University of Niš
Faculty of Mechanical Engineering

PROCEEDINGS

XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '22

October 13 - 14, 2022, Niš, Serbia

Publisher

Faculty of Mechanical Engineering Niš
Prof. dr Goran Janevski, Dean

Editor
Prof. dr Milan Banić
Prof. dr Dušan Stamenković

Technical preparation
Prof. dr Aleksandar Miltenović

Cover design

Prof. dr Miloš Milošević

Number of copies

120

Printing

Grafika Galeb, Niš

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

629.4(082)
656.2(082)
625.1(082)
338.47(497.11)(082)

SCIENTIFIC-Expert Conference of Railways (22 ; 2022 ; Niš)
Proceedings / XX Scientific-Expert Conference on Railways - RAILCON '22, October 13-14, 2022, Niš, Serbia ; [editor Milan Banić, Dušan Stamenković]. - Niš : Faculty of Mechanical Engineering, 2022 (Niš : Grafika Galeb). - XIV, 200 str. : ilustr. ; 26 cm

Na vrhu nasl. str.: University of Niš. - Tekst štampan dvostubačno. - Tiraž 120. - Napomene uz tekst. - Bibliografija uz svaki rad. - Registar.

ISBN 978-86-6055-160-5

а) Железничка возила -- Зборници б) Железнички саобраћај -- Зборници в) Железничке пруге -- Зборници г) Србија -- Саобраћајна политика -- Зборници

Ministry of Education, Science and Technological Development of the Republic of Serbia has participated in printing costs of the Proceedings of the XX International Scientific-Expert Conference on Railways - **RAILCON 2022**

All the publications in these Proceedings have the authorship, whereas the authors of the papers carry entire responsibility for originality and content.

University of Niš

XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS

RAILCON '22

Faculty of Mechanical Engineering

Program Committee

Prof. Milan Banić, President, University of Niš, Faculty of Mechanical Engineering, RS
Prof. Boban Anđelković, University of Niš, Faculty of Mechanical Engineering, RS
Prof. Milan Bižić, University of Kragujevac, Faculty of Mechanical&Civil Engineering Kraljevo, RS
Prof. Nebojša Bojović, University of Belgrade, Faculty of Traffic Engineering, RS
Prof. Branislav Bošković, University of Belgrade, Faculty of Traffic Engineering, RS
Prof. Dragan Đurđanović, University of Texas at Austin, USA
Prof. Ratko Đuričić, University of East Sarajevo, R. Srpska, BA
Prof. Juraj Grenčak, University of Žilina, SK
Prof. Daniel Kalinčak, University of Žilina, SK
Prof. Goran Janevski, University of Niš, Faculty of Mechanical Engineering, RS
Prof. Dragutin Kostić, University of Belgrade, Faculty of Traffic Engineering, RS
Prof. Predrag Jovanović, University of Belgrade, Faculty of Traffic Engineering, RS
Prof. Vojkan Lučanin, University of Belgrade, Faculty of Mechanical Engineering, RS
Prof. Dragan Marinković, TU Berlin, DE
Prof. Dragan Milčić, University of Niš, Faculty of Mechanical Engineering, RS
Prof. Miloš Milošević, University of Niš, Faculty of Mechanical Engineering, RS
Dr. Rešad Nuhodžić, Public Works Administration, ME
Prof. Nenad T. Pavlović, University of Niš, Faculty of Mechanical Engineering, RS
Prof. Michaela Popa, University of Bucharest, RO
Ass. Prof. Sanel Purgić, TU Sofia, BG
Prof. Danijela Ristić-Durrant, University of Bremen, DE
PD Dr. Andreas Schöbel, TU Wien, AT
Prof. Szabolcs Fischer, Széchenyi István University, Gyor, HU
Prof. Miloš Simonović, University of Niš, Faculty of Mechanical Engineering, RS
Prof. Dušan Stamenković, University of Niš, Faculty of Mechanical Engineering, RS
Prof. Jovan Tanasković, University of Belgrade, Faculty of Mechanical Engineering, RS
Dr. Cristian Ulianov, Newcastle University, UK

