Increasing the endurance of railways

G Garleanu¹, D Garleanu¹, C Borda¹, V Popovici¹ and A T Gheorghian²
¹University Politehnica of Bucharest, Department of Materials Technology and Welding, CE 205, Splaiul Independenţei nr.313, sector 6, Bucharest, Romania
²University Politehnica of Bucharest, Department of Thermodynamics, Motors, Heating and Refrigeration Equipment, CG 008, Splaiul Independenţei nr.313, sector 6, Bucharest, Romania

Abstract. The paper presents an innovative technology for increasing the endurance in the operation of the railway by mechanized loading with welding and an optimization for the choice of addition material using finite element method – FEM. In the first part of the paper there are presented specific defects of the railway paths and the loading technology by welding with different materials. Load technology is based on a mechanized welding installation that successively deposits welds on the horizontal running surface. The welding process chosen is of MAG type with tubular wire with/without protection gas. The welding length is 24 m. They are presented metallography, welding structures and hardness values depending on the additive material used. In the second part of the paper there is presented a FEM modelling of the welded layer for each used material. The values of the obtained mechanical properties, hardness, tensile strength, resilience, were compared with the real properties. In this way, one can predict the values that can be obtained both in the deposited layer and in the base metal. Depending on the type of stress, contact pressure, travel speed, rolling friction, etc. it is possible to make an optimal choice of the addition material meaning mechanical properties - price - endurance. There is no possibility of access for the operator; thermodynamics - heat exchangers, indifferent of the type of construction, with pipes, plates or spirals; Industrial plants - pipeline; metal structures of any kind - bridges, boats, halls, buildings; automotive industry - construction or repair.

1. Introduction
The railways are steel bars laminated according to a certain profile, used as a driveway for a wheeled vehicle: train, tram, technological bridges or guiding driveways for certain mobile parts in a technical plant. The composition and mechanical properties of the rail are different and are selected depending on the place of use. For economic reasons, the rails are made of unalloyed or low-alloy carbon steel with a high content of carbon from 0.6 to 0.9%, thermally treated or not. The hardness value is about 250-400 HB. Certain parts of the driveway, such as: point rails, frogs, etc., are made of manganese steels, highly alloyed with Cr, Mn and Ni.

The rails are subject to different kinds of mechanical stress, such as: compression, tension, friction, shock, bending, weariness, etc. Due to these stresses, after a period of use, it appears a quite pronounced wear and the rail must be replaced or reconditioned through loading by welding. The present paper treats the rails without channel, the loading being performed on the running surface.

Generally, according to the stress mode, the following types of wears can appear, which can be reconditioned by loading through welding: lateral wear and vertical wear. The lateral wear usually occurs in curved rails, which describe a circular arc. The vertical wear occurs mainly because of
friction force and specific weight between the wheel and the running surface. Generally, the running bridges have a load (weight) on the wheel that is quite big, between 1-100 tons/wheel. This leads to a very high value of the contact pressure (compression stress) wheel/rail. Under these circumstances, wear and deformations can be noticed on the rail and wheel running surface, the phenomenon of material flowing occurring, phenomenon that can be acknowledged by the occurrence of the lateral barb, see figure 1. This barb is cut by the lateral guidance of the wheel, with its passage from one direction or the other.

![Figure 1. Rail without channel – the wear of the driveway with the flowing phenomenon.](image)

In addition to the flowing phenomenon, a reduction of the contact surface between rail and wheel was noticed, this contact surface being reduced up to 25% (visibly being a shiny surface), increasing therefore the crushing phenomenon, see figure 2.

![Figure 2. Rail without channel – the contact surface is only the shiny one.](image)

The biggest wears, and which appear quickly are those in areas of rail curvature, where the tram must change its travelling direction with an angle of minimum 90 degrees. In case of a normal traffic, these rails must be replaced or reconditioned every 2 years.

