Materials Research Proceedings **5** (2018) 160-165 doi: http://dx.doi.org/10.21741/9781945291814-28

FEM Thermal Analysis of Thermal Weldings of Tramway Rails, 60R2 and 60E1 Type

KOWALCZYK Dariusz

[1]Instytut Kolejnictwa, Kolejnictwa Materials and Structure Laboratory, Chlopickiego Street 50, 04-275 Warsaw, Poland

dkowalczyk@ikolej.pl

Keywords: FEM Thermal Analysis, Cracking Tram Rail of Thermite Welding, 60E1 Rail, 60R2 Rail, Tram Rail

Abstract. In many newly built tram tracks by means of the thermite method, after putting them into operation, cracks appear in tram rails in the areas of splice rails [1]. In the case of solutions used in the tram infrastructure, there are requirements for railways in accordance with PN-EN 14811 + A1: 2010 [2]. For rail connections intended for the construction of tramway tracks, there are no precise records of such requirements, and their scope may be determined by the Contractor. The article presents and discusses examples of broken rail joints in tramway tracks. Thermal analyses were carried out using the FEM method of cooling welds / thermite connections of the 60R2 and 60E1 tram rails [3-5]. The microstructures of rails and welded joints in the area of the heat affected zone were observed. In the light of the quite common problems related to the cracking of rails and rail joints in tramway tracks, it seems reasonable to introduce durability and quality tests of rail joint connections in order to improve safety in rail transport, reduce cracks in newly built and renovated tracks, and reduce costs related to repairs during operation. In this article, thermal analysis of cooling of thermal welds based on the FEM method was performed.

Introduction

There are various techniques for the construction of railways. The classic track, i.e. in which the rails are connected by splinters, requires careful maintenance due to the dynamic impact of the rolling stock wheels on the rail contacts. The first tram tracks, e.g. in Warsaw, were built and put into service as early as 1866, and electrified in 1908. Until 1899, as many as 20 cities in the area of the present Polish territory had tramlines [6]. The development of new solutions used in the construction of railways has led to the possibility of using the so-called contactless track [7], by introducing rails connected in a permanent manner as a result of using, for example, thermite welds. This solution has made it possible to introduce higher travel speeds, increase safety and increase travel comfort. Modern solutions used in the construction of high-speed rails and modern tram tracks include properly designed tracks, arcs with appropriate radii, cant selection, selection of appropriate rails, application of other infrastructure elements such as modern fastening systems, etc.

The most commonly used method of joining rails in tramway tracks is the method of thermite welding. Thermite or ferromite is a mixture of fine iron and aluminum oxide fractions with alloy additions. After igniting this mixture, with the so-called immediate enthusiasm, giving a focused source of heat, a highly exothermic chemical reaction that generates temperature of over 2500[ºC] is initiated. The SoWoS method is the basic method of thermite welding of rails in tramway tracks, i.e. welding without a riser with upper preheating of the ends of the rails. The technology of welding rails using the thermite SoWoS method consists of the following processes: preparation and setting of the contact of rails to be welded, inserting and sealing the mold, filling and setting the crucible, heating the ends of the rails, welding, cooling the joint, removing the mold and finishing [7].

Materials Research Proceedings **5** (2018) 160-165 doi: http://dx.doi.org/10.21741/9781945291814-28

Rail connections - rail connectors and areas around them - are usually places with an increased risk of cracks, defects, damage etc. This is due to the thermal impact on the rails in which a heat affected zone is created that introduces changes to the material microstructure. In the construction of new tram tracks or modernized tramways, the 60R2 grooved rails are being increasingly used. The advantage of this type of rails is the ability to make a track surface in the system of integrated track and road surface, track in a continuous watering, green track with elastic fastening, green track on a concrete slab with flexible point fixing of rails. Fig. 1 shows examples of solutions using the 60R2 rail.

Fig. 1 Green track and pavement integrated using the 60R2 type rail.

