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Analysis of the Causes of the Cracks in the Thermit Welds of the Tram Rails Type 60R2

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Abstract. According to the PN EN 14578-1:2007 and PN EN 14578-2:2009 regulations and European standards, the requirements for the rail joints used in the rail roads point out that it is necessary to carry out research that confirms technology correctness and the quality of welded joints. The range of tests shall include the following: alignment, hardness, fatigue testing, macro and microstructure of the material, non-destructive magnetic particle examination (to identify cracks) and so on. As long as there are PN-EN 14811 + A1:2010 requirements for rails used in the tram infrastructure, no accurate regulations and requirements exist for tram rail joints and only the customer is able to specify the range of tests. In the light of fairly common problems associated with the rail and their joint cracks in the tramway tracks it seems to be reasonable to implement required research, in order to improve safety of the rail transport and reduce amounts of cracks occurred in the newly built and renovated tram roads, as well as minimize the costs of their maintenance during operation. In this article, examples of broken rail joints in the tram roads are shown and discussed and FEM simulation of loaded rails type 60E1 and 60R2 is analysed.

Introduction

One of the grooved rail's type 60R2 advantage is a possibility to build modern tram superstructures in common with road and, the so-called green track characterised by lower noise is becoming more and more popular. However, the obtained results of calculations indicate that, in the case of 60R2 rail, there are higher stresses in the rail foot area. FEM calculations and analysis of the cracked rail connections indicate that, due to a high concentration of stresses in the foot of 60R2 rail, rail road maintenance has to be of particularly high quality, and above all, perfect technologies of rails connection process. Rail connections should be made according to proven technology, requirements of the standards and relevant provisions of rules that demand keeping the registry of made welded connections. In this article there are presented difficulties that can occur in public transport (tram transport) as a result of rail connections damage or cracked rail.

In the case of road solutions used in the rail it is necessary to meet the following standards [1-3]: PN-EN 14587-1:2007 "Railway applications – Track – Flash butt welding of rails – Part 1: New R220, R260, R260Mn and R350HT" grade rails in a fixed plant and PN-EN 14587-2:2009 "Railway applications – Track – Flash butt welding of rails – Part 2: New R220, R260, R260Mn and R350HT grade rails by mobile welding machines at sites other than a fixed plant".

Rail connection techniques are designed to increase smooth running of trains (rail vehicle), and thus upgrade their speed (shortening the travel time) and increase the comfort of travelling [4, 5]. However, the construction of roads and railways of such characteristics requires connecting rails. Connections quality should guarantee safety and reliability during operation. They are obliged to carry out research on rail joints by accredited and independent research bodies which confirm the

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correctness of the execution of the work, technology and security solutions. In the case of trams and subways superstructure constructions such a range of research is not mandatory and only the customer himself defines the scope of requirements and expectations regarding studies, certificates, authorisations, etc. One of the most commonly used techniques for rails connecting in the tram superstructure is thermite welding. The basic technique is called SoWoS, i.e. welding without excess weld metal, with upper preheating of the rails ends. SoWoS technology consists of the following: preparation and setting contact rails for welding and seal forms, filing and setting the crucible, heating the rail ends, welding, cooling of connections, mould removing and post treatment [6-8].

Rails connections – joints and areas around them – are the most common places of the higher risk of cracks, defects, damage etc. This is due to thermal effects during the execution of the rails connections, in which emerges a heat affected zone that makes changes in the microstructure of the material. Connections quality closely depends on their technology. All important parameters of performed works should be written and recorded in the daily register of made welds [9, 10].

While analysing the documentation of the new tram tracks, lack of such records was stated and in many cases there were serious gaps that made it impossible to analyse and reconstruct process conditions and determine the causes of defective rail joints, and even the location of the performed works. For example, one of Daily Registers Made Welds did not contain such relevant information as ambient temperature, method and time of the rails ends preheating, pressure of the gases mixture, time of the molten metal pouring to the mould, temperature of the excess weld metal removing, method of the joint cooling, etc. Sometimes it happens that in the newly-built tracks there are many problems in the maintenance of track (even in less than 1 year) due to “cracked rails”.

In the construction of new or upgraded tram tracks grooved rails are increasingly used, mainly the 60R2 type [11]. The advantage of this type of rails is the ability to make integrated road-rail track, green track with elastic sleepers fastening, green track on the concrete plate with elastic rails fastening system. In Fig. 1 there are samples of solutions using 60R2 rails.

Fig. 1 Integrated on-street tramways and green tramway with used rails 60R2 type.

