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Article

Twin-Disc Wear Assessment of Solid Stick Flange Lubricants †

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Abstract

Lubrication between the rail gauge face and wheel flange is necessary to improve vehicle performance and reduce component wear. One way to achieve this is to use a solid stick loaded against the wheel flange. This paper details twin-disc testing of eight stick products according to Annex H of EN 15427-2-1:2022 (previously Annex L of EN 16028:2012) and then describes a new assessment methodology using conditions more relevant to field application. EN 15427-2-1:2022 specifies a test involving the application of the product during wheel–rail specimen contact. Once a specified time has elapsed, product application ceases, and performance is assessed as the time taken for the friction coefficient to return to a nominal dry value. This is described as "retentivity". In the new test, the product is applied whilst wheel and rail are out of contact, to allow the product to build up on the wheel, then the specimens are put into contact, under conditions representing 150 m of continuous, heavy flange contact; this process is repeated a set number of times. The new test showed that products that failed the current friction criteria successfully protect the wheel and rail from wear, which is ultimately the aim of the product application.

Keywords: wheel–rail interface; solid stick flange lubrication; retentivity; friction; wear

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1. Introduction

Lubrication of the wheel flange–gauge corner interface is necessary to reduce damage to both the wheel and rail. The rail suffers damage in the form of wear and rolling contact fatigue, incurring maintenance costs through rail grinding and replacement. Wear of the wheel reduces steering performance, requiring re-turning of the profile and eventually replacement.

Wheel flange/gauge corner lubrication is well established, usually in the form of grease applied via wayside applicators (grease distribution units (GDUs)) and picked up by passing wheels that then transfer it back to the rail further along the track. Generally, wayside applicators are only used in problem sections of track because of the costs associated with accessing the track to refill the grease reservoirs and maintain them. To overcome these issues, on-board grease application systems and solid stick equivalents were developed to run against the wheel flange; these provide network-wide coverage whilst reducing maintenance costs since the product can be replaced when the vehicle returns to the maintenance depot.

In order to develop a lubricant for the wheel flange/rail gauge corner interface, it is necessary to be able to assess the performance of the product under realistic usage conditions; scaled assessments can be performed much more quickly than complex, expensive full-scale field trials. Twin-disc-type testing is well documented as a scale testing method for the wheel–rail interface. It can simulate the rolling–sliding nature of wheel–rail contact and has been previously used to assess many aspects of wheel/rail interface tribology [1]. These include, for example, friction/adhesion in the interface [2–9] (it should be noted that these are selected examples from many papers; a wider selection of references can be found in [1]); wear and rolling contact fatigue [10–18]; and electrical isolation, which can compromise track circuits used for train identification [19–21]. Many of these studies include the application of friction management products, including liquid and solid stick products applied to the wheel tread to achieve intermediate friction, or other third bodies, and investigate the subsequent effects.

The standard EN 15427-2-1:2022 [22], "Railway applications. Wheel/Rail friction management. Properties and Characteristics. Flange lubricants", defines a twin-disc test procedure for assessing the performance of solid stick flange lubricants; the procedure was decided by a committee of experts in the field of rail friction management and associated scale testing. The procedure can be found in Annex H of the EN 15427-2-1:2022 [22] document (previously Annex L of EN 16028:2012 [23]). According to the document, the purpose of the procedure is to quantify the following key performance criteria of products:

1. The ability to reduce and control the coefficient of friction (CoF) when the solid stick product is applied to the wheel flange; the friction level could be used to give an indication of relative material wear rates.
2. The durability of the applied film once the solid stick product is removed; this provides an indication of how long the applied film will last when transferred from the wheel flange to the rail gauge side face and, therefore, how effective the film will be at protecting wheelsets not equipped with the product.

To clarify the terminology used in the literature for friction levels, the "coefficient of friction" mentioned above is defined for a contact fully saturated with slip. This normally occurs above a creepage level of 1–2%. "Coefficient of traction" and "adhesion", which are also used to describe friction conditions in the interface, apply to both partial and full slip conditions. So, for slip values above 2%, both the coefficient of friction and the coefficients of traction/adhesion have the same value.

The procedure can only be used to assess performance in a comparative manner; the absolute values are not meant to suggest any particular behavior in service running, and the results are not intended to be comparable between tests performed on different test machines. The procedure defined in Annex H [22] specifies conditions for a test involving the application of the product during twin-disc wheel and rail specimen contact. Once a specified time has elapsed, the application of the product is ceased; product performance is assessed as the time the product continues to perform (coefficient of traction remains lower than a nominal dry value) after application ceases; this figure is known as "retentivity". Other possible assessment criteria include the coefficient of traction achieved and consumption of the product. It is also possible to determine the mass loss from the test specimens during each test; however, the results are not suitable for comparison since the time in contact varies between tests.

The brevity of product application introduces significant uncertainty to the product consumption results, and the varying length of the test means that wear results do not provide a satisfactory comparison between tests. Furthermore, it was also noted that the prescribed test could be more representative of actual wheel–rail contact conditions under lubricated conditions. Generally, flanging contact is considered to produce greater contact pressures than tread contact [24], and these retentivity tests are run at tread contact pressures. Under this methodology, it was found that higher pressures prevent the products from functioning completely.

