Analysis on the Operation Methods of Rail Welding and Postweld Heat Treatment in the Track Change Overhaul of Existing Railway Lines

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Abstract. Based on the analysis of operation methods of rail welding and postweld heat treatment in the track change overhaul of existing railway lines at home and abroad, this paper puts forward the existing problems in the operation methods of off-line welding and on-line welding in China, and puts forward the solutions to the existing problems. When this operation mode is used for on-line welding, it can reduce the quality risk in the heat treatment process of low-temperature locking joint; in case of broken track and urgent repair of broken track, this method can eliminate secondary shunting and facilitate the recovery of the line as soon as possible.

Keywords: flash butt welding, induction heat treatment, operation method, one machine operation.

1. Introduction
Overhaul of existing railway tracks is one of the key construction and maintenance tasks of the railway department. Continuously improving the quality of track replacement is an important way to ensure transportation safety and economy. As the weak link of the continuous welded rail (CWR), the on-site welding quality of the rail welding joint has become the key and difficult point that must be overcome in the process of ensuring transportation safety and economy.

Railway field welding is mainly composed of mobile flash welding for welding main rails and thermit welding for welding turnouts. Mobile flash welding for overhaul of existing lines is divided into online welding and offline welding. The construction of new lines is basically on-line welding. Offline welding and online welding in the process of changing rails on existing lines are mainly distinguished by the position of the rail to be welded. Offline welding is mainly for long rail welding, that is, welding a 500-meter long rail into a unit rail section of 1.5 to 2 kilometers. On-line welding is mainly the process of welding the unit rail sections that have been welded offline into the circuit, and then welding with the existing circuit.
2. Construction work forms and analysis adopted worldwide

Among the major developed countries in the world, countries such as Europe, the United States, Australia and other countries mainly use flash welding combined with thermite welding in rail change overhaul.

Take Russia as an example. Russia uses a self-propelled rail welding vehicle with simple power at the end of the field for online and offline welding. After the welder completes the welding, the worker puts a simple induction heating device on the joint. The advantage of heat treatment is that welding and heat treatment can be carried out at the same point, which has certain benefits to the quality of the joint, but the disadvantage is that a simple heating coil cannot ensure that the flatness of the joint before and after heat treatment does not change. Judging from the current demand of Russian railways, this type of operation can meet the joint quality requirements of the low-speed vehicle operation.

Australian railways are mainly freight transport, which is characterized by a large amount of ore that needs to be transported by Western Australia railways. Its unique features of sparsely populated land and gentle terrain make it adopt the welding method of rail-changing operation of container-type rail welding car and road-rail dual-use rail car, that is, the joints after welding are not heat treated. However, with its further pursuit of transportation economy, Australia imported a large number of high-hardness U78CrV rails from China and Japan, even including a certain number of quenched rails. And it is currently working on joint post-weld heat treatment to ensure its joints life cycle.

Welding machine manufacturer Schlatter mainly recommends the use of AMS60, AMS100 and AMS200 series welding machines for on-site welding, and the use of container-type systems or truck-based road-rail dual-use vehicle systems for loading integration. The company's idea is to highlight that the container system can be used as a semi-fixed welder near the station or construction site and take into account the advantages of on-site welding. In addition, it highlights the high flexibility and self-movement of the road-rail dual-use vehicle model. In terms of welding, the highlight is the flash welding machine that meets the needs of flash welding for on-line welding process while performing stress relief when changing rails in sections. The welding machine has a large welding stroke and upsetting force. In fact, this joint is often called tensile lock welding or Longkou welding in China.

The welding machine manufacturer Plasser&Theurer recommends the flash welding method with the most controllable welding heat affected zone for on-site welding. In accordance with the European mobile flash welding specification EN14587-2, the pressure-maintaining push-up and more demanding load test conditions are required, and it is believed that its latest welding machine can meet the requirements. The loading type of its latest welding machine adopts a two-way driving end welding rail car. An important highlight of this car is Closure welding, which is also the commonly defined tension lock welding in China. Another important highlight of the car is to control the cooling rate of the joints by applying electric pulses and air jet cooling again after welding, and realize a machine-based welding and heat treatment for high-alloy steel rails (Temperature guidance of the cooling-off curve of high-alloy rails) in order to control the TTT curve (supercooled austenite isothermal transformation) of high-alloy steel rails [1].

