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Material concepts for top of rail friction management – classification, characterization and application.

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Abstract

The concept of managing and adjustment of friction between the wheel and rail has a long history within the operation of railways systems. In the past, adjustment/management has been limited to gauge face lubrication and the use of sanding equipment. The introduction of the top of rail (TOR) friction modifier (FM) over the last 20 years now allows for the modification of the friction at the top of rail – wheel tread interface. This paper focusses on the concept of TOR friction adjustment. Recent developments have led to a new generation of products, defined here as, TOR lubricants (oil and/or grease-based) and hybrid materials (oil/water mixtures), which are non-drying or slow drying. Definitions and functional difference are detailed and contrasted with that of the water-based drying FM. The water-based TOR FM once applied rapidly dries, mixes with the existing third-body layer, and allows for the accommodation of shear displacement. TOR lubricants and hybrid materials rely on mixed boundary layer lubrication, contrary to application of the water-based TOR FM. It has been shown that the adhesion level is highly influenced by the lubricant application rates. The risks and benefits (lateral force reduction, corrugation mitigation, and impact on energy consumption and influence on rolling contact fatigue) are discussed for all product classifications. However, a lack of data exists for the TOR lubricants especially in the area of rolling contact fatigue where laboratory studies have identified the possibility of crack interaction. Whilst it can be seen that TOR lubricants have the ability to provide similar benefits to that of a water-based FM, they exhibit a strong dependency on the application rate which may lend itself to adhesion and RCF issues. Further work is recommended in this area.

Keywords:
friction management, friction modifier, TOR material, friction, lateral forces, adhesion, wear, RCF

1. Introduction

The concept of managing and adjusting friction between the wheel and rail has been applied to the railway system since the early days of steam engine operations. Depending on the location of the wheel relative to the rail, different functional targets have to be achieved. On the gauge face (GF) / wheel flange contact, the main target is to reduce wear of both partners. Consequently, a GF lubricant or grease will be applied. On the top of rail (TOR), effects like squealing noise, damage development (corrugation, rolling contact fatigue – RCF, wear) and energy consumption are addressed by friction management. The product of choice for TOR is a material that reduces the friction to an optimised level to provide the described benefits while allowing for safe train operations. This paper will focus on the TOR / wheel tread area and the impact of different TOR materials with respect to selected immediate and long term (or delayed) effects/benefits.

2.) Friction, Traction, Creepage and Lubrication

The frictional contact problem [1] relates frictional forces (tangential forces, traction forces, creep forces) to velocity differences between bodies in rolling contact (creepage). Increasing creep will result in an increasing creep force as shown in figure 1. The contact zone between the wheel and rail can be divided into stick and (micro-) slip regions. Starting at full stick under pure rolling conditions, the slip region in the contact will increase in size with increasing creep force until full slip of the contact is reached (i.e. saturated creep). At full slip conditions, the creep force is limited by the coefficient of friction for a given normal load (figure 1).

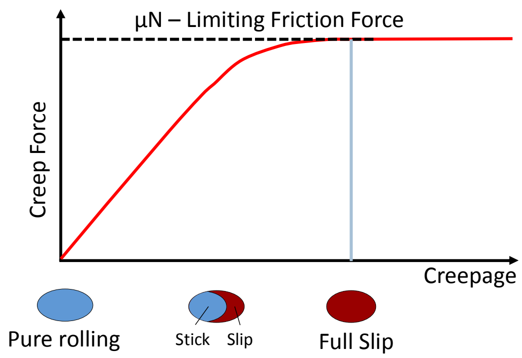


Figure 1: Theoretical traction-creepage relationship. The maximum possible creep force is limited by the coefficient of friction µ (for a given normal load). The slip region in the contact patch will increase with increasing creep force until a full slip condition is reached.

Lubrication aims at reducing friction between two surfaces in close proximity and moving relative to each other. For rail/wheel contact applications, liquid lubricants are predominantly used. As shown in figure 2, different lubrication regimes can be classified for liquid lubricants [2]:

- Boundary lubrication: constant contact between two surfaces despite the presence of a lubricant.
- Mixed lubrication: two surfaces partially in contact and partially separated by lubricant.
- Hydrodynamic lubrication: two surfaces separated by the lubricant film.

The different lubrication regimes and the resultant friction depend on the amount of lubricant present in the contact, the viscosity of the lubricant, the velocity between the two bodies, and the contact pressure.

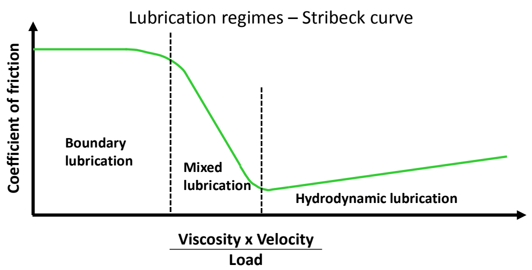


Figure 2: Lubrication regimes for liquid lubricants (Stribeck Curve) [2].

