ARTICLE IN PRESS

Tribology International ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

# Correlations between wear mechanisms and rail grinding operations in a commercial railroad

P.A. Cuervo [a,*], J.F. Santa [a,b], A. Toro [a]

[a] Tribology and Surfaces Group, National University of Colombia, Medellín, Colombia

[b] Grupo de Investigación Materiales Avanzados y Energía—MATyER, Instituto Tecnológico Metropolitano, Medellín, Colombia

ARTICLE INFO

*Article history:*
Received 1 October 2013
Received in revised form
16 May 2014
Accepted 30 June 2014

*Keywords:*
Rail grinding
Rolling contact fatigue (RCF)
Corrugation
Contact profile

ABSTRACT

Rail grinding is a typical maintenance procedure for railways in which an abrasive wheel is used to restore the rail profile while eliminating defects such as corrugation, fatigue cracks and detachment marks. In this work, the grinding procedures performed during 10 years in 22 curves of a commercial railway (*Metro de Medellin* railway, line B) were studied and classified to understand the most important causes of damage. Periodical inspections were done to identify the main wear mechanisms in the field and the defects were classified into corrugation, fatigue and loss of profile. The results showed that corrugation took place preferentially on the low rail while fatigue was observed preferentially in the high rail.



## 1. Introduction

The Metro de Medellin railway is composed of two lines, A and B, accounting for 28.6 km and several more in cable transport. Lines A and B have 23.2 km and 5.6 km in length, respectively. Line B has six stations and travels from east to west of the city while line A has nineteen stations and travels from north to south. In such a railway system, rail maintenance procedures change both the sub-surface microstructure and the surface roughness, influence the wear performance of the rail and preserve its profile. It has been shown that after the grinding procedure a hard layer composed of untempered martensite can be formed at the surface due to localized heating and fast cooling, as reported by Chandrasekar et al. [1], Kanematsu et al. [2] and Zapata et al. [3]. Also, plastic deformation plays a role in hardening of the sub-surface, which in many cases can reach hardness values up to 400 HV or more [4]. Rail grinding (RG) has been performed in commercial railways since the 1980s to remove surface defects such as head checks and corrugations. It is a common practice in railroad industry to maintain the profile and remove wear marks (fatigue cracks, head checks, etc.) from the rail's surface, so RG has been introduced in order to extend the service life of rails by removing the rolling contact fatigue layer on the running surface and preventing the shelling damage [5]. RG is currently carried out by trains equipped with rotating grinding wheels driven by electrical motors, so the success of the operation depends on the characteristics and condition of the abrasive wheels, the applied pressure and the speed and angle between the grinding stones and the rail, among others.

Since the artificial wear caused by rail grinding controls the actual wear rates of rails it is crucial to study the grinding procedures in detail when high wear rates are systematically found in the field. With this in mind, several studies have focused on the parameters affecting the grinding procedures [5,6], optimal maintenance design and profile modification. For instance, in the work performed by De Vries et al. [7], the authors studied preventive grinding to reduce maintenance costs by increasing the grinding frequency in tight curves and optimizing profiles. They also increased grinding speed and reduced wear in the field. Satoh and Iwafuchi [8] concluded that rail grinding directly removes the surface layer with accumulated strain due to rolling contact fatigue, while Zapata et al. [3] studied the effect of velocity and grinding pressure on the artificial wear caused by the grinding wheels. They found that for higher pressures new cracks are induced in the rail's surface, and a white layer is formed. Taubert [9] studied high-speed grinding with no traffic interruption and found that removing frequently a thin, plastically deformed layer increases the productivity during rail grinding. The results of these investigations show that potentially harmful features such as micro cracks or heavily deformed regions at the surface of the rail can be removed by an adequate rail grinding practice. However, if new defects are induced during a poorly performed grinding operation, the wear rates can significantly increase and the overall effect of the procedure on the estimated lifetime of the rail can be negative.

* Corresponding author
*E-mail addresses:* pacuervo@unal.edu.co (P.A. Cuervo), jfsanta@gmail.com (J.F. Santa), aotoro@unal.edu.co (A. Toro).

http://dx.doi.org/10.1016/j.triboint.2014.06.025
0301-679X/

**Table 1**
Wheel/rail contacting modes according to curve radius.

| HRC | CPG | | CPC | | CPF | | |
|---|---|---|---|---|---|---|---|
| Sharp $R<400$ | Mild $400<R<900$ | Tang Stations | Curve $R<900$ | Tang | Tang | Mild $400<R<900$ | Sharp $R<400$ |