The literature available on investigations of solid stick lubricants is extremely limited. Studies by Eadie & Hui [25], Eadie et al. [26], and Ashofteh [27] investigated the effect of a solid stick flange lubricant on wheel flange wear using full-scale trials and wheel profile measurements; all three studies noted decreases in wheel wear and an increase in service life. A report from the Transportation Technology Center, Inc. [28] investigated the potential mechanical energy savings achieved when employing solid stick flange lubricants using field trials; the results showed that the application of the product has the potential to reduce energy use and, therefore, reduce fuel use. Jin produced a report [29] assessing the wear performance of a solid stick flange lubricant in terms of friction and wear under full sliding conditions; the results noted reductions in both friction and wear rates.

All these papers used the same commercially available product for their trials. More recent work, though, has compared a range of products. Fang et al. [30] studied wear and friction performance through laboratory and field testing for different products. No papers that followed the approach laid out in the EN 15427-2-1:2022 [22] standard could be found, other than the work of Song et al. [31], who carried out a comprehensive study of different solid stick products analyzing wear and friction as well as retentivity and crack formation, and Cebulska et al. [32]. However, in this work, during the tests, the wheel and rail discs were in contact continuously, while in the field, the wheel flange moves in and out of contact, which will change the tribological impact of the stick material. This was the same in the work of Camilo Velez et al. [33], where a similar twin-disc approach was used.

A new wear-based test procedure has been developed and is detailed in this paper, which is an extended version of a conference paper [34]. The new methodology uses higher contact pressures and features constant product application with only occasional wheel–rail specimen contact; more representative of actual contact conditions.

2. Experimental Details

2.1. Products

A total of 8 products from different suppliers and of different formulations were selected for assessment; products are labeled A to H for anonymity. Descriptions of the assessed products are shown in Table 1.

Table 1. Details of products included in the assessment.

Label	Product Description
A	MoS_2-based product (medium content)
B	MoS_2-based product (lowest content)
C	MoS_2-based product (highest content)
D	High-graphite-content product #1
E	Thermoplastic MoS_2 and graphite-based product #1
F	High-graphite-content product #2
G	Thermoplastic soya-based product containing MoS_2 and graphite
H	Thermoplastic MoS_2 and graphite-based product #2

2.2. Test Apparatus

All testing was performed on the SUROS twin-disc machine based at the University of Sheffield [12]; a schematic of this machine is shown in Figure 1, and details of the test discs are shown in Figure 2. For this testing, 900A rail (2.65 GPa hardness) was run against R7 wheel material 2.6 GPa hardness). The disc roughness at the start of the tests was 0.5 μm Ra.

The products were applied to the running surface of the wheel disc with a sprung applicator (Figure 3) designed during some previous work assessing the effect of solid stick products on wheel–rail isolation [21]. The spring force for the product application was calculated to result in the same application pressure as field application, assuming a perfectly conformal contact. A single value of 16 N was used for all products. This is the same approach as used in previous work, where different products were compared [32,33].

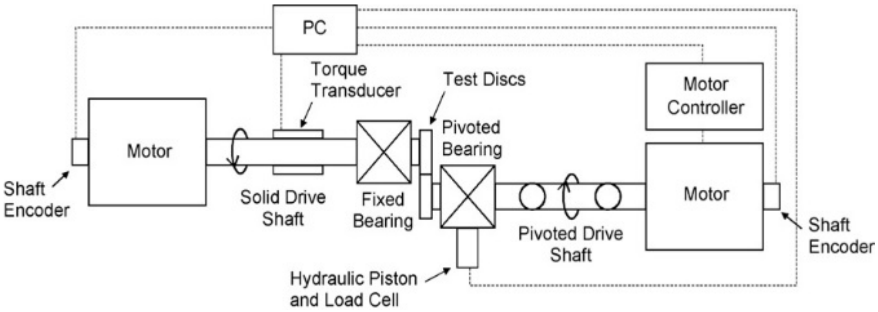

Figure 1. Twin-disc test rig schematic.

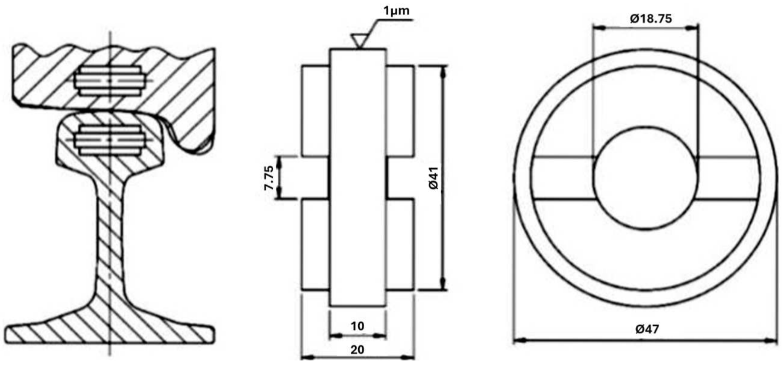

Figure 2. Disc specimen details.

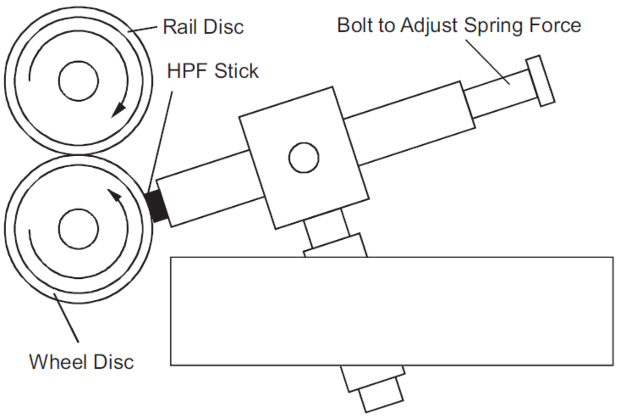

Figure 3. Sprung applicator for applying products [7].

