resistivity to traffic and, therefore, saving of fuel and electricity for traction, which is very important in the context of a continuous increase in energy prices;
- increase in the service life of the track upper structure due to a smaller than in the jointed track of rails damage (cracks in the edges of bolt holes, head dislocation, crushing and saddles). Thus, failures of continuous welded rail strings due to defects (contact fatigue and in the

joints) arise 1.8-2.0 times less often than of jointed track, and without taking into account balancing intervals in 3-4 times;
- reduction in the amount of works on the road correction (up to 25-30%) associated with sinks in the joints, especially works on the elimination of splashes which with the increase of axial loads become a big problem;
- decrease in the intensity of lateral wear of the outer rail line in the curves and, accordingly, the damage to the rails for this reason in 1.5-1.6 times;
- reduction of the need to clean crushed-stone ballast along the coal-ore routes in 1.5-2.0 times;
- reduction of metal costs for track joint fastening (up to 4.5 t-km);
- reduction of expenses for repair of running parts of wagons and locomotives;
- increase the comfort of passengers;
- increase in the work reliability of electric track chains of automatic blocking.

Important advantage of the continuous welded construction of the upper structure of the track is the fact that it allows the reinforced concrete sub-base to be used, which increases the stability margin, resistance to longitudinal and transverse displacements of rails and provides equal rigidity of the track along the length. In addition, the use of reinforced concrete sleepers reduces the consumption of commercial timber.

Welded joint zones are weak sections of the track for all traffic cases (in the case of high-speed traffic and heavy traffic). Removals due to the defects of welded joints the total number of rails removal reach 30%, while the total length of the joint zone is not more than 2% of the length of the rail. The reasons for this are: a change in the homogeneity of microstructure in the zones of weld and the thermal effect; creation of an unfavorable diagram of internal residual stresses; creation of conditions during welding for the formation of internal defects, which are stress concentrators and weaken the rail section with a welded seam; the deformation of the rail in the weld zone with the subsequent formation of “saddlings” during operation.

The creation of rails with a resource of 1500 – 2000 million tonnes is possible only with a comprehensive optimization of metallurgical quality, the structure of the metal matrix, the residual stresses and straightness curves [9, 10]. High metallurgical quality of rails is due primarily to the absence of aggregates and separate large brittle-decomposed oxide nonmetallic inclusions in them, which is ensured by the low content of aluminum (less than 0.004%) and oxygen (total – less than 20 ppm and bind in high alumina inclusions – less than 10 ppm).

The main disadvantages, which reduce the resource of all these rails in operation, remain:
- presence of residual stresses in the head of rails, which are induced there by the last technological operation in the production stream – by cold correction on roller machines;
- creation of soft areas with reduced resistance to wear and saddling in the heat affected zones after welding and subsequent local induction heat treatment of welded joints, which results in unevenness in these places and increased dynamic impact of wheels of rolling stock;
- a noticeable decrease in the impact hardness, fracture toughness and critical size of fatigue cracks during quenching from rolling heating as compared to quenching with a separate recrystallization heating.

All these disadvantages can be overcome by designing and development of welded rail strings with length 800 m welded from solid-rolled rails of 100 m, followed by heat treatment by continuously sequential induction heating of the entire cross section of the rail and further differentiated cooling, aimed at receiving in the rail head of sorbite and troostosorbite structure, maximum possible uniform for all-rolled rail and for the welded joint without heat-affected zones. The obtained rail string with heat treatment should provide overhaul service life at least 1500 – 2000 million tonnes brutto, provided periodic preventive grinding or milling is performed.

Such an approach will ensure the maximal possible strength uniformity of welded joints and solid rolled rails with the production of long rails for a continuous welded track with equal wear resistance and saddling during operation, which will eliminate local unevenness of the continuous welded track during the lifetime of rails. Besides, this provides a favorable diagram of internal residual stresses that contribute to the generation of the greatest resistance to nucleation and distribution of contact fatigue cracks in the head, corrosion-fatigue cracks in the sole and longitudinal cracks in the neck of the rail, both in the rolling and welded parts of rail strings.