The phenomenon is even more intense in the joints area, where one rail ends and the other begins, where, in addition to the static stress, there is also a high enough shock stress, leading in time to the occurrence of basins (rail depressions).

All these processes occur continuously, leading in time to the pronounced wear of the driveway, to the decrease of the rail’s height or of its width in the case of the rail with channel. To solve these problems, the rail can be replaced or reconditioned through the loading by welding.

The solution with the lowest costs is the loading by welding, for there are no longer performed infrastructure works. The loading can be made with different materials, meaning different mechanical properties, variable endurance and different multiple costs, and with a manganese steel, and thus the service life increases of approximately 2-3 times.

2. Current condition

During the use of heat exchangers, various phenomena arise due to fluid flow velocity, viscosity, and hardness of the micro particles in the fluid. Currently, this reconditioning is done through the loading by welding by the processes: S.M.E.I. welding with coated electrode or MIG / MAG, with full/ tubular
wire, in case of semi-mechanized welding being possible to use some devices running the loading by welding, but on relatively small lengths (1-2 m).

The disadvantages of the current technology are:

- low productivity;
- being a manual loading process, the quality of the work is subject to the qualification and the physical and psychic condition of the welder. Very high probability of occurrence of some defects specific to the process;
- the surface resulted after reconditioning has many geometrical discontinuities, requiring extensive grinding works in order to obtain the appropriate geometrical configuration;
- high level of physical stress of the workers, welders and locksmiths, due to the uncomfortable working position, the rail being at the ground level;
- additional measures to maintain the qualities of the filler material in the case of interventions through the SMEI process (calcination of electrodes, maintaining in cabinet dryers, using the waterproofing jackets, etc.).

Tractors are known for linear or circular seam welding, the adjustment of the parameters being done from a control desk. The driveway of these welding tractors is independent from the loading rail. Because of this, the driveway positioning and fixing is made with difficulty, and multiple adjustments on at least 2 axes are required during welding. The operator is always present, performing adjustments continuously to maintain a constant position of the torch gun from the piece. If the adjustment is made late or it is not appropriate, the welding lacks quality and may have various defects, such as: lack of fusion, pores, side burning etc.

Another problem is the misuse of the wire type for the MAG welding. Most often, it is welded with full wire, being absolutely necessary to use a protection gas. If the facility is used in open field, very often, because of air currents, the protection gas is deviated, the metallic bath remaining without gas protection. This will automatically lead to the development of some defects in the welding strap, the respective areas being then repaired by the SMEI process.

3. Modernized reconditioning technology

In order to repair such defects, we started from the analysis of several constructive variants of liquid-cooled pistols. The technical problem solved by this new reconditioning technology through welding is the use of an automatic facility and of an auto-protection tubular wire.

The welding process proposed is MAG. The driveway used for the movement of the welding facility is actually the rail to be reconditioned. In this way, the length of the welding strap is practically unlimited. The welding straps are positioned dependent on the modification of the geometric configuration, due to a mechanical detector, in the form of a copper skid.

The filler material used is from the manganese steels group. The MAG welding head is fastened by a positioning device, see figure 3, which allows its positioning on several directions. The welding device is mounted on a mobile cart, which moves on the drive rails by means of an actuator. On the mobile cart there are also mounted the following: an electronic device for the automatic adjustment of the working parameters, the welding equipment, including the filler material.

The positioning device comprises a mechanical positioning system on 2 axes and a cylinder – fork, which supports two arms, the upper and the lower one. The mechanical positioning system allows the adjustment of the distance of the torch gun from the horizontal ax by triggering screw “1”. On the upper arm “2”, the welding torch gun is fixed into couple no. 3. This coupling allows the positioning of the head on other two directions, vertically and along the rail.
On the lower arm the mechanical sensor (detector) is mounted, a skid 4 to support the bath of molten metal and to track the drive rail subject to reconditioning. This also ensures the continuous positioning of the welding head (see figure 5) without the operator’s intervention. The adjustment of the welding torch gun is made only at the beginning of the welding process.
This article presents the loading by welding of some rails of Burbach A65 type, on a length of 100 m using the welding facility presented above. The width of the rolling surface is of 65 mm. Through welding there have been deposited 7 rows with a single layer, using 3 types of wire, namely:

