A STATE-OF-THE-ART OVERVIEW OF TRAMWAY RAIL RECONDITIONING BY SELF-SHIELDED FLUX-CORED ARC WELDING IN COMPLIANCE WITH EUROPEAN QUALITY REQUIREMENTS FOR WELDED STRUCTURES

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Abstract: An effective technical-economic way to increase the operational life of the urban transportation infrastructure is to recondition the tram rails. With an emphasis on the metallurgical behavior of rail steels, the risks of diffusible hydrogen, and the management of the thermally impacted area, this paper discusses the application of self-shielding hollow wire welding (FCAWS) for the repair and restoration of tram tracks. Solutions for automated weld loading reconditioning are shown, and the relationship between this procedure and the quality standards set by the European standard SR EN 1090 for welded constructions is examined. The importance of standards in guaranteeing the sustainability and security of urban railway infrastructure is emphasized.

Keywords: tram rails, FCAWS, welding reconditioning, SR EN 1090, automatic welding, urban infrastructure.

1. INTRODUCTION

Urban rail transport infrastructure is subjected to severe mechanical stresses, characterized by cyclical loads, intense wear and repetitive shocks in the wheel-rail contact area. Especially when cornering and passing through cranes, tram tracks show accelerated road surface degradation. Complete rail replacement involves high costs and major traffic disruptions, which is why welding reconditioning has become an increasingly widely used solution.

The literature highlights the fact that load welding allows the reconstruction of the track profile and the restoration of the functional parameters of the rails, without dismantling them from the infrastructure [1]. In parallel, recent European standards, in particular SR EN 1090, impose strict requirements on the quality of execution of welded steel structures, including for elements subject to repeated stress, such as railway infrastructure components [2].

2. PARTICULARITIES OF RAIL STEEL AND IMPLICATIONS FOR WELDING

High carbon and manganese steel are used to make tram rails, which are intended to offer strong resistance to wear and contact fatigue. Because of this chemical makeup, the material has a high carbon equivalent, which makes it less weldable and more prone to cracking, particularly in the thermally affected region (ZAT). ZAT is susceptible to the development of hard martensitic structures during the welding of 49E2 type rails, particularly in the coarse-grained region. Diffusible hydrogen and these structures can cause cold cracking, necessitating stringent technological precautions including preheating and careful welding parameter management.

3. SELF-PROTECTION TUBULAR WIRE WELDING (FCAWS)

Self-shielding hollow wire welding (FCAWS) is characterized by shielding gas independence, increased mobility, and high adaptability for field repair work. These advantages recommend it for urban tram infrastructure, where access and intervention time are limited.

Figure 1. Particularities of rail steel and implications for welding

However, FCAWS is associated with a higher diffusible hydrogen content in the deposited metal compared to gaseous shielding processes, especially in the welding of rail steels with low weldability. In this context, the correct selection of wire, classified according to SR EN ISO 17632, as well as the use of preheating and controlled deposition sequences, are essential to avoid hydrogen-induced cracking.

Figure 3. Self-Protection Tubular Wire Welding (FCAWS)

4. TRAM RAIL RECONDITIONING BY AUTOMATIC WELDING

An automated system for repairing tram rails by welding loading utilizing a mobile machine that is computer-programmed and controlled is described in the work published in [1]. This technology ensures that the track's original geometric profile is restored by precisely depositing filler material only in worn sections. By operating directly on rails installed in concrete or asphalt, the machine drastically cuts down on intervention time and does away with the need to disassemble the track. The welding parameters can be adjusted in real time based on the wear level thanks to the computerized process control, producing consistent seams with few flaws and regulated hardness.

According to the experimental data reported in the paper [1], the filler materials, type EN1470 T Fe 9, are manganese steels that show self-hardening behavior in operation, providing high resistance to metal-to-metal friction and shocks.

Figure 4. Tram rail reconditioning by automatic welding

5. CORRELATION OF WELDING PROCESSES WITH THE REQUIREMENTS OF SR EN 1090

The European standard SR EN 1090 sets out the general framework for the execution of welded steel structures, including requirements for traceability of materials, qualification of personnel, welding procedures and levels of control and verification. Although the standard is mainly designed for load-bearing structures, its principles are also relevant for railway infrastructure, especially for elements subject to repeated stress and fatigue.

