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A New Method for the Assessment of Traction Enhancers and the Generation of Organic Layers in a Twin-Disc Machine

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ABSTRACT

Low adhesion presents a major concern for many rail operators. Railway vehicles under these circumstances can experience a serious loss of braking capability giving rise to dangerous situations such as platform overruns and signals passed at danger. One cause of adhesion loss is autumn leaf fall [1]. Leaves are run over by the wheels of a train and a chemical reaction occurs between the leaf and the rail steel [2]. This forms a black layer on the rail which when wet causes very low friction. These leaf layers have also been shown to be isolating and can interfere with railway signalling systems. Traction enhancers (also referred to in this paper as traction gels) have been developed as an alternative solution to using sand alone. They consist of sand particles suspended in a water based gel and are designed to be delivered to the rail by the trackside or via mobile application systems. The aim of this work was to develop a technique for generating a representative leaf layer on the surface of a twin-disc rail specimen and using this to develop a test methodology for assessing the performance of a traction gel in terms of adhesion recovery, wear and its effect on wheel/rail isolation.

1. INTRODUCTION

Low adhesion presents a major concern for many rail operators. Railway vehicles under these circumstances can experience a serious loss of braking capability giving rise to dangerous situations such as platform overruns and signals passed at danger. One cause of adhesion loss is autumn leaf fall; whereby leaves fallen by the line side can be picked up by the turbulence caused by a passing train and deposited directly on the rail head [1]. These leaves are then run over by the wheels of a following train and a reaction occurs between the leaf and the rail steel [2]. This forms a black layer on the rail which when wet causes very low friction. These leaf layers have also been shown to be electrically isolating (non-conducting) and can thus interfere with railway signalling systems. Sand has long been a solution for such problems and is usually fired directly into the wheel rail contact from a hopper on board the vehicle. However, sand can cause damage to the wheels and rail and other railway infrastructure. Traction enhancers (also referred to in this paper as traction gels) have been developed as an alternative solution to using sand alone. They consist in part of sand particles suspended in a water based gel and are designed to be delivered to the rail via pumping systems mounted on either a track vehicle or on the side of the track.

This paper discusses the development of a standard test to assess the performance of traction enhancers. The Sheffield University ROlling Sliding (SUROS) test rig was employed for this experiment and a commercially available traction enhancing gel was used. More information on the development of the rig can be found in [3]. Previous work has shown how sand in the contact can have adverse effects on track circuit isolation [4, 5] and wheel/rail wear [5, 6]. Friction modifiers (a different type of material with different purposes) have also been assessed before using the SUROS rig by Li et al. [7] and leaf layers have also been generated on the SUROS specimens by Vasić et al [8] and Arias-Cuevas et al. [9]. In this work we report development of a new method to generate a leaf layer and use of this method together with electrical isolation measurements to assess traction recovery performance with a traction gel.

The aim of these tests was therefore to develop a standard test to measure the performance of traction gels and other traction enhancing products. A single type of commercially available traction gel was used to develop this standard test.

A technique was also developed to generate a leaf layer on the surfaces of the test discs. This leaf layer provided a benchmark on which the performance of traction enhancers could be assessed.

An electrical circuit was constructed to replicate the internal resistances of a TI21 track circuit. The TI21 track circuit is used widely on the UK rail network [5] and operates in the audio frequency range (approximately 100 Hz to 10 kHz). Track circuits are a vital part in railway signalling systems worldwide. They are used to detect the presence of a train on a section of track, thus adjusting nearby signalling and controlling traffic accordingly. Sections of track are usually electrically isolated from one another by means of an insulated joint as shown in Figure 1. When no train is present the current flows freely from the transmitter to the detector indicating a free section of track. Surrounding signals will hence show a green light. However, when a train is present in a section of track the track circuit will be shorted and thus no current will be seen at the detector. In this situation surrounding signals are automatically turned to a red light to avoid train collision.

