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INVESTIGATING THE EFFECT OF DIFFERENT ADHESION MATERIALS ON ELECTRICAL RESISTANCE USING A HIGH PRESSURE TORSION RIG

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Abstract: This paper presents an assessment of newly-developed conductive adhesion materials (Products A-D) in comparison to standard rail sand used in Britain. The particles were characterised to assess their densities, and size and shape distributions. Bulk behaviour was assessed through three characteristics: angle of repose, bulk shear strength, and particle breakage index. Materials were then assessed using a high pressure torsion approach to measure their effects on adhesion and electrical resistance in dry, wet, and leaf contaminated conditions. It was resolved that all products produced better conductivity than GB rail sand and Product D should be considered for future field testing.

Keywords: wheel/rail isolation; adhesion materials; sanding; particle characterisation; tribological testing.

1 Introduction

The process of sanding has long been established as mitigation against low adhesion conditions in the wheel/rail contact. Whilst the presence of these adhesion materials is necessary for reducing the impact of low adhesion, it can also lead to electrical isolation of train wheels from the track, particularly when rail head contamination is present, which can affect the functioning of track circuits. In the UK, track is split up into blocks, each of which forms a “track circuit” used for train detection. Within a section of track forming the circuit, which is typically bounded by insulated joints, a transmitter at one end sends an electrical signal to a detector at the other end. If a train is present, the track circuit is shorted out, thus the train is detected. When the wheel/rail interface is insulated by the presence of third body materials, there is a risk that the train can no longer be detected and problems arise [1]. A simple schematic of a track circuit is presented in Figure 1 for clarity.

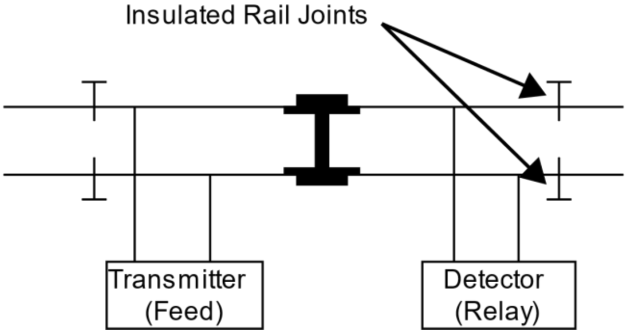

Figure 1. Track Circuit Schematic.

Whilst there have been potential cases of track circuits failing due to the presence of sand [2] in the past there are also cases where the failure of the track circuit was due to contamination on the rail head [3]. It should be noted that in work conducted by the RSSB [4], using field data, the viability of applying sand during braking was assessed using RSSB’s Network Modelling Framework Safety Module. This approach calculated that reduction in risk of signals passed at danger (SPADs) was 170 times greater than the risk of isolation occurring, in fact it was found that only 3% of isolations were caused by sanding with the rest coming from contamination. These findings suggest that whilst it is important to consider isolation when designing a sanding system, the ability of the system to remove contaminants is of much greater importance; outside of these findings, there will naturally be a limit to the amount of sand being applied, which will result in wheel/rail isolation.

A full review paper focussing on the effect of particulate materials on restoring adhesion has been conducted by Skipper et al. [5]. In this review paper, it was observed that little work had been done to study the effect of particles on wheel/rail isolation and how particles could be redesigned to overcome this.

The overall aim of this paper was to test four newly-developed conductive sand consists (Products A-D) to assess their impact on adhesion and electrical resistance when compared with a standard grade of rail sand used in the UK (GB Rail Sand). To achieve this, the different materials were characterised to assess their key particle properties and applied to a high pressure torsion testing rig to measure their effect on adhesion and electrical resistance, the latter measurement was achieved by adapting the rig from previous work conducted by Evans et al. [6] & Skipper et al. [7].

2 Methodology

2.1 *Particle Characterisation*

A range of techniques were utilised to assess particle characteristics. Single particle characteristics such as: particle size and shape distribution and density were assessed. In addition, the bulk behaviours of particle types were assessed through three experiments: angle of repose, direct shear test, and one-dimensional compression. The techniques employed for measuring each characteristic have been included in Table 1; in addition, respective references have been included for each technique which detail the methods for each.