3. Definition of a Friction Modifier

In general tribological terms, a friction modifier (FM) is an additive that modifies (decreases or increases) the frictional properties of a lubricant (e.g. engine lubricants or transmission fluids) [3]. In railway applications, a TOR FM refers to a material that specifically reduces the friction from high levels under dry conditions (0.5 – 0.8) to an intermediate coefficient of friction (COF) of 0.3 – 0.4 as shown in figure 3. However, a friction modifier cannot increase friction from low level conditions (such a material might be referred to as traction enhancer). Friction can be measured by using a hand-held tribometer that is pushed along the rail. However, such a device will only measure the friction between the tribometer wheel (low vertical load) and the rail surface and will thereby only give a partial indication about the actual friction conditions between the wheel and the rail. Besides, factors like dynamic vehicle loading characteristics and changing traction conditions will provide additional variability of friction conditions between wheel and rail that are not considered by a push tribometer. A lubricant shows a clear functional differentiation compared to an FM as it is aiming at reducing the friction to a minimum (e.g. below a friction level of 0.2 at the gauge face).

The Technology Transportation Centre Inc. (TTCI) in the US defines a FM as a product designed to provide one intermediate friction level over a range of material application rates and/or hold the friction constant over a specific range of wheel rail creepage [4].

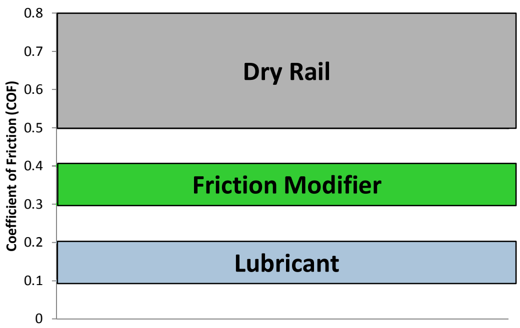


Figure 3: Typical coefficient of friction ranges for dry rail, friction modifiers, and lubricants.

The above explained concept of a FM for TOR application was originally introduced in the late 1980s by Kelsan Technologies Corp. (now L.B. Foster Rail Technologies, Corp.) to overcome a squeal and corrugation problem at the newly introduced Vancouver Skytrain system [5]. For this original application, a solid stick FM was used. Nowadays FMs are available in both solid stick and liquid form.

Besides optimising wheel-rail friction, a FM for TOR application also provides positive friction characteristics between the wheel and rail over an extended creepage range [6].

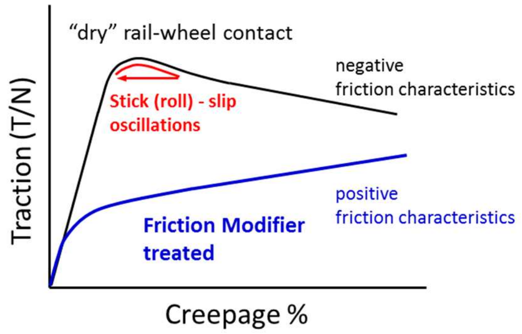


Figure 4: Creepage-traction diagram showing the differences between positive and negative friction. A FM treated rail-wheel contact will reduce the friction level and will provide a positive (inclining) traction-creepage relationship thereby preventing stick-slip oscillations.

As indicated in figure 4, a negative slope in the traction-creepage curve can lead to stick-slip oscillations. This effect is responsible for generating squealing noise and it also plays a major role in corrugation development [7,8]. A FM that provides positive friction characteristics will prevent stick-slip oscillations.

4.) Alternative Material Concepts

With a wider market acceptance of the original FM concept, a number of different products have been developed and partially tested and applied by some railway operators. These alternative materials for TOR application have a significantly different friction mechanism and cannot be classified as a FM. They can generally be classified as TOR Lubricants. This material group can also be divided into three sub-classes:

- TOR Oil (oil-based TOR material)
- TOR Grease
- TOR Hybrid (oil and water-based material)

Some amount of solid particle content is possible for TOR Lubricants. The oil carrier is sometimes vegetable-based. The sub-class of hybrid materials is sometimes referred to as "water-based" materials despite containing significant amounts of oil. Although there is no standardized definition for "water-based" with respect to TOR materials, this paper will refer to any material containing a mixture of water and oil as "hybrid" and not "water-based".

5.) Functional Differentiation

Alternatively, TOR materials can also be classified according to their drying behaviour. In drying materials (e.g. FM), water acts as a transport medium and will evaporate quickly under wheel-rail contact conditions. As indicated in figure 5, the dry FM particles interact with the existing third body layer materials between the wheel and rail providing a shear displacement compensation mechanism. This mechanism is responsible for the optimised friction level between the wheel and rail and will also generate the positive traction characteristics [9].

