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TWIN DISC ASSESSMENT OF WHEEL/RAIL ADHESION

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ABSTRACT

Loss of adhesion between a railway wheel and the track has implications for both braking and traction. Poor adhesion in braking is a safety issue as it leads to extended stopping distances. In traction it is a performance issue as it may lead to reduced acceleration which could cause delays.

In this work wheel/rail adhesion was assessed using a twin disc simulation. The effects of a number of contaminants, such as oil, dry and wet leaves and sand were investigated. These have been shown in the past to have significant effect on adhesion, but this has not been well quantified.

The results have shown that both oil and water reduce adhesion from the dry condition. Leaves, however, gave the lowest adhesion values, even when dry. The addition of sand, commonly used as a friction enhancer, to leaves, brought adhesion levels back to the levels without leaves present. Adhesion levels recorded, particularly for the wet, dry and oil conditions are in the range seen in field measurements.

Relatively severe disc surface damage and subsurface deformation was seen after the addition of sand. Leaves were also seen to cause indents in the disc surfaces.

The twin disc approach has been shown to provide a good approach for comparing adhesion levels under a range of wheel/rail contact conditions, with and without contaminants.

Keywords: wheel/rail adhesion, leaves, sand, oil, water

1 INTRODUCTION

Friction (or adhesion) loss has a large impact on safety and performance of railway networks. Poor adhesion in braking is a safety issue as it leads to extended stopping distances. If a train experiences poor adhesion in traction when pulling away from a station and a delay is enforced the train operator will incur costs. Similar delays will occur if a train passes over areas of poor adhesion while in service.

Work carried out to investigate the causes of adhesion loss has identified the major causes as being: water (from rainfall or dew), humidity, leaves, wear debris and oil contamination [1-6]. More recent work has re-emphasised the effect of the problems outlined above and identified further causes of adhesion loss, such as frost and mud deposited on rails by automobile wheels passing over level-crossings [7-9]. Work on adhesion issues related to high speed lines has shown that adhesion decreases with increasing train velocity and wheel/rail contact force [10, 11].

Leaves are a particular problem in the UK where train operation is significantly affected during the autumn leaf fall due to the resulting reduced adhesion. The leaves are crushed to form a hard slippery layer on the rail, which is extremely difficult to remove [12]. Some testing has been carried out to gain a better understanding of the influence of leaves on adhesion, but this was using a pin-on-disc set-up using full sliding conditions, rather than the rolling-sliding found in an actual wheel/rail contact [6].

The application of sand to the wheel/rail contact from train mounted systems is commonly used to increase adhesion. This has a number of disadvantages as rail and wheel damage can result and build up of sand can cause problems to the rail infrastructure. Again little work has been carried out to actually gain a scientific understanding of what happens when sand is applied to the wheel rail contact, what type of sand should used and how much needs to be applied. Work has been carried out, however, to study how sand affects wheel/rail isolation [13] and how it influences wear of wheel and rail materials [14, 15]. Alternatively, rail or wheel mounted systems are also used to apply other types of friction modifiers in either solid or liquid form, which can be designed to increase or decrease friction.

Adhesion and factors influencing it have mainly been investigated using experimental techniques, although some attempts have been made to model so called third body layers in the wheel/rail contact [16, 17] and Chen et al. [18] have produced theoretical models to investigate the effect of water in a contact.

There is no standard testing approach for assessing adhesion loss. Test methods used have ranged from specimen testing through to full-scale testing and field measurements. Specimen testing techniques have included pin-on-disc [6], disc on flat [5] and twin disc testing (with a line contact) [4, 19]. Twin disc testing has also been carried out with scaled wheel and rail profiles [14]. Full scale testing was used by Jin et al. [20] to study the effect on adhesion of wet, dry and oil contaminated conditions using a range of axle loads and rolling speeds. Field measurements have been taken using track mounted tribometers [2, 21] and instrumented trains [7].

As the testing techniques become more complex, the accuracy of the representation of the contact geometry and loading and environmental conditions increases. However, at the same time the level of control of operating parameters decreases. The twin disc approach perhaps gives the best compromise and has been used extensively for testing fatigue and wear properties of wheel and rail materials.

This is the approach that was chosen for this work, the aim of which was to study adhesion over a range of slip values, to cover both flange and tread conditions. A number of different contaminants were used including oil, leaves and sand.

2 EXPERIMENTAL DETAILS

2.1 Test Apparatus

The twin disc test machine used to carry out the testing is shown schematically in Figure 1. The use of the machine has been described previously [22, 23].

The test discs are hydraulically loaded together and driven at controlled rotational speed by independent electric motors. Shaft encoders monitor the speeds continuously. A torque transducer is assembled on one of the drive shafts and a load cell is mounted beneath the hydraulic jack. The slip ratio required is achieved by adjustment of the rotational speeds. All data is acquired on a PC, which is also used for load and speed control.

2.2 Specimens

The disc specimens were cut from UIC60 900A rail steel R8T wheel steel sections. They had a diameter of 47mm with a contact width of 10mm (see Figure 2). The contact surfaces were ground to a roughness of 1 micron.

Oil used was a standard 15W40 engine oil. The leaves used in testing were a mixture of varieties typically found trackside in the UK. They were dead leaves (mainly maple and oak) collected (from the ground) during Autumn. They were partially broken down prior to testing. The sand used was Standard commercial grade railway silica sand complying to the guidelines issued by Railway Safety, UK, for fitting of sanding equipment to multiple units [24]. In its raw form the sand has an average particle size of around 1.5mm. In previous twin disc testing with this sand entrainment was a problem [13, 15], so for this work the sand was pre-crushed. The grains were then passed through sieves (see B.S. 1377:1975) to ascertain the size distribution. Figure 3 shows the percentage retained at each sieve.