One of the advantages of the 60R2 type rail, made in a grooved and shaped system, is the possibility of building a modern surface of tramway tracks shared with the roadway, i.e. track-road surfaces, as well as the so-called green track, which is more and more frequently used in the construction. The 60R2 rail profile, different from the classical one (60E1, 49E1), has been subjected to the FEM calculations in the field of thermal analysis during the cooling process of rail thermite weld.

Research

Observations were made on the naked eye of broken rail joints made by the 60R2 thermite welding. Samples were cut from the parts of the joint and metallographic specimens were prepared from them. Observations were made on a VHX-5000 Series Digital Microscope - a digital optical microscope equipped with the Z20 and Z2000 lenses for magnification from 50 to 1200x. Sample photos of microstructures are shown in Fig. 3.

Fig. 2 Cracked 60R2 rail in the area of weld occurrence.

Materials Research Proceedings **5** (2018) 160-165 doi: http://dx.doi.org/10.21741/9781945291814-28

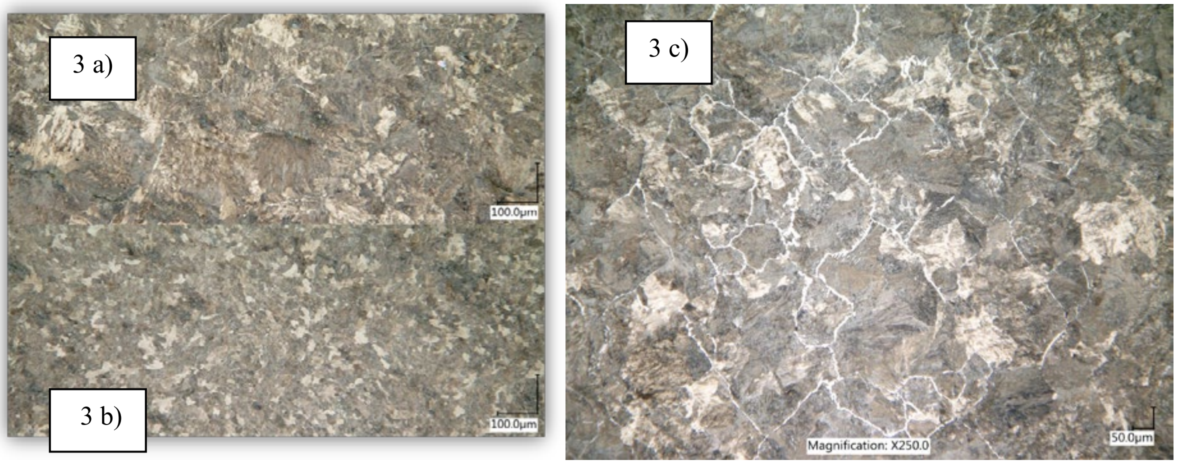

Fig. 3 HAZ microstructure in the area of a) overheating and b) normalization, c) ferrite separation at the grain boundaries.

As evidenced by observations of rail joint microstructures, they are characterized by a large difference in grain size. This indicates a large difference in the temperature gradient during the cooling process. The technological process of making thermite welds should be controlled in such a way as to limit the formation of unfavorable areas of microstructure occurring in the heat-affected zone, such as grain growth, austenite separation at grain boundaries and thermal stresses. The microstructure affects the mechanical properties of the material [7]. This indicates that locally in the areas of microstructure change there are various strength properties of the material (the weld area, 60R2 and 60E1 rails and heat affected zone).

Thermal analysis of cooling thermite welds by the FEM method

Models of the 60R2 and 60E1 rails in accordance with EN 13674-1: 2011 were made in the SOLIDWORKS 2018 program, boundary conditions and FEM calculations were performed in the ALTAIR HYPERWORKS 2017 program [9]. The purpose of the FEM calculations was thermal analysis of the system. Comparative analysis of the distribution of temperature fields during cooling of rail joints in the same variable thermodynamic conditions. The temperature of the thermite joint in the mold and in the area of the rails subjected to the action of the hot medium (liquid weld alloy) can range from over 1500 [^{o}C] to 2500 [^{o}C]. The FEM calculations included analysis of results, heat flow, temperature gradient, and absolute values of temperature.

