
Železniške naprave - Trenje na stiku kolo-tirnica - 3. del: Osnovna načela za zahteve in dodatne osnovne informacije

Railway applications - Wheel/Rail Friction Management - Part 3: Rationale for requirements and further background information

Bahnanwendungen - Reibungsmanagement zwischen Rad und Schiene - Teil 3: Grundlage der Anforderungen und weitere Hintergrundinformation

Applications ferroviaires - Gestion des frottements roue/rail - Partie 3: Justification des exigences et informations générales supplémentaires

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Bahnwendungen - Reibungsmanagement zwischen
Rad und Schiene - Teil 3: Grundlage der Anforderungen
und weitere Hintergrundinformation

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CEN/TR 15427-3:2026 (E)**European foreword**

This document (CEN/TR 15427-3:2026) has been prepared by Technical Committee CEN/TC 256 "Railway applications", the secretariat of which is held by DIN.

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1 Scope

This document provides **background information, rationale, and technical guidance** supporting the 15427 series of standards and technical specifications for **wheel/rail friction management**. It is intended for users who are unfamiliar with friction management, those who are involved in specifying friction management materials and/or application equipment for trainborne or trackside application, or those who are responsible for vehicle or track maintenance. Users also include the friction management supply industry.

Key items described in this document include:

- Fundamental principles of the **wheel/rail interface**, adhesion, friction behaviour, and common issues such as noise, wear, corrugation, and low adhesion.
- The **purpose, function, and performance** of friction management materials, including **flange lubricants, top of rail materials, and adhesion enhancers**.
- An overview of **trackside and trainborne application technologies**, including equipment options, selection criteria, and operational factors.
- General guidance on **maintenance**, operational strategy, environmental considerations, and safe implementation of friction management systems.

Testing and trialling methods, and performance considerations for evaluating friction management solutions.

Overall, the document acts as a technical reference for understanding the **rationale behind requirements**, correct application of friction management solutions, and their role in achieving safe, reliable, and efficient railway operations.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <http://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

4 Introduction to the wheel-rail interface and the role of friction materials

4.1 Wheel-rail interface and adhesion

The wheel-rail interface is the area where all the forces are transferred between the wheel of a vehicle and the rail. It is responsible for withstanding vertical load and transferring the dynamic forces caused by curving, traction and braking performance of the vehicle to the track.

The contact patch between wheel and rail is relatively small in area, approximately 250 mm² ([Figure 1](#)). This results in extremely high stresses at this steel-steel interface that can frequently exceed 1GPa. In addition, this small contact patch transfers the required tangential forces between the wheels and the rails for guiding the vehicle and for accelerating and decelerating as defined in the technical specifications, to ensure not only the expected performance, but also the required safety margins.

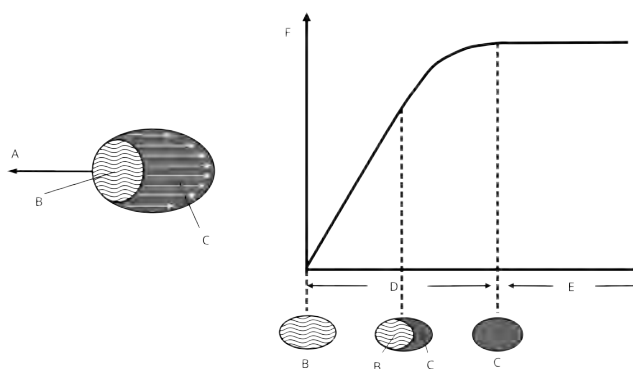


Figure 1 — Demonstration of the size of the contact patch between the wheel and rail

The capability of creating these tangential forces between the materials in contact is known as friction, which is the resistance to relative motion between two bodies in contact. Based on Coulomb's Law of Friction, [Formula \(1\)](#), the higher the coefficient of friction (μ), the bigger the tangential force (F) that the contact will be able to transfer for the same normal load (N).