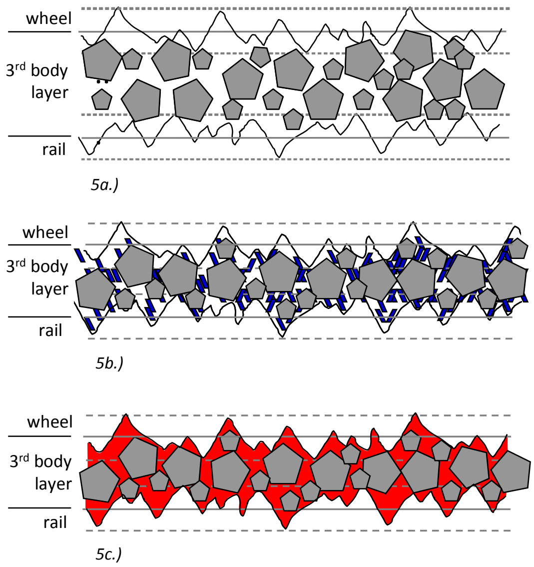


Figure 5: (a) Dry wheel-rail (W/R) contact (not scaled) with third body layer. Mixture of different brittle, solid third body materials like wear debris, oxides, sand, etc. determine friction conditions. (b) Pliable FM particles adjust shear properties of third body layer and thereby adjusting to a desired W/R friction level. (c) Lubricant in rail-wheel contact providing boundary or mixed lubrication conditions. (schematic drawings)

Non-drying materials will provide reduced friction conditions through a boundary or mixed lubrication mechanism. The non-drying material is present between the wheel and rail, but will still allow significant contact between the different surfaces. However, a slight change in the amount of material in the contact area will drastically influence the resultant friction conditions (increase or decrease) and the expected friction benefits cannot be achieved. If the contacting surfaces are completely separated by a high amount of lubricant between the wheel and rail, a full lubricated condition is reached and the friction level will drop to very low values.

There is a significant difference in the surface conditioning mechanism (wheel and rail surface) between a drying (e.g. FM) and non-drying (e.g. TOR Lubricant) material. As long as a drying FM remains in its liquid form, it will be continuously transferred between the wheel and rail (e.g. the wet zone at the application bars of a wayside unit). As soon as the water evaporates, the FM particles will adhere to the surface with higher relative surface velocity (e.g. the wheel under traction conditions) with limited further inter-surface material transfer [10]. A non-drying material will stay wet over a long distance (i.e. not only at the application site) and will thereby be continuously transferred back and forth between the wheel and rail. Consequently, there will be always a liquid phase present on the wheel and rail surface for this type of material.

6.) Benefit and Risk Analysis

The positive effects and possible risks associated with a true FM have been extensively analysed and discussed in previous publications [11,12,13]. Typical benefits can be achieved with respect to reduced lateral forces, improved vehicle steering, reduced wear and RCF of rails and wheels, increased track maintenance intervals as well as fuel/energy savings. On the risk side mainly topics like implementation and maintenance strategies to achieve the highlighted benefits as well as the area of liquid-crack interaction were so far discussed. With reference to non-drying materials, many aspects related to benefits and risks are still unknown or at least not sufficiently understood. Benefits and risks can be classified into immediate effects and long term (delayed) effects but also have to be differentiated according to the operational conditions (heavy haul, transit, mixed traffic, etc.). Immediate effects cover the areas of lateral force reductions as well as braking, acceleration, and noise (squealing) impacts. Corrugation development, wear, and RCF (of wheel and rail) as well as fuel/energy consumption are considered long term or delayed effects. The following sub-sections will analyse selected short and long term effects.

6.1 Lateral Force Reductions

Reductions of lateral forces, especially in sharper curves, can be seen as a main short term / immediate effect caused by the reduced/optimised friction levels due to TOR material application. Lateral forces can be measured by using lateral/vertical (L/V) force detecting stations installed in curves. It can be assumed that in sharp curves, vehicles are in a saturated steering condition (high angle of attack, wheel flange contact) that result in high creepage and high resulting lateral forces. Consequently, changes in lateral forces can be directly related to changes in the friction conditions between wheel and rail under these conditions. The curvature at which saturated steering is achieved depends on the curving capabilities of the vehicle. An L/V station uses strain gauges attached to the web and the foot of the rail in order to calculate lateral and vertical forces based on the measured rail deflections and appropriate calibration. For the analysis, thorough filter methodologies are applied to a sufficient number of trains per test phase resulting in a statistically significant and valid comparison of different products and application settings (see [14] for detailed information). This paper, however, will not further discuss this very important topic.

