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Qualifying the Technology of the Aluminothermic Welding of Tramway Rails on the Basis of Quality Assurance System Requirements in Welding Engineering

Abstract: The article discusses the issue of demonstrating the correctness of a technology dedicated to the aluminothermic welding of tramway rails, recommends that the technology be qualified in accordance with standard PN-EN ISO 15613:2006 concerning the pre-production testing of technologies used when welding atypical joints, proposes the scope of qualification tests and presents test results concerning defective welded joints.

Keywords: aluminothermic welding, welding of tramway rails, atypical joints

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Introduction

According to ISO 9000 series standards, welding is regarded as a special process, the control of which significantly affects product quality and the results of which cannot be entirely verified by subsequent tests, inspections or examinations [1]. Welding-related quality assurance is addressed by the PN-EN ISO 3834 series of standards, supplementing the ISO 9000 series of standards or used as the basis for documenting quality systems including elements directly related to welding processes. Welding is used when making jointless railway or tramway tracks, i.e. tracks where rails are joined permanently using MMA welding, pressure welding or aluminothermic welding.

Quality assurance system requirements related to welding engineering, including the aluminothermic welding of railway rails regarded as a special process are addressed by a number of publications, e.g. [2, 3]. In railway engineering, the aluminothermic welding of rails is governed by standards related to the approval of aluminothermic welding processes (PN-EN 14730-1+A1:2010 [4]), qualifications of welders performing aluminothermic welding as well as the approval of contractors and the acceptance of welds (PN-EN 14730-2:2006 [5]). Requirements concerning rail welding technologies and tests of welded joints contain a number of documents, including specifications related to the aluminothermic welding of railway rails [6] and defectoscopic tests [7] developed by the Polish Railways, *Technical Conditions of the Making and Acceptance of Rail Joints Welded Using the SoWoS-P Method* developed by the Rolf Plötz company [8] and DB Rail 824 series guidelines concerning the making of railway tracks [9, 10].

The documents named above concern the joining of railway rails, different from tramway rails in terms of shapes. There are no regulations

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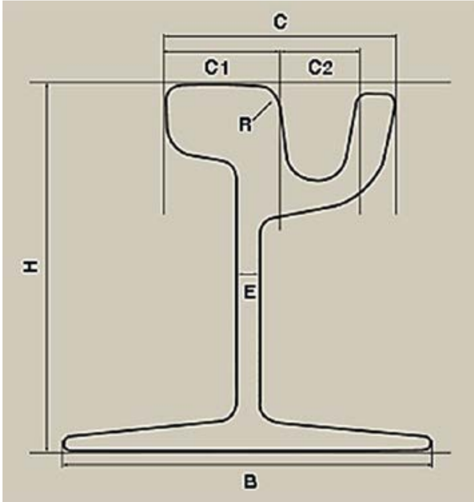
concerning the qualification of the aluminothermic welding of tramway rails as in the case described in publications [4, 6]. In addition, requirements concerning the qualification of the aluminothermic welding of tramway rails are not always defined by the customer. However, due to the responsibility of rail joints it is necessary that the above-named technology be qualified (or in other words approved, accepted or verified) by the manufacturer. For this reason, the article discusses the possibility of qualifying the aluminothermic welding of tramway rails on the basis of existing welding-related standards.



H = 180 mm
B = 180 mm
C = 113 mm
C1 = 55,8 mm
C2 = 36,3 mm
E = 12 mm
R = 13 mm

Fig. 1. Shape and primary dimensions of a cross-section of the 60R2 dock rail [12]

Fig. 2. Aluminothermic welded joints of 60R2 rails

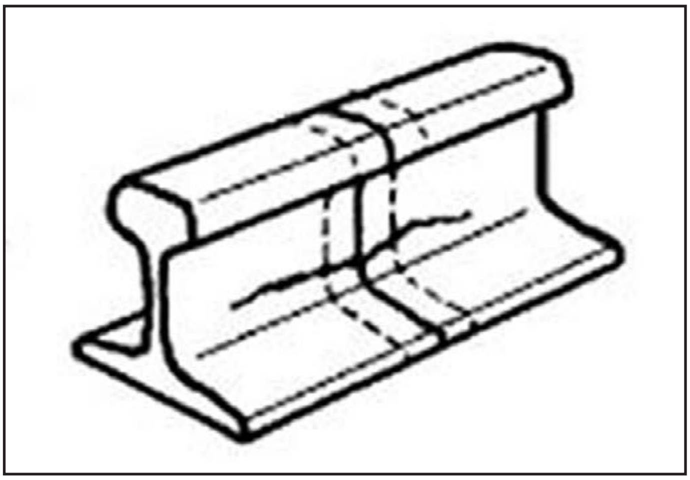


Fig. 3. Schematically presented rail web crack in the welded joint area [13, 14]

Qualifying the Technology of the Aluminothermic Welding of Tramway Rails

In welding procedure specifications, contractors performing the aluminothermic welding of tramway rails refer to the SoWoS welding method or the SRZ LP method used when welding tram dock rails [11]. An exemplary cross-section of a 60R2 tramway rail and an aluminothermic welded joint are presented in Figure 1 and 2.