2.3 Test Procedure

The tests were carried out using the wheel disc as the driving disc and the rail disc as the braking disc, as shown in Figure 4. An environment chamber enclosed the discs. The inlet at the top was used to drip in the water and oil. A nominal disc rotational velocity of 400rpm was used and a contact pressure of 1500MPa, which is typical of the actual wheel/rail contact. The tests were carried out at slips of 0.5%, 1%, 2%, 3% and 5% representing values typical of tread and flange contacts.

Tests were initially run dry with no contamination and then with:

- water at two drops per second (enough to keep the discs completely wetted)
- oil at two drops per second
- leaves (dry and with water)
- leaves and sand

For tests with water and oil the supply of liquid was started prior to loading the discs together so the whole test was run lubricated. For tests with leaves, the discs were run dry or wet until the traction coefficient stabilised and then the leaves were added. Suction was applied to draw the leaves through the contact and prevent them clogging the environment chamber. The sanding tests were run in a similar manner, except that after a certain period crushed sand was added with the leaves. This was not done in a way representative of that which occurs in reality, where sand is mixed with compressed air and projected towards the wheel/rail contact via a nozzle placed a few centimetres away. It is impossible to determine how much sand actually enters the wheel/rail contact in the field, so accurate replication in a test is clearly difficult to achieve. An actual sand valve was used to apply sand to a twin disc contact in previous work investigating the effects of sand on isolation [15]. In this work it was assumed that the amount of sand entering the contact was far higher than that in the field.

Chutes were added to the test set-up to allow the leaves and sand to be added, as shown in Figure 5. Leaves were fed down the chute at a rate sufficient to ensure a continuous supply to the contact. Sand was applied at a rate of 7g/s, most of which entered the contact.

3 RESULTS

3.1 Traction Coefficient Data

Figure 6 shows an example of the raw data collected during the testing. Traction coefficient against number of cycles is shown for the tests run with oil lubrication. Traction coefficient increases as slip increases, with a sharp increase initially between 0.5 and 1% slip and then a slower rise up to 5%. This was typical of the behaviour seen with other contaminants. Wet tests and dry tests actually showed a slight decrease in traction coefficient at higher slip values.

Figure 7 shows the traction behaviour for tests run with water and in dry conditions with leaves at 0.5% slip. As can be seen, the traction coefficient drops dramatically on the addition of leaves, as seen previously [6]. With wet leaves a lower value of traction coefficient was observed. With dry leaves in the contact the traction coefficient fluctuated quite a bit. This was due to the feeding method and the difficulties in ensuring a smooth flow of leaves into the contact. With wet leaves the water clearly helped smooth the flow of leaves.

Figure 8 shows data from a test run with leaves and sand and water. The addition of sand brings the traction coefficient back to the value seen without leaves. There are great fluctuations, which were due to the leaf feeding and also the sand entrainment. A lot of the sand will probably have passed through the contact without having any effect, as the grains will have been smaller than the leaf layer in the contact. Clearly though some particles were able to indent the disc surfaces and cause an increase in grip.

The drop in traction coefficient at around 3000 cycles occurred as the sand application ended. The gradual decrease in traction coefficient from 2400 cycles was due to a reduction in the sand flow rate into the contact during the test. The traction coefficient remained higher than the leaf only level as some sand was retained on the disc surfaces.

For each slip value for all the tests, an average traction coefficient was determined for the stabilised region. These were then compiled to create creep curves for the different conditions, as shown in Figure 9. It is clear from these results, as reported previously for sliding tests [6], that leaves are a very good lubricant! They give a lower traction coefficient than oil, even when only dry. In several cases the traction coefficient is seen to reduce after the saturation point (where the contact is completely in slip). This can be due to temperature rise in the contact at increased slip which can causes oxides to form in dry conditions causing a reduced traction coefficient and in lubricated conditions can reduce the lubricant viscosity which has a similar effect.

3.2 Leaf Layers

During the dry tests, a thick hard layer of compressed leaf material formed on the disc surfaces at every slip value, as shown in Figure 10a. The hardness of the layer was measured using a micro-hardness tester. Different zones in the layer had different hardness depending on the level of compaction that had occurred. Average hardness in the more compacted areas was 40 HV_{1gr}, while the average value in other zones was 14 HV_{1gr}. During wet leaf tests a soft dark layer was apparent on the disc surfaces immediately after the tests (with visible wrinkles), as shown in Figure 10b. This was relatively easy to remove, but underneath was a much harder compacted layer that was extremely difficult to remove (see Figure 10c). Micro-hardness tests on this layer gave values of HV_{1gr} 59. This layer was very similar in nature to leaf layers seen on actual track. It is likely that leaf layers are more likely to form in wet conditions as leaves will cling to the track and be compressed by the passage of train wheels. Dry leaves will probably be blown away from the track by the passage of trains. No leaf layer was seen in tests with sand application.

After the dry tests, separate tests at different slip values were run to see how long it would take to remove the layers. The number of cycles to remove the layers are shown in Figure 11. As would be expected the number of cycles reduced with the amount of sliding in the contact, but the values shown represent many wheel passes. The slight rise seen between 3% and 5% was probably a result of experimental scatter as each test was only run once and the number of cycles was determined by eye.

3.3 Surface Morphology

After the tests the disc surfaces were examined using optical microscopy and roughness measurements were taken. The disc surfaces after the oil tests were smoother than they had been before the test (the wheel and rail discs Ra values of 0.57μm and 0.65μm post test, compared with 1μm before) and exhibited characteristics of mild lubricated wear (see Figure 12).