As reported in [15,16], TTCI conducted a trial at the HTL loop (High Tonnage Loop – 4350 m loop length) to assess different TOR materials under heavy haul conditions. The application site was located only 880 m away from the L/V station. This distance is considered close proximity compared to real track applicator spacing conditions. Different products were tested at multiple, controlled applications rates during different nights of testing. GF application was kept activated in the measurement curve during the whole test. The reported lateral force reductions in percentages (%) were calculated against steady state baseline dry rail conditions (statistically determined) without TOR material application prior to each application phase (see figure 6). The tested materials covered most TOR product classes mentioned in this paper. Due to the short distance between the FM application site and the L/V station, the application rates in mL/1000axles reported are typically lower compared to real track settings.

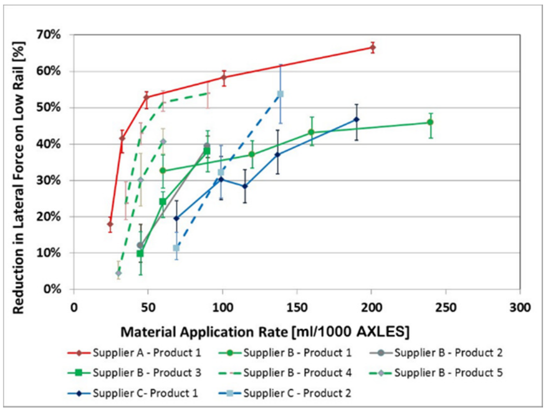


Figure 6: Results from a TOR material trial conducted at TTCI. Relationship of % lateral force reductions with application rates of different materials. Solid lines refer to "water based" products and dashed lines refer to "oil based" products (classification according to supplier information). Graph taken from [16].

For a FM (figure 6 - Supplier B - Product 1), relatively stable lateral force reductions can be seen with increasing application rates. This corresponds well with the definition of a FM according to TTCI. The non-drying products (e.g. figure 6 - Supplier A - Product 1 and Supplier B - Product 4 and 5) show that at lower application rates, there exists a strong dependence of lateral force reduction on the application rate. This can be explained by the mixed mode lubrication mechanism where the achievable coefficient of friction is directly related to the amount of material present in the contact area. Although Product 1 of Supplier A is referenced in figure 6 as "water based" it is classified by the authors of this paper as a hybrid type material with non-drying characteristics as it is containing a mixture of water and oil (see also section 4).

It can be assumed that under saturated creep conditions in the measurement curve (290 m radius), calculated changes in lateral forces can be related to changes in friction conditions. The higher the reduction in the reported lateral forces, the higher the reduction in friction referenced to a baseline dry rail friction level. Accordingly figure 7 shows an interpretation of figure 6. Instead of using "reduction in lateral forces in [%]" on the y axis, COF is used in figure 7. The baseline dry condition COF for each test was assumed at a level of 0.5 as the actual dry-level COF between wheel and rail for each test was unknown. All other COFs were calculated by multiplying the % lateral force reduction with the assumed dry-level COF of 0.5 for each product. This is based on the statement above that a change in lateral forces can be directly related to change in the friction conditions between wheel and rail under saturated vehicle steering conditions. At higher application rates of non-drying materials, the absolute reductions of lateral force / friction levels are not only much higher compared to a drying FM, but also the slope of the projected curve is steeper compared to a FM (figure 6 and figure 7).