3. Construction work forms and analysis adopted in China

In China, the quality control of on-site rail welded joints during rail replacement and major repairs is difficult and responsible, which is the traditional difficulty and focus of various railway bureaus.

At present, the rail welding operation of the existing railway line in China has been widely used in the mobile rail welding mode, which is not only advanced and efficient, but also the welding quality is fully guaranteed. At the same time, on-site heat treatment of rail welded joints is gradually being equipped with heat treatment vehicles to realize the automation of heat treatment. In general, when the self-propelled rail welding vehicle is configured and equipped with a heat treatment operation vehicle, China's on-site rail welding will fully realize large-scale track maintenance mechanization operations, and the overall level of rail welding will be further improved [2] [3].
3.1. Offline welding construction operation form
At present, when welding offline welding joints in China, there are mainly the following construction methods:
1. After the joints are welded by the rail welding car, the rough grinding operation is carried out, and then the flame heat treatment method is used for heat treatment, and then the subsequent fine grinding operation is carried out.
2. After the joint welding is carried out with a rail welding car, the rough grinding operation is carried out, and then the mobile normal train heat treatment method is used for heat treatment, and then the subsequent fine grinding operation is carried out.
3. The air pressure welding rail car is used to complete the welding and normalizing heat treatment offline at one time, and then carry out the grinding operation.
   Figure 1 shows the offline rail welding mode of the self-propelled rail welding car in conjunction with the heat treatment vehicle.

![Offline rail welding mode of Self-propelled rail welding car and heat treatment vehicle](image)

**Figure 1.** Offline rail welding mode of Self-propelled rail welding car and heat treatment vehicle

3.2. Online welding construction operation form
At present, when welding online welding joints in China, there are mainly the following construction methods:
1. After the joints are welded by a non-self-propelled rail welding car, then flame heat treatment is used for heat treatment, and then stretched or naturally released, and finally the line is locked.
2. After the joint is welded with a non-self-propelled rail welding car, it is stretched or naturally released, and then the line is locked. In the next maintenance period, induction heat treatment is carried out with a heat treatment vehicle.
3. Air-pressure rail welding car is used to complete the welding and normalizing heat treatment on the line at one time, stretching or natural release, and finally locking the line. Both welding and heat treatment use flame heating.
4. After the joint welding is carried out by the self-propelled rail welding car through the support car, the follow-up work of method 1) or 2) is carried out. In this way, the self-propelled rail welding vehicle needs to be supported, which is more difficult.

3.3. Existing problems
In the welding construction using online and offline rail replacement, the operation form will involve a large number of manual operations, which may cause problems in the quality of the welded joints, and even endanger the personal safety of workers. This part will mainly analyze the problems caused by the construction operation form.

3.3.1 Common problems. In the above-mentioned on-line welding and off-line welding construction modes, the common problems existing in the current track-changing construction of existing lines are:
The use of flame heating heat treatment to heat the joints accounts for most of the rail welding construction in the entire rail changing operation, as shown in Figure 2. The flame heating heat treatment method is used in the construction process, and its joint performance is poor, and the stability of the work quality is poor (the flame heating heat treatment is due to tempering or the heating status of each part. Frequent adjustment of the heater fire hole size is very easy to cause uneven regional heating. Or the core of part of the large cross section cannot reach the heating temperature, and the situation of "not transparent" appears, see Figure 3). Manual control of the width and frequency of the swing fire sometimes results in the original welding heat affected zone not being effectively normalized, resulting in the normalizing area being too narrow, resulting in two heat affected zones, which will also lead to poor joint performance. The temperature measurement is affected by the flame, and the temperature measurement result fluctuates greatly compared with the actual value, and the heating effect cannot be effectively controlled. The purity and pressure of oxygen and acetylene in different batches vary from place to place. During field construction, lower temperatures will also affect the stability of the gas, and it is also impossible to effectively control the stability of the heating effect. Acetylene gas cylinders are explosive products (acetylene and preheated propane for thermite welding are the last two dangerous gas sources) and tempering often occurs during flame normalizing. All these bring great risk factors to the use of acetylene. Workers constantly carry gas cylinders, cold water tanks, oxygen belts, heaters, etc., which are labor intensive. The consumption of oxygen acetylene is very fast, which also puts a lot of pressure on logistics support and increases costs. At the same time, compared with flame normalizing, induction normalizing has a more obvious effect in improving the performance of joints, and the grain refinement effect of induction normalizing is more obvious than that of flame normalizing [4] [5].

