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welded joints, welding, structure, tensions, rail, heat treatment, joint, defect

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ANALYSIS OF FACTORS AFFECTING FRACTURES OF RAILS WELDED BY ALUMINOTHERMIC WELDING

The thermic welding of rails is carried out in the following sequence: a mould is placed on the rails to be joined; a crucible is mounted on a special bracket; a portion of thermite is charged; the rail ends are pre-heated and thermite is ignited by a special ignition primer. On Latvian Railway, the use of the thermic welding is widespread using the Elektro-Thermit Company technology. Today it is a basic method for rail joints.The analysis of the metal structure in the thermic welded zone of rails showed that the weld metal had inclusions of iron oxides infused (FeO, Fe_2O_3, and Fe_3O_4) and small pores. Pores and infused oxides are concentrators of stresses and sources of cracks development. Pores and infused oxides reduce hardness of the weld joint under the action of tensile forces.

To heat metal during the aluminothermic welding process, a powdery mixture of metallic aluminum (Al~22%) and iron scale (Fe_3O_4~78%) is used as a thermite.

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The following chemical reactions take place with a substantial liberation of heat:

$$Fe_2O_3 + 2Al = 2Fe + Al_2O_3 + \text{[Q heat calories]}; \quad (1)$$

$$3FeO + 2Al = 3Fe + Al_2O_3 + \text{[Q heat calories]}; \quad (2)$$

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where Fe – thermite ferrum (55-56% by weight);
$A1_2O_3$ - slag (44 - 45%), low-density aluminium;
Q - liberated heat, calories.

Thermite mixture burning takes place in reaction chamber (tigle) with that liquid metal gets into welding chamber 7 (Fig. 1).

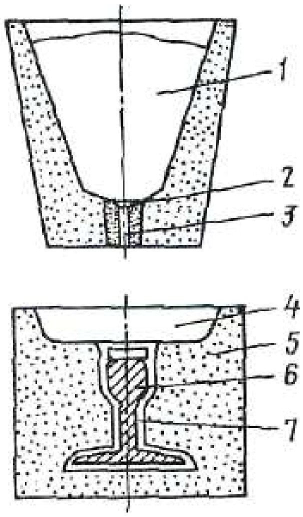


Fig.1. Rail aluminothermit welding scheme: 1 – thermite mixture in reaction chamber (tigle) ; 2 – melted plug; 3 – running channel; 4 – flush choke chamber ; 5 – fire-proof shape; 6 – welded rails; 7 – welding chamber

In ATW thermit metal fills joint gap. While coming from the tigle into the shape, liquid metal heats up rail ends till they melt together at 2400...2600 ^{o}C. During the work of welded rail joint, metal joint undergoes the same dynamic loading as rail steel that has better mechanical properties.

The change of scale oxygen balance on 1 % causes accordant changes in thermite caloric content on kcal/kg. In order to provide a total melting and evener heat distribution in all parts of the enclosure, the size of ferrous oxide grains must be between 0,3 and 5 mm. As the further research had shown, there are 10 mm big grains in thermite portions.

During the process of oxidizing, aluminum is able to release 378 kcal/mole of heat, while 198.5 kcal/mole are absorbed to reduce iron Fe from oxide Fe_2O_3. During this reaction 179.5 kcal/mole difference of the heat balance is obtained which is used for welding. Thus during the process of thermic reaction aluminum reduces iron oxides Fe_2O_3 , Fe O – Fe forming iron and the components in the crucible are heated up to 2600^{0}C.

On Latvian Railway, the use of the thermic welding is widespread using the Elektro-Thermit Company technology. Today it is a basic method for rail joints.

