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Experimental Setup and Methodology for the Analysis of Rail Lubricant Effectiveness

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ABSTRACT

Rail and wheel wear is a complex problem. Lubrication plays an important role in reducing wear and enhancing asset life. Curves and switches are the areas of major challenges. Tight curves when running dry shows wear rates higher to rapid wear, increased maintenance costs and non-availability of track due to maintenance or replacement. The economic analysis based on cut-off radius, lubricants and applicators takes a very long time using field data.

Rail operators often face difficulties when selecting lubricants. Lubricant manufactures use different test standards when specifying lubricant properties. Four-ball test fails to give a meaningful indication of lubricant performance. The result is often a complex decision problem in ranking different lubricants under a particular axel load. An appropriate selection of lubricant for a particular rail application can give financial returns and extension of asset life.

An experimental set up has been proposed in this paper. The experimental results are expected to be used for development of models on effective lubrication. This paper proposes experimental setups and methodology for analysis of lubrication effectiveness in heavy haul lines. Theories along with existing research to date relating to ranking of lubricants for rail applications and a criterion for the ranking is discussed. An analysis is carried out to compare lubricants used in Australian Heavy Haul lines based on manufacturer supplied specifications and experimental results

Keywords: Wheel-Rail Lubrication, Lubricant Performance

1. INTRODUCTION

Ever since the invention of the rail, the wear of rail and wheel has been a major issue in the railway industry. With the developments of high speed trains and heavier axel loads it has become an area of greater importance than ever before. The developments of higher grades of steels, head hardened rails and advanced rail lubricants, there is significant improvement in this area however mechanism of wear is still not fully researched well.

Wear can be studied from many different perspectives. From a solid mechanics perspective the rail wheel imposes a cyclic load on the rail. Depending on this wheel load, stress, contact stress distribution, subsurface stress, Plastic deformation and fatigue crack initiation and propagation, known as rolling contact fatigue (RCF) may occur (R. Enblom, 2004).

From a Tribological Perspective, different wear mechanism may be presented to a particular slip condition, loading and lubrication. No matter which perspective one looks at, the end result is the same where there is material lost on both surfaces in contact. This may be in different proportions and can be in the form of just plain wear or an extreme case of shelling and spalling.

Field experience has shown that tighter radius curves have a higher rate of wear compared to larger radius curves or straight tracks. Tracks that are not monitored for an extended period of time have a higher risk of rail failure due to wear limits and or rail breaks leading to derailments. A derailment can lead to service disruptions for an extended period of time, leading to compensation claims and loss of profit. Where rail corridors are shared with freight, coal and passenger networks, this would have a significant impact.

Currently provided technical datasheets by rail curve lubricant manufacturers specify the physical properties and characteristic of the grease. Lubricant manufactures often use different test standards making it difficult to compare lubricant. They do not give information about field performance of the grease. From the lubricant manufacturers perspective these standard test methods would be adequate. From the end users perspective it is impossible to deduce which grease would perform better in field. The four ball test only gives an indication of the extreme pressure additive in the lubricant. The weld load test conditions are also too extreme for this application.

The effectiveness of a rail curve lubricant is dependent on several factors which include track layout and condition, Traffic type and Density, Characteristic of the lubricant used and the application system (Mutton et. al., 1990).

A rail operator's decision to select a particular lubricant is entirely based on physical properties from lubrication technical data, cost and previous field experiences. Rail operator selects a lubricant from a range of manufactures and need to rank these in order of effectiveness.

ASTM Standard D2596-97 and its equivalent IP239 give an indication of the measure of the properties of the EP additive. Standards often ask users to determine whether results of these test methods correlate with field performance or other bench tests.

Field testing of lubricants can be complex and very expensive. Clean up of rail, wayside lubricators and rail wheels to avoid cross contamination between different greases during tests are extremely important. A fields test can have large number of variables that affect the results. These variables include different rail and wheel profile, range of applicators, environmental factors, axel loads and track geometry are just some common variables.