The FEM calculation results for the rail cooling process (Fig. 4) after 60 seconds.

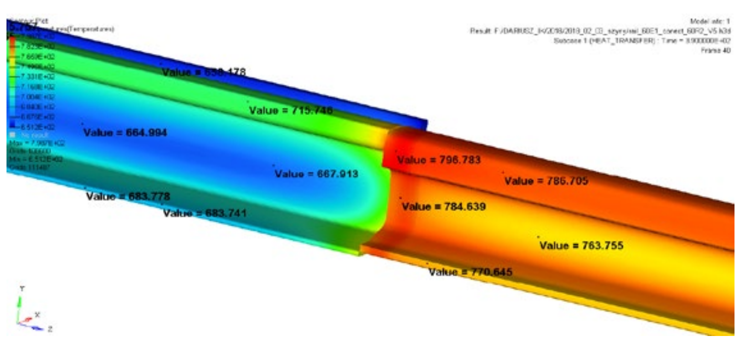

Fig. 4. Temperature distribution on the joint surface after 60 seconds.

Fig. 5. Example of fracture of a rail joint (a thermite weld) of the 60R2 rail.

The temperature distribution on the rail joint surface after 380 seconds of the cooling process using a temperature filter (in this case set at 723 [^{o}C]).

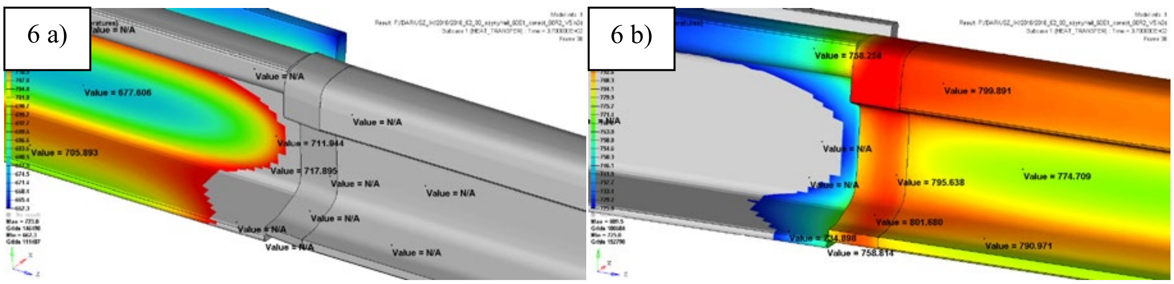

Fig. 6. Temperature distribution on the surface rail joint (a thermite weld)) after 380 seconds. a) a filter was applied showing areas with a temperature below 723 [°C], b) a filter showing areas with temperature above 723 [°C] was used.