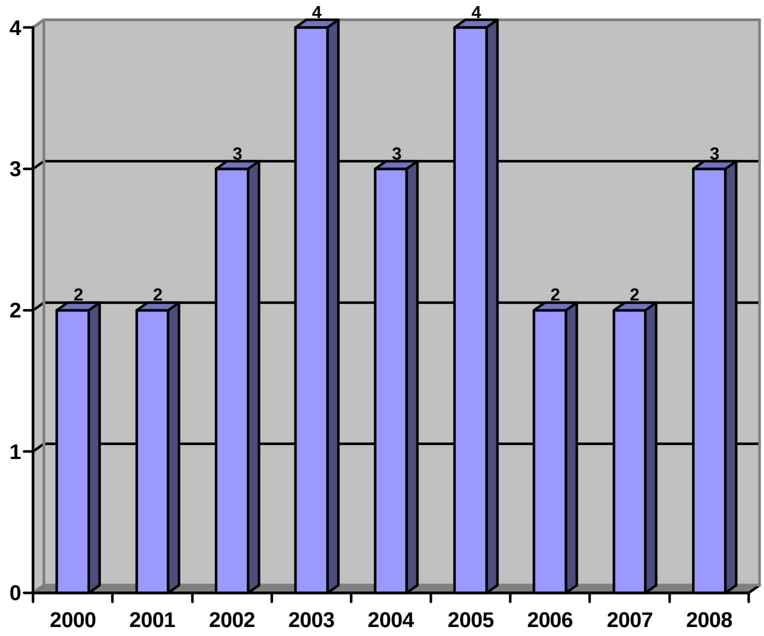


Fig.2. Thermic weld fracture on Latvian Railway

Experience of the operation of rails welded by the thermic welding showed that every year occur from 2 to 3 fractures of thermic joints on the main tracks between stations of Latvian Railway. In more cases these fractures of thermic joints are as shown in Figure 3.

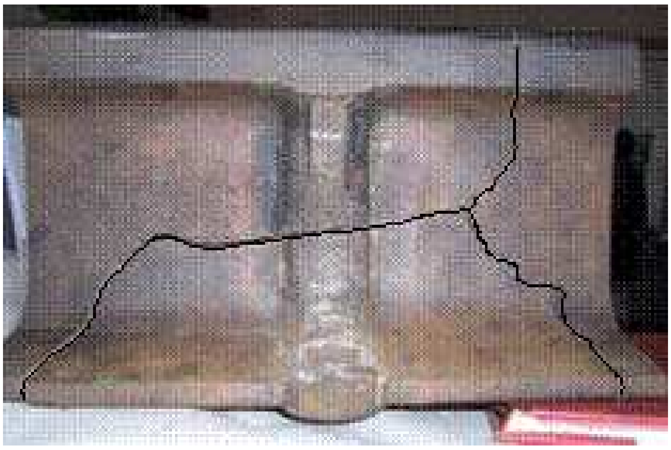


Fig.3. View of a thermic weld fracture

For the purposes of revealing stresses in the thermic weld, some scores were made transverse to the thermic weld along the horizontal axis of 6 rails 1.2 m of length with thermic joint in the centre.

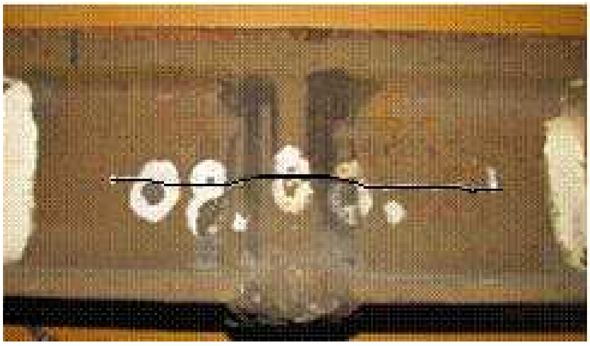


Fig.4. View of a thermic weld score and cracks revealed.

Rails for test were removed from the main railway network in service for more than 1 year. Continuous welded rails were welded using volumetric tempered rails P65 and UIC60 type with unhardened foot. All 6 rail joints welded by the thermic welding had through cracks of 200-300 mm of length on both sides of the weld joint alongside a score (see Fig.4). No load was applied to the rails with scores made on the lugs of the weld joint.

Such emergence of cracks in the weld joint alongside the scores indicates of great residual stresses in the weld joints made by the thermic welding.

In order to reveal the causes of fractures of the rail thermic joints, an analysis of the weld metal structure at the fractured thermic joints was carried out. For the purposes of the metal structure analysis, the section metallographic specimens were cut out from the thermic weld in the region of the rail head, web and foot.