Correctly selected mode of differentially thermally strengthened rail strings will allow the process of straightening after heat treatment to be minimized and internal residual compressive stresses to be kept. It is known that the rails thermally strengthened by the technology of continuously-sequential through induction heating and subsequent differential cooling by compressed air from the side of the head and sole at the enterprises of SISCO (Canada) (currently the plant is closed) and Sozheray (Tata Steel, France), had residual compressive stresses in the head of 100-200 MPa, and in the sole 100-150 MPa. The rails thermally strengthened from rolling heat by differentiated quenching or from a separate heating by volumetric quenching in oil, as a result of cold straightening on rollers, have tensile stresses in the head and the sole up to 250-300 MPa [11].

In the construction, repair and maintenance of a continuous welded track, one of the key technologies is the welding of rails, for which the following methods have been developed and patented:

- pressure welding: electrocontact, gas-press, induction, by laser, friction, etc.;
- aluminothermic welding;
- electric arc welding: by electrodes, under a layer of flux, in the environment of shielding gases, electroslag, by powder wires, etc.

The method of pressure welding is based on the heating of the ends of rails to the temperature of plastic state (above 1000 °C) and squeezing them with a certain force (depending on the cross-sectional area and the physical-mechanical properties of the rails metal) [12]. The ends of rails can be heated by electric current – electrocontact method, by gas burners – gas press, by high frequency currents (inductors), laser, plasma, heat released during friction, etc. When welding by pressure there is no filler metal, i.e. the ends of rails are welded directly to each other.

The aluminothermic method is based on the production of metals and alloys by the reduction of their oxides in exothermic reaction with aluminum. The reaction proceeds with the release of a large amount of heat. The molten metal is poured into the gap between the connected rails [13].

The electric arc welding is based on melting of electrode arc by electrode metal (rod or wire) and filling with it a gap between the connected rails.

Aluminothermic and electric arc methods differ significantly from the methods of pressure welding because a welded joint with a width of 15-25 mm and more consists of a filler metal having a cast structure.

All methods of welding are characterized by the presence of a heat-affected zone (HAZ) – a modified structure of the base metal of rails directly adjacent to the weld. This leads to the occurrence of residual stresses and, as a consequence, to decrease in the strength characteristics of the welded joint. The width of the HAZ depends on the time of exposure of the base metal to high temperatures, weight of the filler metal, welding method and parameters.

On the welded joints performed by the methods of pressure welding, heat treatment (including differentiated, with hardening of the rail head in the HAZ) can be used to increase their mechanical properties [14].

Since during aluminothermite and electric arc welding there is an additive metal in the weld seam that is very different in terms of chemical composition and structure from the metal of the rails, the heat treatment of these joints does not give a tangible increase in their mechanical properties.

Among these methods of rail welding by pressure the electrocontact method (EM) is most widely used – in 95% of all cases. In Russia on the railways EM is only applied, by which annually about 600 thousand joints of rails are performed by rail-welding trains and up to 50 thousand joints by moving rail-welding machines [15]. Consider the advantages and disadvantages of existing EM technologies.

Advantages of EM:

- high quality of the welded joint;

- the presence of monitoring system in the welding machine that allows the deviation of welding parameters to be controlled;
- high mechanization and automation of works (in stationary conditions);
- high performance of the process.

Disadvantages of EM:

- impossibility to weld joints in the area of turnouts;
- expensive equipment;
- need for long schedule gaps in the movement of trains during welding operations.

At present, the method of pulsed flash welding has become most widespread in contact welding of rails. This method of contact welding is the most economical and technological in comparison with continuous flash welding. During contact welding of rails and welding by other methods, heating and continuous cooling of the metal in the HAZ occurs. Depending on the chemical composition of steel, the welding process is selected using the existing methods of flash welding: continuous or pulsed, which determine the linear magnitude and temperature fields in the HAZ of welded joint [16, 17].

The choice of thermal regime is based on the exclusion of the formation of quenching structures (martensite and bainite), causing additional stresses and cracks, which lead to destruction of rails [8]. In connection with this [18], the development of such regimes for rails of high-speed railways made of chrome steel is of particular importance.

However, when using the continuous welded construction of the track top structure, a number of issues remains unsolved, in particular, the issues of increasing the strength of welded joints and the HAZ influence require further work as the number of dangerous defects in this area is 13-15% of the total number of defects on the rail string.