2.3. EN 15427-2-1:2022 Retentivity Test Methodology

To comply with EN 15427-2-1:2022 [22], the original tests used the following summarized methodology:

- Discs in contact throughout test, 900 MPa maximum pressure, 10% creep at 400 RPM. Discs cooled using air flow.
- Product applied for 200 s and then released.
- Test ends when friction level rises above 0.4.

- Coefficient of traction and creepage are monitored throughout the test. Mass loss of both product and test discs is also recorded.
- EN 15427-2-1:2022 [22] specifies that testing should be repeated at least three times. Each trial has at least three repeats; however, some results had to be discounted as faults were uncovered (i.e., a significant misalignment between product and disc).
- The assessment criteria specified in EN 15427-2-1:2022 [22] are as follows:
- Product response ($t_1 - t_0$)—time taken (s) for the product to lubricate the interface upon product application.
- Coefficient of traction during product application (mean).
- Retentivity ($t_4 - t_2$)—time taken (s) for the coefficient of traction to return to 0.4 after product application has ceased.
- Product consumption—the amount of product consumed during the test (mm^3).
- Typical performance data is shown in Figure 4.

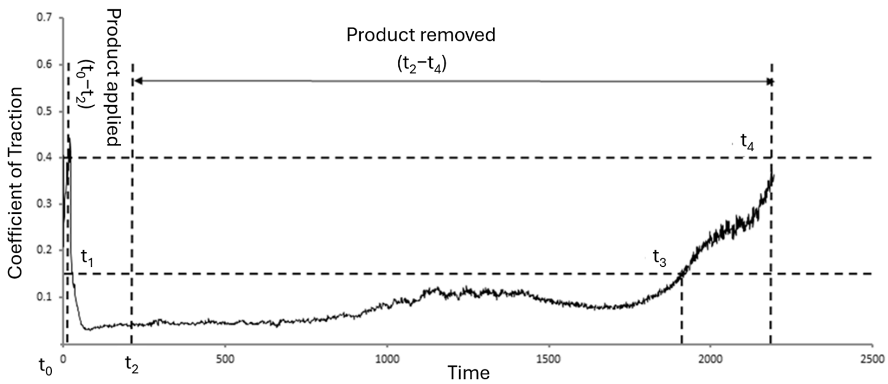

Figure 4. Typical retentivity test traction profile.

The following are considered to be desirable friction performance characteristics for a solid stick flange lubricant:

- Low product response time (s);
- Low coefficient of traction;
- High retentivity (s);
- Low product consumption—by volume (mm^3).

In addition to the methodology mentioned above, small experiments were performed with the effect of air cooling and additional product application pressure. The results of these are discussed in Sections 3.5 and 3.6.

2.4. Revised Wear Test Methodology

In order to develop this methodology, some preliminary tests were performed to trial a few methodology options. Variables explored included the periods of the product buildup, periods of disc contact, and the total length of the tests.

The chosen contact period of 1000 cycles of specimen contact is equivalent to 150 m of constant flanging contact, calculated using the surface speed of the specimens. In reality, a railway wheel will have a much larger circumference, so each point on the wheel surface will contact less often in 150 m, reducing the consumption of the product layer. To counteract this, the rail material was not cycled in the contact; any product transferred to the rail was not returned into the contact (although it may help lubricate subsequent wheelsets). Wear tests were performed with the following methodology:

- Product constantly applied to wheel disc.

- Discs out of contact for 2000 cycles (300 s) to allow product layer to form; discs in contact for 1000 cycles (150 s). Repeat 6 times.
- More severe contact conditions, 1500 MPa max pressure, 10% creep at 400 RPM. Discs are cooled in air flow.
- Coefficient of traction and creepage were monitored throughout the test. Mass loss of both product and test discs (post cleaning with acetone in an ultrasonic bath) is also recorded, using weighing scales with μg resolution.
- At least 3 repeats are recommended. Each trial had at least three repeats; however, some results had to be discounted as faults were uncovered (i.e., a significant misalignment between product and disc).

The following are considered to be desirable wear performance characteristics for a solid stick flange lubricant:

- Low wheel disc mass loss;
- Low rail disc mass loss;
- Low product consumption—by volume (mm^3).

3. Results

3.1. EN 15427-2-1:2022 Retentivity Tests

Figure 5 shows traction data from all eight products on one plot. Table 2 summarizes the coefficient of traction results, assigning them into three categories: effectively lubricating products, partially lubricating products, and non-lubricating products. The categories are defined according to the thresholds set by EN 15427-2-1:2022 [22]; $\mu \leq 0.15$ for effective lubrication, and $\mu \geq 0.4$ for dry contact. Table 3 summarizes the results for the products that provided effective lubrication.