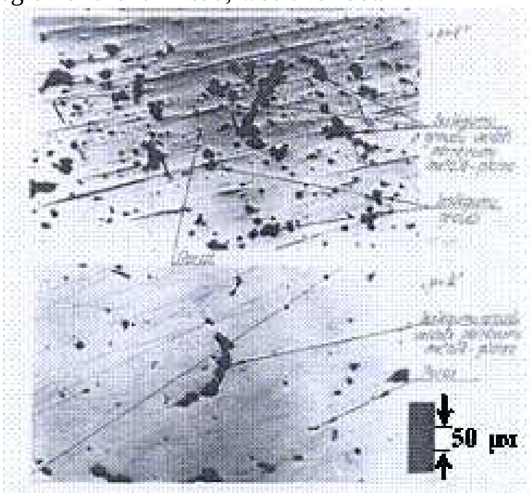
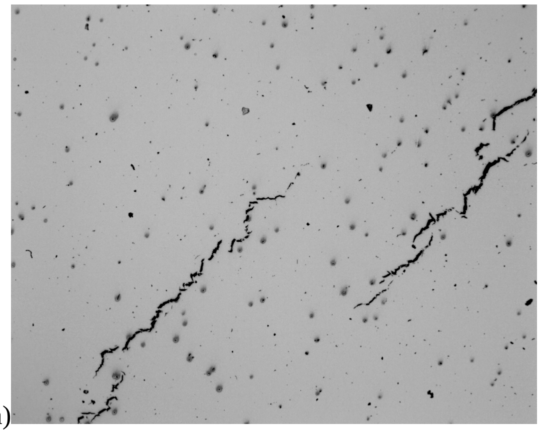


Fig.5. Structure of the thermic weld metal in the rail head

The analysis of the metal structure in the thermic welded zone of rails showed that the weld metal had inclusions of iron oxides infused (FeO, Fe_2O_3, and Fe_3O_4) and small pores (see Fig.5). The emergence of pores was caused by ingress of moisture into the thermite during the welding process on rails. Pores and infused oxides are concentrators of stresses and sources of cracks development. Pores and infused oxides reduce hardness of the weld joint under the action of tensile forces.


a)

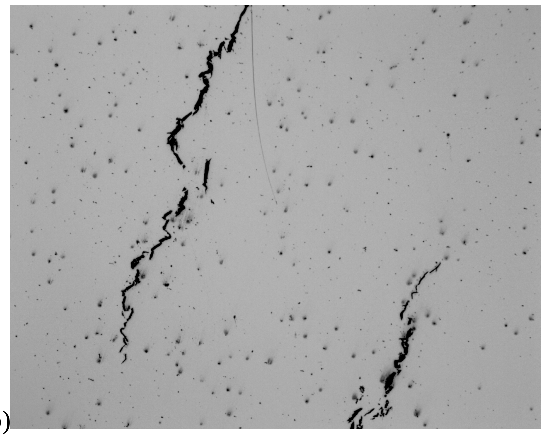
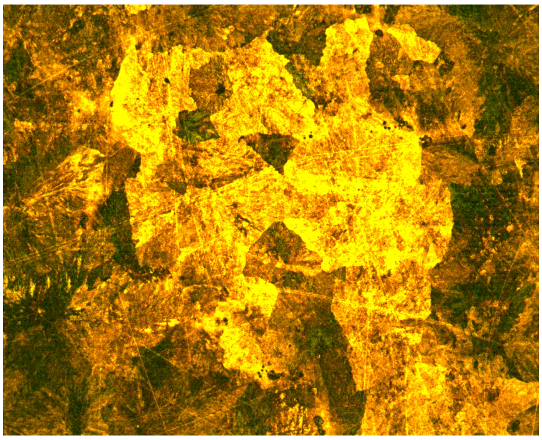
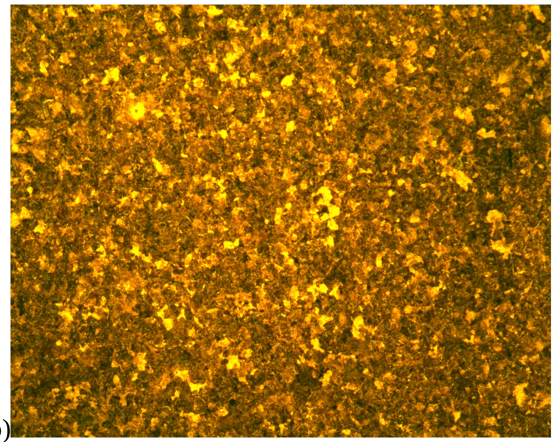

b)

Fig.6. Cracks in the structure of the rail, x5

Welded joint microstructure analysis showed that metal of these joints has hard-grained pearlite-ferrite structure (Fig. 7 a), but the structure of welded rail (Fig. 7 b) is fine and typical for rail metal. The grains are of various shapes and sizes. All of this points at incomplete crystalline transportations.



a)



b)