This problem in the process of construction continuous welded tracks is solved by the obligatory thermal treatment of the welded joint. Heat treatment is performed by induction units, which increases 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 adjusting the cooling rate [18]. At the same time, partially using the method of continuous flash welding, welding defects may appear.

It is proposed in [19] after welding the rails during their cooling to perform a quasi-isothermal exposure in the temperature range of the formation of fine structure by passing pulses of alternating electric current through the welded joint maintaining this temperature until the end of the transformation. Quasi-isothermal exposure at a temperature of 600 – 650 °C makes it possible to obtain a finely dispersed structure of the welded seam of railway rails without additional heat treatment.

Until recently, the main method of rails welding was electrocontact method ES. However, due to the impossibility of rails welding in the turnout zones by contact machines, since 1995 the aluminothermic rails welding (ATRW) has been used on the railways of Russia, and at present the issues related to the use of ATRW not only in the zone of turnouts but also on the running line are being solved.

Advantages of ATRW:

- mobility;
- small duration of schedule gaps in the movement of trains;
- welding process does not consume electricity.

Disadvantages of ATRW:

- there is no possibility to monitor and control the welding process;
- a wide and uncontrolled zone of thermal influence;
- the influence of mixture quality on the quality of welded joints;
- a strong dependence of the welding quality on the experience of a welder.

In order to understand the processes occurring in ATRW, it is necessary to understand the basic principles of this welding method. In general, the technology is described in [20 - 24]. The termite, used for welding rails, is made of iron scale – wastes of steel production and metal aluminum. They

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are crushed to obtain grains of 0.1 to 2.5 mm in diameter. Primary aluminum should contain at least 98-99% of pure aluminum. Before grinding, scale should be well burned in order to remove moisture and oil from it. Dust from the grinded scale and aluminum is removed by an air separator. Scale in its chemical composition is different. The smaller content of silicon in the scale, the better it is for a welding thermit. The content in the scale of oxygen should not be below 25%. Iron with oxygen can form three oxides: FeO – iron oxide; Fe_2O_3 – ferric oxide and Fe_3O_4 – black of iron. Under normal conditions, the constituents of the thermit mixture do not interact, but if the thermit mixture is heated to 1100 – 1200 °C a chemical reaction begins between its components. As a result of this reaction, metallic aluminum is oxidized and converted to alumina, and the scale is reduced to iron. This reaction is accompanied by a large release of heat spontaneously and uncontrollably. The thermit mixture contains: 23.7% of aluminum and 76.3% of scale. When combusted 1.0 kg of thermit mixture releases 3188.22 kJ of heat, which makes it possible to obtain a temperature of molten metal 2700 – 3000 °C.

Scale and aluminum may contain various impurities. Therefore, the percentage of aluminum and scale in the thermit mixture is calculated taking into account the purity of aluminum and the oxygen content in the scale. The practice of thermit welding showed that the scale in the thermit mixture should be (7-8)% higher than the calculated content. Then the termite metal is denser and welds better with the metal of the rail.

To use effectively the heat generated during the reaction and increase in the metal yield, finely grinded pieces of steel – wastes of nail-making production are added to the thermit mixture during manufacture for the welding of rails. In the process of flash, steel increases the yield of the thermit metal and lowers the initial temperature of the thermit reaction products. Depending on the weight of the thermit batch, these wastes are added to the thermit mixture from 12 to 20% of the estimated yield of the thermit metal. To improve the mechanical properties of the weld metal, ferroalloys are introduced into the thermit mixture, in most cases ferromanganese, ferrosilicon, ferromolybdenum, ferrotitanium, ferrovanadium. Ferroalloys cause the production of thermit metal with mechanical properties close to the metal of the welded rails. Thus, the chemical composition of the metal formed from the thermit mixture is far from welded rail steel with all the consequences. In addition, the thermit component itself is a source of oxides of both exogenous –unreacted iron oxide and endogenous – formed during oxidation-reduction reactions. It should also be noted that slag inclusions and gases that are not always formed during the reaction time manage to float out of the reaction zone. As a result, the welding zone becomes contaminated with non-metallic oxide inclusions and various micropores, which are the centers of crack initiation.

For the welding of rails, an intermediate casting method can now be used in which only molten metal without slag is used from the products of thermit reaction increasing the quality. However, ATRW welding is a joint obtained by casting processes in which non-metallic oxide inclusions, pores, cavities, g bleed, slag inclusions, internal cracks and micropores are possible.

