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Abstract. Existing methods of rail welding, which are enable to get continuous welded rail track, are observed in this article. Analysis of existing welding methods allows considering an issue of continuous rail track in detail. Metallurgical and welding technologies of rail welding and also process technologies reducing aftereffects of temperature exposure are important factors determining the quality and reliability of the continuous rail track. Analysis of the existing methods of rail welding enable to find the research line for solving this problem.

Introduction

Railroad communication in Russian Federation and its condition have a high effect on the economical development in the country. Length of railroad and intensity of freight traffic put in new claims on truck superstructure, especially on its main element – rails. Nowadays on Russian railways as well as abroad jointed track construction is rejected. One of the main disadvantages of the jointed track is a rail joint. Development of the technologies enabling to ensure the possibility of continuous rail track realization is a technological direction of a current interest [1-6]. It should be taken into account that maintenance of rail tracks in Russia takes place under difficult climatic and operational conditions (in Russia, unlike in European countries, the same tracks for passenger and industrial traffic are used).

Advantages of continuous rail track are the following [7-8]:

- 30-40 % decrease of track maintenance costs, higher safety of traffic, reliability of construction;
- 8-10 % reduced specific train resistance and, therefore, saving of fuel and electrical energy for the haulage, which is relevant in the context of continuous growth of energy sources' prices;
- increase of service life of the truck superstructure due to lower rails' damageability than in jointed track (cracks in bolt holes' edges, indent of a railhead, crushing and saddles). So, defect failures (contact and in joints) of continuous string occur 1.8-2.0 times more rarely than for jointed rail track, and without including equalizing span – 3-4 times more;
- reduced volume of work on track surfacing (up to 25-30 %), connected to low spots in joints, especially liquidation of pumping, which becomes a big problem with increase of axle loading;
- reduced intensity of external rail's side wear in curves and, therefore, rail damage is reduced in 1.5-1.6 times;
- 1.5-2.0 times reduced demand for ballast stone purification on coal-mineral routes;
- reduced take of metal for joint assemblies (up to 4.5 t per km);
- reduce of costs for trucks' repair;
- increase of travelling comfort for passengers;
- increase of working reliability of electrical track circuits of automatic block.

One of the important advantages of continuous track construction is also that there is a possibility to use reinforced-concrete slab, which increases safety against buckling, longitudinal and lateral motion resistance and ensure equal rigidity of track lengthwise. Also use of reinforced-concrete sleepers reduces the take of industrial wood.

The most damageable place of the rail is a welding joint. Withdrawing from service due to welding defects may reach 30% of total withdrawing, however total length of joints is less than 2% of rail length. In order to fit purpose and for consistent performance welded joints have to have the same properties as the rails itself. They have to be firm (moment of inertia and resisting moment have to be big enough for bending and torsional stresses not to exceed allowed values); long-lasting (to have high hardness, wear resistance and toughness, including at low temperatures); to have high contact-fatigue endurance. Also, vertical and horizontal straightness have to be ensured, major defects such as reed marks, microcracks, nonmetallic inclusions have to be eliminated.

One of the key technologies for construction, repair and maintenance of continuous rail track is rail welding, for which the following methods are developed and patented:

– Pressure welding: electro-contact, gas-pressure, induction, laser, friction, etc.;
– aluminothermic welding;
– electric arc welding: covered-electrode, submerged, gas-shielded, electro-slag, flux-cored, etc.

Method of pressure welding is based on heating the rails' ends up to plastic state temperature (more than 1000 °C) and squeezing them with a certain force (depending on cross-section area and physical and mechanical properties of metal of the rails)[9]. Rails' end can be heated up with electric current - electro-contact method, with gas welding torch – gas pressure method, with high-frequency current (inductor), with lasers, plasma, friction heat, etc. In pressure welding filler metals are not used, i.e. two rails' ends are welded to each other directly.

Aluminothermic welding method is based on desoxydation of metals and alloys in the exothermic reaction with aluminum. Great amount of heat is generated while the reaction proceeds. Liquid metal is poured between welded rails[10].

Electric arc welding method is based on the fusing of electrode metal (bar or wire) with an electric arc and filling the gap between rails with it.

Aluminothermic and electric arc welding methods differ from welding in pressure in the fact that weld of width 15-25 mm and more consists of filler metal which has cast structure.

In all welding methods there is heat-affected zone (HAZ) – area of changed structure of base rails' metal bordering on the weld. It leads to residual stresses and, as following, to reduced strength properties of the weld. The width of HAZ depends on the high temperatures exposure time on the base metal, on the mass of filler metal, welding method and parameters.

For the welding joints made by pressure welding it is possible to use thermal treatment to increase their mechanical properties (including differential treatment with rail-end hardening in HAZ)[11].