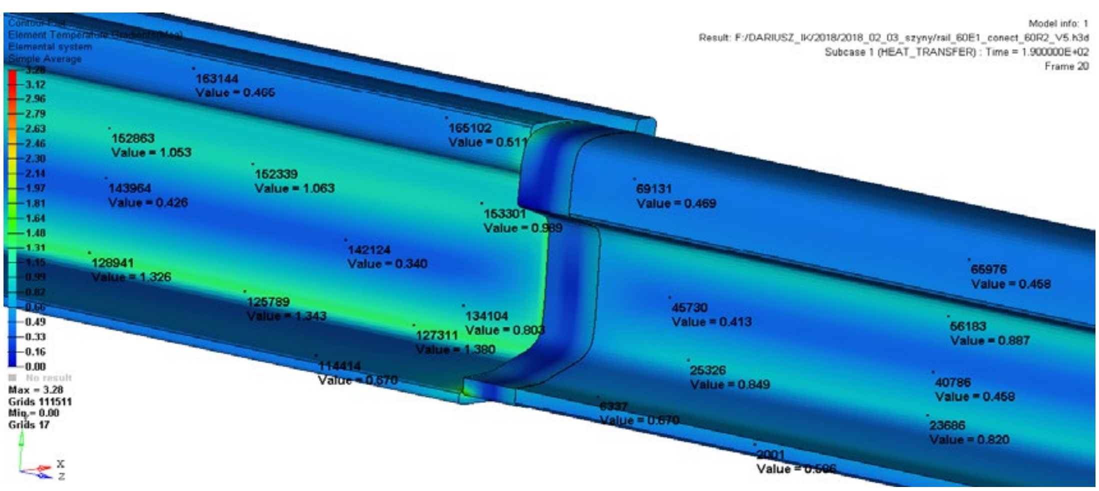

Fig. 7. Temperature gradient in the rail during the cooling process.

Materials Research Proceedings **5** (2018) 160-165 doi: http://dx.doi.org/10.21741/9781945291814-28

Fig. 8. Temperature gradient in the 60R2 rail, cross section 10 mm away from the joint (thermite weld).

Table 1 presents the temperature [^{o}C] values of the selected nodes of the rail.
Table 2 presents the temperature [^{o}F] values of the selected nodes of the rail.

Table 1. Temperature values for individual nodes in the rail [^{o}C]

Time [Frame, second]	60R2 head rail	60R2 web rail	60E1 head rail	60E1 web rail	Temperature difference in the rail 60R2	Temperature difference in the rail 60E1	Temperature difference in the rail 60R2/60E1
1 - 10 s	1000 [^{o}C]	1000 [^{o}C]	1000 [^{o}C]	1000 [^{o}C]	0 [^{o}C]	0 [^{o}C]	0 [^{o}C]
6 - 60 s	958 [^{o}C]	929 [^{o}C]	967 [^{o}C]	951 [^{o}C]	29 [^{o}C]	16 [^{o}C]	38 [^{o}C]
40 – 400 s	715[^{o}C]	664 [^{o}C]	783 [^{o}C]	763 [^{o}C]	51 [^{o}C]	20 [^{o}C]	119 [^{o}C]
100 - 1000 s	417 [^{o}C]	381 [^{o}C]	540 [^{o}C]	522 [^{o}C]	36 [^{o}C]	18 [^{o}C]	123 [^{o}C]

Table 2. Temperature values for individual nodes in the rail [^{o}F]

Time [Frame, second]	60R2 head rail	60R2 web rail	60E1 head rail	60E1 web rail	Temperature difference in the rail 60R2	Temperature difference in the rail 60E1	Temperature difference in the rail 60R2/60E1
1 - 10 s	1832 [^{o}F]	1832 [^{o}F]	1832 [^{o}F]	1832 [^{o}F]	0 [^{o}F]	0 [^{o}F]	0 [^{o}F]
6 - 60 s	1756 [^{o}F]	1704 [^{o}F]	1772 [^{o}F]	1743 [^{o}F]	84 [^{o}F]	60 [^{o}F]	100 [^{o}F]
40 – 400 s	1319 [^{o}F]	1227 [^{o}F]	1441 [^{o}F]	1405 [^{o}F]	123 [^{o}F]	68 [^{o}F]	246 [^{o}F]
100 -1000 s	782 [^{o}F]	717 [^{o}F]	1004 [^{o}F]	971 [^{o}F]	96 [^{o}F]	64 [^{o}F]	253 [^{o}F]