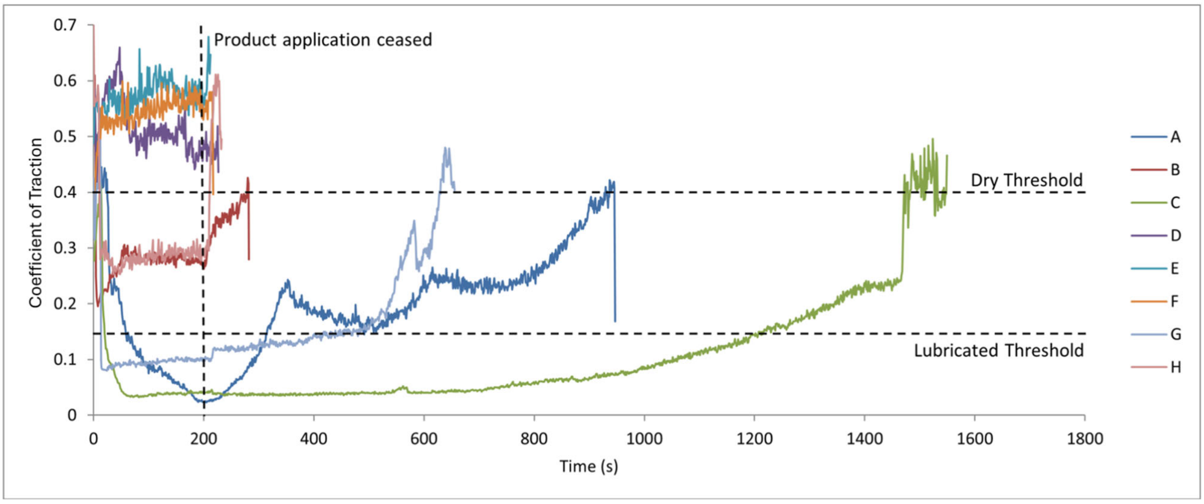

Figure 5. Comparison of retentivity traction profiles for all products.

Only three out of eight proved capable of effectively lubricating the interface: Products C, G, and A. The remaining five products did not achieve the $\mu \leq 0.15$ lubrication threshold, preventing a full retentivity assessment.

Of the three effectively lubricating products, Product C produced the lowest coefficient of friction and is retained in the contact the longest. Product G has the quickest product response, but also the highest consumption rate. Product A has the lowest consumption but does not perform as well in all other measures.

Table 2. Summary of friction results in order of coefficient of traction.

Lubrication Effectiveness	Product	Number of Successful Repeat Runs	Coefficient of Traction
Effectively lubricating products $\mu \leq 0.15$	C G A	3 3 2	0.056 0.094 0.103
Partially lubricating products $0.15 \leq \mu \leq 0.4$	H B	3 2	0.258 0.332
Non-lubricating products $\mu \geq 0.4$	D E F	3 3 3	0.535 0.558 0.562

Table 3. Summary of retentivity results for effectively lubricating products.

Products	C	G	A
Lubricated Coefficient of Traction at t^2	0.056	0.094	0.103
Product Response: $t_1 - t_0$ (s)	4	2	52
Retentivity: $t_4 - t_2$ (s)	1502	484	1202
Consumption (mm^3)	4.81	6.73	3.57

3.2. Drawbacks of EN 15427-2-1:2022 Testing

The methodology defined in EN 15427-2-1:2022 [22] assesses product performance under conditions representing constant flanging contact. In service, product layers will be formed on the wheel flange whilst the flange is out of contact; the product only lubricates during occasional flanging contact periods. Contact pressures during flanging contact are also thought to be higher than those used in the retentivity test [24].

The retentivity methodology is a standard test, but it does not represent product performance in the field. The wear test methodology outlined previously addresses these issues by replicating the occasional nature of flanging contact and using contact pressures more representative of flanging contact [24].

A further drawback of the retentivity testing is the variability of the results produced; Figure 6 shows the variability of the product C test results. One of the key factors causing variation in the results is the alignment of the solid stick product with the discs for application; for example, the delayed lubricating layer formation exhibited in Run 1 was caused by a misaligned product application, and this run was discounted from the results. Whilst Run 1 is an extreme case, even slight alignment issues are exaggerated by the short application time of the products in retentivity testing. The short application period leaves very little time for the product to conform to the specimens and form a consistent product layer; the wear test has a longer application period, allowing the product to conform to the specimen and therefore reducing the effect of any initial misalignment.

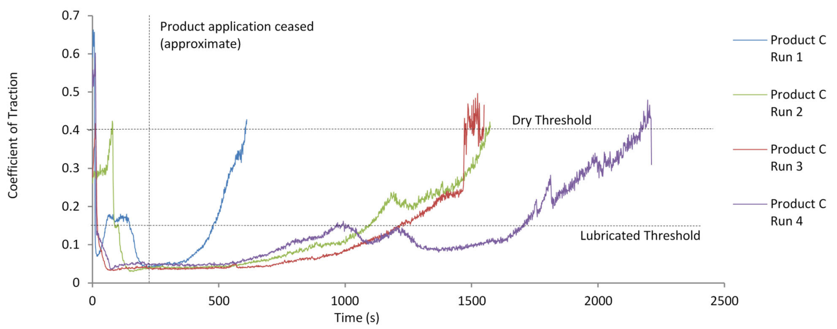

Figure 6. Results from Product C tests showing the variation between tests of the same product.

3.3. Revised Wear Tests

Only three products were tested with the wear methodology, namely the two best-performing products (C and G) and a product that had performed badly in the retentivity tests (E), and there was a control test run without a product. Only a limited number of successful repeats were performed for Products C (four valid repeats), E (two), and G (one).

A coefficient of traction plot for each product is shown in Figure 7; these plots show the periods when the discs were out of contact, as well as the periods of contact. The products were applied to the wheel disc throughout.