Table 1. Summary of Particle Characterisation Methodologies.

Characteristic	Technique	Ref
Particle Size	Sieve Analysis	[8]
Particle Shape	X-ray micro Computer Tomography	[9], [10]
Particle Density	Gas Jar	[8]
Angle of Repose	Plane Strain	[11]
Bulk Shear Strength	Direct Shear Loading under varying Normal Stress	[12]
Particle Breakage	Measuring Evolution of Particle Size Distribution under 1D Compression	[13]

2.2 *High Pressure Torsion*

A high pressure torsion (HPT) rig was used for assessing adhesion and electrical resistance under a range of contact conditions. A schematic of the HPT is shown in Figure 2. The top and bottom specimens (1 & 2 respectively) were cut from R8T wheel and R260 rail respectively and were fixed into specimen holders (3). Initially, the specimens were out of contact, but were brought together during testing and a normal pressure of 600 MPa was applied using the axial hydraulic actuator (5). The specimen faces were then rotated against each other using a rotational hydraulic actuator (4). The third body layers being applied into the contact between the wheel and rail specimen change the amount of torque needed to turn through a set sweep length (0.4 mm), and the coefficient of traction is calculated from ratio of the shear stress and the normal stress.

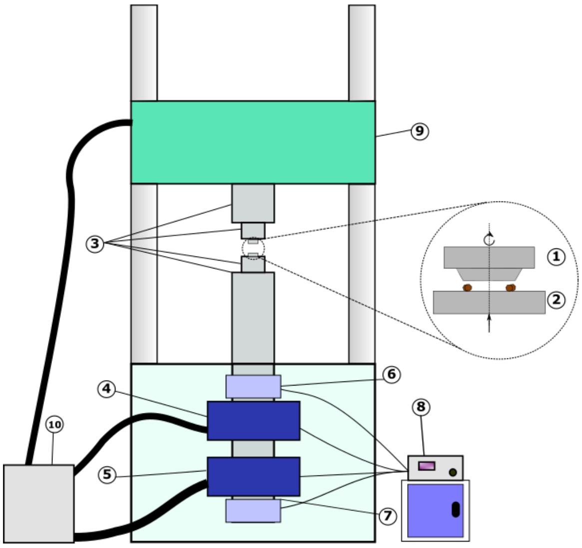

Figure 2. Full Schematic of the High Pressure Torsion Rig.

For the purposes of this work, a 0.5 V_{DC} circuit was set-up in order to measure conductivity between the wheel and rail specimens; a schematic of this has been included in Figure 3. The value of 0.5 V_{DC} was chosen so as to represent the worst-performing track circuit found in UK rail operations i.e. low voltage DC.

A sub-schematic of the insulated rig has also been included in Figure 3; the bottom sample holder was isolated using a polyethylene layer and the bolts were insulated with electrical tape and nylon washers.

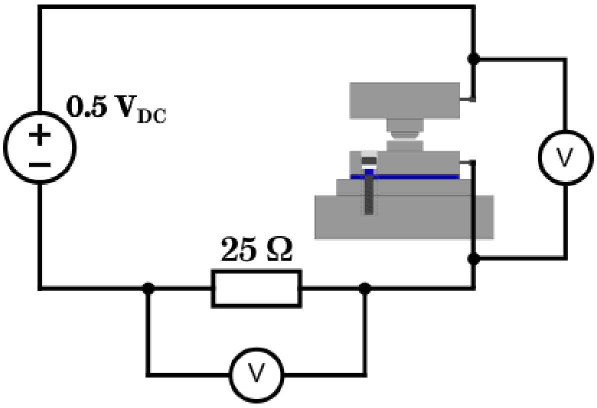

Figure 3. HPT Set-up for Conductivity Measurements.

Tests were conducted in dry, wet, and leaf contaminated conditions. Each adhesion material was tested at representative amounts of 7.5 g/m [1] and with an amount of material needed to physically separate the top and bottom HPT specimens (i.e. enough material so that the contact is flooded with adhesion material). An example of the application amounts used has been included in Figure 4. Two tests were conducted for each contact condition, with three passes over each application of material for each test.