Defects troubling the operation of tracks related to improperly performed aluminothermic welding include horizontal cracks located in the rail web (Fig. 3) and transverse cracks located in a place close to the normal cross-section of a rail (e.g. a fatigue crack in the vertical plane of a rail initiated at a gas pore [13÷16]). Cracks pose hazards to safe transport, require the closure of a track, the removal of a rail fragment containing a defective joint and the placement of a new rail fragment.

Aluminothermic welding-related potential reasons for crack generation include unfavourable stresses (cracks occur in the zone of the highest tensile welding stresses in the rail web; Fig. 4) [17-19] as well as the failure to satisfy the technological conditions of welding processes:

- overly short heating time favouring weld porosity formation [19] (porosity mentioned in the publication was referred to as micro-shrinkages formed in welds),
- overly low temperature of heating applied to rail ends [20],
- asymmetric (non-uniform) heating of rail ends,
- overly short gap between rails being joined [20].

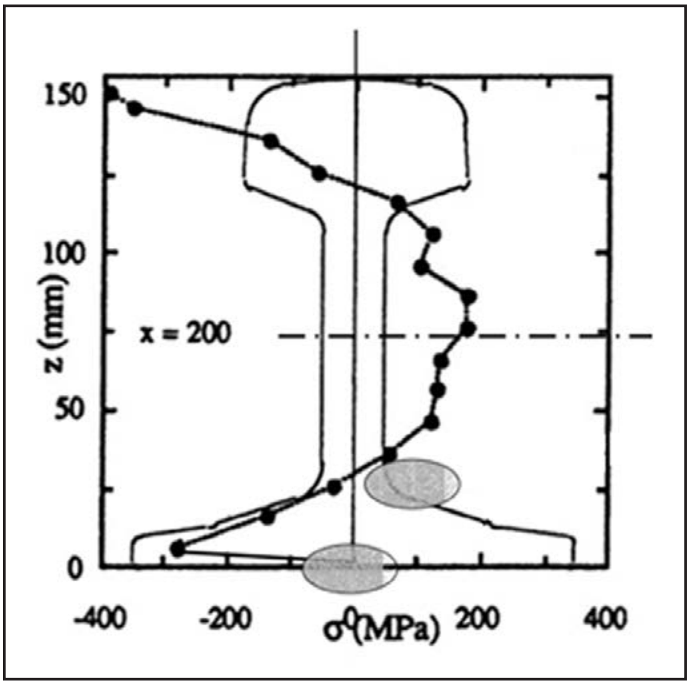


Fig. 4. Distribution of stresses in a aluminothermic--welded joint of railway rails [17, 19]

In order for the manufacturer to demonstrate the correctness of an aluminothermic welding technology applied when joining tramway rails, it is necessary to qualify the above-named technology. In accordance with requirements concerning quality assurance in welding engineering (entire or standard quality-related requirements according to item 10.3 of PN-EN ISO 3834-2 and PN-EN ISO 3834-3 respectively [21, 22]), welding technologies should be qualified before the commencement of production. Presently, as regards aluminothermic welding, there are no ISO documents necessary to confirm conformity with the above-presented quality requirements (PN-EN ISO 3834-5, Table 10 *Other fusion welding processes* [23]). Hence the question, whether due to the lack of special standards similar to PN-EN 14730-1 as well as because of the lack of regulations concerning the welding of tramway rails, the contractor has the possibility of demonstrating the correctness of the aluminothermic welding technology applied for the joining of tramway rails by an independent certification body, and if so, on what basis.

On the basis of the overview of possible variants concerning the qualification of welding technologies it is possible to propose the qualification of a technology used for the aluminothermic welding of tramway rails according to PN-EN ISO 15613:2006 [24] concerning the so-called pre-production testing of technologies used for welding atypical joints including additional requirements (if any) specified by the investor or inspection personnel (according to PN-EN ISO 3834-2, item 10.3 stating that *Qualification methods should be consistent with related product requirements or specification arrangements*). The process of welding procedure qualification includes four major stages, i.e. the establishment of the scope and conditions of qualification, the making of a test joint, the examination of a test joint and the development of qualification documents [25, 26].

