https://doi.org/10.37434/tpwj2021.11.05

INVESTIGATION OF THE CAUSES FOR APPEARANCE OF DEFECTS IN WELDED BUTT JOINTS OF TRAM RAILS MADE BY THERMIT WELDING

E. Turyk[1], **I.O. Ryabtsev**[2], **M. Lomozik**[1], **K. Krasnovskyi**[1]

[1]Lucasiewicz Research Network-Institute of Welding
44-100, Gliwicc, 16-18 Bl. Czeslava, Poland. E-mail: is@is.gliwice.pl
[2]E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine

ABSTRACT

The results of investigations of the causes for fatigue fracture of rail butt joints on two new tram tracks, made by thermit welding by two organizations are presented. Control analysis of the chemical composition and mechanical properties of the rail material; analysis of the chemical composition of the welds, macro- and microscopic investigations of the weld, HAZ and base metal, and hardness studies in these zones were performed. It was found that pore accumulation and isolated microcracks in the metal of welds are the potential cause for cracking. Violations of the technological process of thermit welding of the tram tracks were determined, which lead to appearance of these defects. The detected defects are the result of the following factors, associated with failure to meet the standard requirements on thermit welding of tram tracks and of the system of ensuring the quality of welding operations, namely violation of welding technology and insufficient control at the respective stages of the production process.

KEY WORDS: thermit welding, tram tracks, fatigue cracks, porosity; microcracks, quality assurance system

INTRODUCTION

Requirements for thermit welding of rails on tram routes and certification of the procedure of thermit welding of tram rails are regulated by the European standard PN-EN 16771:2017–01 [1], and requirements to the chemical composition of the metal of thermit welds are given in the standard PN-EN 14730-1:2017–06 [2]. Additionally, it is recommended that the performer of works complied with the requirements to the quality of welding performance according to the standard EN ISO 3834–2 [3]. Compliance with these requirements allows providing the required quality of butt joints and their life, which is confirmed by many years of experience of operation of the continuous railways, performed by thermit welding.

Recently, in Poland a problem of fatigue fracture of butt joints of new tram tracks, made by thermit welding, appeared which is confirmed by publications on different sites. In this article, two cases of breakage of rails on the tram lines, built by two organizations were considered. On the tram route "A" after three months of operation, cracks of fatigue type in welded butt joints of grooved rails 60R2 (Tv-60) from steel R260, made by thermit welding, by the first organization were detected. On one section of the tram route from approximately 1000 welded butt joints, 32 were fractured. On the tram route "B", similar cracks were found in 90 welded butt joints from 150. Thermit welding of rails on this route was performed by a second organization.

Cracks that led to fracture of the rails, initially propagated across the welded butt joint approximately at a half of the height of the rail web (Figure 1, *a*). The length of the cracks reached 20 cm. Then the cracks changed the direction by 90° towards the head and the flange of the rail and a complete fracture of the butt joint occurred (Figure 1, *b*).

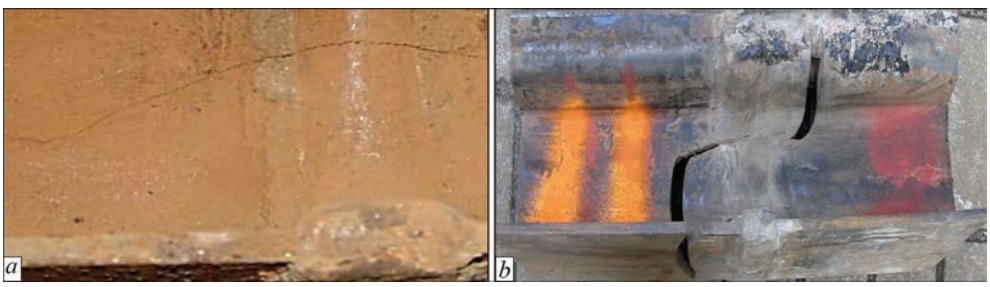

Figure 1. Initial crack (*a*) and nature of fracture of tram rails in the zone of welded butt joint (*b*)

