Technical Report

Recent Application of Rail Joint Welding in Europe - Flash Butt Welding Gains Increasing Importance

H. G. Suk, R. Killing, W. H. Chung, and J. U. Park

Abstract

Continuously welded tracks, first introduced on train lines, are being used increasingly in Europe. And the different arc welding methods are only used on minor lines, private tracks and in the manufacturing of switches and crossings. Mobile flash butt welding belongs the future in rail welding on side if new tracks have to be erected. The following contribution reviews the processes available, usual test methods for welded rail joints and various applications.

Key Words : Rail joint welding, Rail steels, Arc welding, Aluminothermical welding, Flash butt welding.

1. Introduction

Because railroad tracks are interacting with railroad rolling stocks, a systematic methodology for finding design solutions is necessary. So a set of general mechanical design principles are needed to be reviewed :

- sufficient strength
- sufficient resistance to wear
- sufficiently low friction
- optimal use of materials
- easy manufacturing
- easy maintenance
- simplicity

As an optimal design solution we may consider the railroad tracks as one piece system interacting with the railroad rolling stocks. Unconventional railroad tracks without thermal expansion gap by welding, first introduced on tram lines and then in 1928 on railroads, are being used increasingly in Europe. The entirely welded rail, of course, requires certain assumptions in order to prevent distortions of the track. Among these assumptions belong a stable basement, special sleepers and rigid clamping of the rails on the sleepers, as well as erecting of the track at medium ambient temperatures. In this way the forces resulting from thermal expansion can be governed. The gapless installation of the track offers a number of advantages :

* prevention of rail fractures originating from bore holes for the fishplates ;
* less wear at the rail ends and on rolling material ;
* smoother ride, resulting in greater comfort for the passenger ;
* lower maintenance costs.

These advantages led the German railway company, "Deutsche Bahn AG" among others to install all main lines and most of the minor lines continuously by welding.

But the welding of rails by different welding methods has been developed, so it has to be subdivided between welding in the welding shop and welding on site. In reference 1, a review has already been presented about the state-of-the-art of rail welding in

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Europe to the end of the 20th century. In the meantime development made further progress.

The following contribution therefore once more will review the processes available, and report about training of welders in this field, various newer applications in Europe, and usual test methods for welded rail joints.

1.1 Rail steels have only limited weldability

The rail is the girder and the running surface for the railroad rolling stocks. It is exposed to dynamic repeated loading and rolling glide wear. Rail steels, therefore, have a higher carbon content and additional certain amounts of silicon and manganese. Special rails are also alloyed with chromium. A distinct parameter of rails is their tensile strength. Table 1 consists of specifications for the most common rail steels. Most of them correspond with the requirements of the International Railway Association (UIC) and the International Standardisation Organisation (ISO). A new European Standard (EN 13647-1) is just under preparation.

The relatively high carbon contend limits the weldability and makes welding more difficult. To prevent cracking and excessive hardening in the heat-affected zone, therefore, preheating before welding is necessary in most cases. The preheating and working temperatures in arc welding to be applied lie between 150 and 450°C, depending on the welding method and the rail material. In aluminothermical welding higher preheating has to be applied by reasonof sufficient penetration. This will be explained later. In flash butt welding the rail ends are warmed-up before welding by reversing. A separate preheating due to the reasons mentioned before, is not necessary, but it can shorten the reversing time.

Rail profiles are characterised by their meter mass. This value lies between 30 and 65kg/m. The most numerous installed rail profile in Germany for instance is S 49 (49kg/m).

2. Welding in the welding shop

In the workshop butt welds appear in lengthening the rails and in the manufacturing of switches and crossings. By extending the rail length, flash butt welding is applicable. This also is used in switch construction, but additional possibilities include aluminothermical welding and arc welding here as well.