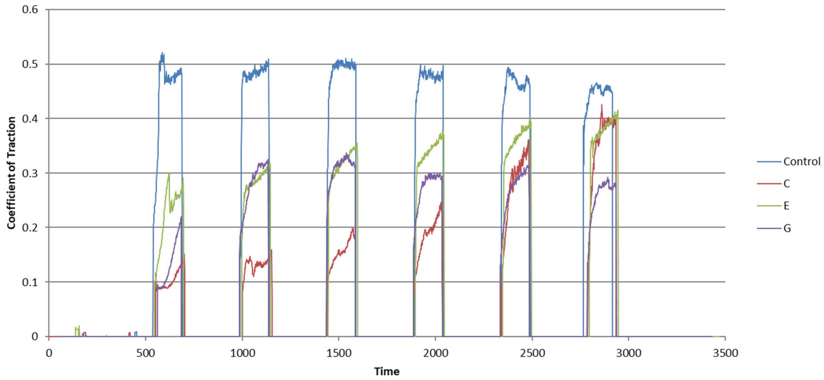

Figure 7. Comparison of wear test traction profiles.

Averaged results of the tests are given in Table 4 and then represented graphically in Figure 8. Product consumption is given as a volume, since this is more relevant to vehicle operators when considering maintenance costs.

Table 4. Average material loss during wear tests (brackets indicate number of successful repeat runs).

Average Mass Loss	Control (1)	C (4)	E (2)	G (1)
Rail (g)	4.430	0.152	0.388	0.467
Wheel (g)	5.426	0.198	0.358	0.443
Product (mg)	N/A	27.1	7.2	5.4
Product (mm^3)	N/A	0.0129	0.0038	0.0046

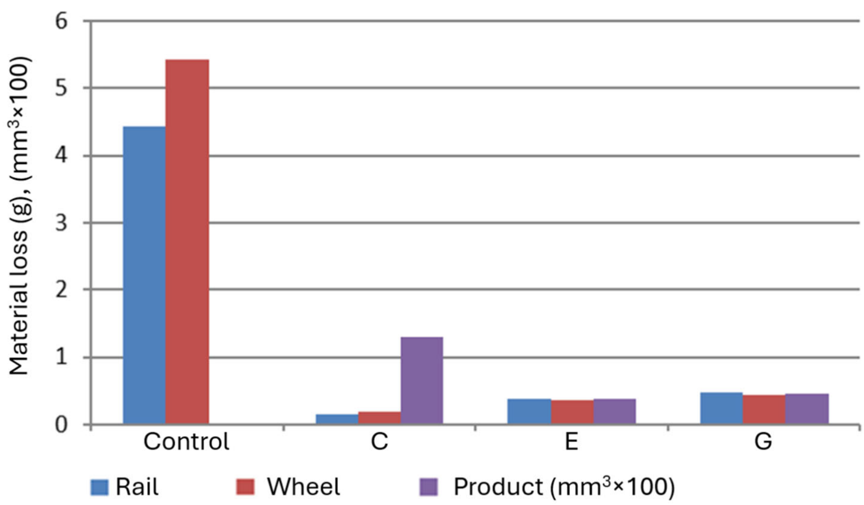

Figure 8. Material loss during wear tests.

During the wear test, the product is applied to the wheel disc before the wheel and rail discs are placed into contact; this will allow the product to transfer to the wheel disc only, unlike the retentivity test, where a layer will be built up on both discs. When the discs are placed into contact, the contact is more severe than the retentivity test (1500 MPa rather than 900 MPa), and the product layer established on the wheel disc will be disrupted as some of the material transfers across to the rail disc. The development of the product layer throughout the different phases of the wear methodology is illustrated in Figure 9.

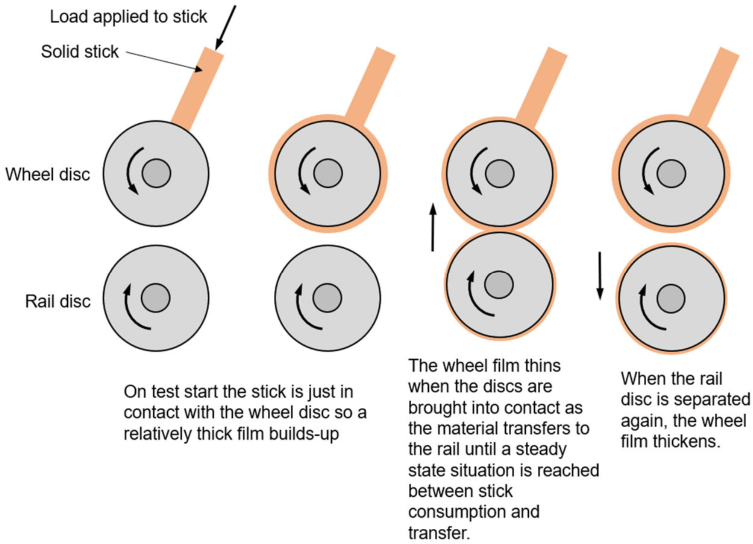

Figure 9. Illustration of product film thickness changes through the different phases of the wear methodology.

The results show that all the products reduce the material loss of wheel and rail material significantly from the control. Whilst no definitive coefficient of traction is given as a result of these tests, a comparison of the plots shows that the coefficient of traction during the wear test is significantly higher than the values recorded during the retentivity testing. This suggests that the products are not so effective at lubricating the contact under the more severe conditions; however, they do still perform a protective function for the wheel and rail material. Further investigations are needed to show what is happening to cause the rise in friction.

Product C performed best, reducing the material loss of wheel and rail materials to almost half that of the other products. Product C was also consumed the most during the test, however, so this would have to be considered in a purchasing decision.

