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The role of constituents contained in water–based friction modifiers for top–of–rail application

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ABSTRACT

Top–of–rail friction modifiers (FMs) represent an up–to–date approach to managing adhesion in the wheel–rail interface. The aim of this study was to investigate the role of typical water–based FM constituents in terms of adhesion and film formation. The ball–on–disc apparatus was employed to reach a rolling–sliding contact. The friction behaviour of various complex substances with different compositions was investigated in terms of adhesion and wear. The results showed that less complex substances, e.g. free of particles for friction modification, can provide required adhesion. Moreover, adhesion was not markedly decreased when the contact was overdosed. The performance of water–based substance/FM is greatly affected by evaporation of water. Surface analyses showed that substances are able to reduce wear and surface damage.

1. Introduction

Efficiency and safety of rail transport is influenced by tribology of the wheel–rail contact, especially by adhesion which is usually expressed using the adhesion coefficient. The exact value of this coefficient depends on the actual environmental and operational conditions [1–5].

An effort to manage friction between the wheel and rail is an idea older than a century. A widely used approach to overcome traction/braking difficulties due to poor adhesion is a sanding process. In last decades, many papers were focused on the improvement of sanding where some important parameters were described, such as feed rate or suitable particle size [6–10]. Other important approach is wheel flange lubrication which enables wear, friction, and noise reduction in curves. Although both these methods are effective and proven, there are still important issues which persist, e.g. rail corrugation, wear and noise generation. With respect to these undesirable effects of rail transportation, friction modifiers (FMs) for top–of–rail application have been recently developed. The main target of FM application is to achieve the intermediate level of friction at wheel–rail interface. In addition, the presence of FM in the contact ensures the change in a trend of creep force characteristic (adhesion curve) after the saturation point from negative, typical for dry conditions, to neutral or positive friction [11]. The negative friction is considered as one of the initiation mechanisms of the rail corrugation which has the impact on wear, dynamic loads, comfort of passengers, and safety of rail transportation.

FMs were originally developed as a solid stick and their ability to overcome corrugation formation and squeal noise was firstly proven by Kalousek et al. using the Vancouver mass transit system [12]. A great deal of research has been focused on a liquid version of FMs which was developed in 1996 [13]. The exact composition of these liquid FMs is designed with respect to the required adhesion level. In general, water–based FMs contain water, solid lubricant, binding agent, friction modifier, and wetting agent. Since 1996, many laboratory and field studies have been conducted in order to better understand the FM effects. Tomeoka et al. [14, 2002] conducted both laboratory and field experiments which demonstrated that spraying of water–based FM can ensure an adequate and stable adhesion in the wheel–rail contact. The positive impact of water–based FMs on squeal and flanging noise was clarified for various railway systems in different countries [15,16]. The authors revealed that a squeal reduction occurred as a consequence of the positive creep force characteristic which was given by suitable properties of so–called "third body" in the wheel–rail interface. Beside noise reduction, the effect of FMs on corrugation formation and growth of amplitude of existing valleys was intensively studied [16–18]. Obtained results clearly showed that the presence of FMs on rail can reduce or completely avoid the evolution of corrugation.

Apart from the field tests, laboratory experiments are a common approach to the railway tribology research. The ability of liquid FMs to change the trend of the creep force characteristic from negative to positive was clarified, both in lateral and longitudinal direction, using a 1/5

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scaled roller stand [19]. Afterwards, the performance of water–based FMs was investigated in dry, wet and leaf contaminated contact a using twin–disc machine [20,21]. Positive effect on the creep force characteristic, corrugation and noise was reported.

On the contrary, traction and braking difficulties can occur under wet and leaf contaminated conditions depending on the amount and size of hard mineral particles contained in FMs. Another study dealt with the interaction of iron oxides and FM was published by Lu [22]. Oxide particles can build up a durable third body layer which can affect the adhesion coefficient in the contact. The thickness of this layer can reach up to 50 μm; thus, the rubbing surfaces can be partially or completely separated [23,24]. Subsequently, Lewis et al. investigated the effect of atmospheric conditions and iron oxide content on the performance of water-based FMs [25]. It was found that the presence both Fe_3O_4 (black oxide) and Fe_2O_3 (red oxide) leads to the faster growth of friction than that of pure-FM. The significant influence of iron oxides on the adhesion coefficient under dry and wet conditions (without FM) was investigated by Nakahara et al. [26]. While α-Fe_2O_3 increases adhesion for both dry and wet conditions, Fe_3O_4 is considered to suppress the increase in adhesion. Experiments using a full–scale rail wheel test rig confirmed that water–based FMs can simultaneously reduce wear and rolling contact fatigue (RCF) [27,28]. If the FM was applied at appropriate application interval, no head checks and no surface cracks were developed, and simultaneously the pre–existing cracks could not grow under FM conditions.

Recent laboratory studies dealt with an interaction of FM with various oxides and components of natural third body; however, the friction modifier itself has been seen as a "black box". It is known that different commercial FMs provide different frictional behaviour, but the contribution of different FM constituents and their combinations has not been published yet. The main objective of this work is to describe the effect of individual constituents of water–based FMs on adhesion and wear. Substances with various complexities are investigated in both liquid and dried form in order to describe how far the drying effect influences adhesion. This study focuses in detail on a time evolution of the adhesion coefficient, which is required for consideration of the FM reapplication interval. Special attention is placed on the lowest adhesion occurring after the application with respect to possible traction/braking difficulties. These findings can be helpful for modelling of FM behaviour and for a design of FMs and traction enhancers.