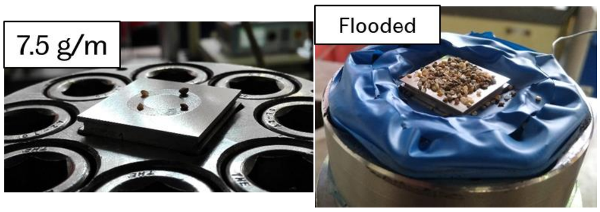

Figure 4. Example of Application Amount for Tests with a Representative Amount of Material and with an Over-Application of Material.

3 Results

3.1 *Particle Characterisation*

A summary of the particle characterisation measurements recorded as part of this project are included in Table 2. Significant differences in particle size and density between the materials were apparent, especially in comparison with GB rail sand, which had the largest particle size and smallest density; little difference was observed between respective particle shapes, which were all mostly compact or flat. Differences in angle of repose (AoR) suggest the flowability of different materials varies, with GB rail sand proving the most flowable and Product B the least. Characterisation of bulk shear strength found GB rail sand and Product D were able to support the highest level of shear stress, whilst Product B was the most cohesive. Product D was found to be more susceptible to breakage in comparison to GB rail sand.

Table 2. Summary of Particle Characterisation Measurements.

Material		GB Rail Sand	A	B	C	D
Size D50 (µm)		1440	380	490	380	900
Particle Shape	Compact	36%	-	37%	-	35%
	Flat	32%	-	30%	-	35%
	Elongated	26%	-	25%	-	19%
	Bladed	6%	-	8%	-	11%
Density (Mg/m^3)		2.61	3.84	3.81	3.07	3.75
AoR (°)		28.6	31.9	32.3	31.2	29.9
Bulk Shear Strength	Friction Angle (°)	34.0	28.2	30.3	32.6	34.1
	Cohesion (kPa)	2.3	2.2	5.9	2.4	1.3
Particle Breakage Index		0.95	-	-	-	1.12

3.2 *High Pressure Torsion*

As an example of raw data acquired from an HPT test, Figure 5 has been included; data from three passes of the wheel specimen over the rail specimen is included and demonstrates the appearance of a clean contact, with high levels of adhesion and very low contact resistance throughout. Between each pass, the specimens were separated and turned to a new position. Where adhesion material was applied, all three passes were over the same application of material.

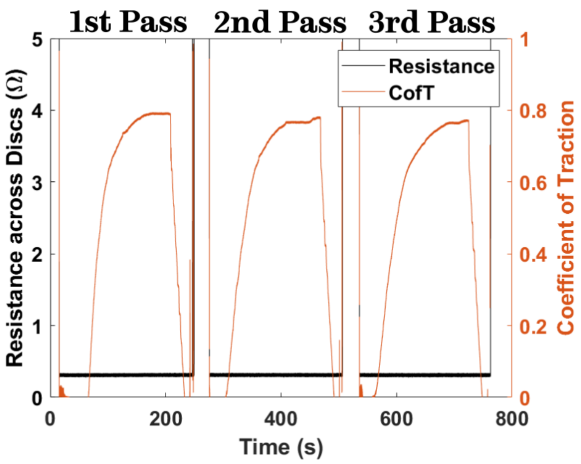

Figure 5. Example of HPT Data from Dry Test with no Application of Adhesion Material.

3.2.1 *Representative Amounts*

The following section includes the results of HPT tests conducted with a representative 7.5 g/m of adhesion material applied to the HPT contact.

In dry conditions, all materials produced no change in resistance behaviour as compared to a clean, dry contact (Figure 5) for the majority of the test sweep, Figure 6 shows an example test in dry conditions when adhesion material was applied.