2. BACKGROUND

Rail Lubrication can be classified into two areas.

1. Gage face lubrication
2. Rail Head friction modification

Gauge face lubrication is where a lubricant is applied on the gauge face of the rail to reduce friction. Friction modification is where a product is applied to top of the rail to maintain a certain level of friction. Gauge face lubrication is considered in this paper.

Lubrication Methods

Trackside Lubrication – Also known as wayside lubrication is where a pot of grease is connected to a set of applicator plates which are fixed to the rail by clamping or bolting. When the wheel passes over the plunger it dispenses a fixed quantity of grease along the applicator plates. The passing wheels collect the grease on the wheel flange and transport it to the gauge face on the rail curve for other wheels to pickup and this helps to carry lubricant over the curve.

There are many variations to this system of lubrication with mechanical, electrically and hydraulically controlled.

On Board Lubrication – Also known as trainborne Lubrication. This is where a lubrication system installed on the locomotive applies grease directly to the wheel flange. The lubricant is transported by rail gage face and wheel flange face contact.

High Rail Lubrication – A dedicated Vehicle equipped with a lubrication system applies lubricant directly to the gage face of the rail as it travels along the rail. This method is not suitable for very high traffic rail corridors.

The aim of any rail wear test rig is to replicate the contact condition in a controlled laboratory environment. George Plint (1995) has explained the purpose in Laboratory testing and differentiated between simulate and emulate. To fully understand the mechanism of interaction of rail and wheel requires the knowledge of the contact mechanics.

A rail wheel contact can be split into two divisions being the stick and slip region. The term slip is generally referred to gross slip where there is no adhesion or stick. This slip occurs in the trailing region of the contact giving rise to the tangential forces and longitudinal creep. This slip region grows from increase of tangential forces. This decreases the stick region on the contact. At a saturation point the stick region disappears and the contact is in pure sliding.

The work of Johnson (1985) on micro-slip and longitudinal creep, this is as a result of surface strain that is caused by normal and tangential forces on the contact. (equation 1.)

$$\xi_x = -\frac{\mu a}{R}\left\{1-\left(1-\frac{Q_N}{\mu P}\right)^{1/2}\right\} \tag{1}$$

Where:

ξ_x = creep Ratio,

Q_N = Tractive force

R = effective contact radius

μ = Coefficient of friction

a = Half ellipse diameter - direction of travel

P = normal force.

Further more Johnson has defined the limits for micro-slip being:

$$\frac{\xi_x R}{\mu a} < 1 \tag{2}$$

$$\frac{Q_x}{\mu P} < 1 \tag{3}$$

This is illustrated FIGURE 1. It is classed as similar to tractive rolling of elastic cylinders. (Carter, 1926)