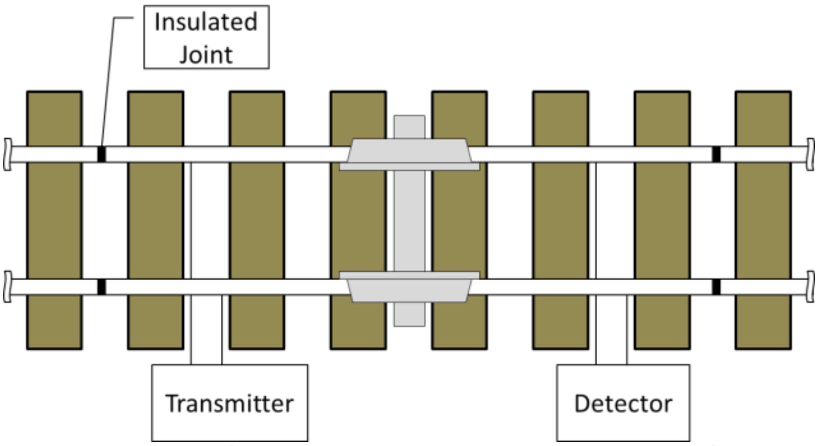

Figure 1. Schematic of occupied isolated rail section and track circuit adapted from [5]

2. TEST EQUIPMENT

Testing was performed using the Sheffield University ROlling Sliding (SUROS) machine (schematic shown in Figure 2). This test rig consists of a Colchester Mascot lathe with an A.C. motor on the tailstock.

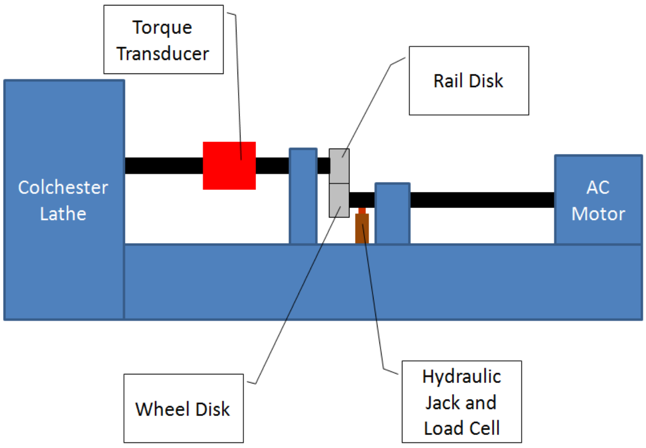

Figure 2. Schematic of SUROS machine

This arrangement allowed two 47 mm diameter discs to be loaded against each other and be independently driven. The discs are cut from sections of wheel and rail (R8T and UIC60 900A respectively) with the rail disc attached to the lathe and wheel to the A.C. motor. Details of the disc specimens are shown in Figure 3. The discs are independently driven allowing a certain amount of creep (difference between surface speeds) between the discs. A hydraulic jack forces the discs together to achieve a required contact pressure. The torque transducer on the lathe shaft allows tangential contact force to be measured and hence a calculation of traction coefficient can be made.

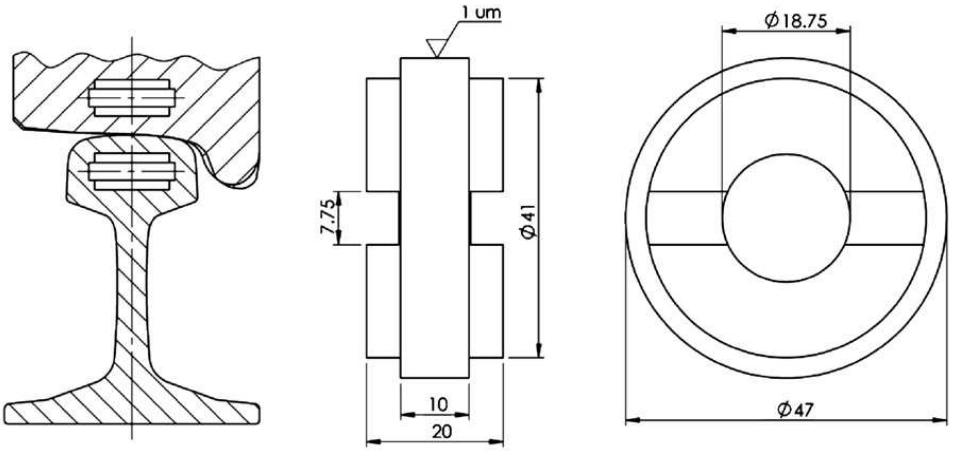

Figure 3. Cutting positions and dimensions of SUROS specimens (dimensions in mm)

An electrical circuit representing the TI21 circuit used in the UK was used in conjunction with the SUROS machine. The circuit represented the transmitter and detector of a TI21 track circuit with two 10 Ω resistors; R1 the transmitter and R2 the detector. The test discs are connected in parallel with R2 as shown in Figure 4. This circuit has been used in previous work [4, 5].