2.1 Flash butt welding in the welding shop

Flash butt welding belongs to the group of resistance welding methods. Heat sources are the contact

Table 1 Properties of most common rail steels

* Germany, x Mo, V possible

Specification	Grade	Tensile strngth (N/mm^2)	Elongation (%)	Chemical composition (%)				Mass/meter (kg/m)
				C	Si	Mn	Cr	
UIC860/Europe	Grade 700	680-830	$A_5 \geq 14$	0.40/0.60	0.05/0.35	0.80/1.25	-	49*
BS11/United Kingdom	-	≥710	$A_5 \geq 11$	0.45/0.60	0.05/0.35	0.95/1.25	-	
JRS /Japan	-	780	$A_5 \geq 10$	0.60/0.75	0.10/0.30	0.70/1.10	-	60
Gost 6944-63 Gost 8160-63/Russsia	-	≥820	$A_{10} \geq 4$	0.67/0.80	0.13/0.28	0.75/1.05	-	51.5
		≥820	$A_{10} \geq 4$	0.69/0.82	0.13/0.28	0.75/1.05	-	64.6
ASTM/AREA USA/Canada		-	-	0.67/0.80	0.10/0.35	0.70/1.00	-	45.6/60
		-	-	0.69/0.82	0.10/0.35	0.7/1.05	-	≥60
UIC 860/Europe	Grade 900A	≥860	$A_5 \geq 10$	0.60/0.80	0.10/0.05	0.80/1.30	-	49*
	Grade 900B	≥880	$A_5 \geq 10$	0.55/0.75	0.10/0.50	1.30/1.70	-	49*
Special Grade	CrMo-Steel	≥1080	$A_5 \geq 9$	0.60-0.80	≤0.90	0.80/1.30	0.70/1.20x	

resistance between the workpieces, the energy of micro arcs and in less extended combustional heat.

Welding takes place on stationary machines. The chucked workpieces, which are connected to one pole of a power source, touch itself with the abutting ends. Local short circuits(micro arcs) are formed and fluid metal is rejected out of the groove by the pressure of metal vapour, generated in the gap. This procedure of touching and removing the abutting ends (reversing) can be repeated several times, till the workpiece is heated-up sufficiently. The heating time can be decreased by external preheating. After this heating-up, welding takes place by suddenly upsetting the workpiece ends together. The welding process lasts approximately 1-6minutes depending from the cross section of the rail and the performance of the welding machine. Welding currents up to 30Ampere/mm^2 and voltages of about 15Volts are necessary.

By flash butt welding the rail length is extended in the work shop to minimize butt welds on side. Normally the maximum length of rails leaving the rolling mill is 30 to 60m. By flash butt welding this length can be extended to 120 to 180m. For trial purpose rails up to 500m in length have already been delivered. Fig. 1 indicates a rail butt joint directly after welding and after trimming by removing the flash. This deflashing takes place directly after welding if the welding site is still red warm by using special trimming tools.

In addition to the stationary flash butt welding, newer mobile flash but welding devices do exist, which can be used on-track. This will be covered in a later chapter.

2.2 Other welding methods in the welding shop

In switch constructions and in the manufacturing of crossings among flash butt welding, other welding methods are applied. According to the number of workpieces, butt welds are also arc welded or aluminothermical welded. The principle of these methods are explained in the next chapter.

Sporadically components for switches such as frogs and blades are also electroslag welded. As backing elements copper shoes as well as refractory ceramic forms are used for this purpose.

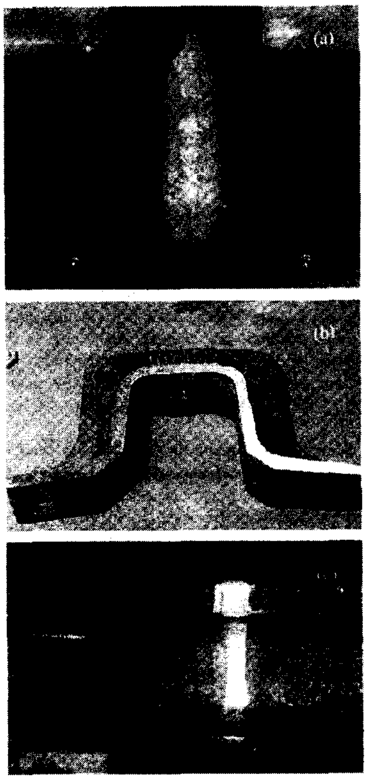

Fig. 1 Flash butt welding of rails
(a) Flush butt welded joint before flash removal
(b) Trimming tool
(c) Rail after flash butt welding and trimming-works
(photograph : ESAB Gothenburg/Sweden)