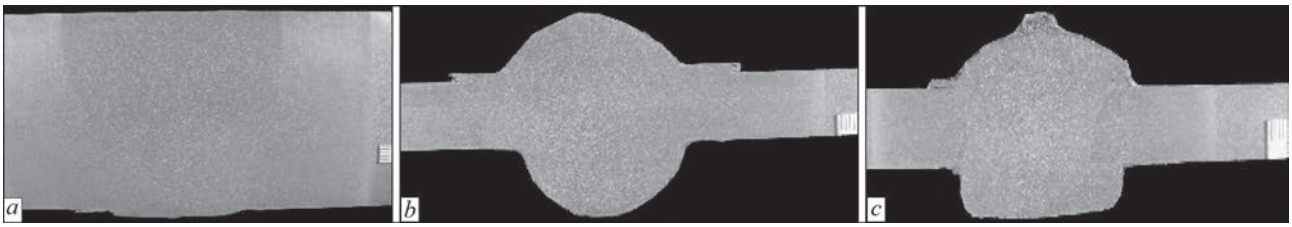

Figure 2. Macrostructure of welded butt joint in the zone of head (*a*), web (*b*) and flange (*c*) of rails

The aim of this work was to determine the defects of welding, which may be the cause of fatigue cracking in the welded butt joints of the tram rails and determine the technological operations, during which violation of the modes of thermit welding probably occurred.

INVESTIGATION OF THE CAUSES OF CRACKING IN WELDED BUTT JOINTS OF THE TRAM ROUTE "A"

The next volume of tests was agreed to determine welding defects that can be a potential cause of fatigue cracks in two welded butt joints C1 and C2 of the rails of the route "A":

- control analysis of the chemical composition and mechanical properties of the material of rails — welded butt joints No. C1 (rails Nos 1 and 2) and No. C2 (rails Nos 3 and 4);
- control analysis of the chemical composition of welds, made by thermit welding;
- metallographic examinations and study of distribution of hardness of weld, HAZ and base metal;
- metallographic examinations and study of distribution of hardness outside the area of fracture in the area of the flange and head of rails.

The analysis of the chemical composition of the material of rails Nos 1–4 was carried out in an optical emission spectrometer Q4 Tasman of Bruker Company. It was established that the chemical composition of the rails meets the requirements of the standard EN 14811:2019 [4]. Tensile strength σ_t = 911.3–

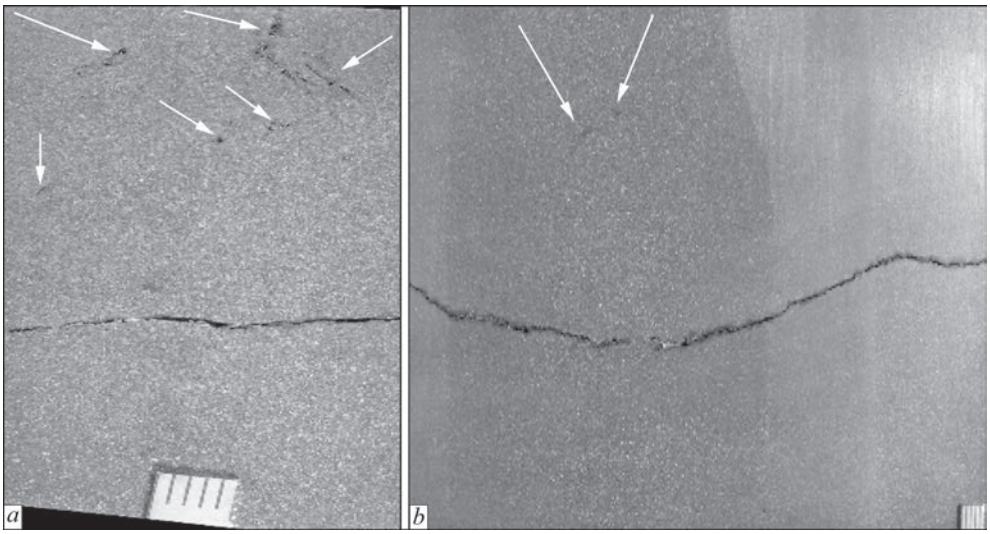

Figure 3. Macrostructure of welded butt joints C1 (*a*) and C2 (*b*) in the crack zone (arrows mark accumulation of gas pores)