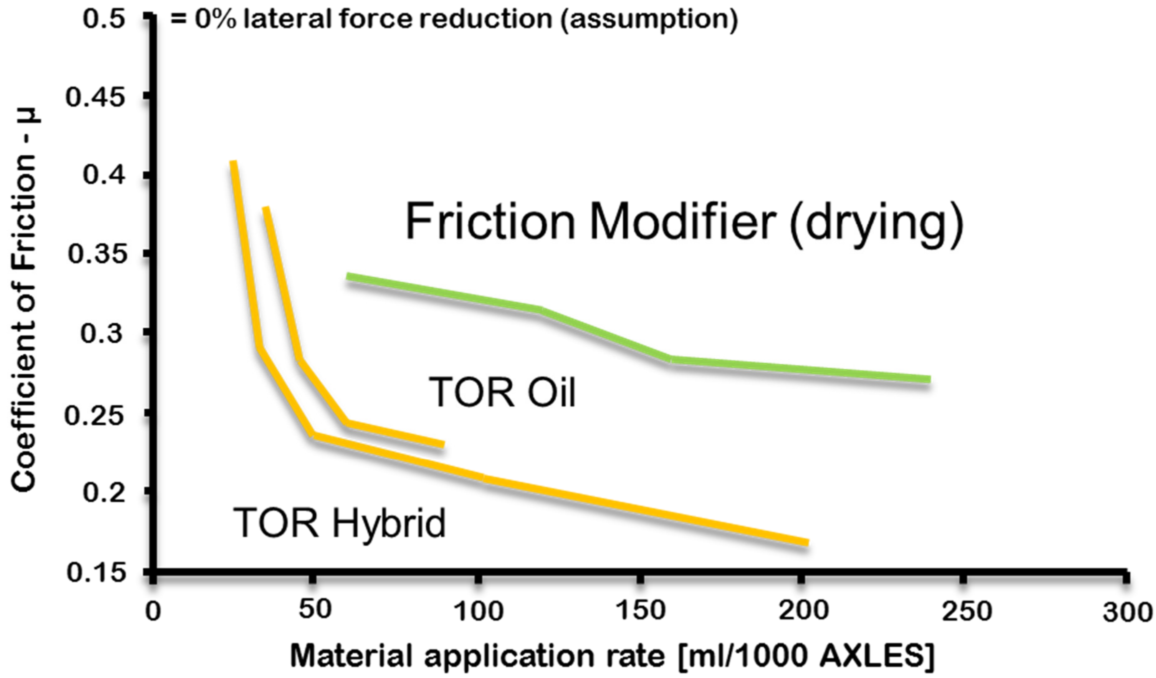


Figure 7: Interpretation and re-draw of figure 6 using only selected products to highlight the characteristics of different TOR material classes. The % reduction in lateral forces (y-axis) is exchanged with the according COF, assuming 0.5 as the COF for dry conditions.

TTCI also conducted friction measurements with a push tribometer. However, these values only give a partial indication of the actual friction values since a push tribometer only measures the friction between the tribometer wheel and the rail surface (as mentioned in section 3). It was reported that these measurements displayed a trend (within a wide scatter) showing lower friction levels for non-drying products, especially at the higher application rates. TTCI refers to Product 1 by Supplier A as a water-based FM. However, per definition introduced in this paper this material should be correctly classified as a hybrid material (i.e. non drying, oil-containing).

Besides lateral forces, carry-down characteristics of a TOR material represent an important selection and differentiation criterion. Carry-down is defined as the maximum distance from the application site where a certain lateral force reduction in % can be measured. For this purpose, L/V force stations are used to measure lateral (L) and vertical (V) forces in curves.

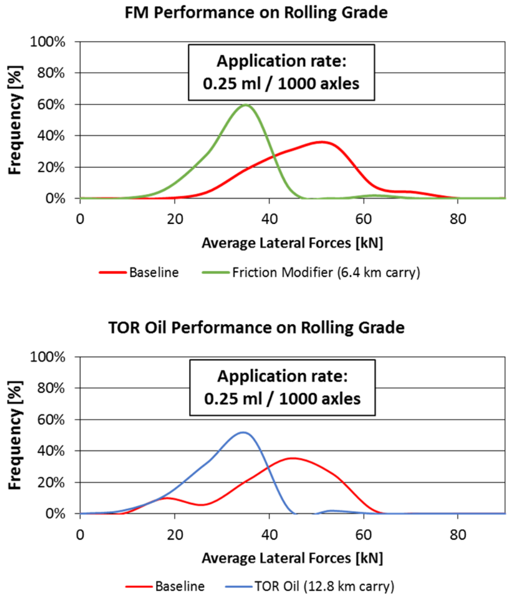


Figure 8: Frequency distribution plots for a FM and a TOR Oil. Both products significantly shift lateral forces to below 10 kips (44.4 kN). Extended carry-down for the TOR Oil of 12.8 km versus 6.4 km for the FM.

High performance FM products can achieve an average leading axle lateral force reductions of 25% or more at a distance of 4 miles for a given application rate. Some TOR Lubricants can achieve similar lateral force reductions at the same application rate with extended carry-down distances. Figure 8 shows distribution charts of lateral forces (after application of the above mentioned filter methodology) for a FM and a TOR Oil product referenced to baseline dry rail conditions tested at a Class 1 railroad in North America on level/river grade. Both TOR products effectively cut-off lateral forces above a 10 kips (44.4 kN) level (most damaging lateral forces); however, the TOR Oil was able to achieve these reductions at a 12.8 km (8 mile) carry-down distance compared to the 6.4 km (4 miles) carry-down distance for the FM (figure 8).

6.2 Adhesion Conditions

Another impact of reduced friction is a change in traction and braking capabilities of trains (adhesion conditions). Extensive data has been published for a drying FM on this topic [17, 18] showing that FM has no negative impact on both braking and traction capabilities in transit environment. Studies under heavy haul conditions have not been conducted as this was never considered a risk in a heavy haul environment based on the functional characteristics of a FM (intermediate COF).

A recent study [19] has analysed the impact of an oil based TOR lubricant on braking in a heavy haul environment. As this material has a strong application rate dependent COF (as explained above) and as this material stays in a wet condition over an extended time period / distance an impact on braking was assumed. Table 1 shows data from the field trial where braking tests were performed with loaded unit coal trains for this TOR oil product. On a level grade subdivision, designated braking points were marked on the track. These points were located about 1.6 km downstream from a TOR application site to ensure that all train wheels have passed the TOR applicator before applying the brakes. The test methodology consisted of applying a fixed reduction (138 kPa) of brake tube pressure (heavy haul air braking system) with no other means of braking applied. Locomotive event recorder data was used to ensure comparable conditions between trains and to calculate stopping distances. To compensate for inevitable human influence (response time, air reduction application time, etc.), steady state acceleration values were also calculated based on event recorder data. Brake tests under baseline dry rail conditions were conducted with no TOR material being applied. The TOR Oil phase used an intentionally high application rate of 0.681 litres / 1000 axles to simulate over-application. Brake tests were performed on at least 3 trains for each condition.