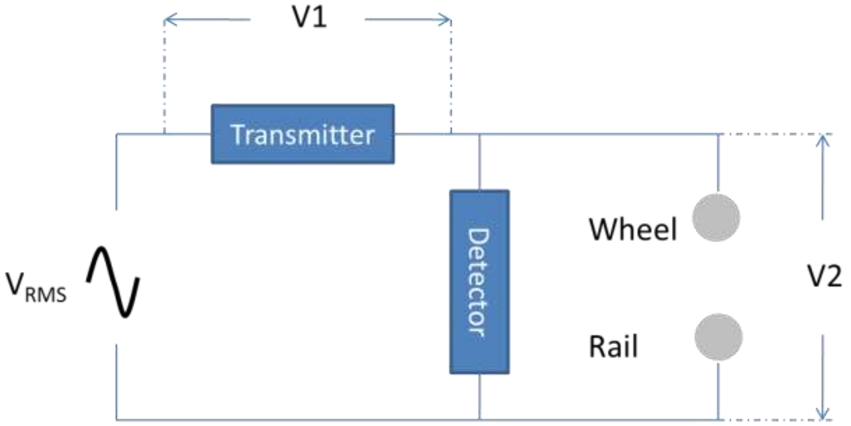

Figure 4. Electrical diagram of circuit used in this testing

When the test discs are brought into contact more current will be drawn through them due to the lower resistance of the contact (between 0.5 – 0.6 Ω) compared to R2 (10Ω). The current following through the discs contact can then be calculated by measuring the voltage across them. Using Ohm’s and Kirchhoff’s laws the impedance of the disc contact can then be calculated

3. DEVELOPING CONTAMINATION/LEAF LAYER

Vasić et al. [8] experimented with techniques to form leaf layers using the SUROS twin-disc rig. The best results were found by covering the running band of the rail discs with thin strips of leaf and then compressing with a jubilee clip. The discs were then left for up to 4 days. After this initial coating process the discs were run in the machine under conditions of pure rolling with continual strips of leaf fed into the contact. It was shown in [8] that low traction levels (< 0.1) under leaf contaminated conditions only occurred when the leaf was wet. Under testing of these layers it was clear that the leaf film would be removed quickly unless moist conditions were maintained using a continuous mist spray or dripping water onto the discs. Although leaf layers were generated in [8] it is clear that these would be unsuitable for the tests in this paper due to the need for a constantly moistened environment. The artificial creation of moisture could skew the results as the traction enhancers may potentially be subject to varying amounts of water. What was needed for these tests was a durable dry leaf layer. For these tests a supply of dead sycamore leaves was sourced. Sycamore leaves have been used in previous studies using leaf layers [7, 9]. It was found in [5] that dead leaves showed significantly higher impedance than fresh ones, thus these tests would represent a worst case scenario. So that the leaves could be applied to the disc interface they were made into a paste. This was done by chopping them into small fragments and then mixing with water to create a mulch. The viscosity of this mulch was then thickened using carboxymethylecellulose added at a rate of 1% of the weight of the mulch. meaning it could be painted directly onto the rail disc surface as in Figure 5a. The machine was then run at half test load (900 MPa) with pure rolling for 40 cycles. This process of painting the discs and running the machine for 40 cycles was repeated another two times to give a black leaf layer on the (top) rail disc as shown in Figure 5b. The amount of leaf paste applied to the discs could not be controlled, however, the mass readings taken before and after the leaf layer generation were relatively consistent. The average amount of leaf generated on the rail discs was 12 mg. The discs were pre-treated in this way before each main test with the traction gel. The traction gel was applied to the surface of the rail disc once the leaf layer had dried.