The results from the retentivity tests show Product E as a poor-performing product failing to lubricate the interface at all, whereas results from the wear tests show Product E performing better than Product G in all measured parameters. This may suggest that the unrealistic nature of the retentivity test is unfairly favoring products that exhibit certain behavioral characteristics. For example, Product G may be capable of providing sustained protection under the higher-temperature conditions of the retentivity test, whereas Product E may be more protective under more representative occasional flanging conditions. The retentivity test gives the impression that Material G may not be transferring at all to the disc surfaces, but the wear test has shown that it must be, as it is protecting the surfaces well.

Further repeats of each test will be required for any sound conclusions to be drawn, but the results as they stand suggest that Product C performs the best, at the cost of a higher product consumption rate than the other two products. The results also suggest that 'better' results in the retentivity test (low coefficient of traction/high retentivity) do not necessarily mean better protection of the wheel and rail material.

There is very little comparative data in the literature on solid stick wear. Figure 10, however, shows a comparison with twin-disc data from tests where the rail disc was constantly in contact with the wheel disc [32,33]. The testing was also carried out at a relatively low level of slip (0.91%) in one test program [32] and at 1% and 5% for the other [33]; also, in this program, the rail material was more wear-resistant as R400 HT was used. This explains the much lower rail wear compared to the current study. The load applied to the stick and the stick materials were different for both. In all studies, the wear rate with a stick product applied was lower. However, differences in how the tests were run (see Figure 11 for an illustration of how the contact severity changes for each test considered in terms of $T\gamma/A$) mean that an in-depth comparison is not possible. This exemplifies the need for a standard wear test and, in particular, one that better represents reality. Moving the discs in and out of contact is a key aspect of this.

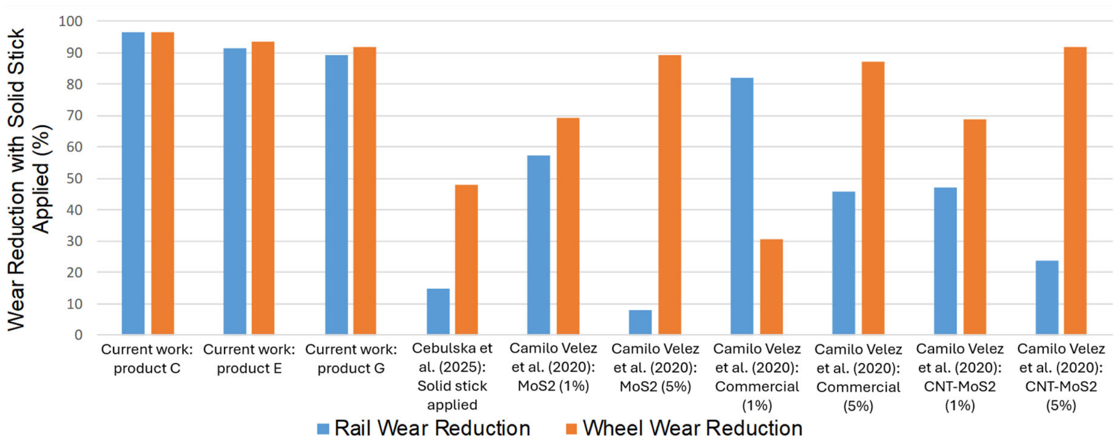

Figure 10. Comparison of wheel and rail wear reductions with solid stick products applied—current study compared with Cebulska et al. (2025) [32] and Camilo Velez et al. (2020) [33].

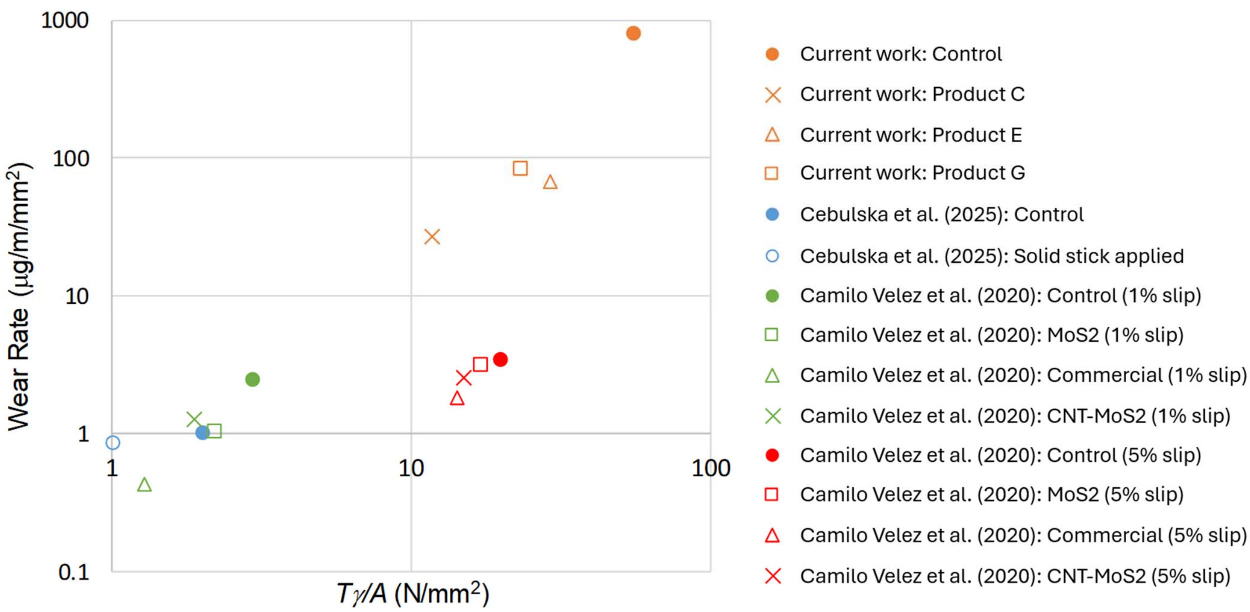

Figure 11. Comparison of wheel and rail wear rates for dry and solid stick conditions against $T\gamma/A$—current study compared with Cebulska et al. (2025) [32] and Camilo Velez et al. (2020) [33].