The discs surfaces showed relatively high damage after the tests carried out with dry leaves. Some deep indents and scratches could be seen (see Figure 13). These were probably due to stalks being entrained in to the contact. This is perhaps surprising, but clearly even leaves when highly compressed are hard enough to indent and score steel. The wheel and rail discs had Ra values of 3.94μm and 1.3μm respectively.

Severe surface damage was seen in the discs after sand application, as shown in Figure 14. Deep indentations were visible on the wheel disc surface and indentations and some scratches were seen on the rail disc surfaces (less than 10 microns in width). This is in line with observations made after previous sand testing [22]. The sand particles had indented into the softer wheel material and then abraded the harder rail material and it was clear something similar had occurred in this work. Post test Ra values for the wheel and rail discs were 13.91µm and 5.541µm respectively.

Typical roughness on a railway line would be of the order of 1 micron (similar to the original disc surface roughness). Clearly the final values seen on the discs are many times higher, but they correspond with values seen in static sand crushing tests carried out with uncrushed sand (1-1.5mm across) between actual wheel and rail specimens [15]. It is likely that this roughness would be worn out after a number of train passes, but as shown in [15] the sand also leads to greater sub-surface deformation occurring.

4 DISCUSSION

The twin disc test approach has been used to produce creep curves for a number of different contact conditions. This method, while not having the scale or geometry of the actual contact, provides a good simulation of the rolling-sliding motion and allows close control of operating parameters not available in more complex test methods.

The results derived for dry, wet and oily conditions compare well with previous testing and actual track measurements as the data in Table 1 shows.

The data shown in Table 1 was collected from the literature and was determined using a variety of full-scale techniques using a bogie on a roller-rig, a rail tribometer and an instrumented train. The roller-rig tests were carried out under closely controlled conditions so load, velocity and slip are known. It was shown in this work, as mentioned previously, that varying load and rolling speed affects traction coefficient. This is something that needs exploring further with the twin disc technique. Clearly in the actual track testing a range of loading and slip conditions will have occurred. The measurements recorded by Nagese [7] in "dry" conditions using an instrumented bogie on a rail test vehicle are lower than those from other testing methods. It is unlikely, however, as noted, that the conditions were truly dry and that humidity levels may have been high enough to influence the adhesion.

The shape of the creep curves derived from the roller-rig tests is similar to those seen in this work. This is significant as the initial slope of the curve is important and this as well as the initial peak and then slight decline seen with some conditions differs from results achieved using analytical modelling techniques (as illustrated in Figure 15, where the dry results are compared with Carter's solution [26]). While Carter's solution has been superseded by other modelling techniques, a similar observation of the difference between model and experiment was made during more recent work carried out Bucher et al. [25].

The techniques used to apply contaminants worked well. The data recorded for leaves further indicates what a good lubricant they are, even in dry conditions. The test method allows for testing of potential friction modifiers to increase adhesion when leaves are present as seen with the sand tests. An added benefit was the generation of a relatively hard leaf layer on the discs, which has not been achieved experimentally before. As was seen in Figure 11, these layers took several hundred cycles to wear away. If each cycle is equated to a wheel pass this represents a large number of trains going over the layer in the real situation before the layer is removed by wear alone and this does not allow for further leaves falling. This may allow testing of different leaf removal solutions. Sand, which is currently used to improve adhesion, is clearly effective at dealing with leaves and prevents the build-up of a leaf layer, but also leads to wheel and rail surface damage. The particles in this case were pre-crushed down to an average size of around 0.3mm (sand grains used in the field are approximately 1-1.5mm in size), however, as seen in this work and previous work [15], the sand on entering the disc contact is crushed down to micron size. It is as this occurs that most of the damage is caused, particularly to the softer wheel disc, which the sand grains actually stick into. Clearly this size is still sufficient to cut through the leaf layer and into the rail disc surface causing the scratches seen in Figure 14, a process that has led to the increase in traction coefficient measured. Sand grain size is important though and it may be that a different size could lead to a similar increase in adhesion without causing the levels of damage seen. No scientific inveastigation was carried out prior to the drafting of the specification for sand application [24].

As shown in Table 1, the twin disc results with leaves are similar to those seen with an instrumented train run over leaves. In that work [7], different leaves gave different results, with oily needle leaves from pine trees giving the highest traction coefficient. The leaves in this work were mixed, so further work may be appropriate to identify which leaves may be worst.

It was interesting to note that even leaves can cause damage to the disc surfaces. It was expected that sand would, and this could potentially be an issue if sand is applied regularly to a stretch of track that suffers from poor adhesion.

Other factors affecting traction coefficient need some investigation, for example, roughness and direction of roughness. Both of these would be likely to have an influence over leaf film formation.

5 CONCLUSIONS

- Twin disc rolling-sliding testing methods have been developed for assessing the effect on adhesion of various contaminants. Tests have been carried out over a range of slip values and creep curves have been generated.

- Dry, wet and oil tests gave traction coefficients in a range similar to that from previous testing. Dry conditions gave the highest values with water and oil giving lower values.
- The addition of leaves to wet and dry contacts gave lower values than oil. Adding sand to a water and leaf contaminated contact increased the traction coefficient to the level seen before the addition of leaves.
- During the leaf tests, leaf layers were generated that were between $14Hv_{1gr}$ and $58Hv1_{gr}$. These layers took between 200 and 600 cycles to remove in dry uncontaminated conditions, depending on the slip value.
- The addition of sand to a contact contaminated with leaves and water increases adhesion back to the level seen before leaves were added.
- Leaves caused some surface damage to the discs, particularly when stalks were passing through the contact, which resulted in long indentations. Sand also caused indents and scratches in the wheel and rail materials.