$$F = \mu N \quad (1)$$

At the same time, if the required tangential forces in the wheel-rail interface exceed the available adhesion, where adhesion is defined as the friction that can be made available to deliver tangential forces between a driving railway wheel and the rail, this will cause a creepage between the wheel and the rail. Creepage being the relative difference between the speeds of both components. The bigger the exceeded tangential force, the bigger the creepage. This relation between tangential force and creepage at each wheel-rail interface is known as the adhesion curve. As it is graphically represented in [Figure 2](#), adhesion or the equivalent tangential force increases up to a limit value defined by the coefficient of friction and the normal load. Once this limit is reached, it can be considered that the full contact patch is slipping, while for smaller adhesion or tangential force values, part of this contact patch remains rolling without any creepage.



Key

- A Direction of travel
- B Stick
- C Slip
- D Creep region
- E Pure slip

F Frictional force

Figure 2 — A creep curve showing the relationship between adhesion and creep. [\[1\]](#)[\[2\]](#)

4.2 Wheel-rail interface issues

4.2.1 Introduction to wheel-rail interface issues

Adhesion is essential for being able to operate railway vehicles properly and safely. Insufficient friction prevents the desired tangential forces from being achieved, which reduces braking and traction capabilities. For braking, this is a safety issue as it leads to extended stopping distances. In addition, high friction is responsible for undesirable phenomena in the wheel-rail interface. A high coefficient of friction can lead to high tangential and lateral stresses on the wheel and the rail surface, which in the case of being repetitive, can cause fatigue in the material and initiate cracks, known as rolling contact fatigue (RCF). Based on [\[3\]](#), high coefficients of friction can cause self-excited vibrations, which is the probable cause of rail corrugation and squeal in small radius curves. However, when the coefficient of friction is not sufficient to withstand the required tangential forces and ensure pure rolling, creepages or even pure slipping occurs between the wheel and the rail, which together with the high coefficient of friction can contribute to the following undesired phenomena:

- Wear
- Flange-hissing noise
- Squealing noise
- Rail corrugation [\[3\]](#)
- Extended stopping distances

On the one hand, traction and braking efforts are mainly transmitted by the wheel tread and top of rail contact, so a sufficient coefficient of friction is required in this contact patch. The necessary minimum coefficient of friction in each wheel rail contact will depend on the required traction and braking performance and the vehicle and track features like the axle load, motorization ratio and the track slope.

On the other hand, as most critical wear rates and part of undesirable wheel-rail rubbing noise happens as a consequence of the contact between the wheel flange and the rail gauge face, in that kind of contact, the aim is to reduce the coefficient of friction.

[Table 1](#) gives typical adhesion conditions that can be found on the rail. The adhesion is stated as a coefficient of friction range and is accompanied by a description of the conditions that can lead to this condition. It is important to note that the values stated are typical and are not to be taken as definitive.

Table 1 — Typical adhesion conditions[\[4\]](#)

Typical adhesion level	Description of conditions
> 0.20	Clean, dry rail
0.10 – 0.20	Steady moderate or heavy rain; “wet rail”
0.08 – 0.10	Steady light or light rain; “wet rail”
0.06 – 0.08	Fine rain or drizzle, dew, mist, fog, snow – clean rail, light leaf film contamination
0.04 – 0.06	Onset of rain, very fine rain or drizzle, dew, mist, fog or snow, light leaf film contamination
0.02 – 0.04	Wet tunnel. Excessive lubricant, mist, fog, dew, drizzle, onset of light rain. Snow, ice. Damp, leaf fall contaminated in leaf fall vulnerable areas
0.01 – 0.02	Damp, leaf fall contaminated in leaf fall vulnerable areas

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The purposes of the materials added to the wheel-rail interface are mainly:

- To modify the value of the coefficient of friction between the wheel and the rail to the desired levels.
- To change the shape of the adhesion curve ([Figure 2](#)).

By providing adequate materials with the appropriate strategy (time and location), the coefficient of friction in the contact patch is enough to ensure the required traction and braking efforts in the top of rail contact when required, whilst damage (mainly wear, RCF and corrugation) and noise are minimized mainly in small radius curves, by reducing the coefficient of friction or changing the shape of the adhesion curve between the wheel and rail.