Great problems arise during ATRW welding in winter. At low temperatures the cooling rate increases and as a result crystallization of the molten metal of the weld pool accelerates, the released gases and slag particles do not have time to float, saturating the metal with pores and slag inclusions. Increased heat removal from the heated metal and increase in the content of gases in it contribute to the formation of cracks in the seam and the HAZ. If the storage rules are not observed, a certain amount of moisture is possible in the materials, which contributes to the saturation of the weld metal with hydrogen. [25] shows the results of operational tests of welded joints welded by various technologies. It is shown that preheating is the main technological operation that influences the development of a necessary structure and provides the required quality of the welded joint. Experiments have shown that if the heating is insufficient or the ambient temperature is low, the temperature of the rails ends drops sharply, which leads to an increase in the rates of cooling of the weld metal and the weld zone. This contributes to the formation of quenching structures, increased brittleness and the formation of microcracks, which reduce the strength of the joints. For example, when welding rails at an ambient temperature of 15 °C, the cooling rates at the peripheral sections of rail base are almost twice as high as in the head.

In [26] experiments on ATRW welding at negative temperatures are presented. The ambient temperature has a negative effect on the quality of welds. The results of experiments obtained at different welding temperatures do not meet standard requirements.

It should be noted that experience of the operation of welded joints of ATRW on the railway network and testing on the Experimental Ring VNIIZhT show that their quality is somewhat inferior to the quality of the joint produced by EM, which is conditioned by the welding method itself. Therefore, the main companies that carry out ATRW of railroads on the railway network ("Snaga", "Welding Surfacing Company", "GT-Aluminothermic Welding", "Railtech", "Welding Technologies") set up this method solely for welding rails within turnout, on bridges, overpasses, in tunnels, when it is difficult to organize the necessary windows in the traffic schedule for the use of ATRW.

In [27] the calculation is made, according to which the cost of electrocontact welding is more expensive than aluminothermic welding of rails by 41.8%. However, when considering the terms of guarantee of the joints welded by the EM and the ATRW according to the quantity of the cargo passed over them (for EM according to the RZD standards 1.08.002 – 2009 for rails of the type R75 and R65 – 150 million tonnes brutto, for rails of type R50 – 120 million tonnes brutto: for ATRW according to TU 0921 – 127 – 01124323 – 2005 for rails of type R75 and R65 – 120 million tonnes brutto: for rails of type R50 – 100 million tonnes brutto) the cost of a joint for each million tonne brutto changes. When EM is used: for rails of type R75 and R65 – 81.33 rub., for rails of type R50 – 101.67 rub. When ATRW is used: for rails of type R75 and R65 – 59.17 rub., for rails of type R50 – 71 rub. Thus, the present costs of EM is more expensive than ATRW by 27.25% when welding rails of type R75, R65 and by 30.17% when welding rails of type R50. Moreover, it should be pointed out that the analysis of data on the removal of 897 defective welded joints of ATRW on the rail network in 2009 and 9 months of 2010 revealed that 89% of the ATSW joints (710 pcs.) did not work during the warranty period. This also reduces the difference between the cost of EM and ATRW. The cost of ATRW increases with the further joints operation. The current periodicity of monitoring the ATRW joints (not later than 6 months from the moment of welding, then at least once a year), most of which are operated with safety pads, are higher than the periodicity of monitoring of joints welded by electrocontact method, operated without safety pads (at least once a year in the first two years after welding, then at least once every two years) [28].

3. Conclusion

From the data given, it follows that welding ATRW today has not proved itself to be a reliable and qualitative method of connecting the rails, the economic component is related to the quality characteristics and safety of transportation by rail. For railway accesses at mining and processing enterprises it is recommended to weld the rails by the electrocontact method.

It should be noted that both methods of welding are continuously developing, in particular, the German company "Elektro-Thermit GmbH & Co. KG" declares about the achieved successes in improvement of quality of a joint made by ATRW. Despite the good advertising component, mass use and introduction of this technology for rails welding should necessarily be preceded by large-scale studies, laboratory and testing tests, operational tests on the sections of railways with different geometries, density of freight traffic and climatic conditions.

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