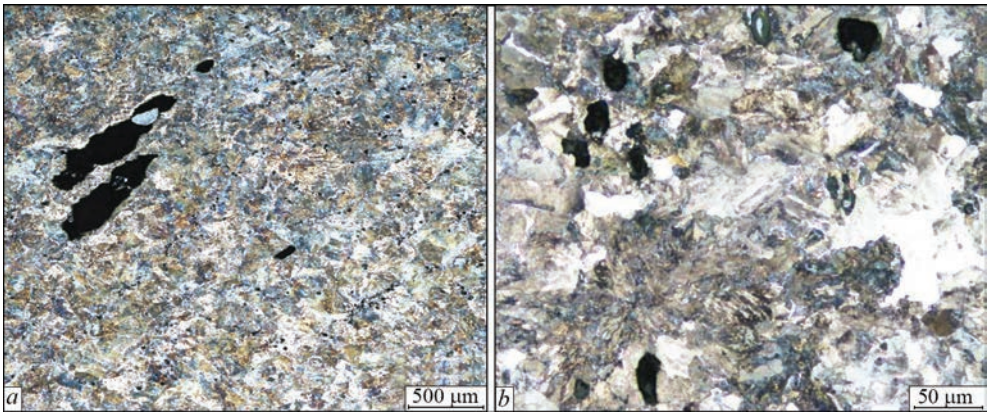

Figure 4. Microstructure of welded butt joints C1 (*a*) and C2 (*b*) in the crack zone. Pores in welds.

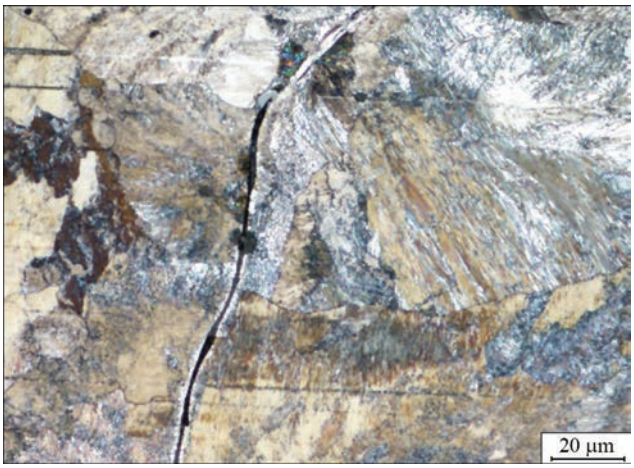

Figure 5. Microstructure of welded butt joint C1 in the crack zone

991.6 MPa and relative elongation δ_5 = 13.0–16.3 % of the material of the rails Nos 1–4 also meet the requirements of the standard for steel R260: $\sigma_t \geq 880$ MPa, $\delta_5 \geq 10\%$. Analysis of the chemical composition of welded butt joints C1 and C2, performed using thermit method, showed that the content of alloying elements in the welds also meets the requirements of the standard PN-EN 14730-1:2017–06 [2]. Examination of macrostructure of the welded butt joints in the area of the head, web and flange of the rails did not reveal defects of welding in the form of lacks of fusion, lacks of penetration and slag inclusions (Figure 2, *a–c*).

However, in the welded butt joints C1 and C2 in the fracture zone, the accumulation of tiny pores were detected (Figure 3).

Porosity of the welds was confirmed by microscopic examinations (Figure 4). The cause for pore formation is reduction in the solubility of gases at a decrease in temperature. Too fast cooling of the welded butt joint increases the probability, that bubbles of gases may not have time to come to the surface and pores will be formed.

Examinations of microstructure showed that the material of the rails has a pearlite-bainite structure with a small amount of ferrite. An unfavourable martensitic structure in HAZ was not detected. The study of hardness confirmed this fact: hardness of HAZ did not exceed *HV* 325.

In the weld of the butt joint C1 in the area of the rail web, single microcracks were detected throughout the grain boundaries, that occur at a considerable distance from the main crack (Figure 5).

Microcracks, apparently, are the result of the exposure to tensile stresses that cause plastic deformation of the weld metal. Microcracking is caused by the appearance of liquid films of easy-melting eutectic on grain boundaries, which have a solidification temperature much lower than the solidification temperature of iron.

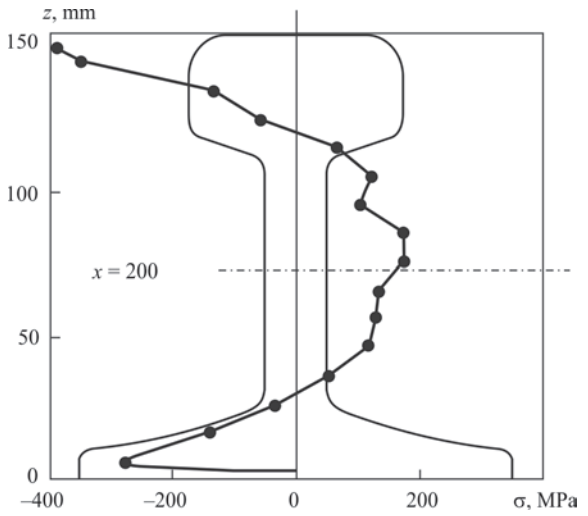

Figure 6. Distribution of residual stresses in the butt joint of rails made by thermit welding [5]

Gas pores and microcracks in the welded butt joints C1 and C2 of the tram route "A" contribute to arising of fatigue cracks that were formed in the web of the rails in the zone of the highest residual tensile stresses (Figure 6).

