RESEARCH ARTICLE

A Lowering Friction Treatment for Railway Materials

Frank Otremba*, José A. Romero Navarrete

Bundesanstalt für Materialforschung und-prüfung (BAM), Berlin, 12205, Germany
Federal Institute for Materials Research and Testing (BAM), Unter den Eichen 44-46, 12203, Berlin, Germany

***Corresponding author: E-mail: frank.otremba@bam.de**

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While the energy efficiency of railway transportation is quite high in comparison with that of the roadway transportation, there are still some aspects that preclude any greater efficiency for this transportation mode. Specifically, during the negotiation of turns, some locomotive energy is lost due to the rubbing of the wheels´ flange with the rail head, being the amount of such an energy a function of a multitude of parameters that are car- and track- related. In this paper, a carburizing treatment is proposed to reduce the friction between the rail and the wheel´s flange, involving the selective carburizing of the lateral surface of one of the rail head´s sides. The proposed furnace´s design is supposed to the installed next to the hot-rolling facility and includes the needed equipment to avoid decarbonization of the non-treated rail material

Introduction

Environmental regulations have posed new demands to generate a more energy efficient and less pollutant transportation [**1**]. However, improvements in railway transportation have been focused on increasing the wearing and fatigue resistance of the materials, without any specific consideration to save any locomotive energy that is significantly lost during turning maneuvers. In this respect, to resist the elevated steering and rolling forces linked to turning maneuvers, railway specifications exist, establishing the use of an upgraded specification for curved tracks [**2**], together with treated head rail profiles [**3**]. The specifications for these materials, however, include a maximum of 0.82 % of carbon content [**2**], regardless if an internal or an external rail is concerned. In this respect, a greater carbon content material is associated to a lower friction coefficient between sliding surfaces, which could decrease the turning resistance of railway cars, and improve this transport´s energy efficiency. However, a general reduction in the friction at the wheel-track interface, could pose risk to the transport safety and to the efficiency of the railway transportation, due to lower braking and driving capabilities of the resultant equipment. Nevertheless, a localized increase in the carbon content of the railway material, just on the vertical part of the rail´s head, could improve the turning efficiency of bogies while not compromising the safety and traction capability of this type of transport. It is on such a surface where the higher friction and rail wearing exist, as it is illustrated in **Fig. 1**.

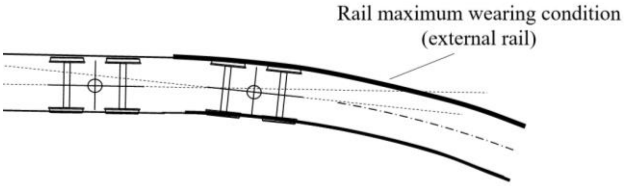


Fig. 1. Rails surfaces subject to higher wearing loads. *Source: own*.

In this context, it should be noted that carburizing parts in the railway industry is a very common practice, including some components of the bogies and other related parts [**4,5**]. However, to the knowledge of the authors, no previous rail materials have been subjected to this superficial thermochemical treatment. Nevertheless, some other steel products have been also subjected to a post-hot-rolling processing [**6**]. The increase of the carbon content in any sliding materials has been reported to significatively decrease the friction coefficient between the parts while increasing the overall wearing resistance of the sliding surfaces [**7**].

In this paper, a carburizing treatment is proposed for the lateral surface of the rail´s head, aiming at improving the railway energy efficiency during turning. An experimental setup is described, for the surface heat- and chemical- treatment proposed herein.

Rail head’s lateral surface selective carbon enrichment process

The superficial carburizing of the rail lateral surface can be carried out under different operating conditions and principles, including different environments: gaseous, solids (pack), liquid and plasma [**8**]. Such different treatments can be performed on a continuous or on batching schemes. The selection of the proper carburizing procedure should be based upon a number of requirements and needs. In this respect, apparently, the most efficient carburizing treatment is the plasma, however, such a process should be adapted to the selective treatment that is proposed in this paper, as a continuation of this research.

A conceptual design of a furnace aimed at selectively carburizing the rail head vertical surface´s is now proposed. This facility considers the relatively small amount of surface that needs to the subjected to this treatment, as well as the intricated shape of the rail head. This treatment is proposed in the context of the hot-rolled process to shape the rails.