Organizing Committee

Aleksandar Miltenović, PhD, President
Miroslav Mijajlović, PhD
Miodrag Milčić, PhD
Nataša Zdravković
Vukašin Pavlović
Miša Tomić
Marko Perić
Damjan Rangelov
Vesna Grozdanović
Dušanka Nikolić, technical secretary

XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '22

WELDING WITHIN THE MAINTENANCE/REPARATION OF RAILWAYS IN SERBIA

Filip PEŠIĆ[1]
Miroslav MIJAJLOVIĆ[2]

Abstract *– Serbia is at a turning point in the modernization of the railways of the Republic of Serbia, especially trains and infrastructure. As for the railways, work is being done on the adaptation of the former main routes, many of which are currently inactive. The paper presents existing and applicable rail welding processes, technological procedure of repair welding and quality control of the welded joints.*

Keywords – Rail, Repair, Surface Welding, Maintenance.

1. INTRODUCTION

Railway is considered the safest transportation mode compared to other means of transportation [1] but the railway infrastructure is a complex system. It comprises systems such as tunnels, bridges, earthworks and track structure. Track structure is the most fundamental railway infrastructure system. It comprises components such as rails, sleepers, ballast, and fasteners, out of which rails are the most critical and maintenance demanding component of the track structure as they are in direct contact with the train wheels.

Many researchers have done their researches of welding as part of railway maintenance and repair. Feng [2] presents problems in the work of replacing damaged rails and their welding into the existing continuous welded rails (CWR) using a mobile electric resistance flash welding process and thermal treatment after welding. A comparison is made of the applied approaches used in several major national railways around the world. Stevanović [3], in her master's thesis, described the technology of repair and surface welding of the turnout rail bound welded frog and processed the results of testing its strength. Popović *et al* [14] presented the application of self-shielded and flux-cored wires for welding in the atmosphere of CO_2 gas used for welding rails. They propose the recommended technological procedure and self-shielding wire that give the best results in their opinion. This application is confirmed by the work of some other researchers [14]. Sedmak *et al* [7] showed that the repaired rails (by reparative welding), due to the improved microstructure and resistance to the cracks-formation, have better mechanical properties compared to the original ones. Furthermore, Kozyrev *et al* shows in their work [4], through the analysis of modern procedures, significant influences on the quality of the welded joint of repaired CWR.

The welding procedures used for repair, the welding technology used for the welding procedures and the required quality of the repaired rail section have to be directly specified in order to get fulfilling results.

2. DAMAGE TO RAILS

On the railways of Serbia, wear and tear is the biggest damage infliction processes to the rails, and it is especially seeable on the joints.

Today's rail failures (based on the nature of their occurrence) can be divided into the following groups:

- fatigue cracks failure;
- rolling contact fatigue cracks;
- wear failure;
- material deformation failure and
- shear failure [16].

Replacing defects with a new piece of rail is expensive and not always desirable because it introduces new discontinuities in the track structure in the form of two weld seams that worsen the properties of the hot-rolled rail.

3. MAINTENANCE OF RAILWAY TRACK

The rulebook on technical conditions and maintenance of railway track [15] defines the

[1] Faculty of Technical Sciences, University of Priština, Kosovska Mitrovica, Serbia, filip.pesic1@masfak.ni.ac.rs
[2] Faculty of Mechanical Engineering, University of Niš, Serbia, miroslav.mijajlovic@masfak.ni.ac.rs

maintenance and determines periods for the regular inspection and measurement of the tracks in the Serbian Railways.

Although most internal defects give some external indication of their presence, they cannot be reliably determined by visual inspection. They are determined using ultrasonic detection and eddy current testing.

4. RAIL WELDING METHODS

The most common welding processes applied to rails are: arc, aluminothermic and resistance welding.

Standard arc welding procedures, such as shielded metal arc welding (SMAW), gas metal arc welding (GMAW), and possibly flux-cored arc welding (FCAW), can be/and are used for welding and repair welding of railway track components.

4.1 Aluminothermic welding

Aluminothermic welding (Fig. 1) is used for CWR in the field, and less often in the plant. Aluminothermite is a mixture of iron oxide (Fe_2O_3) and aluminum (Al) [9]. The mixture is placed in a refractory vessel and is heated to 1300 °C.