In the case of aluminothermic and electric arc welding there is a filler metal in the weld, which highly differs from rails' metal in constitution and structure, so thermal treatment of these weld joints doesn't increase their mechanical properties very much.

From all the methods of welding with pressure mentioned above the most commonly used one is electro-contact method (EC) which is applied in more than 95% of cases. On Russian railways only EC is applied and about 600 thousands of weld joints are made annually by rail-welding train and about 50 thousands joints by moving rail-welding machines [12]. Let's consider advantages and disadvantages of existing EC technologies.

Advantages of EC:

- high quality of weld;
- control system in rail-welding machine enable to control deviation of welding variables;
- high level of mechanization and automation of operations (under stationary conditions);
- high processing rate.

Disadvantages of EC:

- impossibility of joint welding in switch zones;

- expensive equipment;
- need for long occupations during welding works.

Nowadays the most widely applied method of electro-contact welding is pulse flash welding. This method of EC welding is more economical and processible comparing to continuous flash. Under EC welding as well as under other welding methods continuous heating and cooling of metal occurs in HAZ. Depending on steel constitution welding procedure is chosen: either continuous or pulse flash welding. The flash type determines linear quantity and temperature profiles in weld's HAZ [13, 14]. The choice is based on the elimination of hardening structures formation (martensite and bainite), which cause additional stresses and cracks leading to destruction of the rails [8]. As a result [15], the development of such procedures for rails of high-speed networks made of chord steel is coming into sharp focus.

However, when applying continuous rail track structure some questions are still unsettled, in particular questions concerning the increase of strength of weld and HAZ, because the amount of defects in this area is about 13-15% of total amount of defects on a rail bar.

This problem is solved during the fabrication of continuous rail track by compulsory heat treatment of welding joint. Heat treatment is done with induction-heating installation which increases costs. This problem in practice is advised to be solved by combining continuous and pulse flash welding methods, changing the heating rate during welding process and regulating the cooling speed [15]. At that, while partly using continuous flash method, there is a possibility of welding defects.

The paper [16] introduces after the welding during the cooling to carry out quazi-isothermal holding in the interval of highly disperse structure formation temperatures by flashing alternate current through the welding joint and maintaining the temperature till the end of transformation. Using the quazi-isothermal holding at a temperature 600 – 650 ^{0}C allows getting highly disperse structure of the weld without any additional heat treatment.

Because of the impossibility to weld rails in switch zones by welding machines the aluminothermic rails' welding (ATRW) have come into operation on Russian railways since 1995 year. Questions concerning application of ATRW not only in switch zones, but also on the runs are being discussed currently.

Advantages of ATRW:

- mobility;
- short occupations;
- welding process is carried out without electrical energy.

Disadvantages of ATRW:

- it is not possible to supervise and directly control the welding process;
- wide and uncontrolled heat-affected zone;
- quality of welding thermite mixture affects the quality of weld;
- weld quality highly depends on the welder's experience.

The technology in general is described in works [17-21]. The thermite used for rails' welding is made from iron dross – steel-rolling industry wastes and metallic aluminum. It is crushed to get grains of 0.1-2.5 mm size. Primary aluminum has to contain no less than 98–99 % of pure aluminum. Before being crushed the iron dross has to be well burnt in order to remove moisture and oil from it. The dust from crushed dross and aluminum is removed by separator. Chemical constitute of the dross differs. The less silicon dross contains, the better it fits for producing of welding thermite. Oxygen content in the dross shouldn't be less than 25%. Iron and oxygen can form three oxides: FeO, Fe_2O_3 and Fe_3O_4. Under the normal conditions components of thermic mixture do not interreact, but if the mixture is heated up to 1100– 1200 °C the reaction starts between its components. As the result of this reaction metallic aluminum oxidizes and turns into aluminum oxide and iron dross reduces to iron. The reaction is spontaneous and uncontrollable and it proceeds with the release of big amount of heat. Thermite mixture contains by weight 23.7 % of aluminum and 76.3% of dross. 1 kg of thermite mixture releases 3188.22 kJ of heat during its combustion, which produces the temperature of heated metal about (2700–3000) °C.

The dross and aluminum might contain different impurities. That's why the percent of aluminum and dross content in thermite mixture is calculated taking into account the purity of aluminum and content of oxygen in the dross. Practice of thermite welding has shown that the dross content in thermite mixture has to be 7-8% higher than calculated content value. In that case thermite metal is denser and is welding with rail's metal much better.