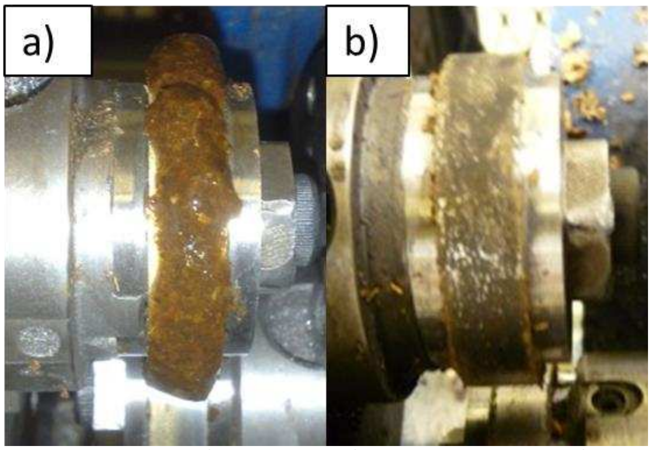

Figure 5. a) Leaf paste painted onto rail disc before generation of black layer b) test discs after 3 applications of leaf paste

4. LEAF LAYER ANALYSIS

A leaf layer was prepared using the method outlined in section 3. The rail disc with leaf layer was then observed using a scanning electron microscope and chemical analysis was done using Energy-Dispersive X-ray Spectroscopy, EDS. EDS works on the principal that each element when stimulated by x-rays will emit radiation of a characteristic frequency. The frequency of the emitted radiation is characteristic of each element and is detected by an appropriate photometer. Figure 6 shows a series of SEM images at various magnifications. The leaf layer can clearly be seen as a dark layer on the surface of the steel disc. Plough lines show the direction of rolling of the disc and are shown on both the steel and dark surface. The leaf layer also appears to be brittle as can be seen in Figure 6b) and Figure 6c) with cracks formed through it.

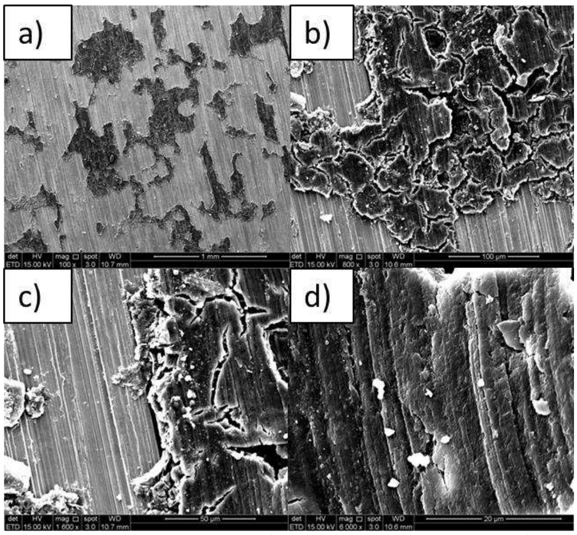

Figure 6. SEM image of rail disc with leaf layer a) at 100 times magnification b) at 800 times magnification c) 1600 times magnification d) 6000 times magnification

Figure 7 and Figure 8 show the results of the EDS for both the metal matrix (a) and the leaf layer (b). Figure 7 shows results from x-rays detected from the smoother surface (lighter surface in Figure 6) and shows a peak in Iron, Fe, being detected. Figure 8 on the other hand shows the energy spectrum from the leaf layer and shows a spike in Carbon which is larger than the Iron peak for the same area. There is also a spike in Oxygen and Calcium in Figure 8 which was not seen for the matrix. This confirms that there is an organic layer on the disc surface. Previous testing by Li et al [7] and Cann [2] showed three main chemicals found in laboratory generated leaf layers. These are Lignin, chemical formula $C_9H_{10}O_2$, Pectin, $C_6H_{10}O_7$, cellulose, $C_6H_{10}O_5$, Water, H_2O and Iron, Fe. All of these complex organic molecules are found in plant cell walls. Figure 8 shows that there is a large spike in Carbon detected from the EDS accompanied with a significant spike in oxygen. EDS cannot detect elements with an atomic number less than 4 as their reflected energy is too low. This explains why there is no spike for Hydrogen as would be expected in organic compounds. However, the strong peaks in Carbon and Oxygen confirm that the layer on the disc surface is constructed of organic constituents and although EDS cannot reveal individual compounds it is likely that this layer is constructed from the chemicals mentioned above.

