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Wear modelling in rail–wheel contact

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ABSTRACT

In rail–wheel transports the maintenance interval for both wheels and rails has become a major issue in reducing costs and increasing safety and has encouraged the development of new numeric procedures for predicting the evolution of wear in order to establish a convenient maintenance schedule. These new tools require the synergy of dynamic analysis and the development of accurate and easy to use wear models. Rail/wheel wear depends on the material properties resulting from contact fatigue and sliding wear. Therefore, all the contact conditions affecting the contact stress distribution will determine the wear behaviour and the contact profiles of wheel and rails. The current research paper investigates the effect of contact conditions on friction and wear behaviour of EN 260 rail steel and R7 wheel steel. Laboratory simulation used twin-disc rolling-sliding tests to study the effect of the creep ratio, contact pressure and tangential speed on the resulting traction coefficient and amount of wear. The volume loss was estimated by weighing both specimens before and after the tests. Wear volumes were used to develop a wear equation based on Archard's model and considering weighting factors to estimate the influence of creep ratio, contact pressure and tangential speed on the specific wear rate. The predicted results were compared with the results of tests performed in the laboratory. Quite small differences between previsions and laboratory tests confirm the reliability of the forecast method. Wear mechanisms were discussed and compared to real rail–wheels sets analysing the fatigue cracks and the strain hardening effects beneath the contact surfaces.

1. Introduction

The railway industry is one of the most utilised means of transportation on land and increasing competition requires an evolution in service times, costs and comfort. These variables are directly dependent on rail/wheel maintenance, in which the major concerns are wear and rolling contact fatigue, typically induced by friction and cyclic overstressing of the rail and wheel materials [1,2].

Some authors [3–6] suggest using Archard's wear model, which relates the proportionality of the wear volume with the sliding distance times normal force divided by the hardness of the material, Eq. (1), mainly because it is widely used and very accurate.

$$V = K_C \frac{X F_N}{H} \tag{1}$$

Others recommend energy approaches, considering wear as an explicit function of the dissipated energy by friction in contact, such as Zobory's model [5,7]. This assumes that the contact area is divided into two zones: the adhesion and sliding zones and that the wear is highly dependent on sliding speed and therefore, the major part of the wear is located in the sliding zone of contact. Another energy approach is Pearce and Sherratt's model [5,8], which is focused on the prediction of wheel flange and rail tread wear, estimating the wear loss as the area of the cross-section removed by distance covered (mm^2/km).

As these types of contact involve the competition of two failure mechanisms, the applicability of these models is a difficult matter. Therefore, some studies predict better wear behaviour, based on Archard's wear models, whilst others have a good performance in prediction of rolling contact fatigue [9]. There are a small number of works directed to quantifying both phenomena, as presented in [10], in which the authors combine wear and rolling contact fatigue rail/wheel prediction models, after determining the contact conditions for predicting the wear volume and the prospect of crack initiation. The main source of inaccuracy of Archard's model is the fact that the wear coefficient is strongly dependent on the contact conditions. In effect, a diversity of parameters can influence the wear behaviour of the wheel-to-rail contact [11–15], especially concerning the amount of material removed by wear. Jendel [3] propose the use of a region map in order to adopt the convenient wear coefficient as a function of the contact pressure and the speed. Lewis and Dwyer-Joyce [12] investigated the effect

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Nomenclature

f_{cr}	creep ratio weight coefficient
f_{cp}	contact pressure weight coefficient
f_s	sliding speed weight coefficient
F_N	normal force (N)
h	wear depth (mm)
$\dot{h}$	linear wear rate (m/s)
H	hardness (HV)
k	specific wear rate (mm^3/N.m)
k_{st}	specific wear rate under standard contact conditions (mm^3/N.m)
K_c	Archard's wear coefficient
P	contact pressure (MPa)
R_r	rail specimen radius (m)
R_w	wheel specimen radius (m)
v	sliding speed (m/s)
V	wear volume (mm^3)
W_r	rail specimen angular speed (Rad/s).
W_w	wheel specimen angular speed (Rad/s)
X	sliding distance (m)

of the creep ratio on the wear rate. In the current work, we study some of the most important contact conditions which influence the specific wear rate, such as: contact pressure, linear speed and creep ratio, aiming to establish a prediction method of wear amount.