For the more effective use of the heat released in reaction and for increase of metal fall, little pieces of steel, which are nail industry waste, are added to the thermite mixture. The steel, when it is melted, increases metal fall and decreases the initial temperature of thermite reaction products. This waste (called cuttings) is added to thermite mixture at the rate of 12 to 20% of the weight of assumed thermite metal fall depending on the weight of thermite portion. Ferroalloys, mostly ferromanganese, ferrosilicon, ferromolybdenum, ferrotitanium, ferrovanadium, are added to the thermite mixture to improve mechanical properties of the metal. Ferroalloys enable to get the thermite metal with mechanical properties close to mechanical properties of the metal of welded rails. Therefore, chemical constitute of the metal occurred from thermite mixture is very far from the constitute of welded rails' steel with all that it implies. Besides, the thermite itself is a source of oxides, both – exogenous (unreacted iron oxide) and endogenous (generated in oxidation-reduction reactions). Also it should be pointed that slug inclusions and gases generated in reactions are not always have time to float from the reaction zone. As the result, welding zone is contaminated with non-metallic oxide inclusions and micropores which are the centers of crack initiation.

At the present time thermite fusion welding method might be applied for rails welding. In this method from all the thermite reaction products only liquid metal with no slag is used which increases the quality. However, ATRW produces joints with casting processes during which there is a possibility of formation of non-metallic inclusions, pores, caverns, bleeds, slag inclusions, internals cracks and micropores.

Huge problems might occur when using ATRW in winter periods. At low temperatures the cooling speed increases, for which cause crystallization of weld pool molten metal also increases. As a result, evolved gases and slag particles don't have enough time to float and fill the metal with pores and slag inclusions. Increased level of heat removal from heated metal and increase of gas content in it enable crack formation in the weld and weld-affected zone. If storage regulations are not observed there might be some moisture in materials leading to saturation of weld with hydrogen.

The paper [22] show the results of operational tests for weld joints welded with the use of different technologies. It is shown that the main operation influencing the generating of needed structure and ensuring required quality of weld is a preheat cycle. Experiments proved that if the preheat is not enough or if the temperature of environment is low then temperature of rails' ends decreases rapidly leading to increase of cooling speed of metal in weld and weld-affected zone. It gives rise to hardening structures, embrittlement and formation of microcracks. So, when rails are welded at the ambient temperature 15 ^{o} C cooling speeds on peripheral area of rail base are almost twice higher than in the top of rail.

The paper [23] introduces experiments in ATRW at the temperatures below zero. Ambient temperature adversely affects the quality of welds. Experimental results obtained at different welding temperatures don't meet the regulatory requirements.

It should be pointed that as the experience of operating of ATRW weld joints on the railway network and tests on All Russian Scientific Research Institute of Railway Transport Test Loop show, the quality of these joints is lower than EC joint's quality due to the welding method itself. That's why main companies, performing ATRW on the railway network ("Snaga", "Welding Filler Company", "Aluminohermic welding", "Railtech", "Welding technologies") claim this method to be fitted only for rail welding within switches, on the bridges, elevated structures, in the tunnels when it is difficult to organize occupations for using welding machines.

The paper [24] introduces calculation showing that electro-contact welding is 41.8 % more expensive than aluminothermic welding. However, if we consider warranty period of joints welded by EC method and ATRW depending on the freight traffic (for EC accordingly to RR Company Standard 1.08.002 – 2009 for rails' type R75 and R65 – 150 million tons gross; for rails' type R50 – 120 million tons gross; for ATRW accordingly to TR 0921 – 127 –01124323 – 2005 for rails' type R75 and R65 – 120 150 million tons gross; for rails’ type R50 – 100 million tons gross) the cost of joint for each million tons gross is changing. For EC: for rails’ type R75 and R65 – 81.33 rub., for rails’ type R50–101.67 rub. For ATRW: for rails’ type R75 and R65– 59.17 rub., for rails’ type R50– 71 rub. Therefore, present value of EC welding is 27.25 % higher than ATRW for R75, R65 rails’ welding and 30.17% higher for R50 rails’ welding. It also should be pointed that analysis of data of 897 defected ATRW welded joints withdraw during 2009 and 9 months of 2010 year done in the work [25] has shown that 89% of ATRW joints (710 pcs) haven’t worked the whole warranty period. It also reduces the difference between EC and ATRW costs. ATRW cost increases with the continued operation of the joints. Inspection period of ATRW joints (no longer than 6 months after welding, then at least once a year) most of which are operated with safety strips is longer than inspection period of joints welded by EC method and operated without safety strips (at least once a year during first two years after welding, than at least once in two years) [25].

Conclusions

Consequently, ATRW welding haven’t proved itself to be reliable and quality method for connecting rails, economical point is connected with quality characteristics and traffic safety.

We should point that both welding methods are developing continuously, for instance, German company «Electro-Thermite GmbH & Co. KG» claims about succeeded increase of ATRW joint quality. Despite the good advertising, before this rail welding technology will become widely applied, there must be conducted large-scale researches, laboratory, field and operating tests on track sections of different geometry, traffic flow and climate conditions.

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