A review on recent wheel/rail interface friction management

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Abstract. Traction is influenced greatly by the climatic conditions, especially under wet conditions induced by rain or snowfall which could cause the loss of adhesion and could reduce the coefficient of traction (COT) to a dangerous level. This is why good adhesion is needed to ensure safe and good traction of train. Poor adhesion between wheel and rail can cause various problems and it could be fatal. Friction modifiers are applied to the contact interface to control adhesion, whether to enhance friction or lubricates, to ensure safe running of the rolling stock. In handling poor adhesion issues, sand is the most popular and the main adhesion enhancer used globally on railway networks. Sand particles enhance adhesion dramatically in contaminated wheel/rail contacts such as rail covered by autumn leaf layers or oil stain, and in wet rails. In this review paper, a compilation of some of the research of over the last decade is presented. The topics that will be presented in this paper are the adhesion characteristics of wheel/rail contacts under wet and dry condition, and the influence of sanding on rails covered with leaf layers.

1. Introduction

The wheel/rail contact is a complex and imperfect link due to its small area and loaded with highly concentrated stresses. The conical wheel shape makes the wheelset a mechanical amplifier, limited by the transverse play, with partially sliding surfaces [1]. Even pure rolling bodies involves sliding though it is minimal. In sliding bodies, the friction force is contributed by the coefficient of friction which depends on the roughness, adhesion of the sliding surfaces, and ploughing caused by asperities [2].

Figure 1 shows the wheel/rail contact area, is divided into two regions; stick and micro-slip regions. Tangential force, also known as tractive force, and longitudinal creep exist because of the micro-slip that occurs in the rear region of the contact region as traction is transferred to rail due to sliding friction in relation to micro-slip. This causes the initiation of yield under the surface. The higher the tractive force, the more the slip increases and the smaller the stick region becomes, resulting in a rolling-sliding contact and also the yielding point to approach the surface. When first yield occurs at the surface, the critical point lies at the boundary between the stick and micro-slip zones. Maximum tractive force is attained at the critical point and is the maximum value of sliding friction which can be

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converted into adhesive weight, which is responsible for the transfer of tractive force. After the critical point, capability of transferring tractive force reduces with the increase in micro-slip. When tractive force is greater than adhesive weight, the saturation value of the tractive force is reached and, resulting in the contact patch dominated by slip. The contact is then considered as pure sliding. [2], [3]

The wheel/rail traction characteristics are significantly related to the upper limit of the running speed and running stability. Traction is influenced greatly by the climatic conditions, especially under wet conditions induced by rain or snowfall which causes the loss of adhesion and it may cause wheel slippage and damage to both the wheel and rail [5]. In tropical countries, wetness and humidity is capable of reducing the coefficient of traction (COT) to a value that is even lower than the allowable minimum COT for stable and safe running of the vehicle, which is 0.20 [6]. The same issue of poor adhesion is also faced by countries with four seasons, where autumn leaves and snowfall could reduce the COT to a dangerous level. The presence of a third-body layer in the wheel/rail contact will dramatically influence the traction creep curve. Good adhesion is needed to ensure safe and good traction of train. While, poor adhesion between wheel and rail can cause various problems such as producing high frequency noises [7], severe rolling contact fatigue (RCF) [8], exacerbate the development of rail corrugation [9], high energy dissipation [10], unstable traction before accelerating [11], and on the other hand causes poor braking performance resulting in extended stopping distances [12]. Furthermore, excessive tangential friction force at sharp curves could cause wheel climb derailment [5].