![Figure 2. Traditional manual heat treatment](image1)

![Figure 3. Poor organization caused by flame heat treatment](image2)
Flame heat treatment has no air spray measures, which cannot meet the requirements of heat treatment rail welding. Under-speed quenching needs to spray air on key parts to achieve a reasonable cooling rate, which cannot be achieved by flame heat treatment at present.

3.3.2 Problems in offline welding. The characteristic problems existing in the current offline welding operations are:

After welding, the joint is still at a relatively high temperature. The rails are located on the ballast shoulder and the placement of the rails is different which will lead to the poor straightness. It is easy to cause the welded joints to be affected by external stress and cause changes in the internal and external quality of the joints during the normalizing process. During this process, the rail is in a non-pressurized state, and the joint is at a high temperature. External force and internal stress have become important factors that may adversely affect the quality of the joint.

3.3.3 Problems in online welding. The welding joints on the existing lines are locked welding joints, which have high quality requirements and high construction risks. According to the current rail section configuration, such joints have reached one-fourth of the total number of joints. However, for the welding joints on existing lines, they belong to locking welding head, which requires high performance of the joint. The current main model has some characteristic problems in both aspects of process and construction organization [6]:

Since the self-propelled rail welding car with only welding function occupies the front line and cannot provide a car space for the operation of the heat treatment operation car, the flame heating heat treatment method has to be adopted.

On-line welding and heat treatment using air pressure rail welding car or small air pressure welding can complete welding and normalizing at one time. However, due to flame heating, this heating method inevitably has large thermal damage and coarse grains of the base material, as shown in Figure 4. When manually controlling the flame heat treatment process, there is still a shortage of the heating zone width (as shown in Figure 5~7, the distance between the small gas pressure welding softening zone is 115mm, the flash welding 50mm, the gas pressure rail car 60mm), which brings difficulties to reducing joint abrasion during long-term use of subsequent lines. From the inspection results, the ratio of hardness of some joints to the base metal only reached 0.91, while the distance between the two softened areas of small gas pressure welding reached 115 mm. At the same time, the air pressure welding mode requires complicated end grinding and other treatments on the rail before welding. The height of the rail support pad is up to 180mm, and the welding time is long. Some railway bureaus even need more than an hour to weld a pair of joints, which also brings construction difficulty. These circumstances show that from the perspective of railway rail welding, it is correct to abolish small air pressure welding and vigorously develop flash welding and air pressure rail welding car.

Figure 4. Comparison of typical microstructure between flash butt welding and gas pressure welding
Figure 5. Hardness of flame normalizing longitudinal section of small gas pressure welding joint

Figure 6. Hardness of flame normalizing profile of Flash butt welding joint

Figure 7. Hardness of flame normalizing longitudinal section of large gas pressure welding joint
In terms of construction organization and implementation, during the on-line welding, the rail is already in the rail groove in front of the vehicle, and the buckle fittings have been unlocked. The self-propelled rail welding car needs to be supported. In this case, a part of the moving end rail to be welded is under the vehicle, and the vehicle needs to travel to this part of the rail first, and then support the vehicle. After supporting the vehicle, some support pads and other treatments need to be carried out on the rails under the vehicle. If in this case, the heat treatment vehicle is used for induction heat treatment, part of the work will be repeated, which will inevitably take up a lot of valuable construction time. Complete the welding of 2 joints and stress relief operations in 180 minutes during the maintenance period. When the workload is large, if the heat treatment operation vehicle is used, the operation time such as the transfer, alignment, and hoisting cannot be guaranteed.

After using non-self-propelled rail welding vehicles for joint welding, flame heat treatment is used for heat treatment, which requires a large number of personnel to carry gas cylinders, flame heat treatment heaters, pumping stations and other equipment. Combined with the period when the vehicle is ready to withdraw, heat treatment is carried out before stretching or natural release. The overall construction process of this construction mode is backward, and some bureaus have carried out online welding process research and testing, as shown in Figure 8, but there is no mature process for large-scale application. The main reason lies in the difficulty of construction organization.