Product	Speed at brake point (km/h)	Avg. stopping distance (m)	Avg. acceleration (m/s^2)
Dry Rail	32	326	-0.26
TOR Oil	32	362	-0.24

Table 1: Brake trial results of a TOR Oil at a very high application rate compared to baseline dry conditions. No significant change in braking distance was noticed for TOR Oil.

The data in table 1 indicates that the over-application of a TOR Lubricant had no impact on braking under these specific conditions. Heavy haul trains are always equipped with tread brakes usually made of polymer-based “composition” brake shoes or alternatively tread-conditioning shoes. It is hypothesized that the material on the wheel surface might rapidly be scraped off/consumed by the application of the brake shoes. However, for many passenger and transit systems disc brake systems are frequently used and the required stopping distances are much shorter compared to heavy haul trains. It is assumed that under these conditions, an over-application of a non-drying material could have significant impacts on the braking capabilities of a train. For example, it was reported that German railways experienced braking problems at some application sites where an unspecified TOR material was applied [20].

The same paper [20] also analysed the interaction of locomotive traction with a TOR Hybrid material. It was shown that even a slight over-application will cause extensive slippage problems for all the (driven) axles of the locomotive. Furthermore they also confirmed that the resultant COF is strongly dependent on the amount of material present on the rail surface.

Passenger and commuter type trains typically have much shorter train lengths, higher acceleration rates, lower axle loads, and higher percentage of driven axles per train compared to heavy haul trains. This would allow for the assumption that a passenger/commuter train is more prone to slippage of driven wheels and train stalling issues compared to a heavy haul freight train. Further data on this topic will be published upon availability.

6.3 Liquid Crack Interaction

Long term effects like RCF development are more difficult to analyse under track conditions as they require an extended period of time with stable test conditions. The interaction of liquids with pre-existing cracks on the rail surface is a topic of past and recent research. According to [21], a liquid present on the rail surface may cause accelerated crack growth by fluid entrapment within a crack by a passing wheel. The entrapped fluid will pressurize the crack tip and thereby drive crack growth. Another mechanism relates accelerated shear crack growth to crack flank lubrication by the entrained liquid. However this mechanism is only likely to occur for friction levels in the crack below 0.2. Although these effects might not lead to a catastrophic failure of a rail, it may manifest in severe spalling. There is only limited reported evidence (mostly anecdotal) from track observations available on this topic. In 2004, a FM application system was unintentionally misplaced in the spiral of a curve in a heavy haul system. Pre-existing crack damage on the rail surface lead to extended spalling over a distance of 15 meters right after the application location (figure 9). Relocating the application system 30 m into tangent track before the beginning of the spiral and grinding the rail for damage correction prevented the problem from re-appearing.

Figure 9: Example of spalling caused by an accidentally misplaced FM application unit in the spiral of a curve with pre-existing cracks on the rail surface. Optimized unit placement and corrective grinding prevented the problem from re-appearing.

In order to get a better understanding of liquid-crack interaction, a series of twin disk tests was conducted at the University of Sheffield in the UK [22]. Every test started with 4000 cycles of dry conditions with test settings (400 rpm, 1500 MPa, 1% creep) that ensured a clear onset of damage on the rail-disc surface. After these initial dry cycles, several different TOR materials were applied to the disc surfaces (controlled application rate and amount) including water, FM, TOR Oil, TOR Hybrid and other lubricants. Each test was continued until a total of 25,000 cycles was reached. Eventual material loss and damage were assessed (visual, metallographic sectioning) after each test. The results of the surface conditions of each test shown in figure 10 clearly indicate that water has the worst impact on pre-existing cracks. All non-drying TOR materials tested also show a clear increase in crack growth compared to the 25,000 cycle dry reference disk (3) in figure 10. Differences among the non-drying materials can be related to viscosity differences. Out of all the tested products, only the FM did not cause accelerated crack growth under the twin disc test conditions. The translation of these results to real track conditions is a more challenging task. The conditions on the twin disc machine represent constant loading conditions, line contact, and crack geometries that easily allow for fluid entrapment. Real track conditions differ significantly from these laboratory conditions (e.g. changing loading conditions, curved rail-wheel contact areas and complex 3D crack geometries). It is hypothesized that under most circumstances, the complex 3D crack geometry would allow any liquid present within a crack to leave the crack while the wheel is passing over the rail. Only specific crack geometries might result in liquid entrapment and consequently cause extensive spalling. The majority of RCF defects might only experience minor crack growth acceleration. Such an effect can only be indirectly measured through more frequent grinding cycles or higher metal removal rates per grinding cycle to remove damage.