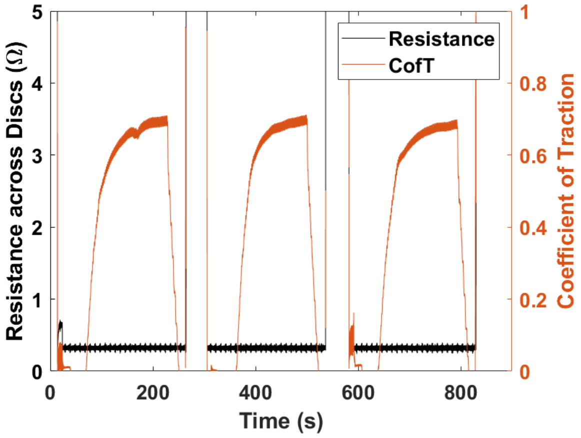

Figure 6. Example of Test Data from Tests conducted in Dry Conditions with Adhesion Material Applied (GB Rail Sand in this Instance).

There was an initial increase in resistance upon the particles first being crushed, Figure 7 illustrates this effect. As further axial load (normal force) was applied and the particles were further crushed, the resistance decreased to that of a clean contact.

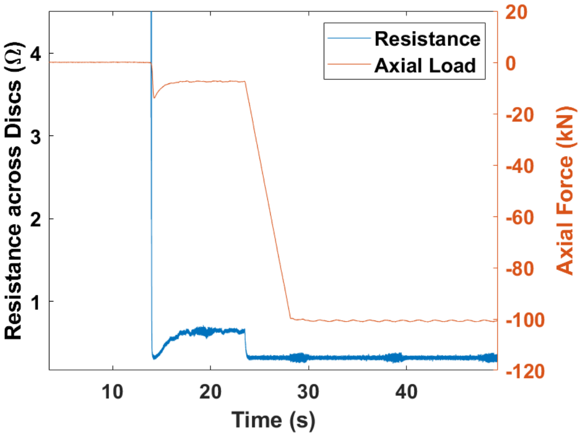

Figure 7. Resistance in HPT Contact upon Initial Crushing of Particles (GB Rail Sand in this Instance).

Whilst resistance measurements were consistent, adhesion behaviour changed considerably from one material to the other in dry conditions. Figure 8 presents the average peak coefficient of traction for each material over three passes. All materials reduced traction to some extent, but not to the extent that they created low adhesion (0.09 for braking, and 0.2 for acceleration according to Fulford [14]). GB rail sand produced traction slightly below that of the unsanded contact. Products A-D all produced even lower adhesion, with Products A, B, and D all showing a reduction in traction with subsequent passes, this effect being most apparent for Product A. The values, however, remained above the safe threshold for braking and acceleration.

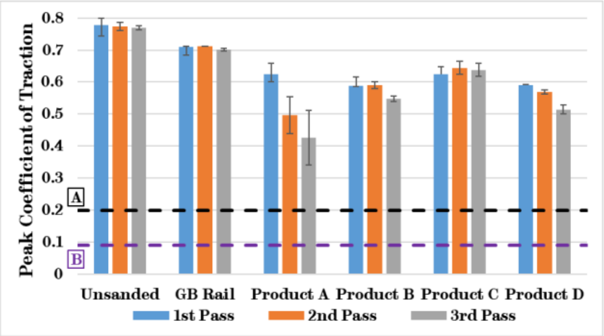

Figure 8. Peak Coefficient of Traction in Dry Conditions for All Tested Adhesion Materials; (Line A) Minimum Level of Adhesion required for Acceleration, (Line B) Minimum level of Adhesion required for Braking [14].

In wet conditions, all materials produced no change in resistance behaviour as compared to a clean, dry contact (see Figure 5). The different adhesion materials did affect the adhesion in the contact, as can be seen in Figure 9. No material produced significant low adhesion in wet conditions, and some acted to increase traction compared to the wet, unsanded case. GB rail sand produced the highest traction and was the only material to not see any decrease in traction with the number of passes. Product C produced slightly lower traction than GB rail sand, and did not see a large drop in traction between passes. Products A, B, and D produced similar peak traction values initially, though Product A reduced relatively sharply in comparison to B & D.