![Figure 8. Large number of operators and difficult construction of on-line welding](image)

4. The solution to the problem

Based on the above-mentioned online and offline welding problems, two solutions are proposed here -- induction heating instead of flame heating and Integrated operation of welding and induction heat treatment, and the advantages of each method are explained.

4.1. Induction heating instead of flame heating

Induction heating is to use the electromagnetic field generated by the induction coil with alternating oscillating current to make the eddy current generated inside the object to be heated to achieve the purpose of heating. Different from the flame method, the electric induction heating mainly relies on the eddy current to penetrate into the workpiece to heat, not only the heating efficiency is high, but the temperature is easy to control, and the heat treatment quality is stable [7].

4.1.1 Improvement of joint quality stability. Meanwhile, an air spray device can be installed on the induction heating machine to spray air on the key parts of the welded joint after heat treatment to achieve an ideal cooling rate. After the heat treatment, the joint structure is controllable, which can solve the
shortcomings of flame heat treatment without air spray measures. Therefore, using induction heating instead of traditional flame heating can improve the quality stability of welded joints after heat treatment.

4.1.2 Low construction safety risk. The induction heat treatment equipment has a high degree of automation and is easy to realize automation. The hidden safety hazards caused by the storage of gas cylinders and the large demand for personnel during the construction of flame-free heat treatment have greater advantages than flame heating in terms of construction safety.

4.1.3 Heating under pressure. The automatic mechanical device of induction heating is conditionally equipped with a rail clamping mechanism. The heating process of the rail welding joint is completed under the pressure holding state of the clamping machine to prevent the joint from being affected by external stress in the high temperature and easy deformation state to affect the internal or appearance quality.

4.2. Integrated operation of welding and induction heat treatment
In the induction heating process, the resistance-capacitance oscillation method is used to form a high-frequency oscillating current inside the object to be heated. Due to the large cross-sectional area of the steel rail, to achieve the required heating effect, the required oscillating current and the corresponding power capacity are also very large. The large current requires a large capacitor and a large oscillating transformer. Traditional induction heat treatment machines mostly use the traditional parallel resonance method, which has low oscillation efficiency, and the overall size of the head oscillating transformer and capacitor is close to $1 \text{m}^3$, and the weight is about 500kg [8].

Through technological advancement in the past few years, the miniaturization and stability of on-site heat treatment power supplies and transformers have moved closer to the forefront of the domestic heat treatment industry. The use of new all-digital IGBT air-cooled heat treatment power supply technology and ultra-compact transformer technology solves the shortcomings of traditional parallel resonance type such as large body and inconvenient application, and realizes the miniaturization of induction heat treatment equipment. Moreover, the mechanism of rail flash welding has been gradually found out, and the level of welding equipment research and development has also been improved. The integration of rail flash welding and induction heat treatment has also become a reality, and the new type of integrated operation has the basic conditions for on-site construction.

Therefore, judging from the current construction mode and the development trend of construction machinery and equipment, for the joining welding joint, under the existing construction method mode, through the use of a flash welding and induction heat treatment integrated machine with the same function of the air pressure welding rail car to complete the welding and normalizing heat treatment at one time, welding and heat treatment, followed by stretching or natural release, and finally locking the line, the complicated construction organization problem of avoiding trains can be solved simply, and the purpose of controlling key processes can be achieved.

5. Conclusion
On the basis of the foregoing, through the innovation of construction and maintenance equipment, flash welding and induction heat treatment are machined together to achieve efficient, high-quality and fast welding and heat treatment. This method not only utilizes the flash welding method that is conducive to the stable welding quality, but also exerts the characteristics of good normalizing effect of induction heat treatment and strong process controllability, and improves some of the shortcomings of existing flame heat treatment. This combination can further guarantee comprehensive quality of rail welded joints.

Meanwhile, when welding on the new line construction, the welding and heat treatment can be integrated to reduce the hidden dangers of heat treatment of low-temperature locking joints. In addition, when the track is broken and the needs to be repaired, the construction work completed by welding and
heat treatment can eliminate the secondary dispatching vehicles and lay a good foundation for opening the line as soon as possible.

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