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Presence and role of the third body in a wheel–rail contact☆

S. Descartes[a,*], C. Desrayaud[b], E. Niccolini[c], Y. Berthier[a]

[a] INSA de Lyon, Laboratoire de Mécanique des Contacts et des Solides (LaMCoS), UMR 5514, Bt Jean d' Alembert, 20 av. Albert Einstein, 69621 Villeurbanne Cedex, France
[b] Ecole Nationale des Mines de Saint Etienne, Centre SMS, Laboratoire Plasticité Endommagement Corrosion Matériaux (LPECM), UMR 5146, 158 Cours Fauriel, 42023 Saint Etienne Cedex 2, France
[c] RATP, Laboratoire Essais Mesures, 1 bis rue des Sablons, 94470 Boissy-Saint-Léger, France

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Abstract

Note: Persons concerned by modelling wheel–rail contacts should take into account the existence of the third body as a boundary condition of their models. Similar articles have been published in two journals: one dealing specifically with this subject in *Fatigue Fract. Eng. Mater. Struct*. while the other, in this special issue of *Wear*, describes a more general experimental approach. Some parts of this article, which describe in details the reality of the wheel–rail contact, have been used in the synthesising article: Y. Berthier, S. Descartes, M. Busquet, E. Niccolini, C. Desrayaud, L. Baillet, M.C. Baietto-Dubourg, The role and effects of the third body in the wheel–rail interaction, Fatigue Fract. Eng. Mater. Struct. 27 (5) (2004) 423–436. doi: 10.1111/j.1460-2695.2004.00764.x Published by Blackwell.

This paper focuses on the presence of the third body, a solid interfacial layer, in the wheel–rail contact. A phenomenological analysis is carried out as thoroughly as possible of the real tribological behaviour of this contact. To improve the understanding of the wheel–rail contact reality and the reconstitution of contact dynamics, this paper is presented a synthesis of different studies coming from: analysis of specimens taken out periodically from rails and wheels in service, and thus under real contact conditions, test laboratories, allowing us to impose rolling–sliding conditions with very high precision. The results show the presence of natural third body ranging in thickness from a few micrometers to several dozen micrometers on the rail and wheel. Initially composed of particles stemming from wheels and rails, it flows into the contact to accommodate the sliding between wheel and rail while absorbing and digesting solid and fluid contaminants. Up to now, the third body is a means of tracing local conditions in the wheel–rail contact, in order to pass through the difficulties of in situ instrumentation. From all these studies and results, a better understanding of the role of the third body and its influence on friction is reached. It also controls the rail's lifetime, the lubrication as well as the wheel–rail adherence via its "degradation and/or reformation" mechanisms.

Keywords: Wheel–rail contact; Third body; Interfacial layer; Friction; Wear; Expertises

1. Background

Although trains have been running for more than a century, the tribological phenomena activated in the wheel/rail contact are more subject to hypothesis than analysis. On the contrary, their various consequences (head-checking, squat, roaring rail, etc.) have been clearly identified and described [1]. This situation stems from the difficulty of instrumenting a wheel–rail contact in situ and industrial companies and scientists have had to cope as well as they can. By taking an approach similar to that of wheel and bogie manufacturers, rail manufacturers have been able to solve construction problems that portend faults in the subsurface. As for the rail networks, they have developed wheel and rail reprofiling (grinding) methods to eliminate surface defects whose propagation into the volume could be prejudicial.

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* Corresponding author. Tel.: +33 472 438452; fax: +33 478 890980.
E-mail address: lamcos@insa-lyon.fr (S. Descartes).

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In parallel, stability studies on convoys have required limit conditions to determine the friction values of the wheel/rail contact [2,3]. The magnitudes of these values have been taken from adherence tests at starting and stopping [4,5]. The number of parameters to be taken into account for these models (track, material) led to the acceptance of an order of magnitude for the wheel/rail contact.

It did not take long for contact mechanics to become interested in the wheel/rail contact as it provided a model problem: the contact of an unstiffened cylinder on one plane. Taking into account the deformations of the wheel and rail led to the reasonable idea of the existence of sticking and sliding zones in the contact plane [6].