3. On-track welding

On site, the rails, already extended in the welding shop, are joined together to continuous rail tracks. In the case of tracks under traffic, short preparation and welding times are very important, so that welding can take place during traffic pauses. In new erected tracks this does not play an important role.

In every case welding begins with the alignment of the rail ends. They are arranged under consideration of shrinkage after welding and begins with the alignment of the rail ends. They are arranged under consideration of shrinkage after welding 2mm higher at the ends, compared with the normal niveau of the rails.

3.1 Arc welding

Over the years several methods for the arc welding of rail joints have been developed. They differ from others by the applied filler metal (stick electrode, flux-cored wire), the welding sequence or the special design of the foot region, as in the Secheron-Method from Switzerland, for instance, which had a reinforced foot region. Among these methods, the ESAB-Method and the Lincoln-Method will be described below.

3.1.1 The ESAB - Method - manual welding with stick electrodes

This method for welding the rail foot uses a ceramic backing without grooves, reinforced on the upper side by a glass fibre mat (Fig. 2 (a)). Both rail ends are aligned with a gap of 15 to 18mm and preheated to 300 to 450°C on a length of 200mm. The preheating temperature depends on the rail steel to be welded. Most of the cross section of the rail is welded with a Mn-alloyed basic coated stick electrode, while high-tensile rails are welded with a MnMo-alloyed basic type. The most commonly used electrode diameter is 5mm, but depending on the gap 4 to 6mm electrodes can also be applied. In welding the rail foot, first one bead is layed on each side of the gap, and then these layers are combined with a third one (Fig. 2 (b)). After finishing the foot, copper backings are fixed to the web (Fig. 2 (c)). These have small distance studs so that a gap appears from about 3mm between backing and web. In this gap the slag can invade. Next the web is welded, whereby the electrode guided in rectangular patterns in the gap and moved up corresponding to its filling. The electrode has to be changed quickly in order to prevent the slag in the gap from solidifying in the mean time. If the rail head is reached, welding takes place in Position PA. Only for the last layers, to give better wear resistance to the upper surface of the head, a stick electrode is used alloyed with 3% Chromium, which delivers a weld metal with a hardness of about 300HB. After finishing the weld (Fig. 2 (d)), a stress relief treatment with gas torches is recommended at 600 to 650°C for 10minutes, and following the head and the side flanks of the foot will be grinded. Notches should be removed in this grinding process and the profile re-established. [2)]

3.1.2 The Lincoln - Method - semimechanical welding with flux cored wires

This method uses innershield flux-cored wire with 2mm diameter as fillers. The gap between the rail ends to be welded is 16-18mm. Before welding, both rail ends will be preheated to min 100°C on a length of 500mm. directly in the joining area the temperature should be 150°C. The root run is welded on a copper

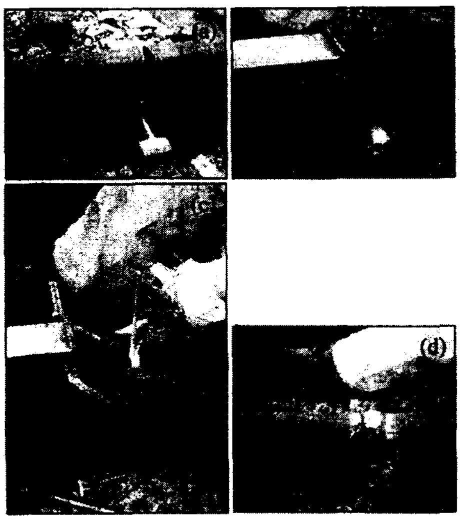

Fig. 2 Rail track welding acc. to the ESAB-Method - works (photograph : ESAB, Solingen/Germany)