Test joints should be welded by a welder holding a valid licence to perform aluminothermic welding using a method subject to qualification. Both the welding and testing of test joints should be performed in the presence of a so-called examiner, i.e. the representative of a certification body (so-called examination body) performing the process of welding procedure qualification (analogous requirement is formulated in standard PN-EN ISO 15614-1 concerning the qualification of a technology used for the arc welding of steel). Test joint examinations should include at least:

- non-destructive tests: visual tests and ultrasonic tests,
- destructive tests: macroscopic tests, hardness tests, microscopic tests, the chemical analysis of weld metal in the zone of the rail head, web and foot as well as the chemical analysis of rail material. The scope of destructive tests can also include transverse tensile tests of welded joints performed on specimens sampled from the foot, web and head as well as impact strength tests of the weld and heat affected zone.

The acceptance criteria concerning test results should be established before the commencement of the process of welding procedure qualification. In relation to non-destructive tests it is possible to rely on requirements of Polish Railways PKP [7] and on the technical conditions related to the making and acceptance of rail joints [8]. In terms of macroscopic tests it should be assumed that cracks and incomplete fusions are unacceptable and it is necessary to specify the acceptable size and density of porosity and solid inclusions. The acceptance criteria concerning test results related to mechanical properties can be based on the requirements of PN-EN ISO 15614-1.

An acceptable test result enables the examination body to provide the manufacturer with a Welding Procedure Qualification Record (WPQR) based on a pre-production test according to PN-EN ISO 15613:2006. The record specifies the scope of qualification, conditions concerning the making of a test joint and test results. If a test result is unacceptable, the examination body provides the manufacturer with a report concerning the examination of a test joint. The report presents the conditions related to the making of the test joint and the results of performed tests and well as test reports (if any). The above named information enables the manufacturer to take corrective and preventive actions aimed to assure the correctness of the aluminothermic welding process and the making of a test joint satisfying qualification-related requirements.

Presented below are examples of joints failing to meet qualification requirements. The failure to satisfy the above named requirements was confirmed by tests performed on rail fragments containing fatigue cracks.

Examples of Welding Imperfections in Aluminothermic Welded Joints of Tramway Rails

In order to determine possible reasons for fatigue cracks of aluminothermic welded joints of tramway rails it was necessary to perform tests of two joints containing cracks passing horizontally through the weld and the rail web, at the half of the rail web height. The characteristic forms of the cracks in joints S1 and S2 are presented in Figures 5 and 6.

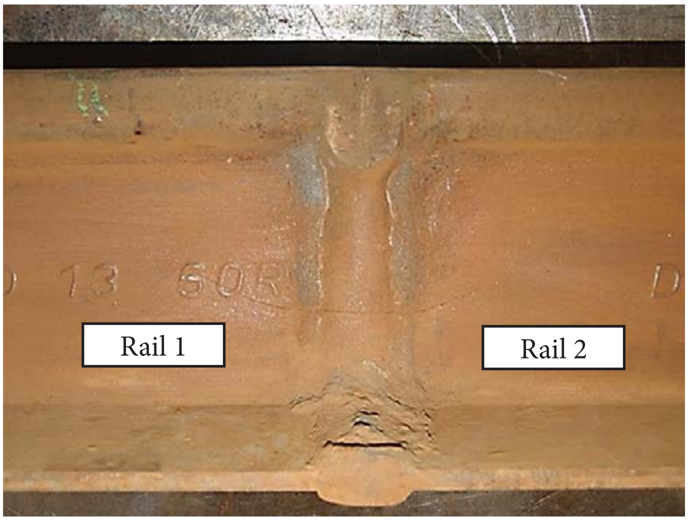


Fig. 5. Fatigue crack in joint S1 of rail 1 and 2

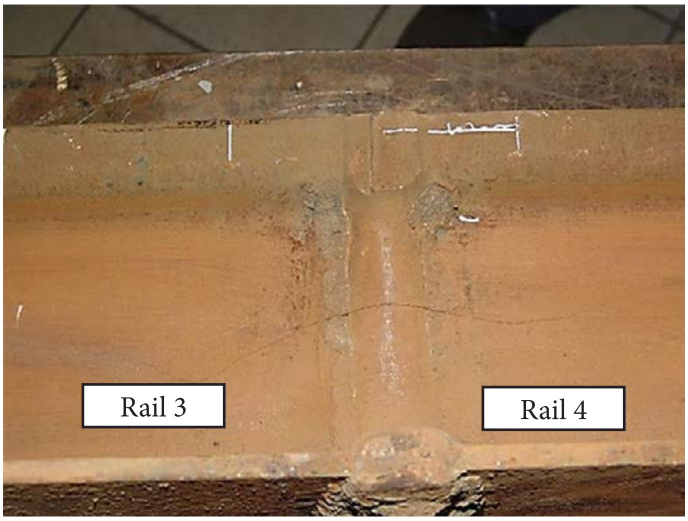


Fig. 6. Fatigue crack in joint S2 of rail 3 and 4

The tests of rails nos. 1÷4 revealed that the chemical composition, tensile strength R_m and elongation strength A_5 of the material of the rails subjected to the tests satisfied the requirements concerning steel grade R260 according to standard PN-EN 14811+A1:2010. In turn, the chemical composition of the welds of joints S1 and S2 satisfied the requirements of standard PN-EN 14730-1+A1:2010, Table 7.