In handling poor adhesion issues, sand is the most popular and the main adhesion enhancer used globally on railway networks. Sand particles enhance adhesion dramatically in contaminated wheel/rail contacts such as rail covered by autumn leaf layers, rainfall, or oil stain, because of the intrinsic interlocking action of crushed sand particles that embedded into the softer part of the wheel and rail surfaces, and therefore, enhancing traction [13]. Sanding does not only restores adhesion but is also able to remove dried leaf layers covering the rail [14], [15]. Even though sanding had been widely used to improve traction in poor adhesion condition, a satisfactory method to enhance adhesion and avoid severe wear of wheel/rail interface at the same time is still uncertain [16], [17]. Sand tends to increase the wear rate of the rail by a factor between two to ten due to the damage caused by asperities in the wheel/rail interface [18]. This is because sand could cause indents and scratches on the wheel and rail surfaces because of its hardness [14] and gives a high value of mass loss [16]. Arias-Cuevas had conducted extensive laboratory tests to study the influence of sanding parameters on traction [15],

![Diagram of Creep curve in the wheel/rail contact](image)

**Figure 1.** Creep curve in the wheel/rail contact adopted from Olofsson & Lewis [4].
Although numerous studies regarding the influence of sand on adhesion and wear had been done recently, the influence of different types and different compositions of sand used for sanding is also unclear as different types of sand exhibit different hardness level which may interact differently in the contact interface. Wang et al. (2014) and Cao et al. (2016) conducted a laboratory test to investigate the influence of alumina particles as replacement for sand in sanding, which yields quite favourable results.

2. Dry and wet wheel/rail contact

Friction modifier (FM) is applied to the wheel/rail contact to manage and generate the required friction coefficients. Generally, there are three categories of FM [4]; (1) Low coefficient FMs such as lubricants which are applied at the wheel flange-gauge corner interface to give friction coefficients less than 0.2, (2) high FMs with intermediate friction coefficients of 0.2–0.4 which are used in wheel thread-rail top applications, and (3) very high FMs such as friction enhancers which are used to increase adhesion for both traction and braking, especially at where adhesion loss problems occur.

When FMs are added into the contact interface, the lubrication effect will kick-in immediately. Figure 2 shows the general trend of COT under dry condition, wet condition and lubricated contact. Applying FM is able to reduce the COT instantly. The fluctuation of COT for lubricated contact after the application of FM is due to the uneven spreading of FM in the interface. After the FM is evenly spread, the COT becomes stable and constant. This is most probably why rail vehicles travelling in the middle of rain and snowfall is hazardous as the steel wheel loses its grip on the rail and causes slippage and difficulties in braking and accelerating. This explains why the climate of a location, such as ambient temperature and humidity, can greatly affect the safety of train operation, as high temperature and humidity can also cause the reduction of COT [11].

The traction curve for contact under dry condition shown in Figure 2 can be divided into three regions; initial stage (steep positive slope), wear stage (steep negative slope), and stable stage (gradual decline). During the initial stage, the oxide film on the disc surface would be gradually reduced due to the increase in sliding distance. Therefore, the shear stress increases at the interface resulting in rapid increase of COT. At the same time, the effective hardness of the disc surface will decrease. At the end

![Figure 2. General pattern of COT after the application of FM (FM).](image)

Note: Values are of general trend, not definite.
of this first stage, the hardness and shear stress varies negligibly due to the formation of mixed layer of steel and the destroyed oxide film which had embedded in the surfaces, thus, resulting in a lower rate of increase in COT. After the COT reaches a maximum value (running-in), the contact tends to experience a decline in COT, which is the wear stage. It is common that the COT decreases after running-in for dry condition. This is because a significant wear on the surface had begun to occur. Subsurface plastic deformation causes the hardness to increase by strain hardening. Although the COT is almost constant with a slight decline in the stable stage, the hardness increases gradually due to the continuous gradual increase of shear stress on the surface. [5]