2. Material and methods

2.1. Test setup

The frictional behaviour of water–based FMs was studied using a commercial ball–on–disc apparatus (Mini–traction–Machine, PCS Instruments) with circular contact area, see Fig. 1. The main parts of this apparatus are as follows: 19.05 mm ball which is loaded by the flexible arm against a 46 mm diameter flat disc. The disc and the ball are driven independently by servomotors, so the value of slide-to-roll ratio (SRR) can be accurately set according to the following equation:

$$SRR = \frac{w_{ball} \cdot r_{ball} - w_{disc} \cdot r_{disc}}{w_{ball} \cdot r_{ball} + w_{disc} \cdot r_{disc}} \cdot 200\% \quad (1)$$

where w_{ball} and w_{disc} are the angular speeds of the ball and the disc respectively and r_{ball} and r_{disc} are denote the radii of these bodies. Friction and normal force is measured with two force transducers and the resulting adhesion coefficient is evaluated as a ratio of the friction to the normal force.

Both the disc and the ball were made from bearing steel AISI 52 100. Vickers macro–hardness of ball and disc was 800–920 HV and 720–780 HV respectively. The initial roughness of the ball and the disc surfaces was Ra 0.01 μm and Ra 0.02 μm respectively. The chemical composition of specimens, as well as their hardness, is different compared to a commonly used wheel or rail steel. This configuration is more suitable for determining the frictional properties of the applied friction layer itself. Otherwise, wear process substantially influences contact conditions. Harder surfaces provide excellent repeatability of friction results and are reasonable in the small-scale point contact device.

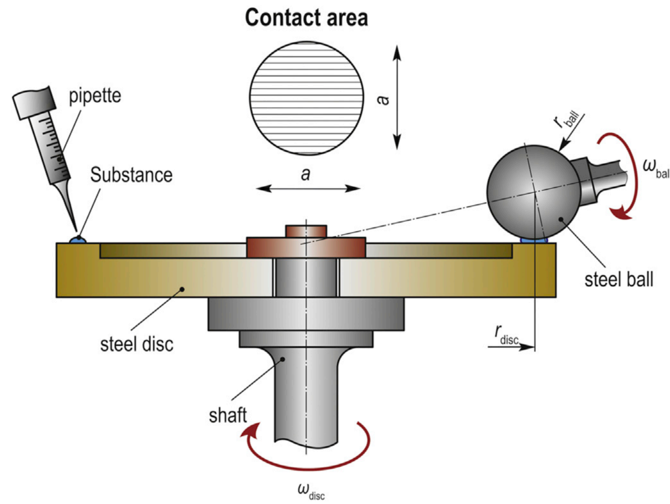

Fig. 1. Scheme of ball–on–disc apparatus.

2.2. Tested substances

This study deals with water–based FMs. Substances with various complexity were used where the following components had been combined: water, binding agent, friction modifier and solid lubricant. The composition of the substances is listed in Appendix. Any other additives, e.g. preservatives, were not used. Binding agents are usually clays, such as bentonite (sodium montmorillonite, which was used in this study) or casine. Particles of the binding agent together with water form a colloidal suspension therefore the apparent viscosity increases, as was previously observed by Dangler [29] and as is evident from Fig. 2. Both mineral

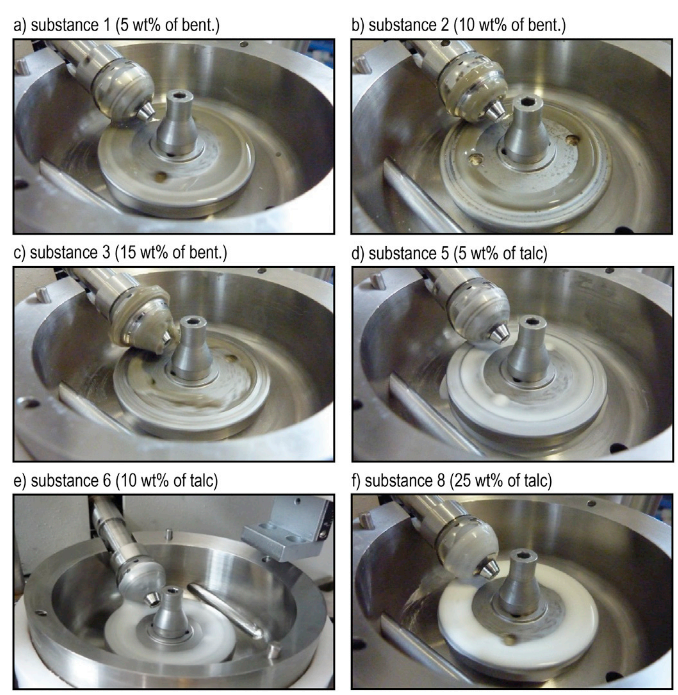

Fig. 2. Illustration of experiments with various substances.

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