The manufacturing of railway rails involves several sequential operations, covering from the conditioning of the billets to eliminate imperfections from the first pouring, to cutting the final products [**9**]. Between these two ends, the rail is hot-rolled, tempered under a controlled atmosphere to prevent decarbonization, straightened and then bended at the desired radius. While the temperature during the hot rolling is about 1250°C, the temperature for tempering is around 600°C [**10**]. Considering that the carburizing treatment of the rails should be carried out at 900°C, this process could thus be performed during the cooling process after the hot rolling. The overall manufacturing processing would thus be changed and would involve the necessary time for the carburizing process to take place. That is, to use the temperature condition of the rails to immediately proceed with the carburizing processing.

In this regard, the required selected carburizing process would be carried out through pack carburizing [**11**]. The carburizing facility should take into account that such a process is controlled by several variables, including the carbon potential of the carburizing agent, the exposure time and the temperature. These variables strongly influence the diffusion of the carbon into the iron matrix, in a rather complex way. The equation describing the dependency of the carbon flow into the steel matrix, F, states such a flow as a function of the eddy diffusivity κ and of the gradient of the concentration C with respect to a given axis, z for example. Such equation reads as follows [**12**]:

$$F = -\kappa \frac{\partial C}{\partial z} \qquad (1)$$

Fig. 2 describes the generic dependency of the carburizing depth on both the exposure time and the temperature [**13**]. The specific time variation for this carburizing process depends on the terms of equation (1), that is, of the carbonization potential, which depends on the carburizing environment and on the carbon content of the carbon-diffusion matrix. Consequently, the rates at which the carbon molecules migrate into the steel matrix, should be experimentally characterized, based upon experimental results in full-scale circumstances.

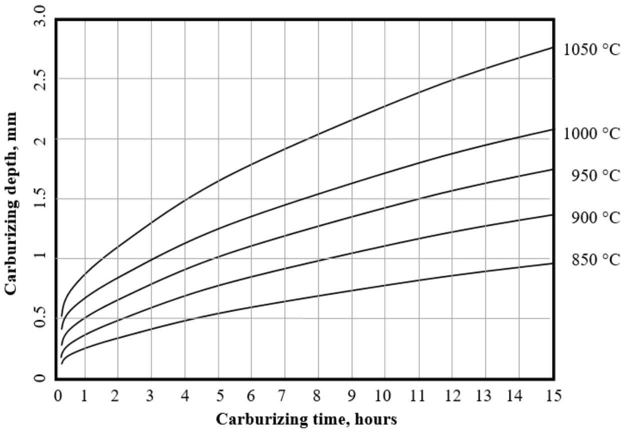


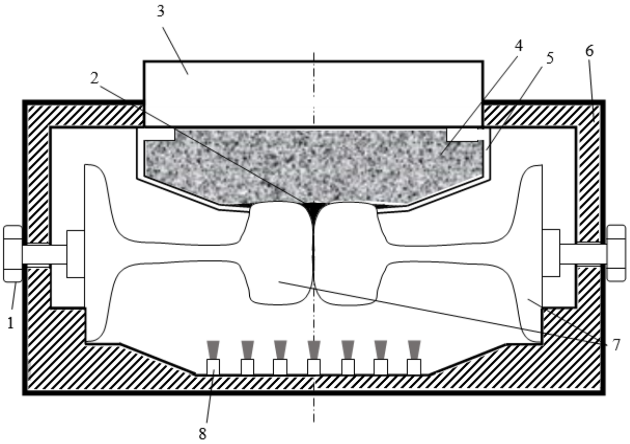
Fig. 2. Carburizing curves. *Source: own, with data from* [13].