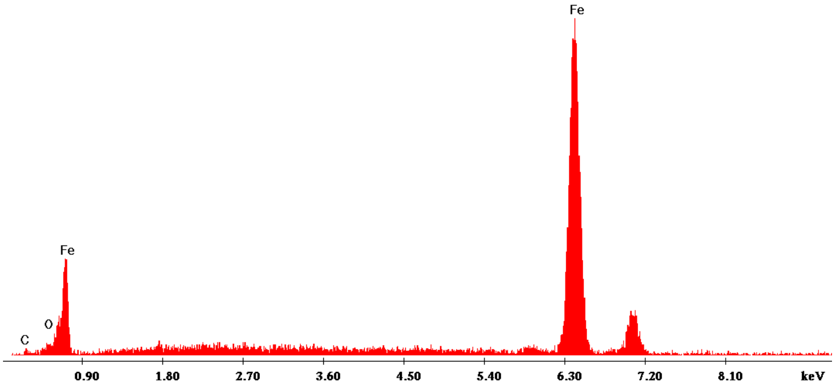

Figure 7. EDS output for exposed steel matrix

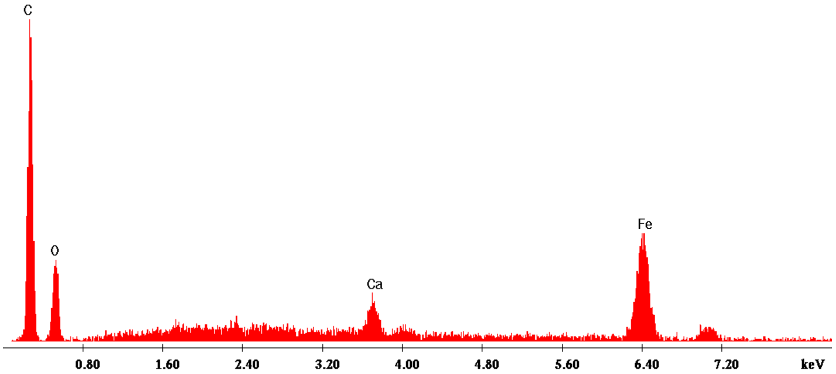

Figure 8. EDS output for leaf layer

5. TEST PROCEDURE

For these tests the lathe was run at 400 rpm with 3% creep in the contact and 1500 MPa contact pressure. A creep of 3% was chosen as it is to the right of the saturation point on the creep curve; representing conditions where a traction enhancer may be required. 1 ml of the traction gel was syringed onto the surface of the test discs, while stationary, before each test. Each test was then run until the traction reached dry levels (between 0.5-0.6). Wear of the discs was measured by weighing the discs before and after each test.

6 RESULTS

Traction results can be seen in Figure 9. It should be noted that the curve labelled “Traction Gel” has been generated with the traction gel placed on top of a dry leaf layer contaminated disc.

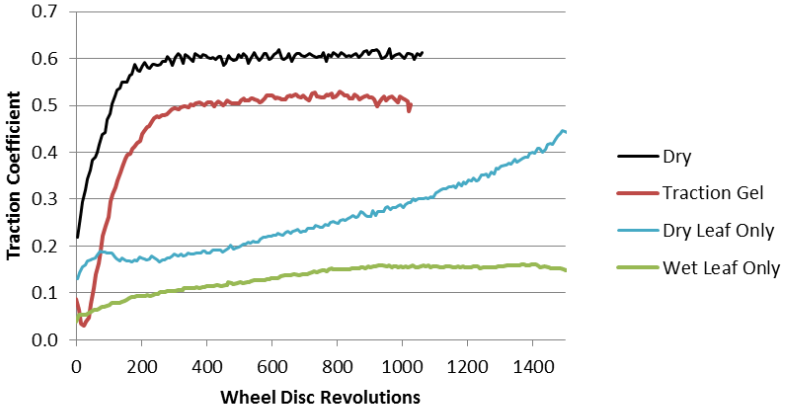

Figure 9. Chart showing traction curves from experiments

Figure 10 shows a typical impedance trace for a test. The trace can be split into 3 phases:

1. As the discs are brought together the impedance drops.
2. As full contact is achieved there is a measurable impedance due to the leaf layer and/or solid and liquid components of the traction enhancer.
3. As the test progresses the impedance level will drop back to that of a dry/uncontaminated contact as the leaf and traction enhancer residue are slowly removed from the contact.