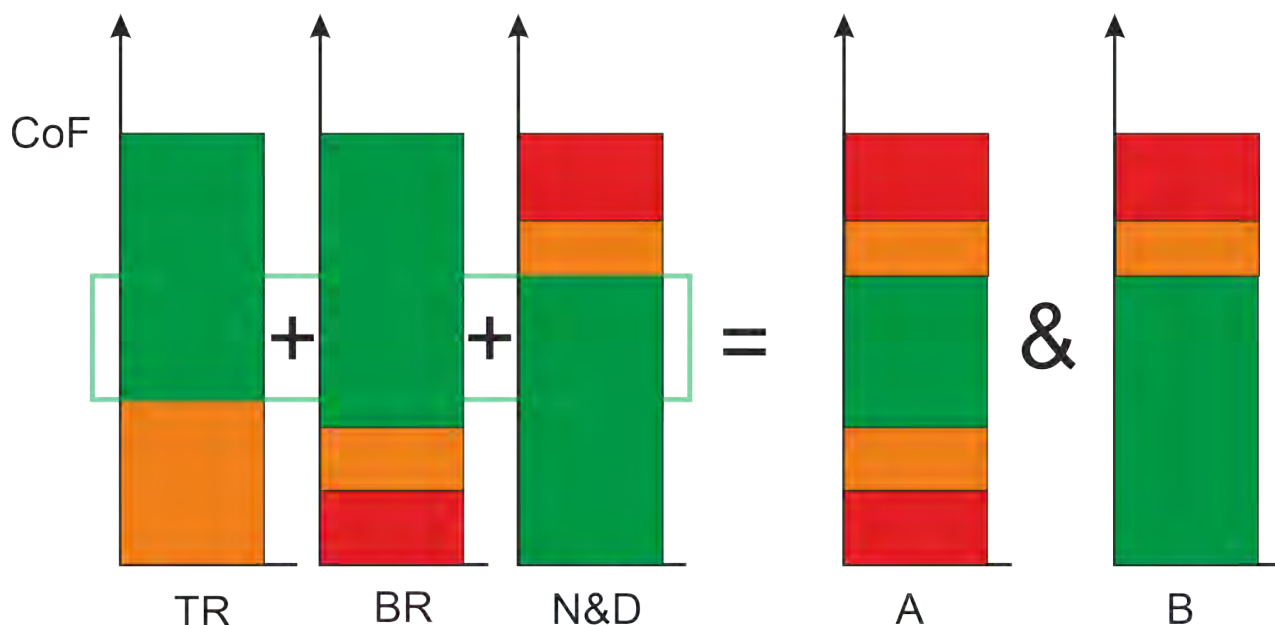
[Figure 3](#) illustrates how changing the coefficient of friction between the wheel and rail can impact on traction, braking, noise and damage. It demonstrates that there are opposing target values which can result in sub-optimal performance and safety issues. There is a narrow band for the target coefficient of friction, which balances the need for reducing damage and noise and the need to maintain traction and braking. This balance and optimal condition can be managed through the application of friction materials.

So, as a summary, depending upon the specific contact point (rail gauge face / wheel flange or top of rail / wheel tread) and the required operational conditions at each moment and track location, the target could be different. i.e.:

- **Flange contact:** A coefficient of friction as low as possible is desired in order to reduce as much as possible wear and plastic deformation of the wheel and rail. Additionally, the same lubricant can be able to isolate the metallic contact and avoid the rubbing or hissing noise caused by the high creepages between wheel flange and rail gauge face. Adding lubricant aims to minimize the coefficient of friction.
- **Tread contact when curving:** On the one hand, positive or neutral gradient adhesion curves, see section [Clause 5](#), are required for avoiding stick-slip phenomena. On the other hand, a recommended friction value of around 0.2-0.4 will ensure steering forces, traction and braking efforts and it also avoids self-excited vibration of the vehicle-track system, which is responsible for some kind of rail corrugation [\[3\]](#). The application of top of rail materials helps these conditions to be achieved.
- **Tread contact under traction/braking:** High coefficient of friction is desired for ensuring required traction and braking efforts. Application of sand or traction gel in the contact patch helps to increase a base low coefficient of friction.