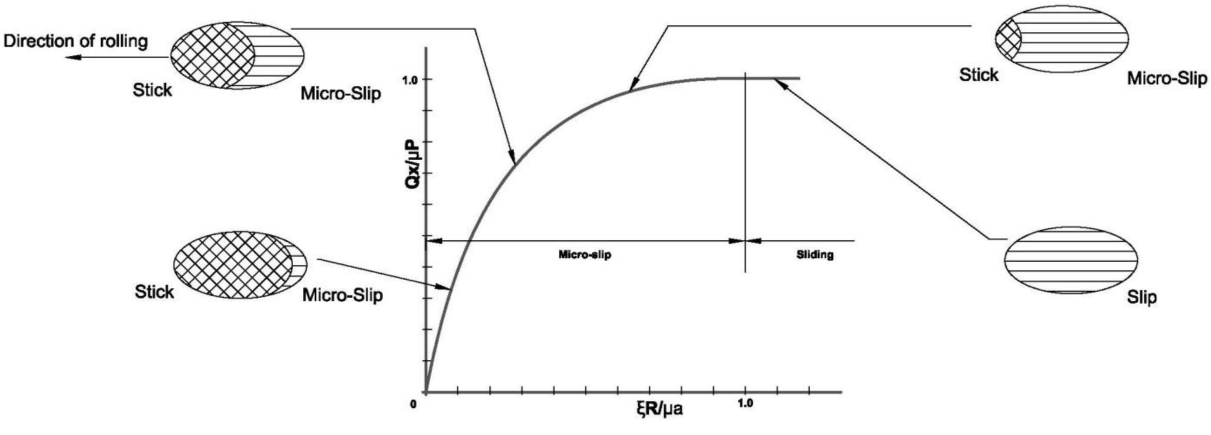

FIGURE 1. Creep curve with stick-slip regions at different parts of the curve. (Johnson, 1985, IHHA, 2001)

On high friction condition where $Q/\mu P$ is small, the slip region on the trailing edge starts to diminish extremely. On the other hand with high values of $Q/\mu P$ the contact is largely composed of slip region.

When this is considered in relationship to an actual wheel rail contact there are two distinct regions in which there is contact between the two surfaces. First is at the gauge flange. This is a pure sliding motion in which there is no stick at all and this contact is often quite large the contact at the top of the rail and at the gauge corner. Second is at the gauge corner and top of the rail. Both of these regions operate in a stick slip. As the rail lubricant is not applied on top of the rail it is not discussed. The gauge corner is usually the point of maximum stress and is usually the area that suffers the maximum stress. These conditions in the rail wheel fall into the boundary lubrication regime.

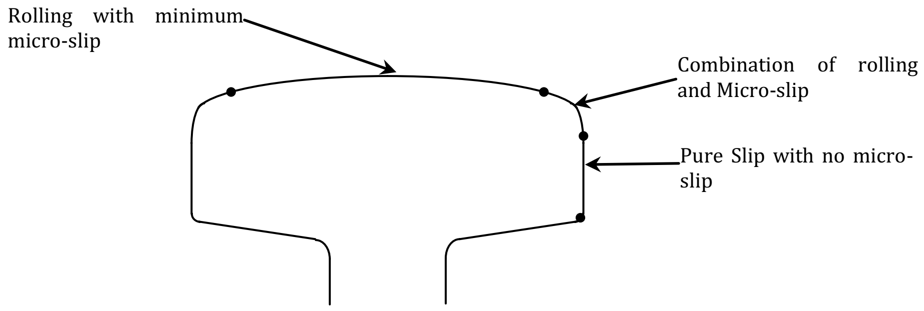

FIGURE 2. Rail head showing different stick slip mechanism.

3. EXPERIMENTAL SETUP

There are several friction and wear testing machines that have been developed to characterise the extreme pressure properties and wear performance properties of lubricants. These tests often provide a single value and do not often reproduce boundary lubrication conditions that exist in rail wheel interface. Therefore these tests are not realistic for the purpose of rail curve lubricant ranking.

Furthermore the criterion used by the rail industry to decide weather a rail is lubricated or not is based on the coefficient of friction. A coefficient of friction of between 0.25 and 0.30 is regarded as acceptable. A coefficient of friction greater then this is regarded as poor or a dry rail. Coefficient of friction between 0.15 to 0.25 is regarded as good to acceptable (Frohling R, De KOKer J et al. 2009). Therefore it would be beneficial to have a ranking based on this field experience.

It is proposed in this paper to use three different tests in combination to rank and compare these lubricants. These include the Cameron & Plint, twin-disc and the viscometer.

3.1 Cameron & Plint

The Cameron & Plint is a high frequency friction machine designed for the rapid assessment of lubricant performance by Cameron-Plint Tribology Ltd. It is a reciprocating friction and wear tester that permits dry or lubricated tests at room temperature or with heated lubricants. Various contact geometries, including ring / linear-contact, can be used with this apparatus. The contacting surfaces may also be heated to an elevated temperature to test performance and wear at such temperatures. One of the key advantages is that the material sample may be cut out from the actual rail wheel and rail and used in the test.