Conclusions of the FEM analysis

The thermal analysis of FEM showed that the 60R2 rail is cooled faster than the 60E1 rail under the same thermodynamic conditions. In the 60R2 rail itself, there are larger temperature differences between the rail head and the web than in the 60E1 rail. From the sample measurements during the cooling process, the temperature differences for the 60R2 rail are over 50[^{o}C], for the 60E1 rail the difference is 20[^{o}C]. In the 60R2 / 60E1 rail joint, temperature differences can be as high as 125[°C]. In Fig. 6a, a temperature filter for the entire joint was used to visualize temperature differences in the changes occurring in the material microstructure during the cooling process - eutectoidal transformation [7]. In the 370 - second cooling period (Fig. 6b), the entire area of the web and the 60R2 rail foot (gray) is a part of the joint in which the course of eutectoid transformation has already been completed (the conversion of austenite into perlite + cementite Fe3C (III)). In the remaining area of the joint - a microstructure (austenite + ferrite) occurs in accordance with the phase-iron balance diagram of iron-cementite. A higher temperature gradient in the 60R2 rail during the cooling process indicates that these joints are more demanding in the field of their manufacturing technology,

Materials Research Proceedings **5** (2018) 160-165 doi: http://dx.doi.org/10.21741/9781945291814-28

and therefore more it is difficult to obtain a homogeneous material microstructure. Fig.5. shows a broken 60R2 rail joint, the shape of the crack run is in correlation with the ISO runlines (designated in Fig.6) defining the eutectoid transformation occurring at 723[°C]. Fig. 7 and Fig. 8 show the temperature gradients in the joint during the cooling process (heat release rate). The highest temperature drops occur in the area between the foot and the web of the 60R2 rail. The inhomogeneity of the temperature gradient over the cross-section of the 60R2 rail (in the area of the joint / thermite weld) results from the offset of the 60E1 rail profile and the maintenance of the proper rail running plane, thus the 60E2 rail is not symmetrically aligned with the 60R2 rail. This also causes the asymmetry of the cooling of the joint in this area.

Summary

Observations of the microstructure of the 60E1 and 60R2 rail areas in the area of the heat affected zone of the thermite weld indicate the existence of a structure with a large grain size differentiation. The FEM thermal analyses have shown that in the 60R2 rail there are greater temperature differences than in the 60E1 rail under the same thermodynamic cooling conditions. There are large differences in temperatures between the 60R2 rail head and its foot.

This indicates that the 60R2 rail, in addition to its advantages related to the possibility of building modern integrated tramway tracks, is a more difficult rail in the manufacture of thermite welds. The technology of making the right thermite weld joint is a process that determines its durability, reliability and safety in rail transport.

References

[1] I.Mikłaszewicz, Wykonywanie i badanie kolejowych złączy szynowych, Instytut Kolejnictwa, Warszawa, Problemy Kolejnictwa, 158 (2013) 35 (in Polish).

[2] PN-EN 14811+A1:2010; Railway applications. Track. Special purpose rail. Grooved and associated construction

[3] Pramod Bhatt, Thermal Analysis of Hollow pipe using Altair Hyperworks,International Jurnal of Engineering Research & Technology, 6 (2012).

[4] Practical Aspects of Finite Element Simulation A Study Guide - Academic Program -3rd Edition Released 05 (2015)

[5] D. Kowalczyk, R. Bińkowski, Zastosowanie obliczeń FEM do określania rozkładu pól naprężeń w szynie typu 49E1 w warunkach eksploatacyjnych wyjątkowych. Infraszyn, Projektowanie budowa i utrzymanie infrastruktury w transporcie szynowym, (2015) 157-168 (in Polish).

[6] Information on tram in Poland; https://pl.wikipedia.org/wiki/Tramwaje_w_Polsce,

[7] Kądziołka A, „Termitowe spawanie - rys historyczny, zmiany, postęp", IV Ogólnopolska Konferencja Naukowo-Techniczna, Spawalnictwo dróg szynowych – jakość, niezawodność, bezpieczeństwo, Bochnia (2010) (in Polish).

[8] Dobrzański L., A., Podstawy nauki o materiałach i metaloznawstwo. Materiały inżynierskie z podstawami projektowania materiałowego, WN-T, (2002) (in Polish).

[9] Altair Engineering, Inc. OptiStruct 13.0 User's Guide.