3.4. Drawbacks of Revised Testing

The retentivity test produces a value indicating the durability of the product film (retentivity value); this value allows the assessment of how well the film may protect other wheelsets not equipped with products; the wear methodology does not include an assessment of this. To resolve this, an additional test could be specified, running a clean wheel specimen against a rail specimen with a product layer formed under representative conditions (such as the wear methodology conditions).

3.5. The Effect of Specimen Temperature on Product Performance

For this investigation, both the retentivity tests and wear tests were performed with a flow of air cooling the discs. Cooling was specified because preliminary tests in the lead up to the retentivity testing showed that the tested product (Product C) performed best under cooled conditions. The hypothesis was that constant contact produced unrealistically high temperatures that burnt off the product layer formed.

During wear testing, the air flow was accidentally left off for one test of Product E (results excluded from previous analysis). The results of this particular run show a lower material loss from the wheel and rail, as well as a higher material consumption, suggesting that the lack of cooling better facilitated product transfer and therefore better lubrication of the interface between test discs. This result raises questions regarding the temperature of the product–wheel interface and whether cooling should be used during product testing.

Temperatures reach high levels during the constant contact of the retentivity testing, whereas temperature buildup is limited during the occasional contact of the wear test. Product layers may be burnt off during retentivity testing; for some products, this may occur even if cooling is used. During the wear testing, the lower temperatures reduce the likelihood of the product layers being burnt off, a possible reason why Product E performs very poorly in retentivity testing, but better using the wear methodology. With the reduced temperatures of the wear test, products may perform better without the cooling, if higher temperatures aid product transfer. Further work is required to determine a cooling arrangement as representative as possible of field conditions.

3.6. The Effect of Application Pressure on Product Performance

As specified in Section 2.2, the products are all applied with the application pressure used by one of the product manufacturers. It is possible that some of the products are better applied with a higher application pressure than the pressure applied for this study and, therefore, may have performed more favorably under different circumstances. For the solid stick products, it is expected that a higher application force will result in increased transfer of product to the specimen surface, a thicker product layer, and therefore, better performance lubricating the interface (at the cost of increased product consumption).

In order to investigate this possibility, the products that repeatedly failed to lower the friction below the dry threshold ($\mu \geq 0.4$) specified in EN 15427-2-1:2022 [22] were applied with significant additional pressure to observe the effect this had on lubrication. No scientific rigor was applied to this process; the additional pressure was applied by hand by the test operator once the 200 s of normal product application had been completed without achieving $\mu < 0.4$ (therefore, a retentivity test could not be performed). The resulting application pressure, whilst unquantifiable, was deemed to be many times that of the original application (as much as the operator physically could exert).

Figures 12–14 show that applying the products with additional pressure did improve the lubricating performance; however, none took the coefficient of friction below the $\mu \leq 0.15$ lubricated threshold. Product F, the worst-performing product under original test conditions, responded best to the additional pressure application, quickly lowering friction to a stable level (still $\mu \geq 0.15$). The layer was also the most stable once the additional pressure was released, but could not maintain the lower friction levels.

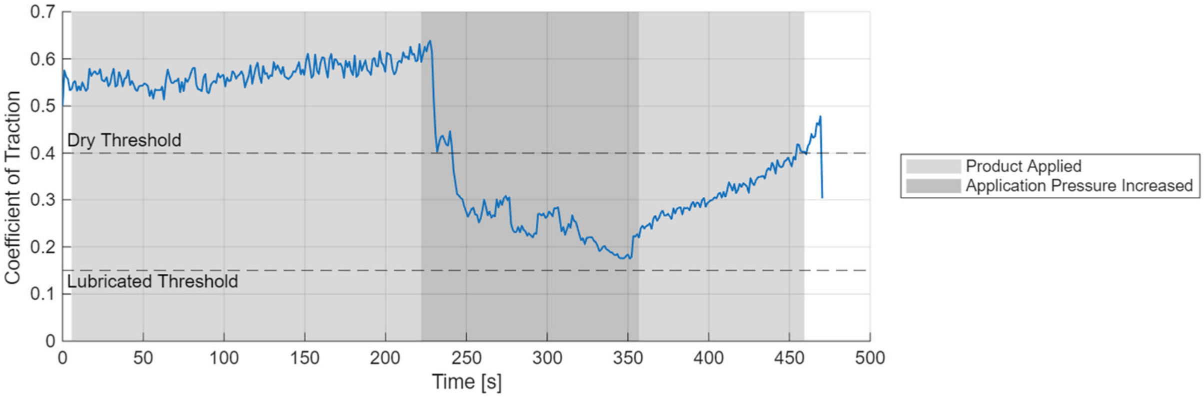

Figure 12. Effect of increasing application pressure (Product D).