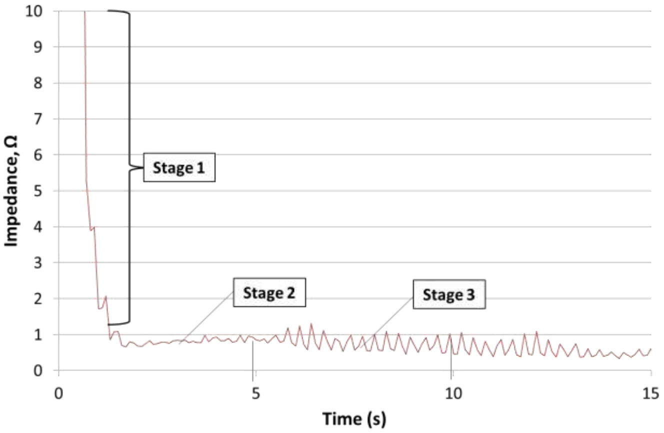

Figure 10. Chart showing typical impedance trace for a test with traction gel

The chart in Figure 11 shows the average impedance calculated for each test condition. Error bars indicate standard deviation between original and repeated test. The impedance was averaged over the first 5 seconds and then 5 - 10 seconds of each test. (Note that for the static case the discs were hand loaded for periods of 5 seconds only hence no 5-10 second data for this column). It was proposed that the traction enhancers remained effective for roughly 20 seconds of the test. Hence, taking the impedance within the first 10 second window of each test would ensure that the impedance due to the traction enhancer was captured.

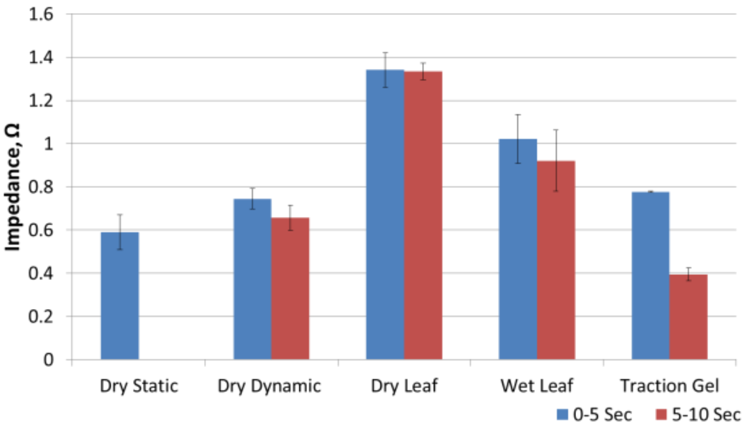

Figure 11. Chart showing average impedance calculated for each contamination condition over 5 and 10 seconds

It can be observed in Figure 10 that the impedance between roughly 0 and 5 seconds is relatively steady. Figure 11 shows that between 5 and 10 seconds, however, the impedance starts to drop towards the dry level. This is not the case for the dry leaf layer, however, where the impedance varies little between the first 10 seconds. This shows that the dry leaf layer is not removed from the contact purely by the mechanical action of the rolling/sliding contact. In the case of the traction gel the average impedance between 0 and 5 seconds is lower that the impedance of dry uncontaminated discs. This may be explained by the presence of steel shot in the traction gel which is added to aid electrical conductivity between the wheel and rail. After 5 seconds, however, average impedances almost halve indicating that a) that the traction enhancer is quickly removing the leaf layer; b) the traction gel has almost been completely removed from the contact. However, the apparent rate of traction increase observed in Figure 9 suggests that the product is still working at least 20 seconds after the test has started. Perhaps at this 5 second mark any excess product has been removed from the contact and any product remaining is not enough to cause a significant rise in impedance. It is interesting also to note that the time taken for the dry leaf layer to reach dry levels of impedance was approximately

170-200 seconds. This again shows how durable a dry leaf layer is. The impedance for the dry/uncontaminated condition was measured with the discs both stationary and rotating. It can be seen that impedance seems to be higher for the dynamic case. This could be due to the vibrations in the electrical connections (slip rings) as the machine is running. There is also a drop in dry impedance after 5 seconds this may be due to mechanical removal of surface oxide layers as the discs start to roll/slide relative to one another.