Problems occurring during operation of the tramways

Problems occurring during operation related to the analysed cracks of the rails and their joints are connected with effects of many factors. The most important issue is the use of proper (proven in laboratory studies) technology of welding rails. In Fig. 2-4 there are examples of additional factors that may affect the durability of the rail connections resulting in a higher state of stresses in the rails, such as: irregular terrain, defects in rail joints, low quality of maintenance, improper construction of the track (sleepers, fastening systems), etc.

Fig. 2 Low quality of the rail joints – clearance, lack of material under rail head.

The following cases of defects, imperfections in the tram tracks come from different cities in Poland, and the dates come from the years 2016-2017 (Fig.2-4). The use of unproven techniques of rail joints and additional, described above, factors may cause cracks in the rail and their joints cracks. Examples of damage to the connections are shown in Fig. 4.

Fig. 3 Low quality of the tram tracks maintenance.

Fig. 4 Crack of the rail in the area of the rails joint.

Research problem

As shown above in the operation of the new tram tracks there are problems arising from cracks in the rails joints. The quality of rail joints depends on many factors: quality of the joints, track construction, residual stresses etc. One of the important issues to be taken into account is also the type of rail in the track, where rails joint, e. g. 60R2 are and 60E1. This issue has been analysed with FEM and its aim was to determine the distribution of stress fields, both rails in the same load condition (different rail profiles 60R2 and 60E1), as well as in the case of normal exploitation loads.

The results are given below. It should be noted that the calculation takes into account ideal conditions, without any imperfections associated with the construction of the track and residual stresses of the rail.

FEM calculation for the 60R2 and 60E1 rail types

The purpose of the FEM calculation, except for the issues described above, that concern rails welding and track constriction works, was to determine the distribution of the stress fields in the 60R2 and 60E1 rails and their joints.

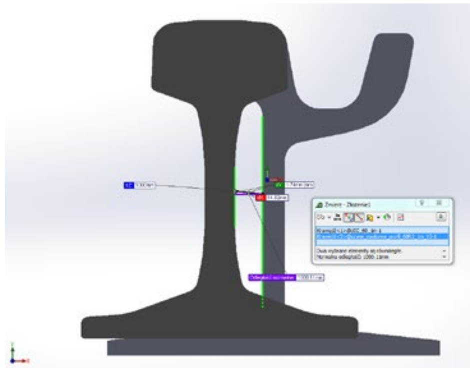

Fig. 5 Comparison of rail profiles 60R2 and 60E1 (profiles according to PN EN 13674-1:2011).

The presented (Fig. 5) layout of the rails profiles follows operating conditions, where appropriate geometry of the running surface of rails should be kept.

As can be seen from the scheme, distance between rail webs is about 15 cm, also rails 60R2 and 60E1 differ in the height and construction of the web and foot.

Models of the 60R2 and 60E1 rails are made in SolidWorks software. Boundary conditions are defined and the properties grid were built, as well as simulation and analysis of the results were done with software HyperWorks - version 14 of company ALTAIR and HyperView [12, 13] and with SolidWorks with Simulation pack.

Three simulations were performed for the 60R2 and 60E1 rails in the following load schemes: *Simulation 1*; fastened and supported rail has been deflected on the Y-axis at -1 mm; *Simulation 2*; fastened and supported rail has been deflected on the Y-axis at -1 mm and X-axis -1 mm; *Simulation 3*; fastened and supported rail has been loaded of 50 kN. Below are presented examples of stress fields distribution for selected loads, and summary results are presented in Table 1.

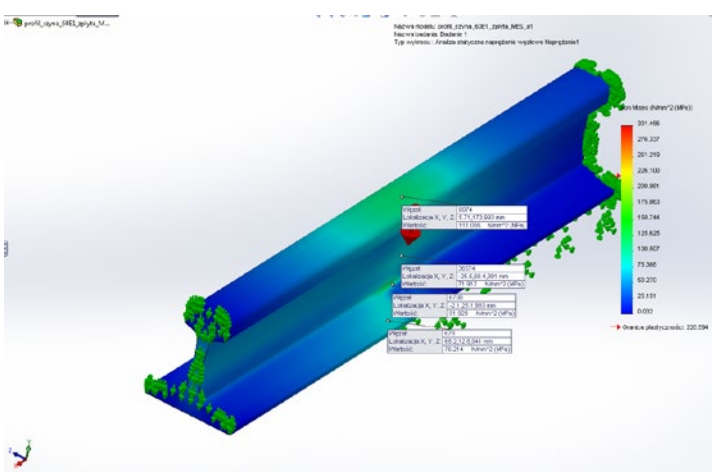

Fig. 6 Stress fields distribution according to von Misses in the rail 60E1 for simulation 1.