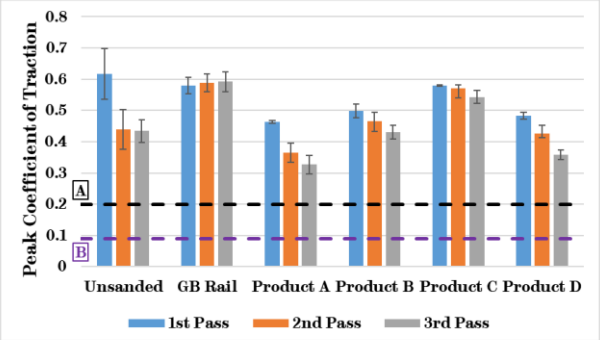

Figure 9. Peak Coefficient of Traction in Wet Conditions for All Tested Adhesion Materials; (Line A) Minimum Level of Adhesion required for Acceleration, (Line B) Minimum level of Adhesion required for Braking [14].

Contrary to dry and wet conditions, the application of adhesion materials had a marked effect on resistance in the leaf contaminated contact. Figure 10 represents the relative amount of time each test condition spent at a given resistance value; in the unsanded case resistance values were between 1000-10,000 Ω throughout the test runs.

Whilst all newly-developed products reduced resistance, some even reduced resistance to similar levels as seen in the clean contact. GB rail sand mostly produced high levels of resistance, though there was a spread in recorded resistance values over several levels of magnitude. Products C & D produced resistance values such that the majority of the time was spent at resistance values similar to that of a clean contact. Products A & B also reduced resistance to that of a clean contact, but the recorded resistance values were more varied throughout the test runs.

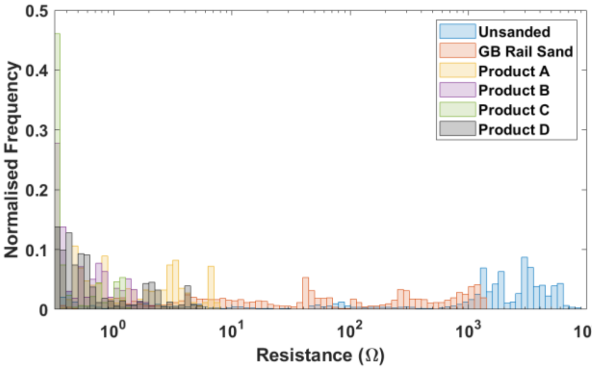

Figure 10. Histogram Plot of Time the HPT Contact Spent at a Given Resistance in Leaf Contaminated Conditions with Representative Adhesion Material Application.

All adhesion materials increased adhesion in the contact by comparison to the unsanded, leaf contaminated case, though all materials also saw a slight reduction with number of passes. All materials produced adhesion values above the minimum adhesion level needed for braking, as can be seen in Figure 11.

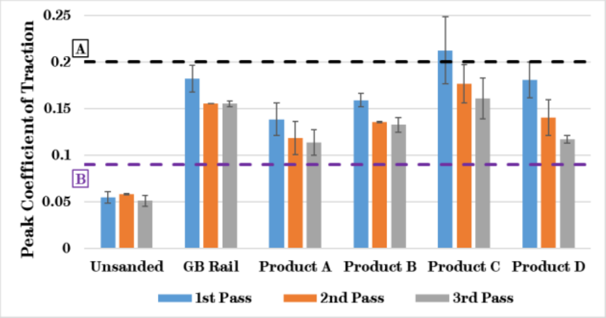

Figure 11. Peak Coefficient of Traction in Leaf Contaminated Conditions for All Tested Adhesion Materials; (Line A) Minimum Level of Adhesion required for Acceleration, (Line B) Minimum level of Adhesion required for Braking [14].

The data acquired from this test method has indicated that there is scope for increasing the electrical conductivity of adhesion materials, whilst maintaining an adequate degree of mitigation against low adhesion conditions when applying material at the current maximum permitted amount (7.5 g/m).

3.2.2 Over-Application

The following section includes the results of HPT tests conducted with an over-application (complete coverage of the bottom specimen) of adhesion material in the HPT contact.