Molten steel flows into the mold, welding the rail ends, which are previously heated with a flame to a temperature of 1000 °C – 2000 °C. After removing the mold, only the surface of the rail intended for the rolling of the wheels is sanded.

Fig. 1. Aluminothermic welding (with melting) [10]

4.2. Electric resistance welding (ERW)

It is used in the railways in the form of flash welding, and is performed by automatic machines. When the melting temperature of the steel is reached, the machine presses the ends of the rails towards each other with a force of 350 kN to 500 kN, and with such pressure force, the joint is achieved. The thickening of the rail at the point of welding is removed by grinding. It is possible to perform the same welding method outdoor in the field, where the generator is located in the wagon.

4.3. Arc welding

The quality of the weld largely depends on the expertise of the welder [11]. The welding of rail assemblies can be done well in the workshop, but it is very difficult to make a good seam in the field.

4.4. Gas welding

This welding process can be used in the field or in the workshop [11]. Using the flame from an acetylene torch, the material from the high-alloy steel wire is applied to the welding object, which was previously heated to the proper temperature by the same torch.

5. THERMAL TREATMENT AFTER RAILS AND TURNOUT PARTS WELDING

Thermal treatment must not cause external and internal deformations of turnout parts [8]..

Heat treatment is performed according to a procedure that can be: annealing, tempering and pearlitization.

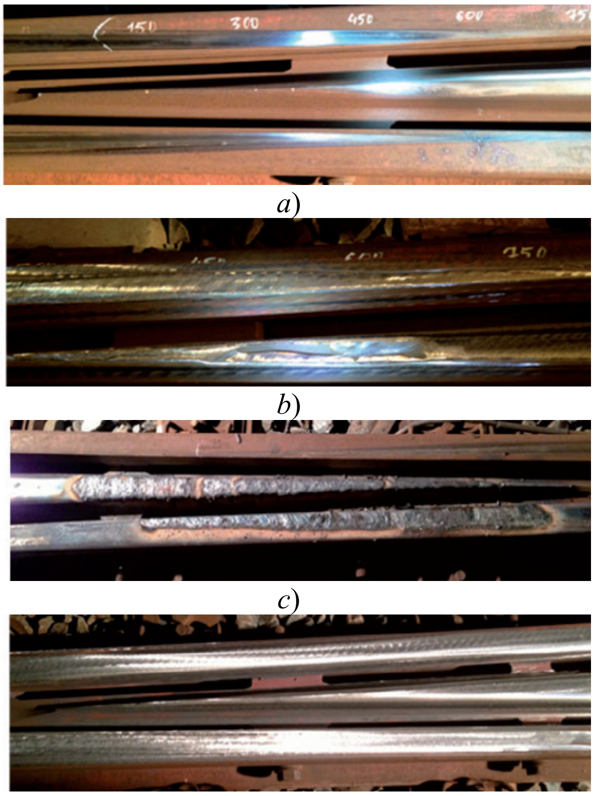
As for turnouts, the material for the frogs to be welded must undergo annealing within 48 hours after welding. If annealing cannot be started after welding, but much later, careful cooling in still air and subsequent annealing must be carried out. The running surfaces and profile of the parts are improved by either softening or pearlitizing.

6. REPAIR WELDING OF RAILS

One of the important areas of modern welding technique is surface welding - the application of molten metal to the surface of the base metal that has been heated to the melting temperature [14]. Welding of rails and frogs of turnouts and crossings (turnouts in the following text) in the field is a very profitable work, which significantly extends their service life [11].