On the other hand, the COT under wet condition, unlike dry condition, increases gradually and then becomes steady. After that, it decreases marginally. Furthermore, rail wear is mild under wet condition compared to that of dry condition because of the lubricating effect of the fluid which reduces abrasion. The traction curve under wet condition is divided into two stages; initial stage and stable stage. In this initial stage, the COT will increase rapidly (but with lower gradient compared to dry condition) with a slight increase in surface roughness. The effective hardness is nearly constant as the wear of the oxide layer on the steel surfaces is minimal due to the tribochemical reaction film with water and the lubricity of the fluid. The oxide film would then be destroyed more moderately, forming a tribochemical reaction film of oxide and hydroxide mixture, which would cause the decrease of the effective hardness. At the end of the initial stage, the rate of increase in COT becomes slower because of the constant surface roughness and slight decrease in effective hardness. In the stable stage, the surface roughness tends to decrease slightly, while the hardness increases slightly. This explains the marginal decrease in COT. [5]

Mass loss of wheel and rail are caused by both abrasion and material removal. Under dry condition, delamination and wear scars can be seen on the rolling surface while there is some peeling on the wear surface under water-lubricated condition as shown in Figure 3 [23]. The mass loss of rail disc after the application of FM tends to be higher than that in dry tests due to flaking and cracks growth assisted by fluid. The wear rates of wheel and rail under dry conditions remains almost constant, as it stabilized after a certain number of fatigue cycles. However, the wear rate of rails with FM is only constant in the beginning and becomes almost double as the number of fatigue cycle increases. The crack angle and crack depth under wet condition is also doubled of that under dry condition. The wear mechanism responsible for the greater wear rates is delamination that leads to spalling [24]. It is the hydro-pressure within the crack that is responsible for the crack elongation which eventually leads to flaking. As fluid enters the cracks on rail initiated by shear and pressed by the rolling contact of the wheel, the contact pressure is transmitted hydraulically via the crack to the subsurface of the rail as shown in Figure 4. The fluid is then entrapped and pressurized inside the crack which then results in the generation of squeeze film pressure. [25]. When two discs slide on each other, a tangential force that varies with the slip will appear. These tangential forces cause compressive and tensile circumferential stresses in and around the contact zone, and the stresses are oppositely located in the wheel and rail.
Figure 4. Mechanism of crack propagation by the pressure of a trapped fluid [26].

Prior to the contact zone the compressive stresses close the tips of the cracks in the wheel avoiding the fluids to enter in the cracks. On the other hand, the tensile stresses open the cracks tips in the rail and facilitate the entrance of fluids; right after the contact zone the stresses are reversed and the crack in the rail closes pressurizing the fluid inside [24].

Abrasion usually causes more removal of wheel material than rail. This is why mass loss of wheel disc tended to be higher than that of rail disc. Another reason why crack elongation assisted by fluid pressure does not occur on the wheel is because fluid on the wheel surface is being removed by the centrifugal force of the rotating wheel. Furthermore, rain and snowfall only falls on the rail and not on the wheel. FMs are also applied on the rail instead of the wheel. There are three FM application methods, which are mobile lubricators, wayside lubricators, and on-board lubricators [4]. Mobile lubricators are railway vehicles designed to apply lubricant to the gauge corner of the track. Wayside lubricators are mounted next to the track and spray lubricant to the rail gauge corner. Only on-board lubricators apply lubricant on to the wheel flange, which is then transferred to the gauge corner of the rail.

Rough surface has high asperity which could provide a better grip than smooth surface. Therefore, greater surface roughness gives higher maximum COT to a wheel/rail contact. This is confirmed by the recent work of Chen et al. [17], both theoretical and experimental analysis, where under wet condition the COT reduces as the surface roughness decreases regardless of the contact pressure. However, based on the theoretical analysis, which employed a numerical model that adopted Elasto-Hydrodynamic Lubrication (EHL) theory and Greenwood–Williamson’s (G–W) stochastic model, different trends of COT can be obtained by varying the surface roughness, as shown in Figure 5.

Figure 5. Theoretical simulation result of influences of Hertzian pressure and surface roughness on COT [17].
Figure 6. The influence of slip on COT under wet condition with (a) various axle and (b) various angle of attack [23].