In dry conditions, it is unsurprising that in the unsanded case the resistance measured is the same as that of a clean contact throughout the tests runs, as is illustrated in Figure 12. When over-applied, all materials had some effect on resistance measurements, notably GB rail sand appears to have increased resistance measurements to very high levels. All other materials had less of an effect, with none creating resistance values >10 Ω.

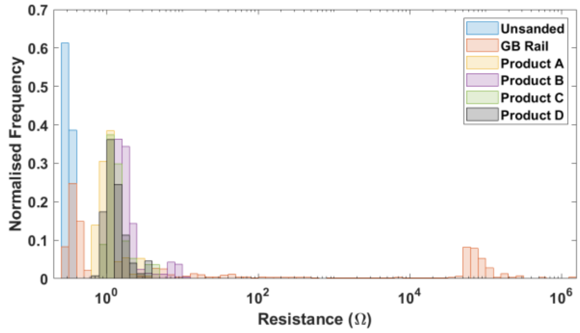

Figure 12. Histogram Plot of Time the HPT Contact Spent at a Given Resistance in Dry Conditions with Adhesion Material Over-Application.

All over-applied materials reduced traction compared to unsanded conditions, though not to the extent that low adhesion conditions were created, see Figure 13. As seen when representative amounts of material were applied, Product A saw a sizable drop in peak traction with increasing passes.

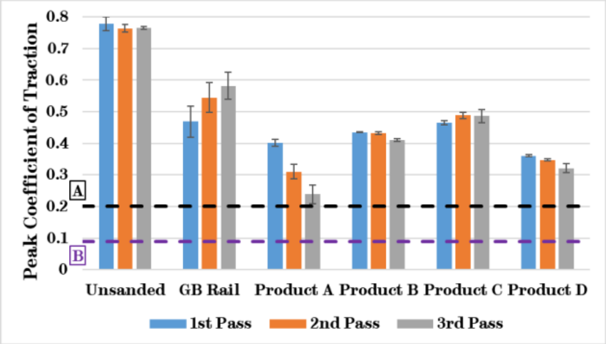

Figure 13. Peak Coefficient of Traction in Dry Conditions for All Tested Over-Applied Adhesion Materials; (Line A) Minimum Level of Adhesion required for Acceleration, (Line B) Minimum level of Adhesion required for Braking [14].

Compared to dry conditions, the spread of measured resistance values is much greater in wet conditions with an over-application of material, as can be observed in Figure 14 (the unsanded case was at the level of a clean contact at all times and removed from the plot for clarity). GB rail sand produced high resistance values for the entirety of its test runs. Other products mostly stayed <10 Ω, with some materials partly reaching clean contact conditions, notably Product D spends a lot of time at these resistance values.

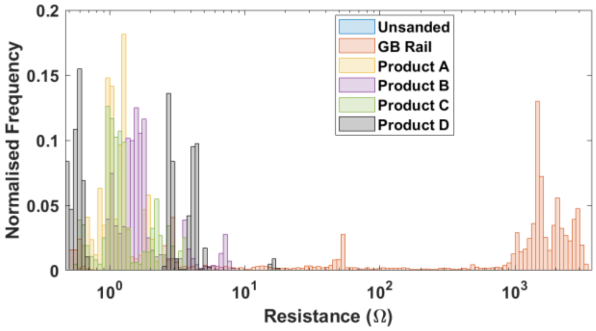

Figure 14. Histogram Plot of Time the HPT Contact Spent at a Given Resistance in Wet Conditions with Adhesion Material Over-Application.

The overall peak traction trends are similar in wet conditions to what was observed in dry conditions though at lower adhesion values. In Figure 15 it can be seen that no material significantly improves peak traction when over-applied and Product A even created an adhesion value below 0.2 (the required adhesion level for acceleration).