On the other hand, any potential decarbonization of the rail´s steel, should be also minimized through providing a moderately carbon-enriched atmosphere around the material that is not subjected to the carbonizing process. In this respect, there are heat sources which could provide both the heat for the diffusion process to take please, and the needed relatively high carbon potential. One of such gases is generated through oxy-acetylene burners, where the combustion occurs in several stages [**8**]:

$$C_2H_2 + O_2 \rightarrow H_2 + 2CO \qquad (2)$$

$$2CO + O_2 \rightarrow 2CO_2 \qquad (3)$$

(a) Cross view



1: Lateral setting bolts
2: Sealing paste
3: Cover
4: Carburizing coal
5: Coal pan
6: Carburizing box
7: Carburizing parts
8: Oxyacetylene torches

(b) Lateral view

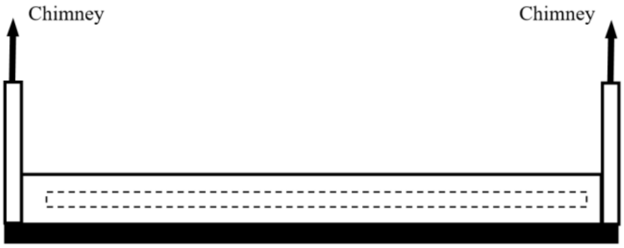


Fig. 3. Schematic description of a twin rail carburizing box using coal as a carburizing agent and oxy-acetylene flame to avoid decarburizing. *Source: own*

Fig. 3 illustrates a schematic representation of the conceptual design of a carburizing facility based on the solid carburizing of two railway head-to-head rails. Coal is poured on the coal pan (5) and covered by the element (3). The carbonizing process goes downwards on the rails´ lateral surface. The rails are set in position through setting bolts acting from the lateral ends of the so-made furnace.

A battery of oxy-acetylene burners at the bottom of the furnace provide a carbon-rich atmosphere to avoid rail´s material decarbonization. The temperature of the rails should be maintained at around 900°C for a period on the order of 4 hours, as a function of the effectiveness of the whole thermal process.

The carburizing facility should be installed as a continuation of the hot rolling process, in such a way that the material enthalpy is used to have a material temperature around 900°C, further minimizing the need for the heat coming from the battery of burners.

The handling of the rails to put them into the furnace should be carried out by specialized equipment to avoid any damage to the rails. While the external case of the furnace could be metallic, a high-temperature resistant internal filler material should be provided, with the necessary mechanical strength to support the rails. Once the rails are put into the furnace, they should be pushed against each other at a moderate rate by the horizontal setting bolts (1).

An important feature of this design is the use of a sealing paste (2) at the border of the tray (5) and the rails (7). Part (b) of this **Fig. 3**, illustrates the longitudinal view of the furnace; showing the disposition of the chimneys at both ends of the furnace.

It should be noted that a great number of parts and other equipment is necessary for this furnace to operate. However, the concept has been described, in order to proceed with its dimensioning and instrumentation.

For developing the detailed design and final dimensioning for the post-processing of the hot-rolled rails, an experimental device should be built and tested, aiming at the following:

i) Checking the toughness of the final product, as a function of the cooling rate and the time-of-exposure to carburizing. In this respect, there is a small risk that the increase of carbon content generates martensite in the carburized material. To avoid the embrittlement of the material, the cooling rate should be kept between 0.15 and 0. 3°C/s [**14**].

ii) While the sealing substance identified as part 2 in figure 3 has been added to selectively perform the carburizing process, the experimental model should validate the effectiveness of such procedure, in order to validate the nature of the isolating substance, as recommended in the literature [**15**].

iii) Characterizing the potential microstructural changes in the material as a result of the selective carburization process. Some relevant safety aspects should be tested for the final rail, including toughness characterization and uniformity of the carburizing, as suggested by quality assurance standards [**16**].

Conclusions

A facility is proposed in this paper to apply a selective carburizing process to the lateral faces of a railways´ head, aiming to increase its carbon content and to decrease the friction coefficient in case that the flange of the railway car wheel gets in contact with the rail during turning. Such a treatment would reduce the energy that is lost during the turning maneuvers performed by the vehicle, further improving the energy efficiency of the railway car. The facility consists of a furnace, which should be set next to the rails´ hot-rolling facility, in order to use the available enthalpy. The proposed furnace is equipped with what is necessary to avoid the decarbonization of the remaining rail material, based upon batteries of oxy-acetylene burners that are installed at the bottom of the furnace, on the opposite side to the carburizing surface.

An experimental facility is necessary to validate the operational principles for the equipment proposed in this paper. On the other hand, a study should also be carried out to assess the effect of any rail welding process on the carburized surfaces.

Keywords

Transport efficiency, dry friction, carburizing, selective carburizing, decarbonization, furnace design.

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