INVESTIGATION OF THE CAUSES OF CRACKING IN WELDED BUTT JOINTS OF THE TRAM ROUTE "B"

The subject of the study was two fractured butt joints No. I and No. II of the tram rails 60R2, made by the SRZ method [6]. The tests of mechanical properties showed that the material of the rails does not meet the requirements of PN-EN 14811:2019-06 concerning the minimum elongation for steel R260, and tensile strength, yield strength and relative elongation significantly differ from the data in the act on the results of the acceptance tests 3.1 according to EN 10204:2017. [7].

The use of a low-quality material of the rails with reduced plastic properties indicates insufficient control before welding, which does not meet the requirements of EN ISO 3834-2:2019, item 14.2.

Insufficient control before welding confirms also the lack of qualification certificates of welders of thermit welding of tram rails using SRZ method. The certificates of the qualification of welders of thermit welding of railway rails by the welding method SoWoS [9, 10] without reinforcement, with the upper preheating of remnants of rails and with the SkV method [11, 12] with a short preheating time were presented according to PN 14730-2:2006 [8]. This does not meet the requirements of EN ISO 3834-2:2019, item 7.2.

Metallographic examinations revealed accumulation of pores in the welds of the butt joints I and II in the area of head and flange of the rails (Figure 7).

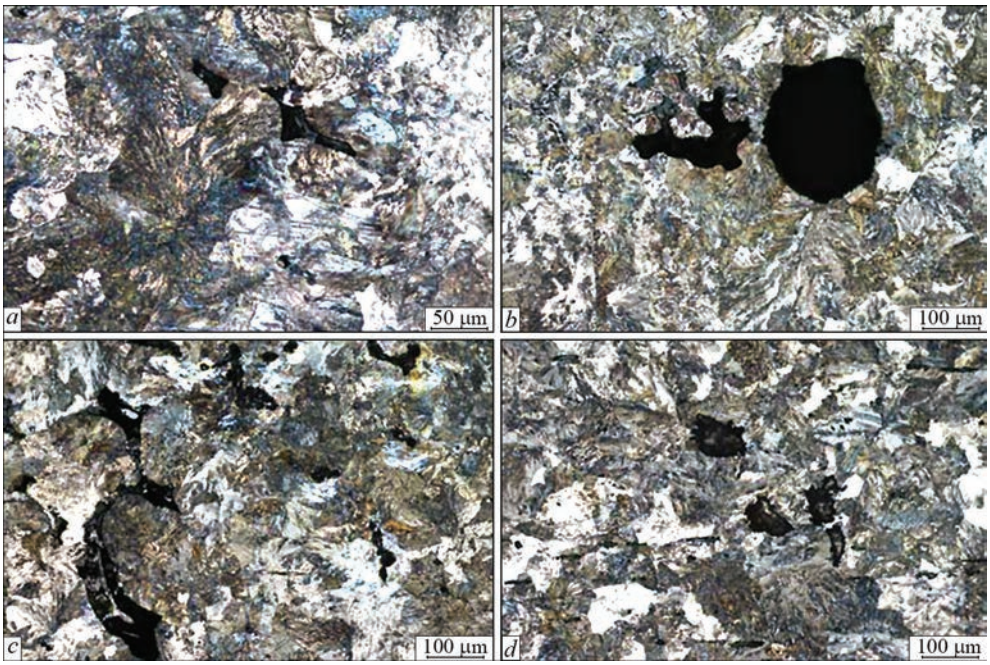

Figure 7. Gas pores in the head (*a*, *c*) and in the flange (*b*, *d*) of rails of welded butt joints I and II, respectively

As a result of examinations, the probable causes of premature fatigue fracture of welded butt joints of rails of the tram route "B" were established:

a) use of rails material, which does not correspond to the technical requirements of the standards, with reduced plastic properties;

b) violation of the technology of thermit welding, as a result of which in the metal of rail welds, microcracks and accumulation of gas pores in their zone were revealed;

c) insufficient technical supervision of the technology of rails welding, which is s evidenced by:

- incomplete operating charts of welding WPS (temperature and time of preheating, height of the torch above the rail head, time from the end of pouring the thermit melt into the mould to chipping of the excess metal from the upper part of the rail head and over the radius parts are not indicated);
- lack of qualification certificates of welders of thermit welding of tram rails using SRZ method.