The macroscopic metallographic tests did not reveal the presence of welding imperfections such as local lacks of penetration and solid inclusions in the joints.

The heat affected zone of the weld made using aluminothermic welding did not contain the unfavourable martensitic structure; the HAZ hardness did not exceed 325 HV.

The metal of the welds in joints S1 and S2, in the crack zone, contained welding imperfections in the form of localised porosity (Fig. 7, 8) caused by the excessively fast cooling of the weld metal precluding its entire degassing.

The weld of joint S1, in the rail web area, contained a welding imperfection in the form of a microcrack along grind boundaries (Fig. 9).

Cracking in welds results from a strain which the metal of the weld is unable to transfer because of its limited ductility. Microcracks formed during welding are caused by films of fluids (low-melting eutectics having a solidification point significantly lower than that of iron) formed during solidification and incapable of transmitting stresses connected with the shrinkage of the weld during its cooling and solidification [27]. Similar to gas pores, microcracks of this type (welding imperfection 1001 according to PN-EN ISO 6520-1:2009 [28]) may initiate fatigue cracking.

If the above named welding imperfections are present in a test joint performed during the process of welding procedure qualification, the contractor has the possibility of analysing and eliminating the reasons for the formation of such imperfections. Porosity (Fig. 7, 8) and microcracks in the weld (Fig. 9) may be caused by an overly short time during which rail ends are subjected to heating and an excessively fast cooling rate following the formation of a joint. This conclusion was confirmed by the results of works described in publication [19]. The elimination of the above named reasons should enable making another test joint free from unacceptable welding imperfections as well as result in the confirmation of the correctness of the aluminothermic welding of tramway rails performed by the contractor in a related Welding Procedure Qualification Record (WPQR).

Summary

In addition to providing qualified welding and coordinating personnel, supervising base materials and filler metal as well as coordinating and controlling the welding process itself, the coordination of the aluminothermic welding of tramway rails should also include the qualification of the process aimed to demonstrate the correctness of the welding procedure applied by the contractor.

The qualification of a technology used for the aluminothermic welding of tramway rails could be based on standard PN-EN ISO 15613:2006 concerning the pre-production testing of technologies used for welding atypical joints, including additional requirements (if any) formulated by the investor or inspection personnel.

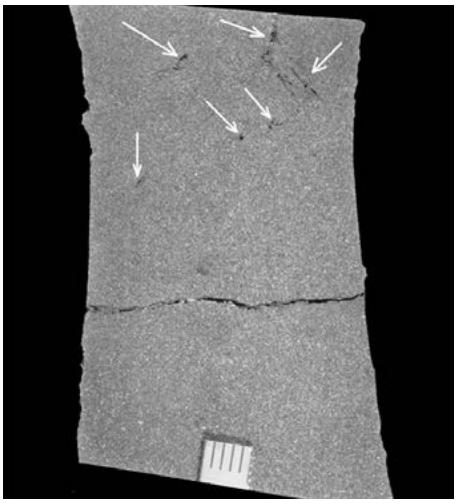


Fig. 7. Macrostructure of the weld of joint S1 in the crack zone. The arrows indicate the location of gas pores in the weld

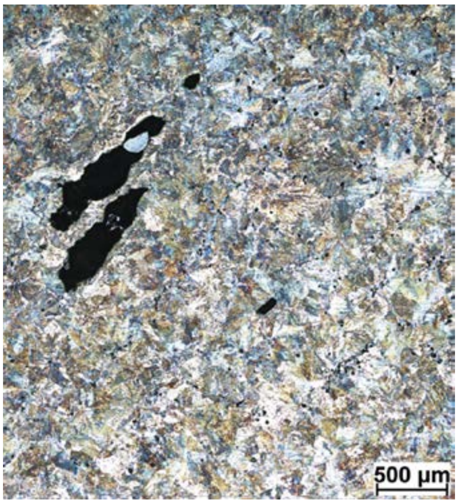


Fig. 8. Microstructure of the weld of joint S1 in the crack zone – main view (mag. 50x); visible porosity in the weld material

Fig. 9. Microstructure of the weld of joint S1 in the crack zone – microcrack along grain boundaries at a significant distant from the main crack (mag. 500x); etchant: $FeCl_3$

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