The experimental analysis of Chen et al. [17] showed that the COT seems to decrease when axle load increases in slow rolling speed condition, regardless of surface roughness. However, at faster rolling speed the COT for high surface roughness decreases drastically while for low surface roughness decreases slightly before increasing as contact pressure increases. The COT will not be affected much in the case of the high-speed region. However, under low-speed condition such as metro and commuter, the maximum COT will decrease with an increase in rolling speed [11]. From both theoretical and experimental analysis, though the results are slightly different, the influence of axle load on the COT was clearly found to be dependent on angular velocity and surface roughness. The increase in load causes the reduction of COT because the increase in axle load results in the expansion of the contact area between the wheel and rail and can transfer more tractive force. However, the ratio between tractive force and normal force would decrease, which will reduce the COT. But when water is added into a dry contact interface, the COT dropped dramatically to a similar value, regardless of the axle load [23]. Though the COT varies as slip increases, the effect of axle load on traction is minimal and almost constant, as shown in Figure 6(a). If water of higher temperature is applied into the contact interface, the maximum COT is higher compared to that of lower water temperature, but with the same declining trend [27].

The wheel/rail contact on a curved rail is simulated by adjusting the angle of attack of rail disc in a twin disc roller rig machine. Sharp curves would result in a greater reduction in COT than that of a curve with larger curvature radius, in both dry and water-lubricated condition as shown in Figure 6(b). This is because the longitudinal creep force of the contact area would reduce by decreasing the curve radius, which leads to the loss of adhesion [23]. According to the experiment conducted by Baek et al. [11] with setting of 800 MPa of contact pressure, there are three types of transient traction characteristics dependent on slip, as shown in Figure 7. In cases where slip is less than 0.3%, the COT increased linearly and then became steady. In cases where slip is above 0.3%, the peak appeared at a certain sliding distance. In cases of slip greater than 2.8%, the COT increased gradually after the peak.

The dependency of COT on the presence of iron oxide layer on the wheel is unclear. However, the COT under dry condition is undeniably high regardless of the thickness of iron oxides and surface roughness. A rough rail surface with thick oxide layer on the wheel can help to gain extra adhesion during taking off, but at the cost of severe wear. The surface of the rail tends to suffer severe surface delamination if the oxide layer is too thick. On the other hand, the presence of the iron oxide layer is very critical under wet condition. Thin oxides are able to protect the interface from wear and ploughing for rails with smooth surface roughness even though the adhesion is high. While, thick oxides break off becoming debris, enhances the ploughing effect and increases wear. Surprisingly, the COT of thick oxide layer under wet condition is low because wear debris tends to destroy more of the
Figure 7. Schematic patterns of the COT curve [11].

Surface to produce more debris. This process continues on until the quantity of wear debris is enough to form a lubricating paste with water which eventually reduces COT. [28]

3. Sanding

Figure 8 shows the mechanism of a sanding apparatus. In practice, the sanders are fitted on only certain axles of a train so that the amount of sand laid on the rails is first used by the wheels of sanding axles, while the following wheels roll over the remaining crushed sand [19]. An effective sanding at the leading wheels could condition the railhead so that the following wheels will not experience poor adhesion problems. Sand does not only enhance adhesion but also acts as a solid lubricant under dry wheel/rail contacts at different slips, feed rates, and particle sizes. Therefore, a proper adjustment on the most influencing parameters, which are the feed rate, particle size, and wheel slip, are needed in order to provide good friction management on the railhead.