1) Lincore 33, low alloyed steel, see figure 6a:
   - the chemical composition is the closest to the rails’ composition, 0.2% C; 2.1% Mn; 0.7% Si; + 1.3% Cr and 1.8% Al;
   - the hardness obtained after welding was between 28 – 30 HRC;
   - hardness after cold-straining 30 – 34 HR;
   - the super-elevation is uneven;

2) Lincore M, manganese steel, see figure 6b:
   - the chemical composition 0.6% C; 0.4% Si; + 13% Mn and 5% Cr;
   - the hardness obtained after welding 30 – 32 HRC;
   - after cold-straining 40 – 45 HRC.

3) Lincore 15CrMn, manganese steel, see figure 6c:
   - the chemical composition 0.4% C; 0.3% Si; + 15% Mn and 16% Cr;
   - the hardness obtained after welding 26 – 28 HRC;
   - after cold-straining 38 – 42 HRC.

The parameters of the welding conditions were: $I_s = 290 – 300$ A, $U_s = 28 – 30$ V, Welding speed $= 40 – 45$ cm/min. It can be noticed from the macroscopic images (figure 6) the thickness of the deposited layer and area of thermal influence.

Analyzing the 3 samples, the following have been acknowledged:

1) in terms of metallographic structures, version 1 is the best and cheapest, but with the lowest hardness value, thus with low endurance;
2) in terms of endurance, version 3 is the best, but it is also the most expensive;
3) the version which best suits the analysis criteria, ensuring the best endurance/cost price/metallographic structure is version 2.

Figure 5. The welding device and the rail to be reconditioned; 1 - screw; 2 - upper arm; 3 - couple; 4 - skid.
Figure 6. Microscopic images of the welding:

(a) welding with Lincore 33; (b) welding with Lincore M; (c) welding with Lincore 15CrMn.

The welding technology and the facility proposed for use has the following advantages:
- very high productivity, the process being limited only by the depositing rate of the filler material and by the process used;
- the execution quality does not depend on the qualification or of the physical - psychic condition of the welder;
- in case of reconditioning the side wear, by using a skid to support the bath, it is ensured a geometry appropriate to the reconditioned area, being necessary only a superficial finishing polishing;
- high efficiency of use of the filler material;
- the possibility of reconditioning on long lengths;
- being a fully automated process, the monitoring by the welder is made intermittently, no adjustment being made during the welding process, thereby decreasing the welder’s demands;
- the number of risks from the point of view of labour safety are greatly diminished;
- the machine is achieved in a sturdy construction, its movement being made only on the rails being reconditioned, practically not being any risks of shock occurrence that may affect its proper functioning;
- it decreases the risk of occupational and labour illness due to the intermittent monitoring of the process, the operator being at an appropriate distance from potential hazards;
- the possibility of automatic adjustment of the parameters of the welding regime depending on the variation of the value of the existing wear on the length of the rail, thus obtaining an appropriate geometric configuration and an important increase in productivity.

The samples reconditioned were tested in a certified laboratory, and the results were above expectations, thus achieving a special quality of the rails of the driveways, with metallographic structures that behave well to the wear of metal on metal and do not show defects (pores, cracking, lack of fusion).