Once the samples are set up, a fixed quantity of grease is applied to the surface. The quantity of lubricant is critical and the test duration will depend on this. If a large quantity of lubricant is placed on the contacting surface then the test would run for an extremely long duration with very small change in the coefficient of friction. This is due to the lubricant film being maintained between the contacting surfaces. Once this lubricant film starts to degrade there would be an increase in and a fluctuation in the coefficient of friction. To control the runtimes it would be necessary to use small quantities so that there is lubricant starvation after a certain number of test runs. Extremely low runtimes would yield small wear which would be difficult to measure and quantify. Therefore it is critical to have a balance between runtimes and quantity of lubricant. It is critical that consistency is maintained so that different lubricants can be compared properly and repeatability is ensured.

The quantity of lubricant in the trials was maintained by use of a plastic stencil where by excessive grease was wiped off leaving a fixed quantity. To validate this method each sample were weighed and these were consistent.

FIGURE 3. The Cameron and Plint apparatus used.

3.2 Twin Disc

The twin disc apparatus consists of two rotating discs. Each disc is on a separate shaft and can be controlled individually at different speeds. This is to control the slip. The discs contact each other on the curved side under load. A fixed amount of grease is smeared on the surface at the interface between the two discs. Initially the discs are started with no load and at a low speed and then speed is increased to the test speed. This will smear the grease evenly to the disc surface. This may lead to some grease being flung off the surface thus reducing the amount of grease on the surface. The apparatus is then run at a load not exceeding 500Mpa in order to prevent the material be work hardened which would change mechanical and wear properties of the disc. This test will emulate the contact at the gauge corner of the rail where the contact is in stick and slip motion. The test can be run until a coefficient of friction is reached to a level of 0.25 or when there is a metal to metal contact, which ever comes first.

Microscopic examination is proposed to determine if any rolling contact fatigue has taken place on the surface. As with Cameron and Plint the quantity of grease applied has to be consistent throughout all tests and consistency is to be maintained in cleaning of samples for weighing and capturing wear loss.

3.3 Rheology

The cone and plate Viscometer is proposed for rheological properties of the grease by exerting the grease in the state of yield stress and the shear thinning behaviour. This provides some indication of the transport characteristic of the grease. The test can be based on appropriate ASTM or IP test standard.

This test provides a direct rheological determination of the yield stress value, preferably within a period that correlates to practical use of lubricating greases. The yield stress, used as a engineering value, is a value that is specific for certain types of materials and can be used for the selection of the right product for a given application by itself or, more likely, in combination with other engineering values

There are many types of viscometers available for this test such as the cone and plate, Plate and plate. Cone and plate is proposed for this test.

4. RESULT AND DISCUSSION

Initial tests on the Cameron and Plint were carried out in order to determine the repeatability of the tests and to determine the run times and load conditions. This has shown a very good repeatability as often in tribological test it is very difficult to get a good repeatability.

In this test the material surface that was used for sliding was the rolling elements in the bearings. This is made of hard bearing steel. The rolling elements were selected for multiple reasons. They are cheaply and readily available. Being rolling elements in bearings they are machined and ground to a high precision. Using this material would mean that the initial wear in state will have low amount of wear debris that have broken of in this phase. Having large concentration of wear debris would make the grease work like a grinding paste.

A normal force of 150N was applied to generate a contact stress of approximately 550MPa. This would be a similar contact stress experienced at the gauge face contact.

TABLE 1. Lubricant tested with the properties.