Fig. 2. Welded layers [13]

It is understandable that surface welding becomes particularly interesting and profitable with CWR. It can also be used to equalize the height of the rail composition in order to obtain a flat driving surface, then to remove lunkers (holes) and fill in rough places on the driving surface of the rails. It is used for corroded and damaged points of frogs. Welding can be done by gas and arc welding method. Depending on the nature and size of the damage to the rail, the repair welding is carried out in several passes, and in one or more layers (Fig. 2). Today, surface welding is standard practice in railway in almost whole Europe.



a) *b*) *c*) *d*)

Fig. 3. Frog reparation: (a) before; (b) defects treated by the machine; (c) welding done; (d) polishing [12]

6.1 Materials for making rails

A typical rail is made of high-carbon steel, 0,4 %C - 0,8 %C, where high hardness and wear resistance are achieved at the expense of poor weldability and toughness [14]. Due to their pearlite microstructure, these steels typically have low toughness and crack growth resistance, making them prone to rolling contact wear and fatigue [7].

On the tracks of the Serbian Railways, are installed rails with a minimum tensile strength of 700 MPa [6]. Rails with higher tensile strength were installed only in sharp curves, in tunnels, on large slopes, in places where trains are braked and stopped, at turnout elements and other special track constructions. Damaged parts manufactured from high carbon steel can be surface welded despite their poor weldability. With the correct choice of welding technology, it is possible to obtain a microstructure with improved properties that corresponds to the new generation of steel, i.e. the bainitic microstructure. In this case, the surface welded layer has a higher resistance to crack growth, which improves the overall reliability of the rails and the turnout frog. Such technology is not only a way of reparation, but also a way of improving the initial properties of rails and turnouts.

6.2. Repair welding of rail steel

Semi-automatic arc welding processes, with flux-cored and self-shielded wires [7] are most often used for repair welding. The basic difference between them is that the first one requires an external shielding gas, and the second does not. Repair welding of rails and turnouts using a semi-automatic process has significant techno-economic advantages compared to replacement with new parts [14]. Repairing just one turnout pays for the purchase of a welding device. The most effective surface welding method is the semi-automatic one with self-shielding flux-cored wire. The entire process of reparation of the frog is roughly shown through photographs (Fig. 3).

Technological procedure of repair welding of rails

After welding, the material is annealed in the same way as before welding [13]. Before annealing, the surface should be cleaned to undamaged material. If the cracks open deeper, to a depth greater than 10% of the height of the profile, it is not recommended to carry out welding, i.e. surface welding, because there is a high probability that, due to the thermal action during preheating, the cracks will only increase due to the microstrains that arise. If this happens, such rail section must not be released into further traffic.

However, if the cracks do not spread, and they are within the permitted depth, welding can be started.

For welding, you need: equipment (generator, grinders, etc.), tools, electrode wire (electrode in the following text) for welding, qualified welding experts, and you need to know the type of basic rail material and choose and prepare the electrode.

Preparation of welding electrode

Since rail steels belong to the group of materials that are difficult to weld, care should be taken in the choice of electrode [13]. The common feature of all electrodes used for surface welding is their basic coating. This is a reason why a very high density direct current for surface welding is needed.

The basic coating of the electrode is very hydroscopic, which means that it strongly absorbs moisture from the air. The presence of moisture in the coating of the electrode is very unfavorable.

It is avoided (or minimized) by: annealing or drying-out the welding consumables.

Additional materials for repair welding of rails

Different additional materials can be used for repair welding of rails and turnouts, depending on the selected welding procedure [14].

In Serbia, arc welding with coated electrodes is still widely used. For semi-automatic welding processes, the world uses flux-cored wires that melt in a protective gas atmosphere (usually CO_2 or a mixture of CO_2 + Ar) or self-shielding wires.

Cooling after surface welding

With steel type 700 (rail group according to the UIC 860 standard), no special cooling measures are required, unless surfacing is carried out at low, winter temperatures. With steel types 900 and 1100, we must prevent sudden cooling of the welded part. This can be achieved with thermal insulation caps that are lined with asbestos. The same effect can be achieved by subsequent slow reheating with a soft flame for a few minutes. At the same time, care should be taken not to heat the material over 300°C by reheating.

In the case of highly alloyed manganese steels, preheating must not be carried out, but on the contrary, the base material must be cooled during surfacing. It is recommended to weld this type of steel in winter, at low temperatures.

7. QUALITY OF WELDED JOINTS

7.1. Inspections of welded joints in the track

Inspecions of welded joints in the railway track include: visual-direct inspection and ultrasonic inspection [15]. The most suspicious welds are taken as representative samples and subject to other additional tests. During and after welding, one should strive to obtain homogeneous properties within the welded objects [12].