6.3 Wear Rates

Figure 12 shows the mean rail disc wear rates measured during the tests.

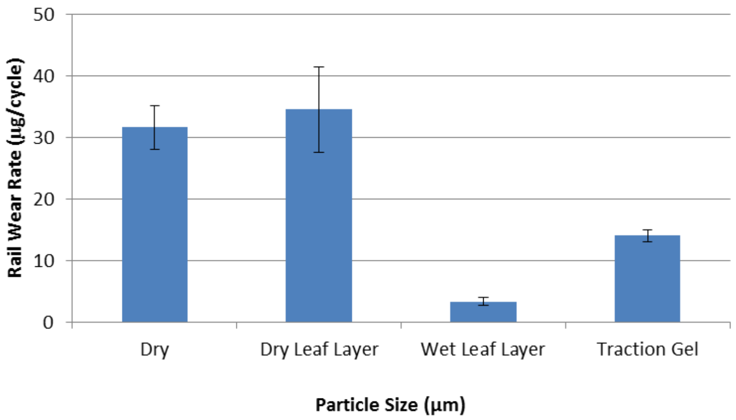

Figure 12. Chart showing rail disc wear rates

Counter intuitively a higher wear rate is seen under dry conditions as compared to when there was traction gel in the contact. All of the tests were run for approximately 1000 cycles and wear rates were averaged over that period. A dry leaf layer shows similar levels of wear as dry conditions. The lowest wear rate was seen by a wet leaf layer. It is noteworthy that the traction gel condition results in less wear than the dry case, perhaps because of the liquid component providing some lubricating effect.

7. DISCUSSION

In this paper a technique has been developed to measure the performance of traction enhancing products in terms of traction, wear and electrical impedance. This was done using the University of Sheffield Rolling Sliding test rig (SUROS). It should be noted that any performance measures seen in these tests cannot be translated directly to the actual wheel rail contact due to the relative difference in the size of the contact patch. It is therefore more important to focus on relative changes in these measures if different variants of traction enhancers were to be tested using this method rather than absolute values.

Traction results can be seen in Figure 9. It can be seen that the traction enhancer quickly restores the traction back to a dry level. A key parameter therefore for assessment of traction enhancer performance would be the initial gradient and also how consistent it is in repeated tests.

The rate of increase in traction, as measured by the initial gradients of each of the cases above, are shown in Figure 13.

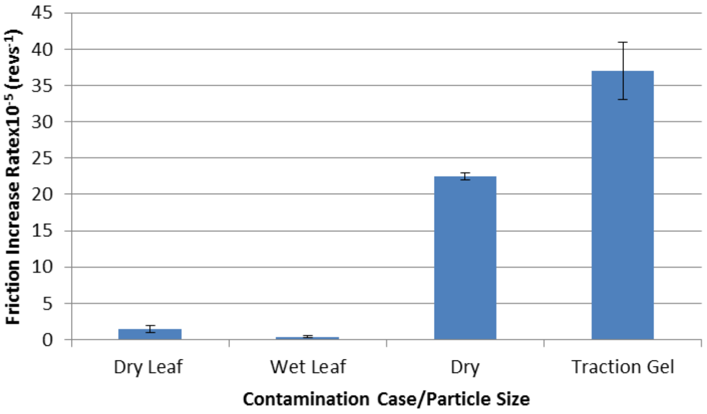

Figure 13. Chart showing rate traction increase

Rail operators around the world employ electrical track circuits to manage the signalling systems across their networks. It is therefore vital to know the effect of contamination/traction enhancers upon impedance levels within the wheel/rail contact. It is difficult to define exactly what impedance level would prevent the shunting of an occupied section of track because any impedance below the resistance of the detector (in this test the detector was simulated by a 10 Ω resistor) would still allow a proportion of the current to be shunted by the occupying vehicle's axles i.e. the current will follow the path of least resistance). If it is assumed that shunting of the occupied track would fail to happen only if the impedance in the contact is greater than or equal to the resistance of the detector, then neither the particular product tested here or even leaf layer would have prevented the track being shunted because the highest impedance measured was 1.6 Ω almost one tenth of the resistance of the simulated detector (10 Ω). It must be noted however, that these tests were dynamic and do not simulate a situation where a stationary wheel comes to rest upon a layer of traction gel and or crushed leaf. It is also the case that the SUROS machine represents a worst case scenario of one axle occupying the track section. This could potentially be the case where a train may have stopped within two sections of track. However, locomotives have multiple axles representing multiple contact patches per section of track. In order for a contaminant/friction modifier/ traction enhancer to present a significant signalling threat it would have to cause enough impedance at each of those contact points as to prevent shunting.