The act of introducing external materials to the wheel-rail interface, considered as part of the naturally existing 3rd body layer in the wheel-rail interface, could also lead to the contamination of the environment, which could be considered as another non-desired consequence.

Some of the most relevant non-desired phenomena related to the wheel-rail interface and adhesion will be briefly explained below, together with the role that friction materials play in mitigating them.



Key

TR Traction - desired friction for traction

BR Brake application - desired friction for braking

N&D Noise and damage - desired friction for minimising noise and damage to the rail

A Top of rail desired friction

B Gauge face desired friction

CoF Coefficient of Friction

Green Optimal friction conditions

Orange Compromised friction conditions

Red Critical friction conditions

Figure 3 — Optimising wheel-rail friction for all conditions

4.2.2 Wear and rolling contact fatigue

The wheel-rail interaction, as any other mechanical interaction between two metallic surfaces, causes damage to both surfaces. Focusing on the most common and frequent damage mechanisms occurring due to the wheel-rail interaction in curves, damage can be separated into two primary mechanisms: wear and rolling contact fatigue (RCF)[5].

Wear is the loss or displacement of material from a contact surface, while the rolling contact fatigue presents as repeated cracks on or near the surface of the wheel or rail. The wheel-rail contact patch is divided into regions of stick and slip, as shown in Figure 2. Simplifying the wheel-rail contact mechanics for understanding, in the regions of slip the common mechanisms of damage usually is wear, while within the stick region the main mechanism of damage could be considered fatigue driven. In other words, the higher the slip between wheel and rail, the more predominant will be the wear mechanism, while in the cases in where pure rolling predominates, the principal damage mechanism will be the RCF [5].

However, it is not only about pure rolling or slipping. Exceeding certain threshold values of forces and creepages cause damage to the materials involved in the interaction. This threshold is dependent on the material properties of the wheel and/or the rail. Lubrication protects the steel surfaces by reducing the coefficient of friction between the wheels and the rail, so promotes sliding. But it also means that

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tangential forces are minimized, usually pushing them below such minimum damage threshold. That is why lubricants are applied in the wheel flange and rail gauge face contact, where adhesion is already saturated.

Regarding RCF, the application of any lubricant or top of rail material, can also help to mitigate it as the coefficient of friction is reduced and thus, the cyclic tangential forces responsible for causing fatigue cracks are limited. However, as some theories show that hydraulic action exacerbates crack growth, as any other liquids, lubricants or top of rail materials could promote crack propagation in the case that the contact forces are not reduced enough for avoiding crack initiation.

A change in coefficient of friction in a wheel-rail interface by applying lubrication, top of rail materials or adhesion materials in curves can change the vehicle dynamics and needs to be considered, but this is not covered within the scope of this report.

4.2.3 Noise

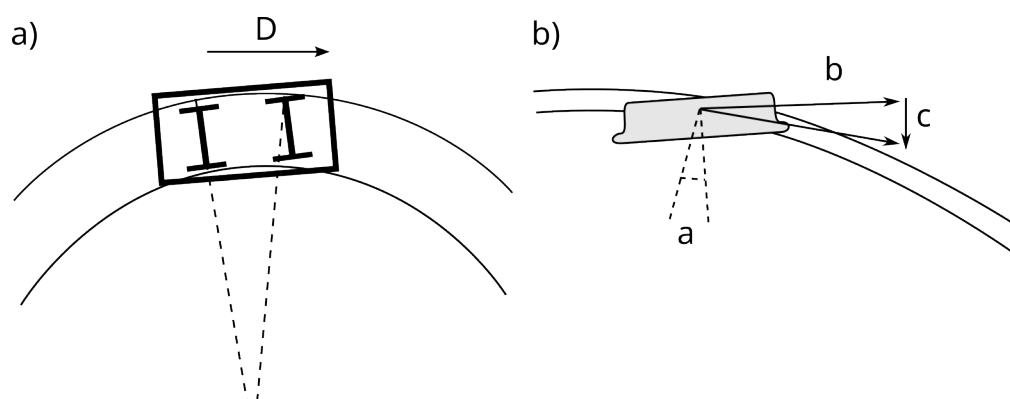
Noise is a common consequence in any metal-metal contact. The wheel-rail interface is not an exception, for example in small radius curves, where the creep gains importance and causes noise due to the flange rubbing of the outer wheel against the rail gauge face.