7.2. Quality of heat treatment

The quality of the heat treatment is checked based on the characteristics of the heat treated parts. The following features are checked: hardness, tensile strength, metallographic tests [8].

Test report

The final report must contain an assessment of whether the results obtained during the tests are within the permitted limits provided for in the provisions of the rulebook and whether they confirm that the appropriate thermal procedure has been carried out correctly.

The final report must have reports of individual examinations attached.

8. CONCLUSIONS

It can be stated that welding as part of maintenance of railway objects is mainly repairing by surface welding. Taking into account, the rail is made of pearlite type of steel and is exposed to a complex deformed state, which leads to its degradation, surface welding is currently the dominant maintenance method for extending the life of exploitation. Considering that the frogs, whether cast or welded, are a very important infrastructural element of the railway system, and by reparation instead of replacement, significant cost savings are made without losses in reliability, but also without losses caused by traffic jams if the same part were to be replaced, repair welding is of great importance in railway maintenance.

ACKNOWLEDGEMENT

This research was financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract No. 451-03-68/2022-14/ 200109).

REFERENCES

[1] Molefe, M., Tapamo, JR., Classification of Rail Welding Defects Based on the Bag of Visual Words Approach, MCPR, Mexico City, 2021.

[2] Feng, Q., Song, H., Analysis on the Operation Methods of Rail Welding and Postweld Heat Treatment in the Track Change Overhaul of Existing Railway Lines, J Phys.: Conf. Ser. 2152 012018, 2022.

[3] Stevanović S., Razvoj programa ispitivanja čvrstoće skretničkog srca repariranog postupkom zavarivanja i navarivanja, Master thesis, Mechanical engineering, Niš, 2004.

[4] Kozyrev N., Modern Methods of Rail Welding, et al 2017 IOP Conf. Ser.: Mater. Sci. Eng. 253 012002, Kemerovo, 2017.

[5] Antić M., Odanović Z., Značaj izbora materijala pri zavarivanju i primer nenamenske upotrebe Hartfieldovog čelika, Zavarivanje i zavarene konstrukcije 3/2004, 119-121, 2004.

[6] Popović Z., Mićić M., Lazarević L., Tehnički zahtevi za izbor kvaliteta šinskog čelika, Tehnika – Naše građevinarstvo 76, 165-171, 2022.

[7] Popović O., Prokić-Cvetković Radica., Sedmak A., Grabulov V., Burzić Z., Rakin M., Characterisation of High-Carbon Steel Surface Welded Layer, Strojniški vestnik - Journal of Mechanical Engineering 56, 295-300, 2010.

[8] Pravilnik za termičku obradu skretničkih delova i krajeva za izolovane sastave, br. 311, Belgrade, 1986

[9] Majstorović A., Jovanović M., Osnovi zavarivanja i lemljenja i lepljenja, Belgrade, 1990.

[10] Riley, J., Basic track, Chicago, 2003.

[11] Milojković T., Gornji stroj železnica, Belgrade, 1990.

[12] Xin L., Markine V., Shevtsov I., Analysis of the Effect of Repair Welding/Grinding on the Performance of Railway Crossings Using Field Measurements and Finite Eelement Modeling, Journal of Rail and Rapid Transit, 2017.

[13] Đokić V., Stevanović S., Hardness Test of Welded Frog, Zbornik Međunarodnog kongresa o procesnoj industriji – Procesing, [S.l.], v. 23, n. 1, 2017.

[14] Popović O., Prokić-Cvetanović R., Grabulov V., Odanović Z., Izbor punjenih žica za navarivanje železničkih šina, Zavarivanje i zavarene konstrukcije 4/2006, 131-139, 2006.

[15] Pravilnik o tehničkim uslovima i održavanju gornjeg stroja železničkih pruga, 39 i 74, Belgrade, 2016

[16] Hassankiadeh S. J: Failure Analysis of Railway Switches and Crossings for the purpose of Preventive Maintenance, Master thesis, Royal Institute of Technology, Stockholm, 2011.