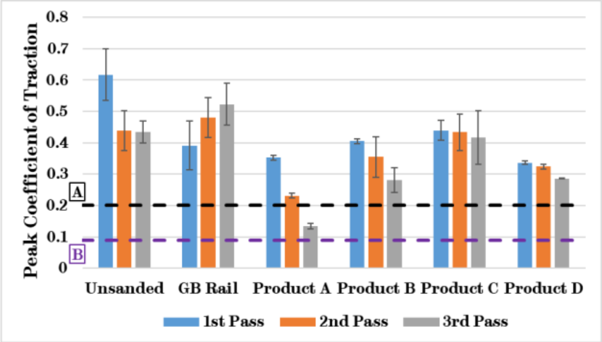

Figure 15. Peak Coefficient of Traction in Wet Conditions for All Tested Over-Applied Adhesion Materials; (Line A) Minimum Level of Adhesion required for Acceleration, (Line B) Minimum level of Adhesion required for Braking [14].

Regarding leaf contaminated conditions, in Figure 16 it can be seen that GB rail sand made little difference to the measured resistance values compared to the unsanded case. Products A-D improve the resistance values observed to <10 Ω, with product C producing some resistance values akin to a clean contact. Generally, the resistance is higher when adhesion material was over-applied than applied representatively (see Figure 10).

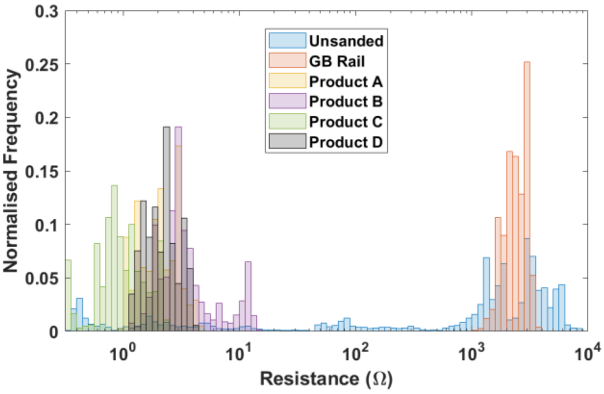

Figure 16. Histogram Plot of Time the HPT Contact Spent at a Given Resistance in Leaf Contaminated Conditions with Adhesion Material Over-Application.

All adhesion materials increased the peak coefficient of traction in the leaf contaminated HPT contact, as illustrated in Figure 17. The overall trend between adhesion materials and peak traction is similar here, as for representative applications of material (see Figure 11), though adhesion levels were generally higher.

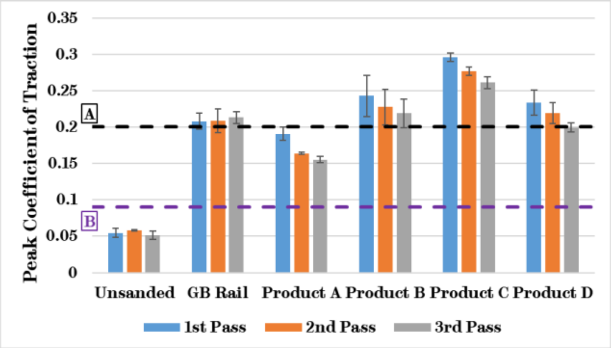

Figure 17. Peak Coefficient of Traction in Leaf Contaminated Conditions for All Tested Over-Applied Adhesion Materials; (Line A) Minimum Level of Adhesion required for Acceleration, (Line B) Minimum level of Adhesion required for Braking [14].

It was observed that electrical resistance was higher in all conditions when adhesion material was over-applied in contrast to when it was applied at a representative, 7.5 g/m. All adhesion materials, applied representatively, did not alter resistance from that seen in a clean contact in both dry and wet conditions, though there were noticeable differences between materials in a leaf contaminated contact. Some of the newly-developed materials produced lower resistances in certain conditions than the GB rail sand and no newly-developed product produced higher resistance when compared to GB rail sand (which is currently approved for use on the railway in Great Britain).

In dry and wet conditions, adhesion was lowered when material was over-applied in comparison to when it was applied representatively, this was the opposite in leaf contaminated conditions. No adhesion material created low adhesion in any test condition or application amount.

4 Conclusions

In this paper, GB rail sand and four newly-developed products designed to aid conductivity in the wheel/rail interface were assessed for their particle characteristics, tribological performance and effect on electrical conductivity.