In addition, the wheel-rail interface in small radius curves can cause another kind of noise, known as “curve squeal”. The particularity of this other kind of noise is caused by exciting a natural frequency of one or more components of the system, due to frictional instability or other external force. This noise is not caused directly by the rubbing contact between the wheel and rail.

Curve squeal is an intense tonal high-frequency noise, which makes it undesirable to human hearing. It is generally recognised that the majority of this undesirable noise comes from the wheel, commonly on the inner rail of the curve.

The paper [6] written by David J. Thompson et al. in 2018 gives a detailed explanation of the curve squeal phenomenon, but for this technical report it could be explained as follows. This stick-slip theory is one of several theories to the source of curve squeal noise, other theories include Mode Couple Instability Mechanisms [7][8].

Due to the angle of attack generated in the curving of a bogie in a small radius curve, creepage is caused both in the longitudinal and lateral direction of the wheel as it is represented in [Figure 4](#).



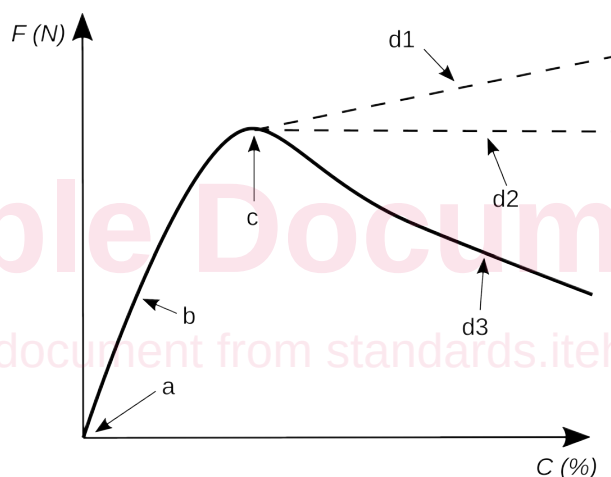
Key

- D Direction of travel
- a Angle of attack
- b Rolling velocity

c Lateral velocity

Figure 4 — Typical curving behaviour for small radius curve (a) showing that the leading wheelset has a large angle of attack; generation of lateral creepage by a non-zero angle of attack on the inner rail (b) [6]

At the large values of lateral creepage caused in a small radius curve, creep forces saturate the available friction. This means that the maximum available coefficient of friction is required by the contact forces and that adhesion reaches the negative slope section of the curve, represented in [Figure 5 a\)](#). Under negative friction characteristics, seen in a dry wheel-rail interface, the forces between the rail and wheel build up to a level at which the wheel will suddenly slip against rail, the force will drop and the wheel will gain traction again until the force reaches the limit and slips [Figure 5 b\)](#). Thus, the negative slope of the adhesion curve, understood as a negative damper from dynamics point of view, is responsible for causing the stick-slip mechanism in the wheel-rail interface, which in some cases, due to its unstable characteristics, triggers one of the resonance modes of the wheel or the wheelset, which usually requires an excitation in the lateral direction of the wheel, exacerbated by the angle of attack. The coupling of the unstable stick-slip behaviour of the wheel-rail interface with a natural frequency of the wheel is the source of the curve squeal noise. That is why this kind of noise has the particularity of being a tonal noise.