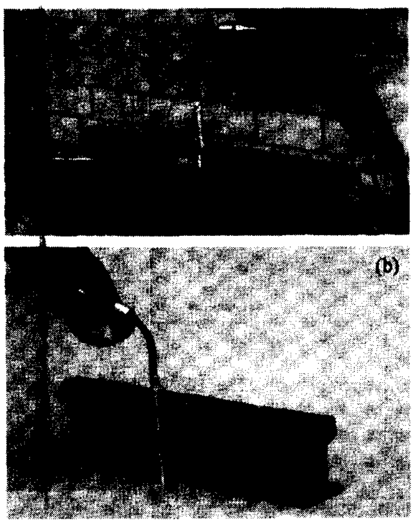

Fig. 3 Rail track welding acc. to the Lincoln-Method - works (photograph : Lincoln-Smitweld, Erkrath/Germany)

backing with a 2mm deep groove in the middle. The first layer is welded with oscillating arc, always directed to the fluid weld pool. This is to prevent copper pick-up from the backing. A special flux-cored wire is used which gives a weld metal with low silicon-and manganese-content, but relatively high carbon-content. The second layer is welded in the sequence left, right, middle, after that, copper backings are installed at the web (Fig. 3 (a)). This also have distance studs, so the slag can penetrate into the gap between the web and the copper backing. When welding the web, an extended current contact nozzle is necessary, as seen in Fig. 3 (b). The contact nozzle consists of copper, insulated by a layer of ceramic. Short circuits between workpiece and nozzle are hindered in this way. The working temperature in the mean time has climbed up to 250°C, so further preheating is not necessary. In welding the head, additional adaptedcopper shoes can be used. The last 6 mm of the head are welded with hard surfacing electrodes or flux-cored wires. They result in a Chromium-Molybdenium -alloyed weld metal with approximately 2% Chromium and a hardness of 300HB. Finally the upper side of the rail foot has to be welded in Position PA. After finishing the welding , the side flanks of the foot are grinded and the profile of the head has to be re-established by grinding. [3)]

3.1.3 Comparison of both arc welding methods

The welding procedures described, differ essentially in the welding sequence and the kind of backing used in welding the root run, as Fig. 4 indicates. While the ESAB-Method uses a ceramic backing and carries out the root layer in three stringer beads, the Lincoln-Method applies a copper backing and welds the root in one oscillated layer. Both have advantages and disadvantages. By welding on a copper backing, the weld is endangered by copper pick-up. The oscillated root run gives the risk of hot cracking. Cracking will be promoted by copper pick-up. The ESAB-Method needs a new ceramic backing bar for each weld, which increases costs a little bit. Additionally, this method tends more towards notches and undercuts because in the root layer there are four penetration zones, compared with only two with the Lincoln-Method. In both procedures the lower side of the root layer has to be controlled by help of a mirror after welding the foot. If defects such as notches or lack-of-fusion are visible in this critical zone, the weld metal has to be gauged and re-welded.

The performance between the 5mm thick stick electrode and the 2mm thick flux-cored wire does not differ very much, because the flux-cored wire cannot bring an essentially higher deposition rate and duty cycle on short beads and in the marrow gaps. So the pure welding time for foot, web and head of a rail in both cases is approximately 21minutes.