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Figure Captions

Figure 1	Schematic Diagram of the Twin-disc Test Machine
Figure 2	Rail and Wheel Disc Specimens
Figure 3	Sand Grain Size Distribution for Every Percentage Retained
Figure 4	Schematic Diagram of the Disc Environment Chamber
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Figure 14	(a) Rail and (b) Wheel Disc Surface Features after Leaves, Water and Sand were Applied
Figure 15	A Comparison of Carter’s Analytical Solution with Dry Experimental Results

Table Captions

Table 1. Comparison of Traction Coefficients Derived by a Variety of Test Methods

Figure 1

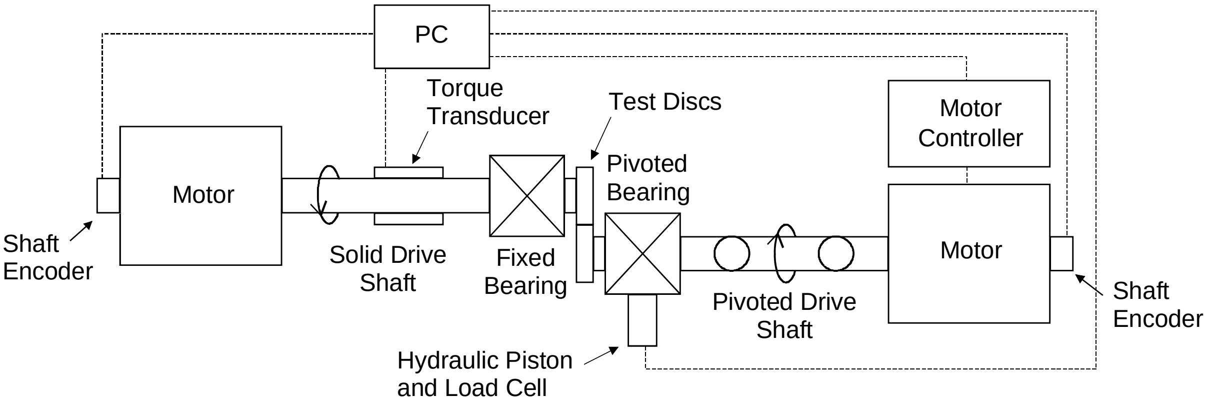
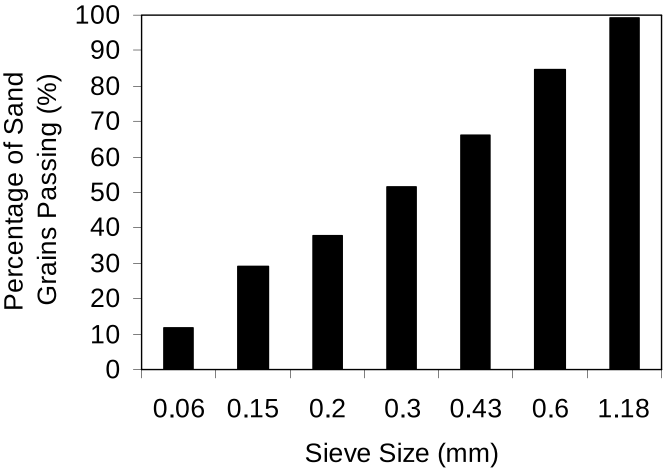


Figure 2

Figure 3



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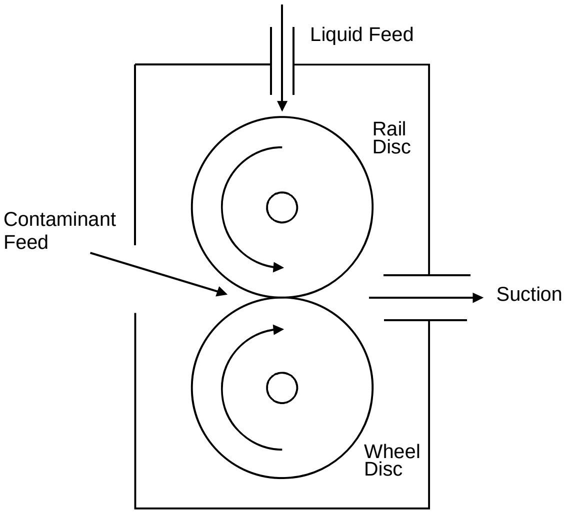