Property	**A1/A2**	**B1**	**B2**
Colour	Grey	Greyish Black	Dark Gray, tacky
Lubricating Solid	Molybdenum Disulphide	Graphite	Molybdenum Disulphide
Thickener	Lithium	Lithium	Lithium 6%
NLGI Classification	2	1	2
Base Oil	Mineral Oil	Mineral Oil	Mineral Oil
Base oil Viscosity	680	150	220

The Lubricants used for the test were all petroleum mineral oil based and were sourced from Australia and North America. These were taken from a standard production batch.

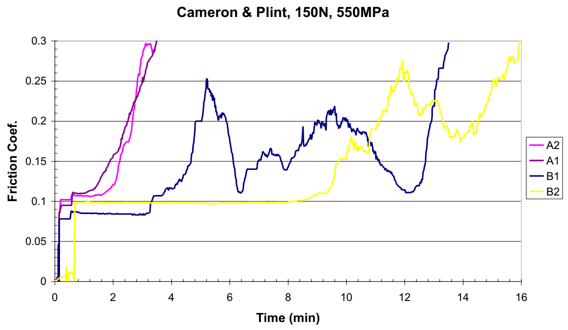

FIGURE 4. Cameron and Plint wear test with two different lubricants.

Lubricant A in the above test maintains a contact film for a very small duration of time compared to lubricant B. The two different trials of lubricants B show that it is able to maintain a coefficient of friction of approximately 0.1 for a much longer duration of time. There is a variation in the between B1 and B2. This is due to a slightly larger quantity of grease used in this run. Having a larger amount of grease at the interface means it takes longer for the lubricant to reach a starvation state.

Field trials which were conducted correspond to the research findings with these tests conducted. For the field trials a lubricator was setup on a dry track and run with the lubricant. The coefficient of friction was measured on the gauge corner and gauge face and these were recorded with respect to distance travelled from the lubricator.

As this work is ongoing more tests are currently underway and results would be presented in the future as they become available.

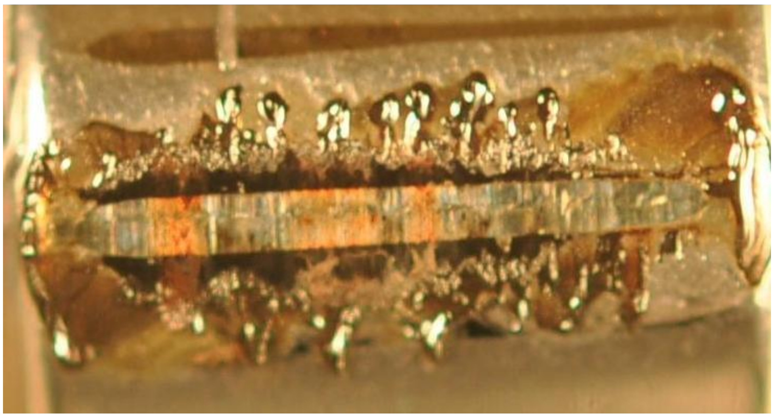

FIGURE 5. The material specimen showing the worn portion in 16 minutes.

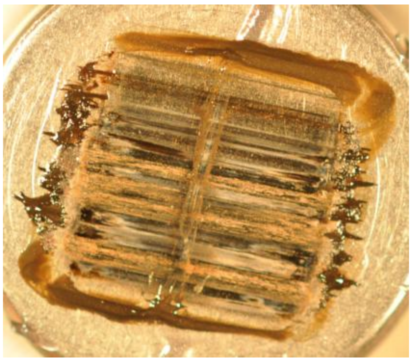

FIGURE 6. Corresponding wear scar for the contact interface

5. CONCLUSION

Selection of rail curve lubricant is extremely complex and can require extensive field trials. This is difficult and expensive for rail operators. Lubricant manufactures often change the formulation of the lubricant without assessing impact or extensive trials. The Proposed tests and methodology for the ranking of lubricant is proposed and initial experiments have been conducted which show repeatability in the tests. These tests also correlate with field trials. Authors are currently working on best practice of rail curve lubrication and results will be reported in future publications.

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