This idea, validated experimentally with contacts between polymers/transparent materials [7,8], has become a parameter of the wheel/rail contact. On this basis, calculations of stresses and wheel and rail faults become possible both analytically [9] and numerically [10,11]. Sticking and sliding zones provide two setting parameters, which is better than a single friction value. These two friction values are used as the limit conditions of wheel and rail volume problems.

Progressively, (1) with the improved resolution of models and their solutions and (2) the improved resistance of the materials composing wheels and rails, the limit condition of friction has become a problem in itself [12,13]. It is now felt necessary to control friction as well as the local phenomena involved in this multi-dimensional problem. This multi-dimensional aspect has led to confusion, since the values of local forces required for contact mechanics result from calculations of railway dynamics based on a global wheel/rail friction parameter, rather than on local friction parameters, such as the sticking and sliding of contact mechanics.

The solution to these problems of scale is now underway. As for contact mechanics, it was possible at a very early stage [14] to calculate the stresses that have to be compared to the values permitted by the materials. Logically, these admissible values have been sought by carrying out fatigue tests. Thus criteria have been defined to adapt as well as possible the specific characteristics of "bulk" fatigue tests under the predominantly "surface" contact fatigue conditions of wheel/rail contacts. Different criteria and approaches have been formulated, some of them seeing the contact taking place from the surface into the volume, whereas others see the contact taking place more from the volume towards the surface [14–17]. Each discipline uses its own scientific culture to converge towards a given reality of the wheel/rail contact. This diversity and the absence of on-site measurements has left the field wide open for using setting parameters to predict with more or less satisfaction the damage observed on wheels and rails. With the development of numeric [18,19] and experimental [12] techniques, it became clear that it was necessary:

- to take into account not only the surfaces of wheels/rails but also the interface between them [20–22], as had been done already for other tribological applications [23];
- that the fatigue tests and damage criteria that always conformed to the nature of the materials, had to brought closer to the actual stress conditions affecting the skin of the wheels and rails.

In this context, the objective here is to highlight the presence of this interface or third body [23,24], and to present its role and use as a tracer of contact conditions capable of reconstituting the tribological behaviour of a wheel/rail contact.

2. Third body layer

2.1. Artificial and natural third bodies

From the moment the concept of third body was introduced [24], it was adopted by wheel/rail studies in order to generalise examination of contaminants: (1) "climatic" contaminants such as dead leaves, frost, water, (2) "operational" contaminants such as ballast stones, sand from sand boxes, lubricating oil from the active surface of the rails, and (3) the products transported (cereals, miscellaneous pollutants, etc.) [4,5].

On the contrary, these studies took longer to become aware of and admit the presence of an interface composed of particles stemming from the wheels and rails formed during rolling. This interface is composed of a "natural" third body, whereas the contaminants compose an artificial third body.

The reason for such recent awareness is due to the fact that the thickness of the natural third body is that of the edge effects produced when polishing metallographic sections. The coating of these sections often requires cleaning of the surfaces and thus the partial elimination of the natural third body, whose remains are often confounded with white phases.

2.2. Condition for highlighting the natural third body

This third body is highlighted here by tribological studies of rail samples of 900A steel taken from a mixed SNCF and SNCB network (passenger and freight) [20], as well as wheels of NF F 01-115 steel from an Alstom "type BB36000" locomotive [25].

The results presented have been validated by other studies [26], and under lower loading conditions: metro and tramway, thus ensuring representiveness. Emphasis is placed on the general characteristics of the third body by relying on a selection of representative images chosen for their pedagogical characteristics. However, things are more complicated in reality. Selection results from different analysis techniques:

- metallographic cross-sections of rails and wheels,
- tribological expertises of the surface of rail sections taken after the passage of an increasing number of trains, via polymer replicas made before and after the passage of wheels,
- observations by optical microscopy and scanning electronic microscopy (SEM) and energy-dispersive X-ray analysis (EDX).