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The results of FEM analysis no.1-3 are presented in Table 1.

Table 1. Maximum stress according to von Misses for each simulation.

FEM calculation option	Distortion direction	Stress [MPa]	
		Rail 60 E1 type	Rail 60 R2 type
Simulation 1	Axis Y -1 mm	91 (foot) 111 (head)	171 (foot) 104 (head)
Simulation 2	Axis Y -1 mm Axis X -1mm	211	305
Simulation 3	Axis Y – 50 kN	82	143

Simulation 4. Scheme of the symmetrical rails joint loading, joining with welds of 30 mm thickness. Symmetric way of fastening and support in the same distance of 250 mm from the joint. Applied material – steel R260 (rail) and PUR (under rail pad). Characteristics of materials are shown in Table 2.

Table 2. Material data used in the FEM calculation.

Material	Young's modulus [MPa]	Kirchhoff modulus [MPa]	Poisson's ratio	Density [g/cm^3]
Steel R260	210 000	80 769	0,3	7,85
PUR	250	100	0,42	0,95

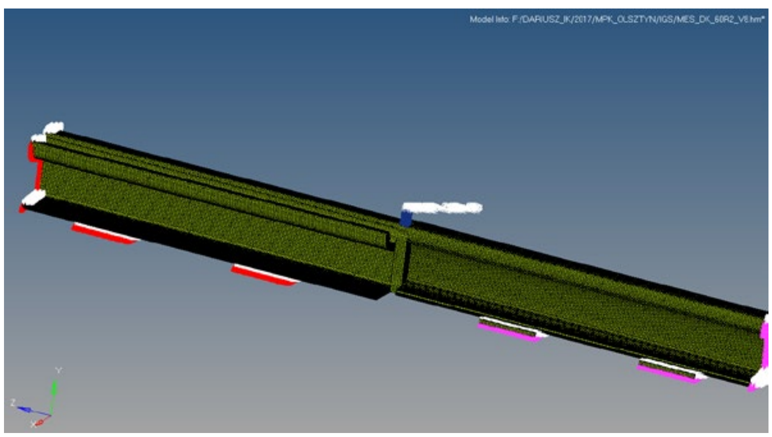

Fig. 7 Structure of rails 60R2 and 60E1 and their joint and loading scheme.

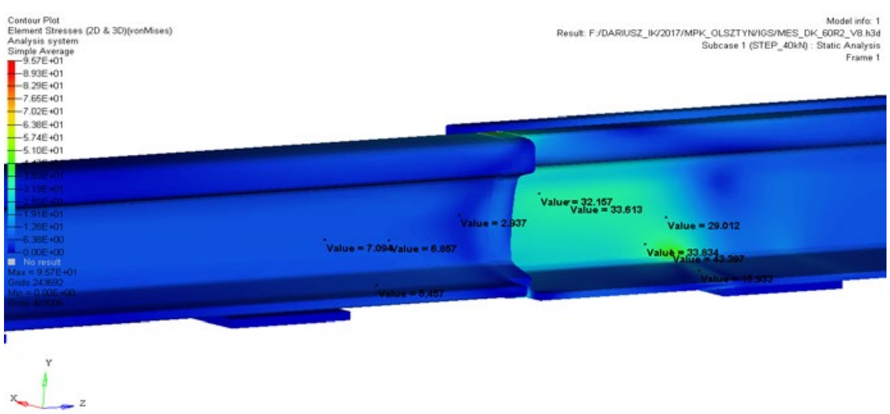

Fig. 8 Distribution of stress fields according to von Misses.

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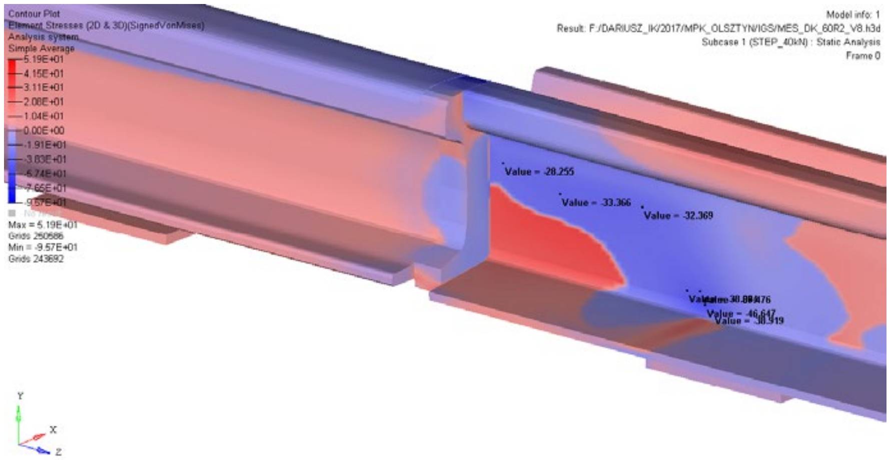

Fig. 9 Distribution of stress fields in the rails 60R2 and 60E1, and their joint.