2. Experimental

2.1. Specimens and contact geometries

A twin roller model was selected to simulate the contact between the wheel and the rail treads and to ensure the compatibility of the results with the real working application. Rolling–sliding tests were used to investigate the contact of wheel and rail along straight tracks. For this type of test, the wheel specimens were machined from the wheel rim, of a wheel of a freight rail car used by CP, the Portuguese Rail Way Company, and present a cylindrical disc shape (Fig. 1). The rail specimens, machined from a piece of rail 54E1 EN 13674, adopt a cylindrical disc shape with a fillet (Fig. 2) in order to reduce misalignment and allow high contact pressure tests under reasonable normal loads.

The volume loss was estimated by weighing both specimens before and after the tests with a precision balance AND GH202. The uncertainty of the balance induces a relative error of 0.15%.

2.2. Materials

Two pearlitic steels were selected to carry out the present research work. The R260 Mn steel, prEN13674-1:2009, was used as rail material while the ER7, EN13262, steel was selected as the wheel material. Table 1 shows the chemical composition evaluated by flame atomic absorption spectrometry.

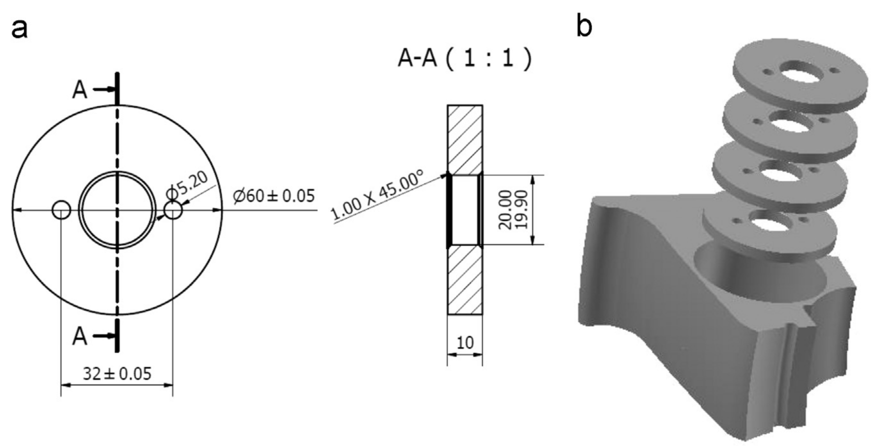

Fig. 1. (a) Wheel specimen drawing. (b) Schematics of roller cutting from the wheel rim.

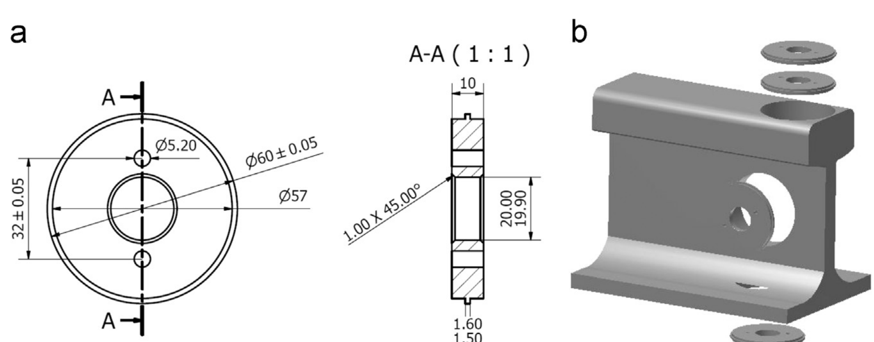

Fig. 2. (a) Rail specimen drawing. (b) Schematics of roller cutting from the rail.