According to [2], structures such as bridges or railway components are usually classified in higher performance classes (EXC3 or EXC4) due to the high consequences of a breakdown and cyclical stresses. The application of welding procedures for the reconditioning of tram tracks must therefore comply with the same principles of quality control, even if the interventions are local and maintenance related.

Figure 5. Correlation of welding processes with the requirements of SR EN 1090

The integration of FCAWS and automated reconditioning systems within SR EN 1090 requirements involves:

- qualification of welding procedures.
- use of competent personnel in the coordination of welding.
- the application of visual and non-destructive tests appropriate to the level of risk.

6. COMPARISON BETWEEN FCAWS AND ALUMINOTHERMIC WELDING FOR TRAM RAILS 49E2

6.1. The role of aluminothermic welding in railway infrastructure

The most common continuous connecting method for railroad and tram rails is aluminothermic (AT) welding. The method, which produces molten steel through an aluminothermic exothermic reaction, enables the rail to be connected without the need for external electricity. Aluminothermic welding is standardized and commonly used for permanent rail junctions because of its durability and repeatability. Aluminothermic welds, however, may have internal flaws such porosity or inclusions that can serve as crack initiation sites under cyclic load conditions characteristic of tram operation, according to studies on rail damage tolerance [3].

Figure 6. Comparison Between FCAWS and Aluminothermic Welding for Tram Rails 49E2

6.2. Fundamental differences in processes

From a technological perspective, aluminothermic welding and FCAWS differ fundamentally:

- Aluminothermic welding is a localized casting process, characterized by limited post-reaction control of thermal cycles and solidification.
- FCAWS is a controllable heat input arc welding process, allowing for multi-layer deposition and local adaptation of welding parameters.

This distinction explains why FCAWS is primarily considered for repair and maintenance operations, while aluminothermic welding remains dominant for permanent longitudinal joints.

6.3. Metallurgical aspects and heat-affected zone (HAZ)

The carbon equivalent values of railway steels that comply with EN 136741 standards, including profiles like 49E2, are comparatively high [8]. Welding steels on rails creates primitive grit in HAZ areas with high hardness, which enhances susceptibility to cracking, as Mansouri and Monshi [4] showed. Due to extended temperature exposure and substantial microstructural variability, the HAZ in aluminothermic welding is often large. Although HAZ is more limited in FCAWS, Kou [5] noted that harsh martensitic structures can result from inadequate control of heat input and cooling rates. Therefore, although they are of distinct kinds, both procedures provide metallurgical issues.

6.4. Hydrogen-induced cracking and process sensitivity

The absence of hydrogen introduced by aluminothermic welding greatly lowers the likelihood of hydrogen-induced cold cracking, which is one of its main advantages. On the other hand, FCAWS is particularly sensitive when applied to high-carbon equivalent rail steels since it is known to introduce larger levels of diffusible hydrogen. Diffusible hydrogen was identified by Farhangi and Mousavi [5] as a crucial component of FCAWS, necessitating stringent technological measures such preheating, controlling heat consumption, and using consumables that are low in hydrogen according to EN ISO 17632A [9]. Such precautions are also required for the safe application of FCAWS on railway steels, according to industry requirements [10].

6.5. Fatigue behavior and defect tolerance

Zerbst et al. [3] suggest that the size and distribution of the flaw, not the nominal strength, control the fatigue performance of welded rails. Internal casting-related flaws in aluminothermic welds could spread under repeated wheel-rail contact loads. Wang et al. [6] showed that the mechanical characteristics of damaged rails may be successfully repaired for FCAWS repair welds; nevertheless, the transition zone between the deposited metal and the base steel is still crucial for fatigue resistance. In contrast to aluminothermic welding, FCAWS minimizes the volume of thermally affected material by enabling localized interventions.

6.6. Practical applicability in tram infrastructure

From an operational point of view:

- Aluminothermic welding is best suited for permanent rail joints, offering high standardization and acceptance, but limited flexibility for localized repairs.
- FCAWS offers high mobility, shielding gas independence, and adaptability to urban environments, making it suitable for repair, welding, reprofiling, and maintenance tasks.

  However, FCAWS requires rigorous control of welding parameters, consumables, and preheating to ensure metallurgical safety.