Figure 5

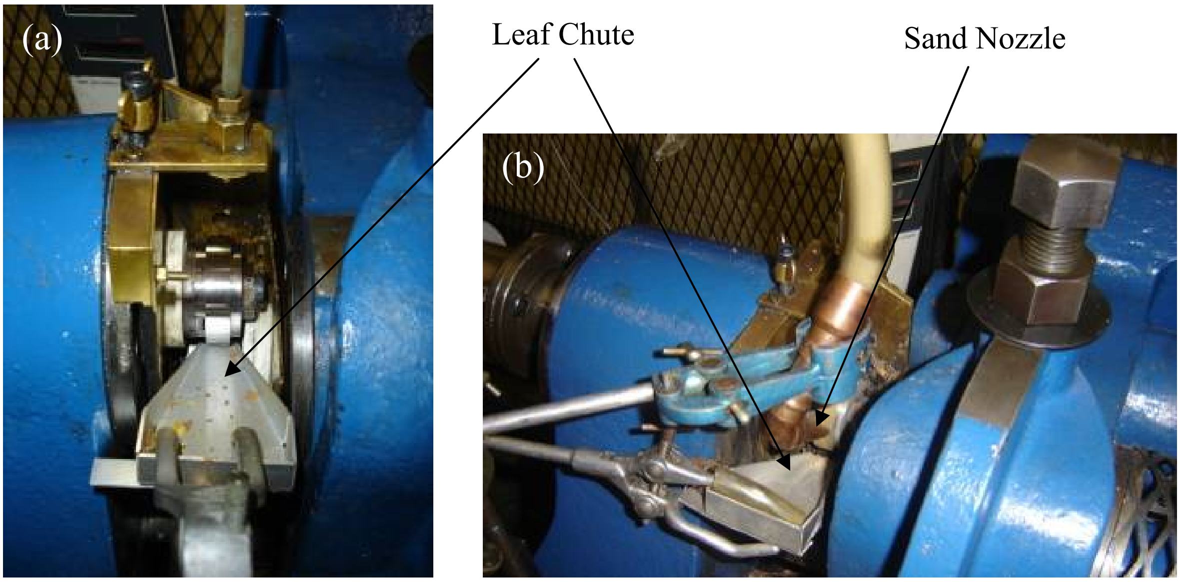


Figure 6

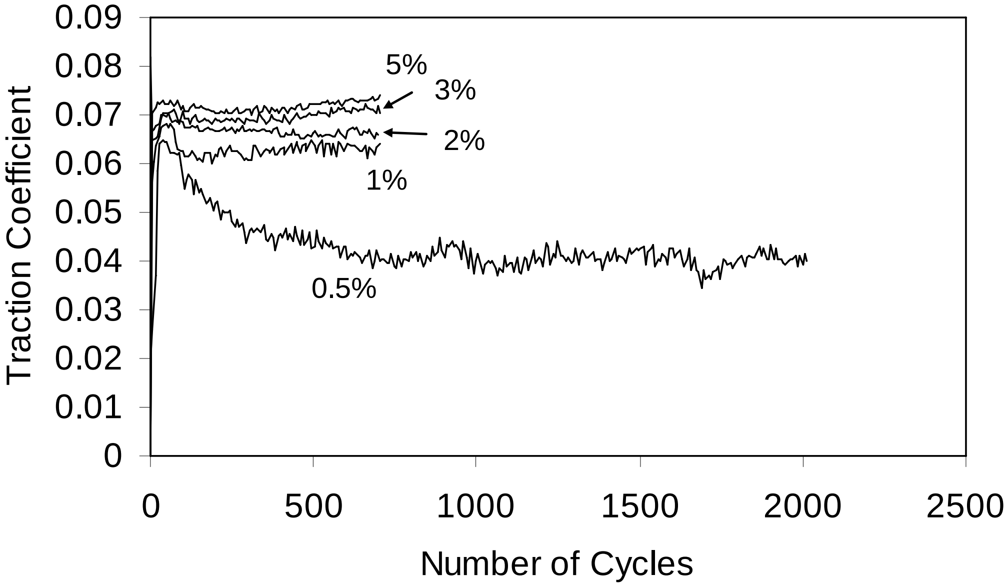


Figure 7

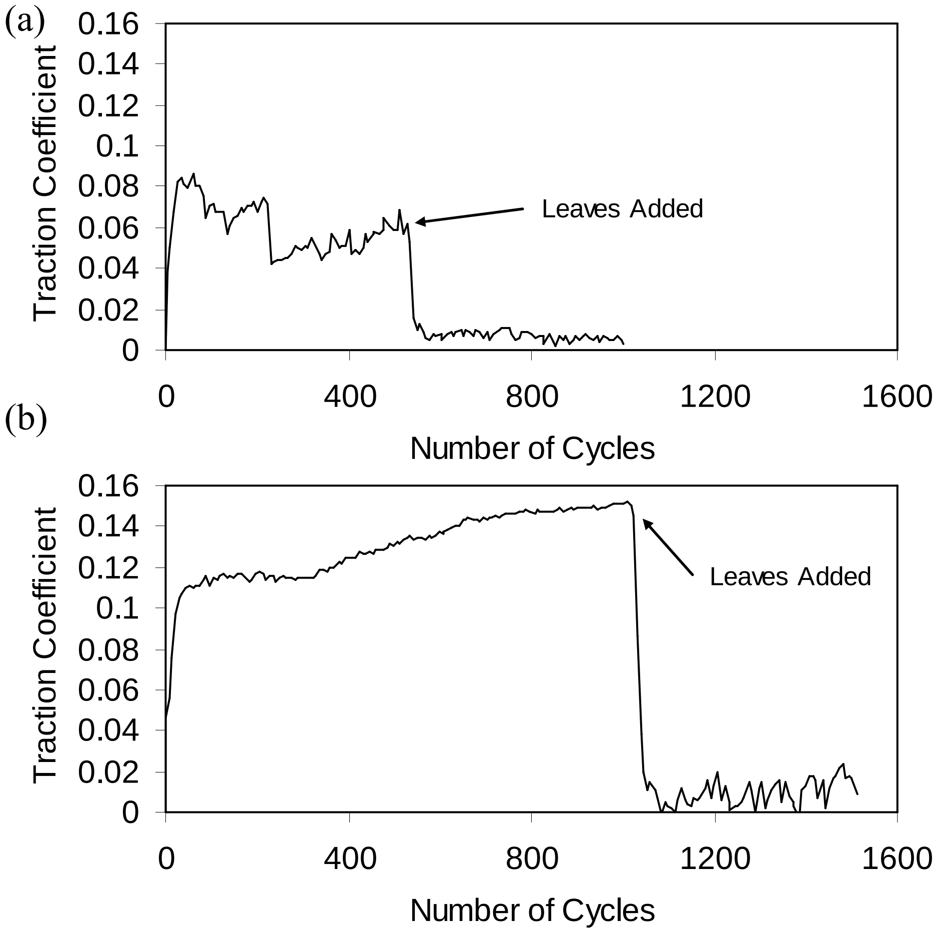


Figure 8

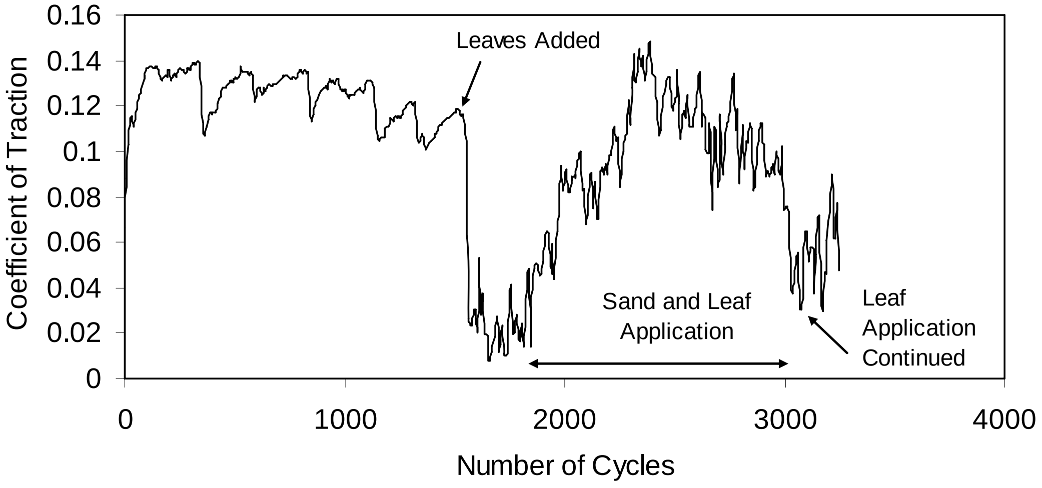


Figure 9

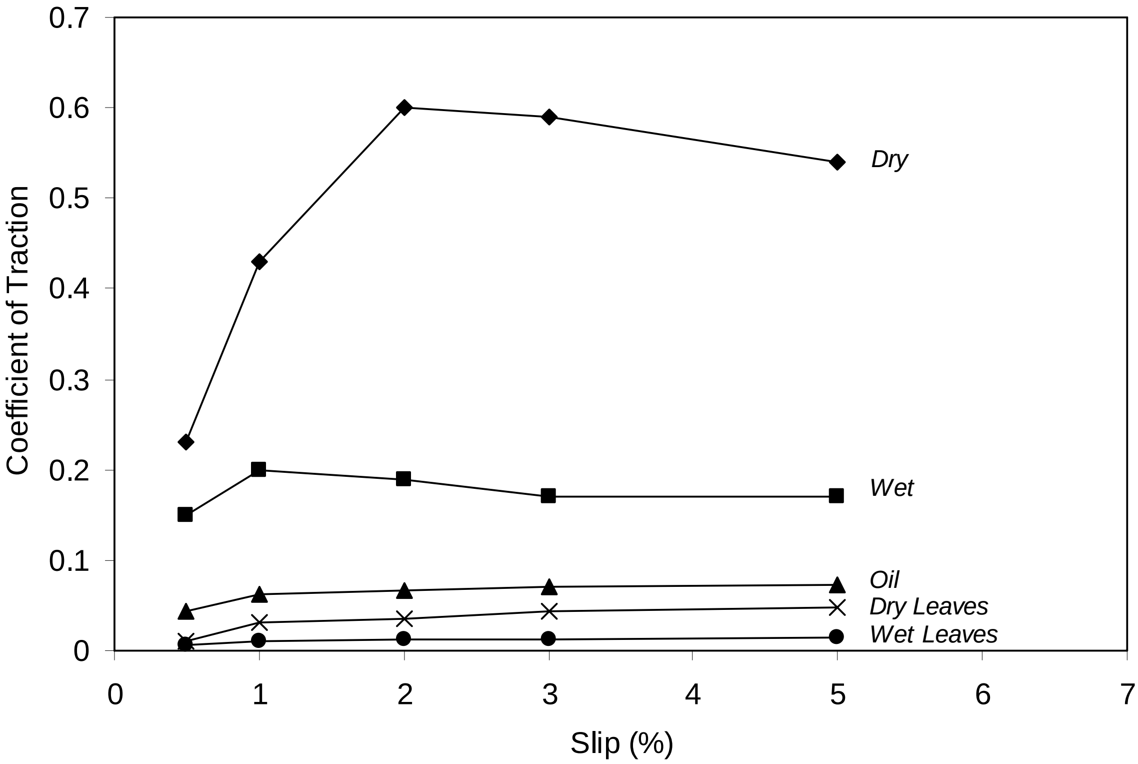


Figure 10

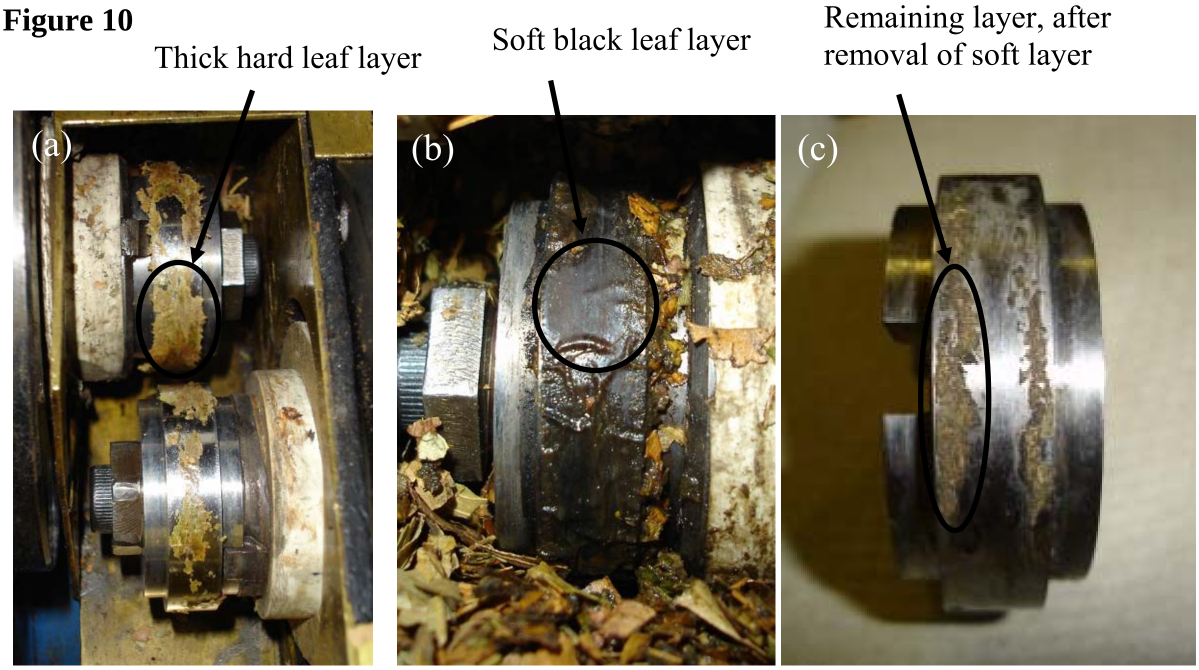


Figure 11

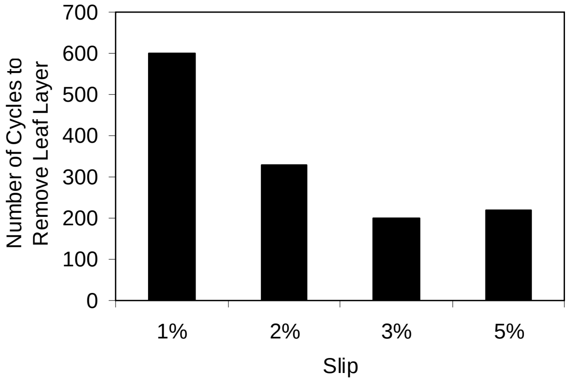


Figure 12

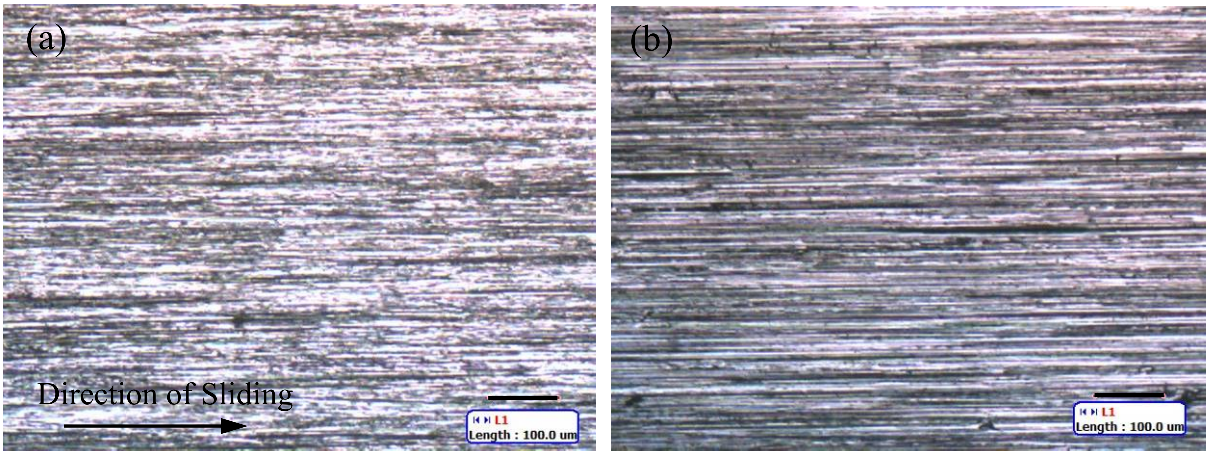