Leaf layer does not only cause the wheel to lose traction but also insulates the rail from conducting electricity [14], [19]. Furthermore, the leaf stalks will cause long indentations and scratches to the wheel and rail surfaces. The adhesion loss caused by leaf is even lower than that of oil stain. The optimum value of COT is 0.35 under dry condition [7], [29] while the minimum allowable COT is 0.2 [24]. Any wheel/rail contact with COT below 0.2 will be considered as unsafe. Sand is able to restore

Figure 8. Sanding apparatus [4].
both adhesion and electrical conductivity by effectively removing the leaf layers from the rail surface. There are two types of sanding method, which are initial sanding and continuous sanding. Initial sanding is used to provide the initial adhesion of the contact interface by ejecting sand particles into the interface for only once, while continuous sanding is the ejection of sand into the interface over a period of time in order to maintain desired lubricity along the travel.

Figure 9 shows the typical influence of sanding on the COT for rail discs with leaf layers contamination in a typical twin disc roller rig test. Typical values of slip found in actual operations of traction and braking are 1%, 5%, and 10% and was found that the baseline of COT under dry uncontaminated contact of twin disc roller rig test is approximately 0.6 for most slip conditions in actual operations and 0.3 for 0.5% slip, while the baseline of COT in leaf-contaminated rail disc in most slips, depending on the number of cycle, ranged from 0.15–0.25 which is considered unsafe [15], [21], [30]–[32]. In initial sanding the COT increases due to the removal of leaf layers as shown in Figure 10 (left). Increasing the number of sanding axles is able to remove the leaf layers even faster and also provides a larger initial adhesion improvement after initial sanding. On the other hand, the influence of slip becomes weaker when fewer number of sanding axle is used. However if more sanding axles are used at high slips for initial sanding, a black powder of broken leaf layers which can be easily rubbed away with fingers, as shown in Figure 10 (right), will form on the disc which will cause the reduction of traction gradually and then be removed eventually due to the abrasive action of the entrapped sand, restoring the adhesion to clean condition [21]. Furthermore, the adhesion recovery is faster at higher slips.

Since sand are ejected continuously into the interface in continuous sanding, the adhesive behaviour of the sand are also different from that of initial sanding even though the sand may have the same particle size ejected into the interface at the same feed rate and slip. An investigation on particle size was conducted by O. Arias-Cuevas, Li, & Lewis [19] on improving adhesion of rail with leaf layers by initial sanding, shows that particle size that ranged between 0.3–0.6 mm (medium-size sand) gives the best result in restoring traction, better than particle size of range 0.06–0.3 mm (small-sized sand), while sand with particle size of range 0.85~1.6 mm (large-sized sand) restores the COT the least among all the other tested sands. Having more particles travelling through the interface is expected to ease the removal of contamination. But medium-sized sand performed better than small-sized sand, which could probably due to the balance in size to promote good particle entrapment and to remove the leaf layers is satisfied. However, another investigation on particle size which was also conducted

![Figure 9. General pattern of the influence of different sanding conditions on COT.](image_url)
by Oscar Arias-Cuevas et al. [15], but with continuous sanding, shows that larger sand particle sizes promotes greater COT. Instead of enhancing adhesion, smaller particle size sand, including medium-sized sand, promotes lubrication with COT lower than that of leaf contaminated baseline, which also confirms the previous study of O. Arias-Cuevas, Li, & Lewis [19].

Furthermore, The investigation of O. Arias-Cuevas, Li, & Lewis [19], which is by initial sanding, also discovered that medium size sand is the best in removing leaf layers and at the same time poor at electrical insulating. But the investigation of Oscar Arias-Cuevas et al. [15] with continuous sanding shows that smaller sand particle sizes, ranged between 0.06~0.6 mm, caused more electrical insulation than larger sands, leading to open circuit conditions. This is due to the breaking of larger particles into smaller particles to withstand the contact load before forming a compacted crushed sand coating on the rolling surfaces with the broken particles that enter the disc interface. When using smaller sized sand, more particles can enter the contact without being broken up which will form the sand coating faster. Electrical insulation is not only dependent on the particle size of the sand but also the feed rate. As the feed rate increases, the disc interface will experience a transition from partial lubrication to full lubrication regime due to the increase in sand particle in the interface [19]. The additional sand particles that enters the interface at higher feed rate will speed up the formation of sand coating on the disc surface.