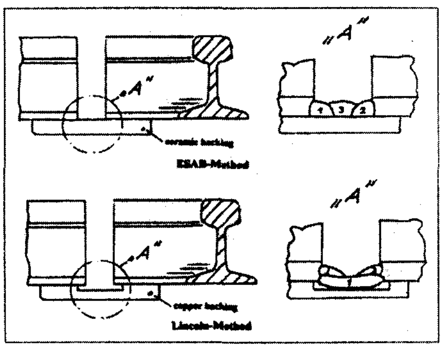

Fig. 4 Welding the rail foot

3.2 Aluminothermical welding

Aluminothermical welding - better known under its company's name "Thermit-Welding" - belongs to the group of cast welding. It originates the weld metal by an exothermal chemical reaction in a crucible, mounted upon the rail joint. The crucible is filled with a special powder, consisting of a fine grained aluminium powder

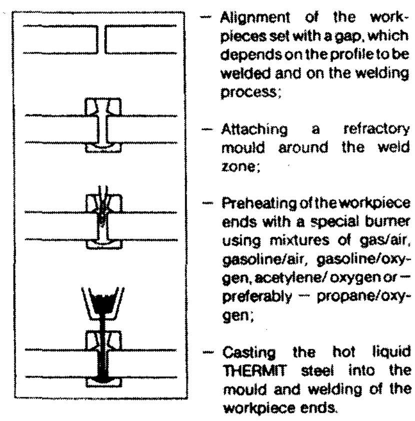

Fig. 5 Stages of aluminothermical welding (source : Elektro-Thermit, Essen/Germany)

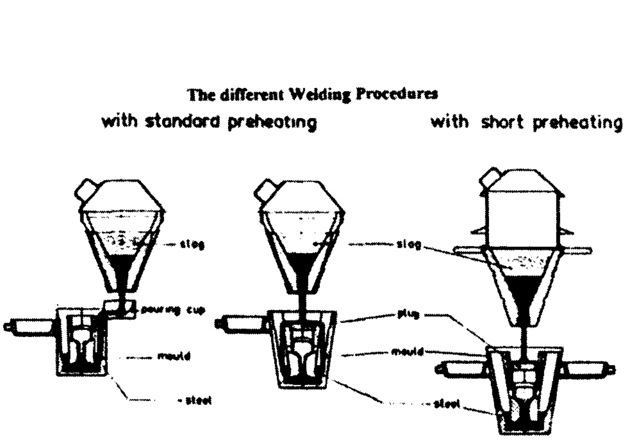

Fig. 6 Aluminothermical welding (source : Elektro-Thermit, Essen/Germany)

and iron oxide, and for desoxidation ferro alloys(FeSi, FeMn) and occasionally alloying elements. With an igniter the mixture is ignited, and the chemical reaction starts according to the following formula :

$$Fe_2O_3 + 2Al = 2Fe + Al_2O_3 + \text{heat}$$

By this reaction iron oxide is reduced to iron and aluminium is oxidized. It takes place under the formation of exothermal heat, so that iron as well as slag become fluid. The heavy iron sinks down into the lower part of the crucible, with the light slag swimming on top. Before the steel can be casted some other preparations have to be completed. These are listed in Fig. 5[4]. The rail ends are aligned and brought together with a gap of about 20 to 25mm. A refractory, bisectional mould is erected around the joint, and after preheating the rail ends with gas torches to sufficient temperatures, the fluid steel can admit to the mould and the workpieces join together.

It is to subdivide into two variants (Fig. 6) : the normal welding with standard preheating and the rapid welding with shortened preheating time. In the first case it is heated to about 1000°C. This takes 4 to 8 minutes depending on the rail profile. In welding under traffic, pauses between two trains of at least 20 minutes are necessary. In rapid welding preheating is done in two minutes only to 600°C and the additional energy is gained from a greater portion of powder mixture. Here traffic pauses of 12 to 15 minutes are sufficient. Fig. 7 (a) shows the prepared rail joint during the reaction in the crucible. In Fig. 7 (b) the ready weldment with the risers can be seen. For shear cutting the burr, special tools are available, while special grinding machines for grinding the head are used. In aluminothermical welding, at the lower side of the weld, a wide bulge with soft transition to the parent material is formed. This delivers ideal conditions for later service life under pulsating tensile stresses.