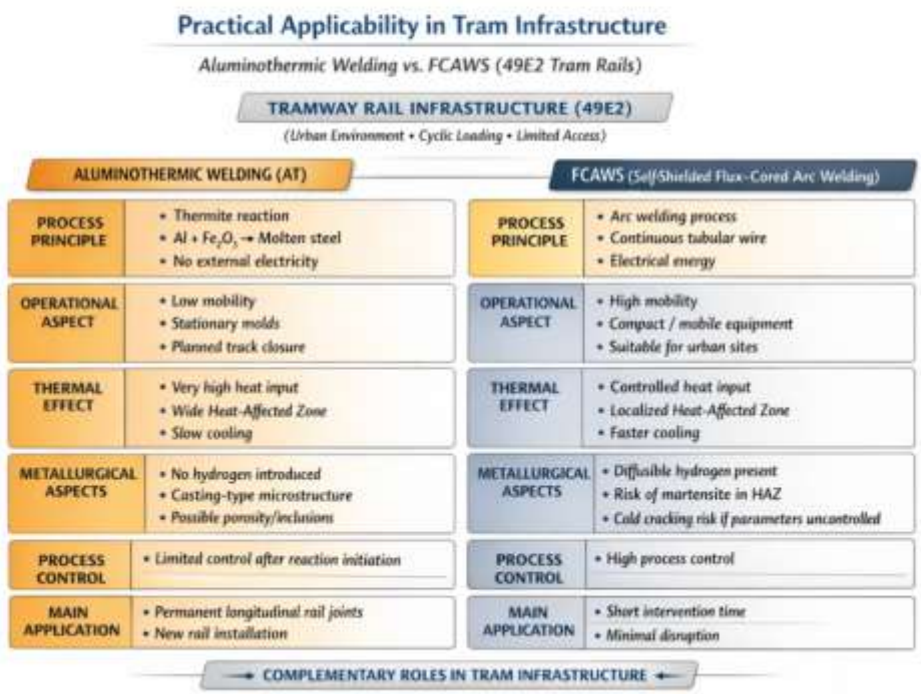

Figure 7. Practical applicability

Table 1. Comparative summary

Criterion	FCAWS	Aluminothermic welding
Process control	Up	Limited
Hydrogen risk	High (managed)	Very low
HAZ Expansion	Localized	Wide
Fit for repairs	Excellent	Limited
Permanent joints	Conditional	Excellent
Standardization	Moderate	Up

7. DISCUSSIONS

The literature review shows that welding with self-protective wire should not be seen as a direct alternative to the established processes for making permanent rail joints, but as a complementary technology, optimized for local repairs and reconditioning. Its mobility and flexibility advantages are outweighed by the need for rigorous metallurgical control, especially for diffusible hydrogen.

At the same time, the use of automated reconditioning systems contributes significantly to increasing the quality and reproducibility of welds, reducing the influence of the human factor and ensuring compliance with the technological parameters imposed by European standards.

The comparative study demonstrates that FCAW S is not a suitable substitute for aluminothermic welding in the fabrication of tramway rails. Rather, if hydrogen control and heat management are properly applied, FCAW S is a supplementary technology that is especially useful for 49E2 rail maintenance and repair.

8. CONCLUSIONS

Based on the analysis carried out, the following conclusions can be drawn:

1. The reconditioning of tram tracks by welding is an effective solution for increasing the lifespan of urban infrastructure.
2. The FCAWS process is particularly suitable for repair and maintenance, due to its mobility and adaptability.
3. The main limitation of FCAWS is the risk of hydrogen-induced cracking, which must be controlled by strict technological measures.
4. Automatic welding systems make it possible to obtain uniform seams with appropriate mechanical and wear properties.
5. Matching reconditioning processes with the requirements of SR EN 1090 is essential to ensure long-term quality and operational safety.
6. According to the literature review, rail steels that meet EN 13674 1 standards have high carbon equivalent values, which makes them more vulnerable to harsh microstructural changes and welding cracking. In this regard, aluminothermic welding and FCAW S both provide unique metallurgical problems that need to be solved with the right technological solutions.
7. Aluminothermic welding is especially well-suited for permanent longitudinal rail junctions because of its high uniformity, toughness, and lack of hydrogen introduction. Its casting-based construction, however, restricts control over microstructural development and temperature cycles, and internal flaws may endure and affect long-term fatigue behavior under cyclic wheel-rail loads.

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