Fig.7. Microstructure of aluminothermit joint pickled polished section: a) in the zone of aluminothermit joint x200; b) in the metal of welded rail x200

In accordance with EN- 13674-1:2003 and ГОСТ Р51685-2000 the macrostructure of metal must not be nonhomogenous (no speckle segregation, rippled surfaces, lemon and black spots, blowholes, foreign metal and cinder inclusions allowed). Because of the presence of such inhomogenuities rail steel has a short life and is exposed to the growth of defects. The chemical composition of metal in damaged aluminothermit joints complies with the requirements of standards, but in some cases an insignificant excess of carbon, silicium, chrome and manganese is detected. In fact, this does not affect the mechanical properties of cast welded rail joints. As the researches shown, the reasons of breakage are tensile temperature forces that are caused by the cooling of rails, defects in welded joint metal and dynamic load of rail transport.

Tensile strength tests of aluminothermit welded rail samples (welded at the air temperature of +10 ^{0}C) have been done to estimate their strength properties. Test samples were prepared from hardened type P_60E1-T rails. In accordance with EN-13674 strength tests have been conducted for the following:

- main rail head metal;
- aluminothermit welded rail head metal;
- welded joint HAZ metal in the rail head with the least hardness;
- aluminothermit welded joint metal of HAZ with the least hardness in rail base zone.

It was found out in the result of strength tests of rails with aluminothermit welded joints that joint metal and welded joint HAZ tensile strength is 6...30% lower than tensile strength of welded rails. Tensile strength of welded rails of one sample turned out to be lower than the regulatory value. In line with EN-13674, type P_60E1-T rail of 350HT steel regulatory value of tensile strength must be at least 1175 H/mm^2.

The analysis of the thermite structure showed that some elements of iron scale Fe3O4 and Fe_2O_3 have dimensions of 5-6 mm (Fig.8), while, according to the standard, their dimensions should not exceed 1-2 mm.

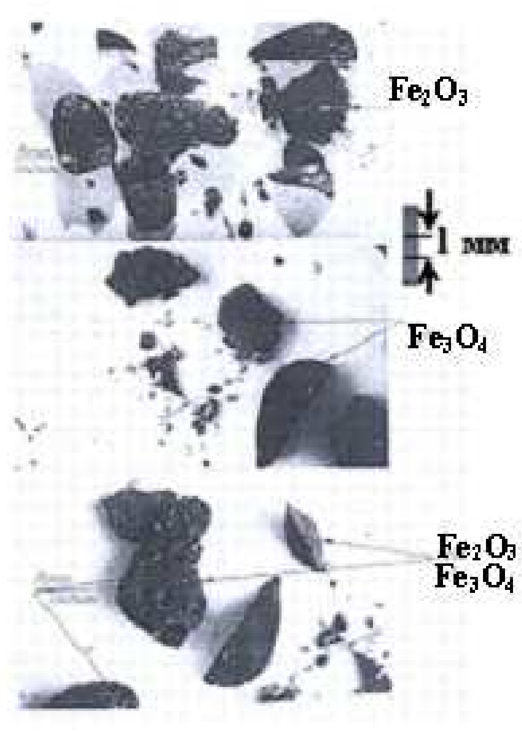


Fig.8. Structure of the thermite

Only at such conditions iron oxides have time to fuse at the temperature of 2600 ^{0}C. Just iron oxides remaining in the weld joint originate cracks formation in the weld metal and reduce its strength.

CONCLUSIONS

As a result of the examination of the factors which affect joints fractures of the rails welded be the thermic welding, the following was established:

- high internal residual stresses are concentrating at the zone of the thermic joint in volumetric tempered rails;
- there are pores and infused iron oxides in the thermic weld which originate cracks formation and reduce weld strength;
- some part of iron oxides (FeO, Fe_2O_3 and Fe_3O_4) of the thermite produced by the ELECTRO-THERMIT Company have dimensions of 5-6 mm and not always may be fused during the thermic welding of rails.
- metal in aluminothermic welded joint and HAZ has fine pearlite-ferrite structure with low strength and elasticity;
- welded rail sample static tests showed that in 75% of cases joint breakages happened in the result of 1200÷1300 kN load action which is lower than the design load 1372 kN.
- rail sample and aluminothermit welded rail tests showed that tensile strength of welded joint and HAZ of aluminothermit welded joint amounts 892÷1081 N/mm2, which is 10-24% less than the tensile strength of an ordinary rail (1173÷1204 N/mm2).

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