Large sand experiences breaking of sand particles from the contact load which will cause the COT to be slightly unstable. The larger sand particles will first bear the load and break up until the number of particles to withstand the load is sufficient. Small sand provides steady COT partly due to the formation of compacted crushed sand coating on the disc [15]. The coating of compacted crushed sand on the disc surfaces is formed by entrapment of crushed sand particles in the softer steel surfaces and are repeatedly compressed under contact load. Furthermore, larger particle size at the same slip forms lesser sand coating. This may be caused by two reasons: (1) Larger sand particles has better abrasive action and could remove more coating, and (2) less sand particles will be entrapped in the interface at larger particle sizes, hindering the coating formation.

Higher slips will also increases the effect of adhesion because slip increases with tractive force [14], as shown in the traction creep curve, until the saturation point reached where the traction is maximum before the contact is dominated by slip contact [2]. At higher slips condition, the COT is almost constant with only slight deviations as shown in Figure 11 [14]. Theoretically, a pure rolling contact, where there is 0% slip, could provide zero COT. However, the experiment of Wang et al. [23] and Baek et al. [11] yielded a slightly positive result, which could possibly due to the error in setting the datum for zero traction force, small vibration, and asperity differences between the two contact surfaces.

In terms of sanding mechanism, the increase of slip enhances the interlocking action of sand due to higher abrasion as a result of sliding of crushed sand particles for a longer distances when travelling.
through the contact interface at higher slips. This interlocking of sand yields higher COTs. Such increase in tractive force is able to remove leaf layers, coatings of FMs, thin film coatings, and compacted crushed sand coating. Therefore, there seemed to be a threshold dependent on both sand particle size and slip above which no sand coating would be formed. This explains the sudden drop of COT, as shown in Figure 9, for continuous sanding [15]. Increasing slip could reduce the probability of sand coating formation as embedded crushed sand particles abrade the surface of the opposite disc due to the relative motion, but lead to surface wear. This abrasive behaviour also promotes the removal of rail and wheel material on the rolling surfaces. In addition, high strains on the disc surfaces, as a result of the high tangential stresses occurring at higher slips, causes surface strain hardening and could have led to greater grain deformation.

Besides slip and particle size, feed rate of sand also influences the COT. Feed rate of 7.5 g/m is representative of the ones used in practice [18]. As solid lubricants, sand can reduce the COT of 0.6 for dry condition to a range of 0.1~0.4 according to the grain size. There will be an instant reduction in COT when sand is fed into the contact. Higher feed rates of sand during sanding promote the continuous reduction of COT at all slips as shown in Figure 12, due to the flooding of particles which reduces abrasion and promotes coating formation [19]. However, the rate of reduction is only severe for low slips while the rate of reduction for higher slips is lesser due to the increased abrasion which prevents the formation of sand coating.

Although larger particle sizes can enhance adhesion, it also causes indentations and cracks on the disc surfaces while smaller particle sizes only cause abrasion and formation of coating. In addition, larger particle sizes give higher strains near the disc surfaces. These strains, if high enough, could form cracks on the rolling surfaces. The subsurface plastic deformation layer is deeper and greater for large sand particle size while smaller sand shows only little plastic deformation. This is because the elastic limit is exceeded and introduces residual stresses when the contact stress is first applied. Continuous application of load will subject the materials to the combined action of contact stresses and residual stresses which causes a process known as shakedown, where initial plastic deformation introduces residual stresses which make the steady cyclic state purely elastic which are protective to the rail. One of the effects of shakedown is strain hardening of material due to the exceeding of shakedown limit which causes orthogonal plastic shear in the subsurface elements. In repeated rolling cycles the plastic deformation will accumulates and causes the surface layers to be displaced 'forward' as shown in the result of Figure 13, which shows that the grain deformation in the near-surface region. The deformation increases in larger particle sizes and caused more strain hardening of the disc surface for both wheel and rail, which means that larger particle size can cause a greater effect of shakedown.
However, large sand seems to cause less rough surfaces than small sand. This could be related to the balance existing between the number of particles entering the disc interface and their effective abrasive size. [3], [15]