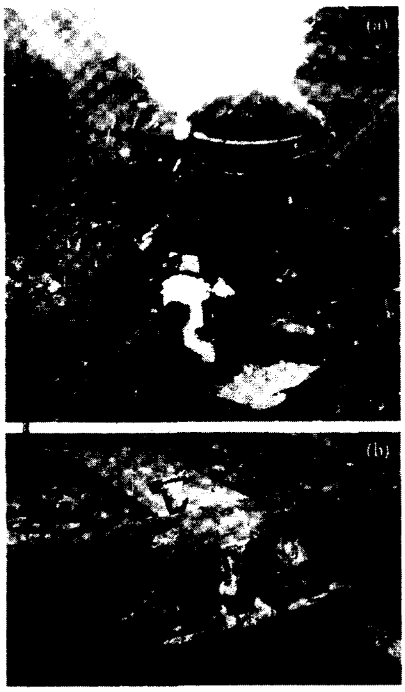

Fig. 7 Aluminothermical welding
(a) Reaction in the crucible
(b) View of the ready made weld with risers

3.3 Mobile flash butt welding on site

Fig. 8 Dual-way vehicle equipped with flash butt welding device (photograph : Zweiweg-Schneider, Leichlingen/Germany)

Fig. 9 Mobile flash butt welding on-track at night (photograph : Schlatter, Schlieren/Switzerland)

Most of the joints in a continuously welded track have been made in the workshop using the flash butt welding method. Thus it presents itself to welds the joints on site in the same method. Until recently this was not possible, because the necessary high current and the needed forces for reversing and upsetting were not available.

In the mean time mobile flash butt welding machines are on delivery, either mounted on railway wagons or on dual-way vehicles. Fig. 8 shows such a dual-way vehicle, which can drive on the road as well as on tracks. The real welding device is sloped down on the rails with the help of a hydraulic crane. The diesel engine supplies welding current up to 40,000 Ampere via a generator and generates also the hydraulic forces that are a clamping force of up to 1350kN and an upsetting force of max 500kN.[5] Whilst in stationary flush butt welding DC-current is advantageous, for welding on-track, the use of AC-current has positive effects.

Because mechanical reversing with such long rails is difficult, preheating is done by a current programme which brings similar effects as the current/voltage -development during reversing. The axial pressure is constant during welding. The welding time is about 3 minutes only, and each hour up to 12 welds can be carried out. After welding a retarded heat escape is recommended, for instance by additional post-heating with gas torches.[6]

4. Testing of welded rail joints

Most of the railway companies ask in procedure tests for a statical bend test and a dynamical pulsating test with the rail foot in the tensile stress area. Fig.10 and 11 contain the conditions to be observed. It does not cause difficulties to fulfil the requirements of the railway companies with respect to the statical test for every method. In 80 tested aluminothermical welded rails, for instance, the determined fracture loads lay between 900 and 1150kN with deflections between 12 and 27mm.[4)] It is more difficult to pass successfully through the fatigue test. Because of their smooth lower foot surface, aluminothermical welded rails usually sustain the required 2 million load cycles, and the same can be said for resistance welded joint, because the lower foot region is grinded after welding.

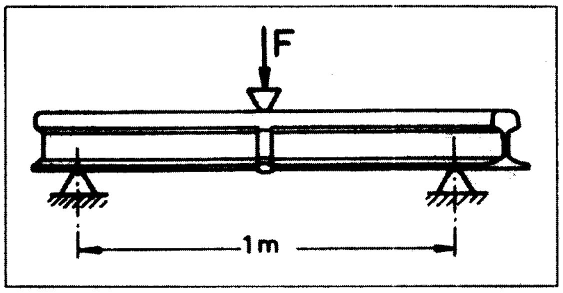

Fig. 10 Bend test (statically)
(source : Elektro-Thermit, Essen/Germany)