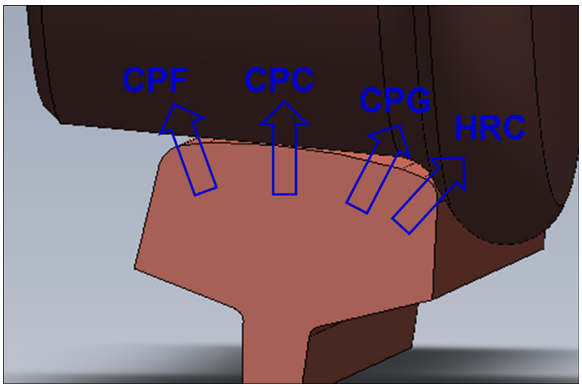
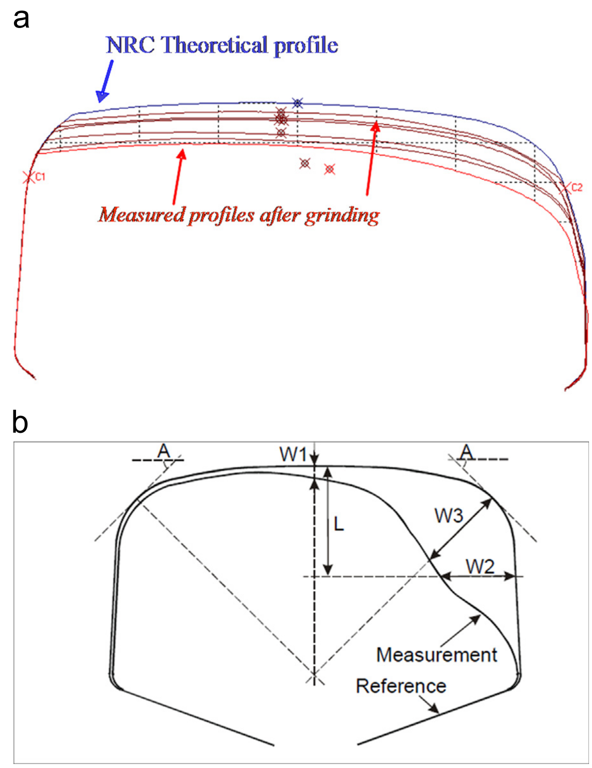



**Fig. 1.** Wheel/rail contacting modes in NRC rail profile. HRC: high rail contact, CPF: contact profile field, CPG: contact profile gauge, CPC: contact profile center.




c

| Wear mechanism | Average of material removed with each grinding intervention (mm) | |
|---|---|---|
| | W1 | W3 |
| Fatigue predominates over corrugation | 0,46 | 0,43 |
| Corrugation predominates over fatigue | 0,61 | 0,42 |
| Only Fatigue | 0,69 | 0,53 |
| Only Corrugation | 0,69 | 0,46 |

**Fig. 2.** (a) Comparison between the theoretical NRC profile and a number of measured profiles obtained after several grinding operations. Low rail, curve 1, line B, Metro de Medellín [9]. (b) Quantitative parameters extracted from the profile, and (c) values of the quantitative parameters on an specific curve of line B.

Although many studies have been developed to increase productivity of rail grinding in the field, a fundamental understanding of the wear mechanisms acting on the rails is required to optimize rail grinding as a tool to increase productivity in a railway system. In this work, the grinding procedures performed to the rails were studied and classified to understand the most important causes of damage and to correlate the rail grinding events with the operation conditions of the railway system.

## 2. Experimental

The grinding procedures performed during 10 years to the rails in 22 curves of a commercial line were studied and classified to understand the most important causes of damage. The defects were classified into corrugation, fatigue and loss of profile. Although there are other reasons to perform grinding operations such as the presence of braking marks, welded joints, etc. only wear-related issues were taken into account in this analysis. The term fatigue includes fatigue detachments (spalling) and head checks. Corrugation relates to undulatory wear, noise and vibrations, and loss of profile includes plastic deformation, reprofiling marks and negative geometry caused by welding.

The analysis included the classification of defects for every curve and for low and high rail. The mean time between rail grinding for every curve was also evaluated. Field inspections were performed during the last 2 years of the timeframe studied to identify the most common defects found in the railway. Several curve parameters (curve radius, super elevation, and type of profile) were also evaluated to understand their effect on rail grinding procedures.

In the field, the decision to perform rail grinding is usually based on the magnitude of fatigue damage, which is determined after visual examination. However, in order to decide when to perform rail grinding due to excessive corrugation, quantitative measurements can be made with the aid of the Corrugation Analysis Trolley (CAT). In this work, CAT analysis was done to decide about rail grinding and two groups of parameters were analyzed, namely: 1. Roughness amplitude parameters such as average roughness (*Ra*) and Root-mean-square (RMS) displacement, and 2. The proportion of the rail profile that lies outside the band specified by an exceedence level set with respect to the CAT profile [10–12]. In this article the CAT analysis is not shown.

The grinding procedures were performed in the field using a Harsco Track Technologies TG8 rail grinding machine equipped with 8 heads (4 for each rail) and several grinding patterns available. Each grinding wheel can be adjusted to an attack angle between $+45^{\circ}$ and $-40^{\circ}$ and the travel velocity can be varied between 1.6 and 13 km/h.

Please cite this article as: Cuervo PA, et al. Correlations between wear mechanisms and rail grinding operations in a commercial railroad. Tribology International (2014), http://dx.doi.org/10.1016/j.triboint.2014.06.025