CONCLSUIONS

1. In the metal of the welded butt joints of the rails C1 and C2 of the route "A", welding defects in the form of accumulations of gas pores were revealed, which are formed as a result of quite rapid cooling of weld metal. Porosity was also detected in the welded joints I and II of the route "B".

2. In the welded butt joint C1 of the route "A" on the area of the rail web, inadmissible welding defects in the form of single microcracks throughout the grain boundaries were revealed.

3. The appearance of gas pores and microcracks is associated with the following violations of the technological process of thermit welding of tram rails:

- low temperature and short time of preheating of rail ends;
- nonuniform heating of welding ends of the rails;

underestimated gap recommended between the ends of rails before welding;

- rapid cooling of weld metal as a result of preliminary removal of the forming device (too short time from the moment of metal tapping from the crucible to removal of the forming device).

4. The found defects are the result of two factors associated with noncompliance of the performers with the requirements of the standard on thermit welding of tram rails and systems of quality assurance of welding works:

- violations of welding technology;
- insufficient control at the corresponding stages of the production process: incomplete operating charts of welding WPS, absence of qualification certificates of welders of thermit welding of tram rails by the SRZ method, and in the case of a tram route "B", also absence of material of rails, which does not corresponds to the specification.

5. The found defects of welding (gas pores and microcracks) are a potential cause of fatigue cracks in the welded butt joints of tram rails during operation.

REFERENCES

1. PN-EN 16771:2017–01: *Railway applications — Infrastructure — Aluminothermic welding of grooved rails*.
2. PN-EN 14730-1:2017–06: *Railway applications — Track — Aluminothermic welding of rails*, Pt 1: Approval of welding processes.

3. DSTU EN ISO 3834-2:2019: *Quality requirements for fusion welding of metallic materials*, Pt 2: Comprehensive quality requirements
4. PN-EN 14811:2019–06: *Railway applications. Track. Special purpose rail. Grooved rails and associated construction profiles*.
5. Lawrence, F.V., Chen, Y-R., Cyre, J.P. (2014) *Improving the fatigue resistance of thermite railroad rail weldments*. http://fcp.mechse.illinois.edu/files/2014/07/Lawrence-presentation.pdf
6. *Thermit SRZ/SRZ L50/SRE welding process for grooved rails*. https://www.elektro-thermit.de/fileadmin/et/user_upload/PDF/Produktbrosch%C3%BCren/SRZ_SRE_DEF.pdf
7. DSTU EN 10204:2017: *Metallic products — Types of inspection documents.*
8. PN-EN 14730-2:2006: *Railway applications — Track — Aluminothermic welding of rails*, Pt 2: Qualification of aluminothermic welders, approval of contractors and acceptance of welds.
9. (2010) *Code of Practice for the THERMIT — Quick Welding Procedure SoWoS*. Elektro-Thermit GmbH & Co KG.
10. (2019) *Instrukcja spawania szyn termitem Id-5*. PKP Polskie Linie Kolejowe S.A.
11. *Code of Practice for the THERMIT — Quick Welding Procedure SkV*. Elektro-Thermit GmbH & Co KG, 2010. https://www.thermit.com.au/media-centre/technical-information/PI_8.5.1-296_TA_TS-Code-of-Practice-SkV-Elite-Welding-Procedure.pdf.
12. *Elektro-Thermit. Technology of aluminothermic welding of rails with short time of heating (SkV, SkV-L 50, SkV-L 75)*. https://docplayer.com/27763010-Elektro-termit-tehnologiya-alyuminotermitnoy-svarki-relsov-s-korotkim-vremenem-podogreva-skv-skv-l-50-skv-l-75.html.

ORCID
I.O. Ryabtsev: 0000-0001-7180-7782

CONFLICT OF INTEREST
The Authors declare no conflict of interest

CORRESPONDING AUTHOR
I.O. Ryabtsev
E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine
E-mail: ryabtsev39@gmail.com

SUGGESTED CITATION
E. Turyk, I.O. Ryabtsev, M. Lomozik, K. Krasnovskyi (2021) Investigation of the causes for appearance of defects in welded butt joints of tram rails made by thermit welding. *The Paton Welding J.*, **11**, 29–33. https://doi.org/10.37434/tpwj2021.11.05

JOURNAL HOME PAGE
https://pwj.com.ua/en

Received 16.09.2021
Accepted: 29.11.2021