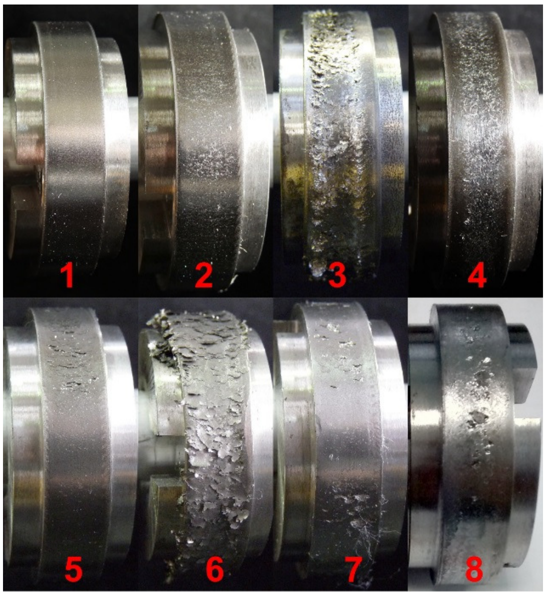
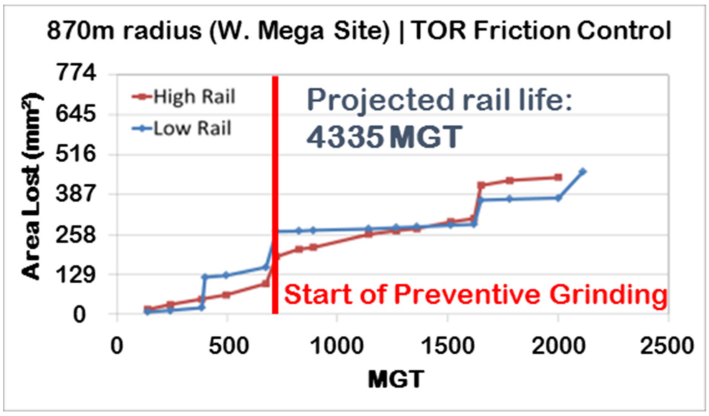


Figure 10: Disc surface images after RCF tests on a twin disc instrument at 1.5 GPa, 1% creep and 400 rpm [22]: (1) dry after 4000 cycles; (2) dry after 25,000 cycles; (3) water after 25,000 cycles; (4) TOR-FM after 25,000 cycles; (5) GF lubricant after 25,000 cycles; (6) TOR lubricant (oil) after 25,000 cycles; (7) TOR lubricant (grease) after 25,000 cycles; and (8) TOR hybrid after 25,000 cycles.

A limited number of full scale test rig tests have been done where a FM was applied to a rail surface with pre-existing head-check type defects. Similar to the twin-disc tests, no accelerated crack growth was observed for FM conditions compared to baseline dry conditions [23].

Furthermore, the abovementioned full scale rig tests and extensive track tests have demonstrated the potential of FMs to delay the formation of damage and thereby extend the necessary maintenance intervals and rail life. Heavy haul track tests have demonstrated grinding interval extensions of at least 15-20% by FM application compared to dry rail conditions [24]. Recent results, published by TTCI [25], also confirm these findings at a revenue service test that compared a preventive grinding strategy with a combined FM and grinding strategy. The results clearly indicate the potential of a "combined FM and grinding strategy" to extend the rail life by reducing RCF formation and at the same time also extend the necessary grinding intervals (figure 11). This study also highlights the necessity of a system approach/optimisation. The rail welds that typically showed the same lifetime as the rails in the preventive grinding approach were found to be the track-life limiting factor in the combined FM and grinding approach.



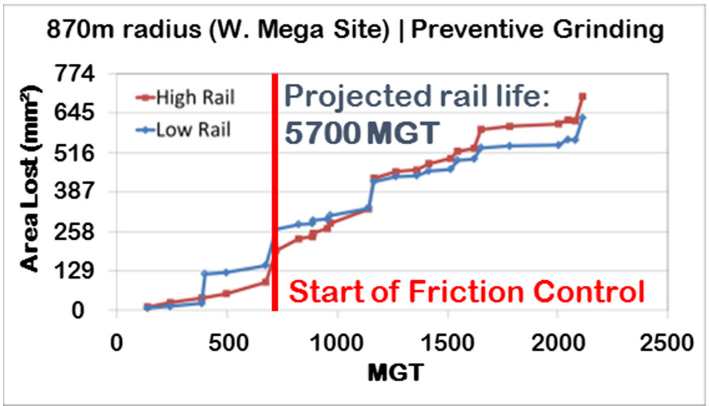


Figure 11: Comparison of a preventive grinding strategy with a combined FM and grinding strategy at the Western Megasite in the US. managed by TTCI (redraw and conversion to metric system from [25]). Rail life extension for the combined approach due to RCF reduction and grinding interval extension.