It must also be noted here that the level of impedance seen in these tests will not necessarily match what would be seen in the field. Due to the relatively larger contact patch in the actual wheel/rail contact, impedances would be expected to be much lower. The impedance across an actual uncontaminated railway axle is likely to be in the region of milliohms whereas the lowest impedance measured in this test, for the dry static condition, was 0.55 Ω, an order of magnitude higher. There are a number of possible reasons for this including the relative size of contact patch described above. The distance between the discs and the point of measurement i.e. the simulated track circuit will also play a part. The further away the point of measurement from the discs the longer the wires from the discs to the circuit and hence their resistance. However, there is a limit to how close the circuit can be placed to the machine due to the rotating shafts and safety guards.

Wear rates were measured by weighing the discs before and after each test as used in [6]. A mass loss was measured for the rail discs and this was then divided by the number of cycles which the test had run for to give a wear rate in terms of µg/cycle. Figure 12 shows that a higher wear rate is seen under dry conditions as compared to when there was traction gel in the contact. All of the tests were run for a distance of approximately 1000 cycles and wear rates were averaged over that period. Tests done with sand in a twin-disc contact [6] showed that entraining dry sand into the twin disc contact increased levels of rail wear by a factor of 2 and in wet conditions a factor of 4. Wheel wear was more greatly affected, increasing by a factor of 6 with dry sand and 10 with wet sand compared with baseline dry conditions. The tests in [6], however, were carried out under much more severe contact conditions with a slip of 20% and 3000 cycles being used as compared to 3% and 1000 cycles used in this work. Results from [6] show that rail wear is not affected as much as wheel wear when sand is entrained in the contact. Considering that in the tests reported here the sand particles are carried within a lubricant and also the fact that the sand is not being continuously applied to the contact as is the case in [6] it is perhaps not surprising that the rail wear rate is lower. It needs to be noted that in this work there was also the presence of a leaf layer in the contact for the tests with traction gel. However, data from Figure 12 shows that, within error, the presence of a leaf layer does not seem to affect rail wear. It is likely then that there are much different wear mechanisms at play in these tests compared to [6]. Another way of viewing the data in Figure 12 is to compare the wear rate of the traction gel to the wear rate of the wet leaf layer. By placing the traction gel on top of the leaf layer we effectively have a wet leaf layer. It may be that the low wear rate of the wet leaf layer is being increased by the additional presence of sand in the contact, but that this increased wear rate is still below that of a completely dry contact.

The interaction between wheel steel, leaf layer sand, gel and wheel steel is also likely to be very complex. However, it remains to be said that testing different variants of traction gel using the method described in this paper would still allow a relative comparison of the wear performance of each gel tested.

8. CONCLUSIONS

A technique has been developed using the Sheffield University Rolling Sliding (SUROS) test rig to measure the traction, electrical isolation and wear properties of traction enhancing products. The technique also includes a method to generate a low adhesion leaf layer on the rail disc.
Specific findings of this study are:

- Differences in traction can be seen between dry, leaf layer and traction gel coated discs.
- The performance of the traction gel tested could be assessed in terms of a leaf “traction increase/layer removal rate” (revs^{-1})
- Impedance at the disc contact has been reliably measured using a simulated TI21 track circuit and measurable differences in impedance have been shown between different contaminant/traction enhancer conditions
- Wear rates for different contamination/traction enhancer conditions can be calculated and notable differences in wear rates have been seen
- Leaf layer and gel seem to significantly lower wear rate over that of sand alone
- There is significantly higher impedance in the first 5 seconds of the test where the traction curves show dominance by gel as opposed to sand. Between 5 and 10 seconds the impedance falls close to uncontaminated levels. Coincidentally this is the point where the gel starts to evaporate. It therefore may be the case that the gel caused more impedance than the sand
- By testing different variants of traction gels or other products designed for application to the railhead/wheel rail contact a reliable performance assessment of each product in terms of: traction, wear and impedance can be made using the technique described in this paper

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