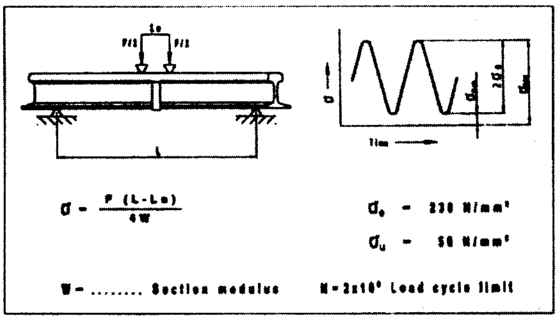

Fig. 11 Fatigue test (dynamically)
(source : Elektro-Thermit, Essen/Germany)

Arc welded rails, free from defects, fulfil the requirements, too. However, there is often severe scattering by early fracturing even if only small notches lay in the foot area.

Nevertheless, all welding methods and filler metals described here are approved by the Deutsche Bahn AG and other railway companies for butt welds on rails with tensile strength up to 885N/mm^2.

5. Education and training of welding personal

According to the rules of the Deutsche Bahn AG welders which are chosen for welding work on tracks of the German Railway Company, have to participate in a course in which theoretical and practical know-how about rail welding is provided and they have to pass successful through the corresponding examinations.

Courses are offered for thermal cutting, arc welding, and aluminothermical welding. On the field of arc welding it is to subdivide into joint welding and surfacing. The examinations have to repeat every year.

For welding engineers and foremen theoretical courses are offered, to put them into the position to supervise welding work of their personal.

6. Application of the methods in practice

Although all methods described, fulfil the requirements of the Deutsche Bahn AG and arc welding is cheaper, aluminothermical welding in the past has been applied in Germany on all main lines and most of the minor lines for welding on site. This is justified by long lasting positive experiences with this method. In Germany, therefore, only minor lines and private railways, such as subway tram lines, work trains, harbour railways and manufacturing of crossings and switches, remained as applied fields for other methods, such as arc welding.

On the other hand, in Skandinavia the Swedish, Danish and Norwegian railway companies have been applying for many years the ESAB-Method for butt welding of rails.[7]

In all industrial countries in Europe, flash butt welding is used for lengthening the rails in the shop. The mobile flash butt welding on site was standing at the beginning of its development at the end of the 20th century.[1] The first dual-way vehicle had been sold to a Swiss company which intended to make rail butt welds on behalf of the Swiss railway company with that method in July 1998. The Deutsche Bahn AG was only using this method sporadically that time.

In the meantime about one half of all rail welding on-track in Germany and Switzerland is done using the mobile flush butt welding method.[8] New erected tracks are completely welded with this method for instance in Germany. So last year the track for the highspeed train ICE from Cologne to Frankfurt has been new erected by use of three mobile flush butt welding trains working the same time. Fig. 9 shows the mobile flash butt welding device in welding position on site. Welding time could be reduced drastically compared with aluminothermic welding. In other European countries also, flash butt welding is in application for new erected tracks.

Aluminothermic welding in the area of Deutsche Bahn AG since that time is only used in repair of tracks, were only single rails are to be exchanged. Here this method offers advantages because of short traffic pauses and the use of the full equipped flush butt welding train is not worth to do. Another application for aluminothermic welding is still welding in switch constructions.

7. Summary

Continuously welded tracks do not only provide more comfort for the passengers, but also advantages for the railway company because the wear on rail ends and rolling material is decreased. A high speed line that is not completely continuously welded is unimaginable. European railway companies, therefore, are tending to continuously weld all their tracks more and more. In Germany, for example, all main lines and most of the minor lines are gapless. For this reason in the work shop the as-rolled lengths of the rails are extended to increased lengths by flash butt welding. The method most used on site in the past was aluminothermical welding. This method among short welding time, offered great security against rail fractures. The different arc welding methods are cheaper to apply, but contain the danger of fatigue cracking if notches and undercuts appear in the rail foot. In Germany, therefore, these methods are only used on minor lines, private tracks and in the manufacturing of switches and crossings. Mobile flash butt welding belongs the future in rail welding on side if new tracks have to be erected.

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