In addition to the device used, mechanical effects on the rail have been studied. By means of finished item programs, the efforts from the rail contact area and its deformation according to the deposited material have been studied. It was started from the weight stress of a bridge of 40 tf, distributing its weight on 4 wheels with diameter of 450 mm. Making the calculations necessary related to the contact pressure, the following data resulted:

1) for the unloaded rail,
   a. Vertical deformation, in our case axis “Y” is of 0.294mm, see figure 7a;
   b. Vertical movements see figure 7c;
   c. Translation along the rail, see figure 7e;
   d. Internal tensions Von Mises in contact area 325,806 see figure 8a;
2) for the reconditioned rail

a. Vertical deformation, in our case axis “Y” is of 0.196 mm – see figure 7b;
b. Vertical movements, see figure 7d;
c. Translation along the rail, see figure 7f;
d. Internal tensions Von Mises in contact area 300.257 see figure 8b;
e. Internal tensions Von Mises in section, see figure 8d.

Figure 7. FEM for the unloaded rail and for the reconditioned rail.
After the finite element analysis of the deformation of the structure in a plane parallel to the contact area, located at approx. 5 mm, the displacement of the points on the height of the rail was plotted (figure 9, a). It can be noticed that there was a reduction of the deformation of the rail after reconditioning (figure 9, b).

![Figure 8. Von Mises stress in contact area and in cross section.](image)

![Figure 9. The deformation of the structure for the unloaded and reconditioned rail.](image)

4. Conclusions
The new technology of mechanized loading by welding allows the reconditioning of the driveways, with or without channel, used for the transportation of passengers/ goods or in the industry for the technological bridges. The loading technology is based on a welding facility with mechanical detector, by which the loading can be achieved both on the horizontal rolling surface and on the side surface, the guiding one. The welding process chosen is MAG with tubular wire with/ without protection gas,
using 3 types of filler materials, 2 manganese steels, 1 low steel alloyed with Cr. The advantages of this technology are given by the possibility of local loading of the driveways, as well as the increase of the service life by approximately 2-3 times.

The technology presented above can be applied to any type of rail at low costs and with very good results; with this new facility, the rails may be very easily reconditioned in curves or in straight line, leading to a cost reduction by 25-40% compared to the usual technologies or the costs related to their replacement.

The metal layer deposited is more resistant than the base material. The service life of a rail may increase 2 to 3 times after a process of reconditioning. The reconditioning process can be carried out several times.

The loading material must be a self-protection wire and it is chosen depending on the chemical composition of the rail to be reconditioned. The grinding of the loaded area is not always necessary. However, if necessary, the grinding can be made using an oval stone.

The productivity obtained after the modification of the technology is very high due to the use of the mechanized welding facility with mechanical detector, the length of the strap being no longer limited.

5. References

[1] Borda C 2015 Technology of materials Bucuresti
[2] Solomon G 212 Curs de Inginer Sudor Internațional [International Welder Engineer Course] /European IWE/EWE, Chapter 2.16 Oțeluri înalt aliate (inoxidabile) [Highly Alloyed (Stainless) Steels], ASR
[3] Micloși V, et al 1984 Basics of Welding Processes (Bucharest: Didactică și Pedagogică Publishing House)
[4] Gărleanu G 2007 Informatization and optimization of technological processes (Bucharest, Romania: PRINTECH Publishing House)
[5] Gărleanu G 2014 Course on Welded Structures Design - Course Notes (Bucharest: Bren Publishing House)
[6] Welding Processes Welding handbook vol. 2 8th Ed. 1991 (Miami: American Welding Society)
[7] Zgură G, Răileanu D and Scorobetiu L 1983 Welding Technology by Melting (Bucharest: Didactică și Pedagogică Publishing House)
[8] Gărleanu G, Mazareanu G and Dedu I 2001 Dispozitiv de sudare a cailor de rulare a patent 25814
[9] Dehelean D 1997 Welding by Melting (Timisoara: Sudură Publishing House)
[10] Dehelean D 2012 International Welder Engineer Course / European IWE/EWE, Chapter 1.7 WIG Welding, ASR
[11] Repair and maintenance welding handbook ESAB 2010 https://www.scribd.com/doc/50014395/ESAB-Repair-and-Maintenance-Welding-Handbook
[12] Focus on welding www.fronius.com