It is undeniable that slip had a clear influence on the subsurface deformation as the sliding distance of sand particle in the interface is elongated. Figure 14 shows the plastic deformation of wheel and rail discs tested at 1%, 5%, and 10% slip. The deformation in 1% slip is almost unnoticeable, while 5% and 10% slip caused severe deformation [15]. With the increase in slip ratio, the tangential force grows and the plastic deformation results in an increase of surface hardness. The maximum shear

**Figure 12.** Average COT of S sand (0.06~0.3 mm) during feed at 1%, 5%, and 10% slip and different feed rates under dry conditions [19].

**Figure 13.** Subsurface micrographs of rail (top) and wheel (bottom) after tests with S (0.06~0.3 mm), M (0.3~0.6 mm), and L sand (0.85~1.6 mm) at 5% slip, 7.5 g/m feed rate [15].
stress is located on the subsurface, while the point closer to the surface at higher slip will have a harder surface. The hardness of the disc surfaces for both wheel and rail increases dramatically, up to double its original hardness, after tests are done for all slips [33]. Cracks, deep indentations, and spalling defects can be found on the disc which may cause break-off as a flake. Such micro-fracture contributes to the mass loss and surface roughness as a result of wear due to fatigue. The wear rate of rail increases linearly with the increase of slip, but the wear rate of wheel will have a great increase at a certain point of slip [33].

4. Summary
Friction management in wheel/rail contact is extremely important as poor friction management could cause various problems and issues as mentioned earlier. There are numerous studies and journals on friction management of wheel/rail contact over the past ten years while this review paper only covers some of the journals on contacts under dry/wet condition and sanding in rail contaminated with leaf layers.

Even though FM and sand had been used for many years in friction management of wheel/rail contact, applying liquid FMs and sand causes more wear on the rail surfaces when used to improve adhesion. A satisfactory method to enhance adhesion and avoid severe wear at the same time is still uncertain. The influence of different types and different compositions of sand used for sanding is also unclear as different types of sand exhibit different hardness level which may interact differently in the contact interface. Furthermore, Leaves are actually good lubricating agent due to its high lubricity effect on wheel/rail contacts. Perhaps leaves can be used as dry solid FMs, instead of water-based FM which promotes crack growth, to control friction at high friction rail sections for smoother traction.

Besides applying FM, there are also other approaches used to improve traction in low adhesion condition. A new method of friction enhancer, which is mixing sand into traction gels was proposed by S. R. Lewis, Lewis, Cotter, Lu, & Eadie [30]. Different chemical compositions of thin film rail coating such as polytetrafluoroethylene (PTFE) [34], molybdenum disulphide (MoS₂) and tungsten disulphide (WS₂) [35] had been used to reduce friction of the rail. Thin films bonded with graded coating [36], and laser cladding layer [37] were also tested and are still testing on their tribological characteristics in order to find a better solution to improve traction in low adhesion condition.

The dependency of COT on the presence of iron oxide layer on the wheel is also uncertain for both contacts under dry and wet condition. Thin oxide layer seems to be able to lubricate the interface...
under wet condition, but the inconsistent COT shows independency to the thickness of the oxide layer, especially under dry condition.

The reason why the increase in ambient temperature could cause the reduction in COT is also unknown. Perhaps this phenomenon occurs because of the conversion of heat energy from the fluid into kinetic energy stored in the steel molecule which results in metal expansion, thus, reducing the surface hardness. The contact patch is then enlarged and reducing the ratio of tangential force to normal force, resulting in reduction of COT.

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