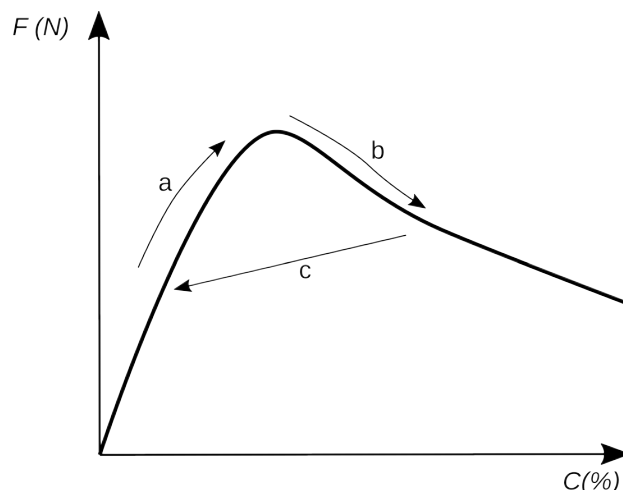


Key

- a Free rolling
- b Sloping portion
- c Saturation
- d1 Positive friction
- d2 Neutral friction
- d3 Negative friction
- C Creep rate
- F Creep force

a) Schematic diagram of the friction coefficient as a function of the slip, showing the different elements of the curve on a traction force (F) vs. creep (C) plot

Figure 5 (continues)



Key

- a Force between wheel and rail increases with increasing creep
- b Past the saturation point force decrease with increased creep until wheel starts to slip
- c As the wheel slips the force drops and the wheel gains traction again
- C Creep rate
- F Creep force

b) Diagram showing the slip-stick cycle on a traction force (F) vs creep (C) plot where negative friction properties are present

Figure 5

Regarding the role of friction management materials, it is taken into consideration that the materials used for mitigating the flange hissing or rubbing noise and also the wear caused by it, look to reduce as much as possible the coefficient of friction between the outer wheel flange and the gauge face of the rail. Nevertheless, the aim of the materials added to the top of rail and wheel tread contact in the inner rail of a small radius curve are different.

First of all, it is necessary to guarantee a minimum coefficient of friction between the top of rail and the wheel tread in order to be able to transmit the required traction and braking efforts between the vehicle and the track. This allows vehicle accelerating and braking as expected. Based on this requirement, the use of lubricant on the wheel-rail interface of top of inner rail in small radius curves are to be avoided.

Furthermore, the material added to the wheel-rail interface to the top of rail of the inner rail of small radius curves is not cause a negative slope in the adhesion curve, in order to avoid the unstable stick-slip phenomena and coupling it with any of the natural modes of the wheels or wheelset. Materials that do not attempt to minimize the coefficient of friction as much as possible but have the aim of modifying the adhesion curve, avoiding any negative slope on it, are known as top of rail materials [5.3](#).

4.2.4 Rail corrugation

Rail corrugation is a kind of rail damage which combines a material damage mechanism with a dynamic response of the system. The damage mechanism can be related to plastic deformation or wear.

The causes, damage mechanisms and wavelength-fixing mechanisms of the corrugation are very extensive, as it can be seen in [Table 2](#) or in Ref. [\[3\]](#). Corrugation can appear even in straight track or in small radius curves. Regarding the excitation mechanisms, in some cases corrugation is strongly related to the coupling of the vehicle-track system, which can be triggered by the stick-slip phenomenon described previously in this document, or it can also be self-excited if a certain value of the coefficient

of friction is exceeded and the minimum exciting forces are generated in the wheel-rail interaction. Finally, an artificial trigger can also excite a natural frequency of the system, which depending on the receptance of it, will be damped or not.

While in some railway systems the stick-slip behaviour of the adhesion at the wheel-rail interface couples with a high frequency natural modes of the wheel or wheelset causing curve squeal noise (1-5kHz), the same stick-slip phenomenon on the wheel-rail interface can excite lower frequency modes (50-500Hz approx.) of the rolling stock or track, which can have as a consequence an irregular wear of the rails, known as corrugation.

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