Particle characterisation work identified key differences between new products and the GB rail sand currently in use. Whilst differences between GB rail sand do not necessarily mean a prospective new particle will not perform as well as GB rail sand in the wheel/rail contact, it does increase the chances of incompatibilities with current sanding standards and equipment. Bearing this in mind, product D appears most similar in terms of particle size and has a similar angle of repose. In addition, products C & D produce similar bulk shear strength to GB rail sand.

The HPT tests, showed that product A produced consistently lower peak coefficients of traction across all conditions, with a decrease in traction seen over multiple passes. Product C consistently produced marginally higher traction than the other particles, which all produced similar traction levels. Products B, C, and D all generally produced the lowest amount of resistance in the contact, producing resistance values approaching that of a clean contact in leaf contaminated conditions when applied at representative amounts. In general, all newly-developed products mitigated against low adhesion conditions, did not create low adhesion themselves, and reduced or equalled electrical resistance in the HPT contact compared to GB rail sand.

Due to its performance in HPT testing and it having similar particle characteristics to GB rail sand, Product D has been identified as a material of interest for further field testing with GB rail sand to be used as a control.

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References

[1] Rail Safety and Standards Board, “GMRT2461 Sanding Equipment (Issue 3).” pp. 1–24, 2018.

[2] Network Rail, “Group Standard GE/RT8250 Class 66 Sanding Defects (NIR 1481),” 2002.

[3] Rail Accident Investigation Branch, “Rail Accident Report: Near Miss Between a Passenger Train and Cars at Norwich Road Level Crossing, New Rackheath, Norfolk, 24 November 2019 (Report 15/2020),” 2020.

[4] Rail Safety and Standards Board, “Research brief: Review of the risks and opportunities from the application of sand during braking (T1046),” 2015. [Online]. Available: https://www.rssb.co.uk/library/research-development-and-innovation/research-brief-T1046.pdf. [Accessed: 12-May-2017].

[5] W. A. Skipper, A. Chalisey, and R. Lewis, “A Review of Railway Sanding System Research: Wheel/Rail isolation, Damage, and Particle Application,” *J. Rail Rapid Transit*, vol. 234, no. 6, pp. 567–583, 2019.

[6] M. Evans, W. A. Skipper, L. Buckley-Johnstone, A. Meierhofer, K. Six, and R. Lewis, “The development of a high pressure torsion test methodology for simulating wheel/rail contacts,” *Tribol. Int.*, vol. 156, no. 106842, Apr. 2021.

[7] W. A. Skipper, S. Nadimi, A. Chalisey, and R. Lewis, “Particle Characterisation of Rail Sands for Understanding Tribological Behaviour,” *Wear*, vol. 432–433, no. 202960, 2019.

[8] The British Standards Institution, “BS 1377-2:1990 Methods of test for Soils for civil engineering purposes — Part 2: Classification tests,” *British Standard Institution*. 1990.

[9] V. Angelidakis, S. Nadimi, and S. Utili, “Elongation, flatness and compactness indices to characterise particle form,” *Powder Technol.*, Nov. 2021.

[10] V. Angelidakis, S. Nadimi, and S. Utili, “SHape Analyser for Particle Engineering (SHAPE): Seamless characterisation and simplification of particle morphology from imaging data.,” *Comput. Phys. Commun.*, vol. 265, no. 107983, 2021.

[11] Y. Nakata and S. Moriguchi, “Round robin test of angle of repose (AOR),” *Universal Benchmark of DEM Simulation*, 2019. [Online]. Available: http://geotech.civil.yamaguchi-u.ac.jp/tc105/.

[12] The British Standards Institution, “BS 1377-7:1990 Methods of test for soils for civil engineering purposes. Shear strength tests (total stress).” 1990.

[13] R. J. Marsal, “Large scale testing of rockfill materials,” *J. Soils Mech. Found. Div.*, vol. 93, no. 2, pp. 27–44, 1967.

[14] C. R. Fulford, “Review of low adhesion research (T354) (RSSB Report),” 2004. [Online]. Available: https://www.sparkrail.org/Lists/Records/DispForm.aspx?ID=9539.