Conclusions of the FEM analysis

For simulation: the 60E1 rails and 60R2 joint, which is 30 mm thick, while equiaxial and heads of rails layout is ensured, and with the use of symmetrical supports layout (defined the same edge condition) and the load of 40 kN placed at the joint (perpendicular to the rail head) it was found that for such a system in the area of-the 60R2 rail occurred higher stress than in the 60E1 rail for the same distance from the rail joint, and for the 60R2 rail occurred large differences in stress (+ 31 MPa, -50 MPa) in the close areas of the joint.

In the analysis of FEM residual stress has been ignored, which does not exist in reality.

Rail material after production process, transport and build into the track has its own residual stresses and in addition it is changed locally in the area rails joint made by the welding process (thermal impact, which also affects locally the structural changes of material).

The correct joint technology and other factors described in this article, as FEM calculation shows, are of crucial importance to the durability of the joint.

The FEM calculation showed that for symmetric load rail joint in the layout of the 60R2 and 60E1 rails, stress occurs in the 60R2 rail than 60E1. In addition, in the 60R2 rail web a big difference in the stress of compression and stretching occurs. Having regard to that fact and thermal stresses created during joint producing, it can be concluded that this area is particularly vulnerable to cracks. The load of 40 kN is not maximal but operational – at maximum tram axle loading it can be 55 kN. In addition, there should be taken into consideration track irregularities, its inclinations and curvatures, defects (lack of the ballast, absence of fastenings, etc.), and dynamic excess occurred during driving. In the adverse cases forces of about 70 kN can be present.

Summary

Problems with rail joints derive from the more difficult process of connecting the 60R2 rail type (profile less compact, more sensitive, higher stresses after thermite welding, in relation to the 60E1 rail profile). Due to the fact that there are no requirements for rail joints in the tram tracks, checking of them is provided during operation. Quite often there are joint cracks because the approved materials are not the only factor that guarantees high quality of the joints. Moreover, the technology is of great importance. The poor quality of the track works such as bad sleepers arrangement, bad construction of the track – lack of the ballast, improper operating fastening systems or their absence, etc. affect the increase of stress fields in the rail, and this can bring problems during operation of the track.

References

[1] PN-EN 14587-1:2007: Railway applications – Track – Flash butt welding of rails – Part 1: New R220, R260, R260Mn and R350HT grade rails in a fixed plant.

[2] PN-EN 14587-2:2009: Railway applications – Track – Flash butt welding of rails – Part 2: New R220, R260, R260Mn and R350HT grade rails by mobile welding machines at sites other than a fixed plant.

[3] PN-EN 14811:2006+A1:2010: Railway applications. Track. Special purpose rail. Grooved and associated construction.

[4] I. Miklaszewicz, Making and testing of the rail joints, Railway Research Institute, Warsaw, Railway Reports, 158, (2013) 35.

[5] B. Bogdaniuk, K. Towpik, Construction, modernisation and maintenance of the railway trucks, PKP, Warsaw, 2010.

[6] User ID-5 of the rails thermite welding, PKP, Warsaw, 2005.

[7] PN-EN 13674-1:2011: Railway applications. Track. Rail. Vignole railway rails 46 kg/m and above.

[8] PN-EN 14730-1+A1:2010: Railway applications. Track. Aluminothermic welding of rails. Approval of welding processes.

[9] PN-EN 14730-2:2006: Railway applications. Track. Aluminothermic welding of rails. Qualifications of aluminothermic welders, approval of contractors and acceptance of welds.

[10] Technical conditions WTWiO No ILK3d-518/1/08, joints making and acceptance of the new railway rails performed in the fixed plants. Requirements and tests, PKP, Warsaw, 2008.

[11] R. Wielgosz, Weld of railways rails, Technical Transactions, 106 (2-M) (2009), pp.7-19.

[12] Altair Engineering, Inc. Radioss and Optistruct Theory Manual 11.0 Version Jan, Large displacement finite Element Analysis (2011).

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