It should be emphasized that the benefits reported here for RCF mitigation are only proven for one specific drying FM. The deliberate addition of any non-drying materials to the TOR is not covered by this reference work and the potential for aggravating RCF damage on rails and/or wheels should be taken into careful consideration until more data is available on this topic.

6.4 Other Long Term Effects

Effects that require an extended time period in order to be measured (slow defect development, high data scatter due to multiple influential factors) are defined in this paper as long term effects. Such effects that can be directly related to the reduced COF on the TOR will benefit from any type of material that is added to the rail-wheel contact. By reducing the COF typically also the wear rate is reduced. However, as there is no direct dependence between wear and the COF (e.g. in the Archard wear law the COF is tied into the wear coefficient) the wear behavior of each new material needs to be analysed separately. Consequently, non-drying materials might provide a different wear impact compared to drying materials [23, 26].

Fuel consumption is dependent on multiple factors (e.g. engineer driving style, wheel/rail friction conditions, track geometry and territory characteristics, the make-up of the train consist, and train resistive forces). Friction control on the TOR will impact only rolling and curving resistive forces that are directly related to the friction conditions between the wheel and rail. Achievable fuel savings of up to 10%

have been reported in extensive studies [27] in heavy haul environments. Similar results might be expected for a non-drying TOR product. Currently there is a Class 1 railroad that implemented TOR friction control with a TOR synthetic oil material on level grade territories. However no published data on fuel savings is available.

Corrugation formation is related to multiple factors [28]. Most of these factors include wear as the main damage mechanism. Specific corrugations types are also related to stick-slip oscillations in the rail-wheel contact. A FM can address both mentioned contributing factors – wear by the optimized friction and stick-slip oscillations by the positive traction characteristics [8]. Very limited data is available for non-drying TOR materials and their effect on corrugation. Data published in [8] also indicated that FM is considerably more effective than traditional grease lubricants (used on TOR) in retarding rutting corrugation development.

6.5 Additional considerations

Besides the topics highlighted in this chapter also other factors can influence the performance of a TOR material. In some cases there can be unwanted TOR contamination with a GF lubricant (e.g. in the case of GF grease over-application or misaligned GF applicator bars). In this case the GF lubricant will "override" the characteristics of the TOR material. Also the current weather conditions (precipitation, humidity) will impact the friction conditions (and TOR material performance) between wheel and rail. Selected data on the weather impact can be found in [29]. It can also be assumed that maintenance activities like tamping, re-gauging, grinding, etc will change the geometric conditions of the rail and the track and will consequently impact the lateral forces transmitted between wheel and rail and will thereby impact the effectiveness of any TOR material [AREMA]. Although not specifically mentioned, all these factors were recorded and at least observed during the above mentioned tests to keep the impact on the FM performance as low as possible or at least to ensure constant conditions during the course of a trial.

7. Conclusions

This paper has shown that nowadays there are multiple different materials for TOR application available that allow the successful reduction of friction (and consequently lateral forces) between the wheel and rail. These materials can be divided into Friction Modifiers and TOR Lubricants. Friction Modifiers are fast drying materials that provide optimised friction conditions (in the dry state) through a shear displacement compensation mechanism in the third body layer between the wheel and rail over a wide range of application rates. TOR Lubricants are considered to be non-(or slow) drying products that provide reduction of COF through an application rate dependent mixed-mode lubrication mechanism. They can be sub-classified into TOR Oils, TOR Greases or TOR Hybrids (i.e. containing a water-oil blend).

It has been demonstrated through extensive research studies that a FM provides a number of proven benefits (wear reduction, RCF mitigation, fuel savings, corrugation suppression) without interfering with safe train operations (train adhesion). Non-drying TOR materials might provide similar benefits in areas that are directly related to a reduced COF (rail/wheel wear, fuel savings). With respect to carry-down characteristics, non-drying materials can provide improved benefits compared to drying materials. However, in areas like braking and traction, RCF and corrugation development these non-drying materials might pose some unintended side effects or even risks. Further investigation is recommended to fully understand these aspects of TOR Lubricants.

Friction Management (the combination of gauge face lubrication and TOR friction control) is only one of multiple influencing factors in the complex wheel-rail system. Rail and wheel metallurgy, rail and wheel profiles and track geometry conditions will interact with friction management. Therefore it is important to understand that a sub-optimization of only one of these factors without considering the impact on the other factors may eliminate any expected/theoretically achievable benefits on the system level. Therefore understanding the classification, characterization and application of existing and new TOR friction control materials, and their interaction with other components in the railway system, will enable safe and economically optimised asset management for railway operators.

8. References

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