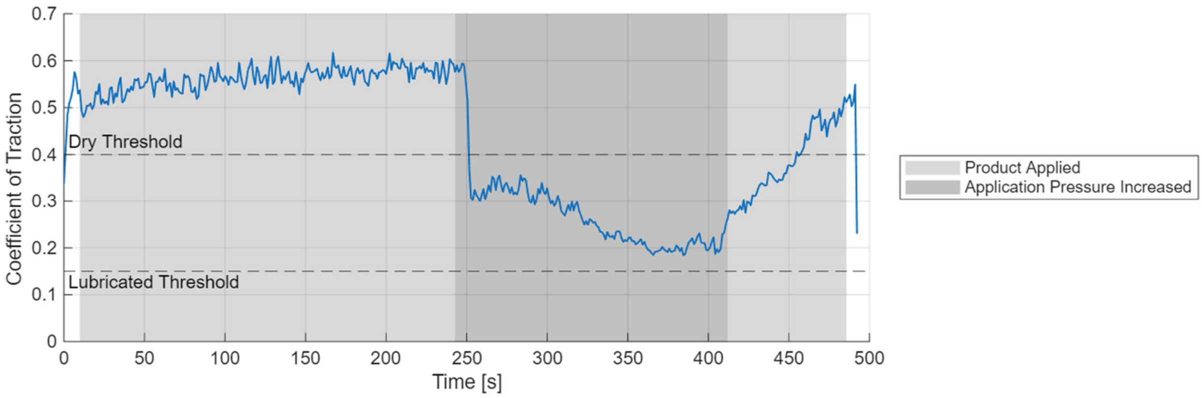

Figure 13. Effect of increasing application pressure (Product E).

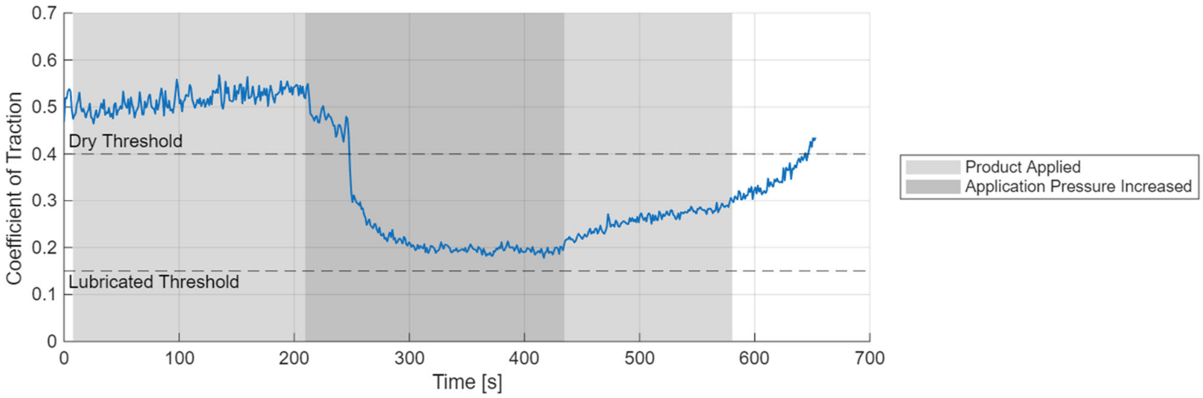

Figure 14. Effect of increasing application pressure (Product F).

4. Further Work

The purpose of this paper is to highlight the areas of improvement required for the procedure specified in EN 15427-2-1:2022 [22] and raise interest in revising the standard. Before recommending the wear methodology as the revised standard, the author recommends carrying out the whole test program again with the following changes:

Whole series:

- Run all trials at the manufacturer's recommended application pressure.
- Redesign of applicator to improve control of application pressure (mass/lever-based system).
- Perform all trials for all products included in the trial.
- Improve confidence in results:

- Run trials until a defined statistical certainty is reached (or maximum trial number, whichever is lower).
- At least three successful trials for each product.
- Record specimen roughness at the following times:
- Prior to the test.
- After the test (including product layer).
- After the test (with product layer cleaned off).

Revised tests:

- Ensure a full product layer has been built up.
- Consider a longer initial product application without specimens in contact.
- Consider a visual check of product layer integrity and product wear scars, prior to putting discs into contact.
- Consider an increase in the number of contact periods, from 6 to 10 (this may be impractical/dangerous for non-lubricated control runs).
- Include additional tests with a clean wheel specimen running against a treated rail specimen, and investigate the "retentivity" of the product.
- Define a method of quantifying friction coefficient values for the revised tests.

Retentivity tests:

- Ensure a full product layer has been built up prior to the retentivity phase of the test.
- Once the application period has been performed, pause the test with discs out of contact, and perform a visual check of the product layer and product wear scars before continuing to the retentivity phase.

5. Conclusions

The methodology defined in EN 15427-2-1:2022 [22] Annex H assesses the ability of a product to lubricate the interface under starvation conditions. This work trials a new methodology designed to assess how well products protect wheel and rail materials from wear, also using more severe contact conditions, closer to those typical of contact between the wheel flange and the rail gauge corner.

An assessment of eight solid stick flange lubricants performed according to EN 15427-2-1:2022 [22] Annex H suggests that only three out of eight products are capable of effectively lubricating flanging contact. The results from the newly developed methodology show that even some of the poor-performing products in terms of friction and retentivity may provide significant wear protection to the wheel and rail materials. This shows that the ability of a product to reduce wear under flange/gauge face contact is not necessarily linked to the performance of the product as assessed by the EN 15427-2-1:2022 [22] Annex H 'Starvation' test.

Further work is required before the new wear methodology can be specified as a replacement for EN 15427-2-1:2022 [22], but this work has shown there are significant improvements that could be made to the assessment of solid stick flange lubricants.

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