Figure 13

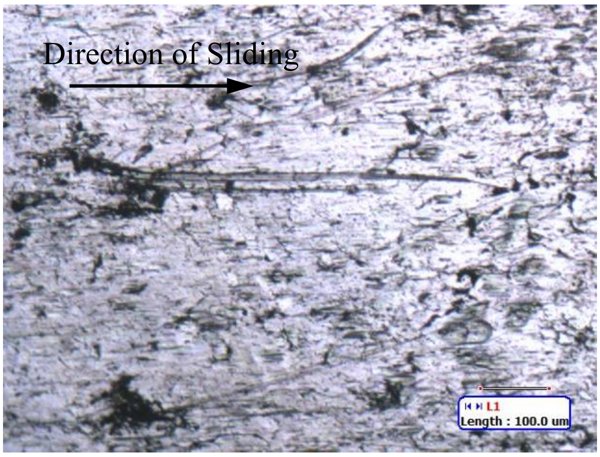


Figure 14

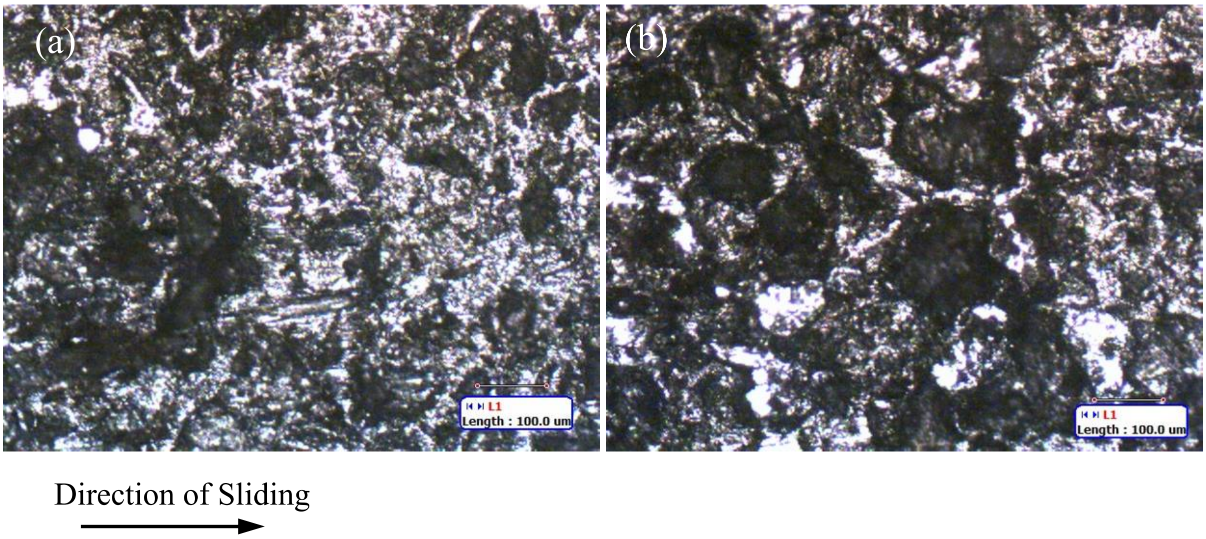
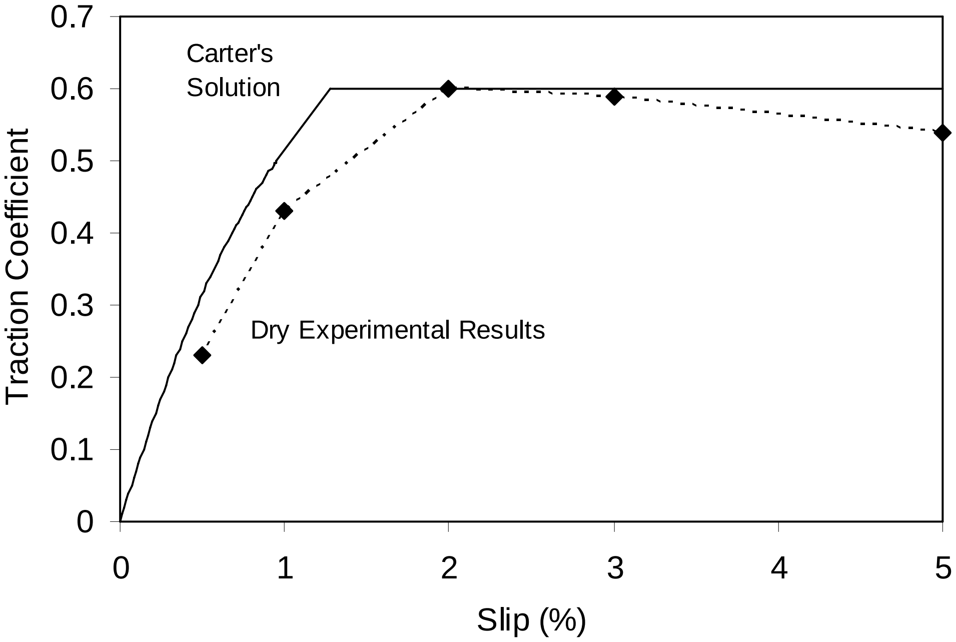


Figure 15



Traction Coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Carter's Solution
Dry Experimental Results
0
1
2
3
4
5
Slip (%)

Table 1

Author	Test Apparatus	Load/Contact Pressure	Rolling Speed (km/h)	Test Conds.	Peak μ	Slip at Peak μ (%)	Stable μ (5% slip)
Zhang et al. [10]	Full-scale roller rig (using an actual bogie)	44kN	10-70	Dry	0.57-0.5	2	0.57-0.5
		67kN	10-70	Dry	0.55-0.44	1-2	0.52-0.44
		44kN	120-240	Wet	0.13-0.07	0.5-1	0.12-0.065
		67kN	80-240	Wet	0.11-0.05	0.5-1	0.105-0.05
Jin et al. [20]		67kN	140-300	Oil	0.055-0.045	1	0.052-0.044
		135kN	140-300	Oil	0.05-0.04	1	0.048-0.037
Harrison et al. [21]	Triborailer (used on actual track)			Dry	0.52	1	0.5
	Push Tribo-meter			Dry	0.7	2-5	0.7
Nagese [7]	Instrumented bogie on test vehicle (run on test track and actual routes)	Variable	Variable	"Dry"	Range of μ: 0.2-0.4		
				Wet	Range of μ: 0.05-0.2		
				Oil	Range of μ: 0.05-0.07		
				Leaves	Range of μ: 0.025-0.10		
Present study	Twin Disc	1500MPa/ 7.7kN	3.54	Dry	0.6	2	0.54
			3.54	Wet	0.2	1	0.17
			3.54	Oil	0.07	1	0.06