EXTENT OF ADHESION LOSSES IN THE WHEEL-RAIL CONTACT UNDER CONTAMINATED CONDITIONS

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ABSTRACT

Railway vehicles require a certain level of adhesion between wheel and rail to operate efficiently, reliably, and economically. Different levels of adhesion are needed depending on the vehicle running conditions. In the wheel tread-railhead contact, the dominant problem is low adhesion, as low adhesion on the railhead negatively affects railway operation. On one hand, the vehicle will lose traction resulting in delay when driving on low-adhesion tracks and on the other, low adhesion during deceleration will extend the braking distance, which is a safety issue.

This research work examines the influence of the contaminants, i.e., water, mud, leaves, oil and grease, with a twin disc machine which is designed and constructed as part of this study to simulate wheel tread-railhead contact. Thus, the research methodology is a laboratory test without and with the different contaminants aimed at studying the extent of adhesion coefficients of each contaminant over the range of slip values 0 to 10% and comparing which of them are the worst to cause loss of adhesion. As the lab results revealed, oil, grease and water have been found to cause less adhesions than leaves. Unlike the research made justifying leaves, they were found the worst in causing adhesion losses.

Keywords: Wheel tread, railhead contact, contaminants, adhesion, slip, twin disc and breaking distance.

INTRODUCTION

Since the beginning of railway transportation, wheel-rail adhesion has been limiting the acceleration and deceleration capabilities of rolling stocks. Sliding and slipping have always been major problems in the railway industry due to the low friction between wheel and rail especially when contaminants interfere in-between the mating wheel and rail. With increased speed, power and complexity of the modern railway vehicle, sliding and slipping phenomena have been seen to increase abruptly. In recent decades, special attention has been paid to the limitations in adhesion due to the requirement for a more rapid, reliable and denser railway transportation that can satisfy the increasing demand on public transportation.

As railway transportation is still characterized by steel wheels and steel rails operating on open system, the wheel-rail contact remains easily contaminated by water, leaves, grease, mud, etc. causing railways to suffer from lower adhesion problems. Thus, to run the vehicles efficiently and economically, the wheel-rail adhesion should be maintained at a certain level.

Adhesion losses can also affect vehicles' performances because the vehicles will lose traction when driving on low-adhesion track. Moreover, low-adhesion is also a safety issue, since poor adhesion when decelerating will extend braking distance [1]. According to Yi Zhu [1] Netherland's railway transportation maximum adhesion requirements are classified as type of vehicle, running speed, type of contaminants and amount of load per axle.

The main objective of this paper is to investigate the effects of contaminants that cause adhesion losses and acquire a better understanding of the adhesion reduction mechanism of the contaminants in consideration. Contaminants such as water, rust, dust or mud, oil or grease leaking from lubrications and track-side leaves are considered in this work.

Adhesion Force and adhesion coefficient

A general scientific definition of the adhesive force is the force of attachment between two contacting objects. If this definition is translated into a railway definition as briefly described in [4], it will be the ability of the wheel to exert the maximum traction force on the rail and still maintain persistence of contact without exceeding the optimal slip. Thus, adhesion is the amount of force available between the rail and the wheel. Therefore, one can say that the adhesive force is a result of friction between the surface and the normal force on the mating surface. .Furthermore, the friction force is a resistance of motion, and as such an undesirable effect, while adhesion is a coupling force and therefore something desirable [1, 2, 4 and 10] but mostly be affected by contaminants which are also considered in this research.

LITERATURE REVIEW

Wheel-rail contact conditions

Unlike road vehicles, such as the automobile, railway vehicles have some unique behaviors and properties, such as hunting motion, self-steering capability, and lateral dynamics. These unique features originate from the wheel-rail guidance system depending on wheel and rail geometry. First, the rail has a specific profile [1, 2, 3], governed by rules, and is mounted at a small inwards inclination (1:30 in Sweden) (indicated by no. 3 in Fig. 1) for better fit to the wheel profile and better load transfer to the sleepers and ballast. Second, the wheel is of a special design, including a wheel tread (where contact point 1 is located on the wheel in Fig. 1) and wheel flange (where contact point 2 is located on the wheel in Fig. 1). Moreover, the wheel profiles are usually conical (indicated by no. 4 in Fig.1), leading to the difference in rolling radius in a curve for the two wheels in the same wheel set. Compared with tire-road interaction, the wheel-rail contact is very small at approximately 1 cm^2 [5]. As a result, the heavy axle load is transferred through a small patch generating high contact pressure.

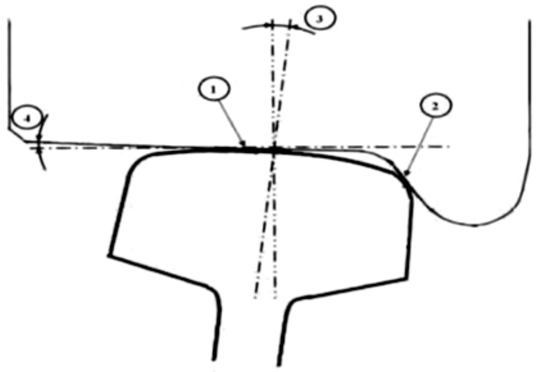


Figure 1 Schematic of two types of wheel-rail contact: 1. wheel tread-railhead contact and 2 Wheel flange–rail gauge contact; 3 rail inclination; 4. conical wheel profile [1, 2]

Due to the above-mentioned factors, the wheel-rail contact area changes when running under different conditions. Generally, when the vehicle is running on a straight track, the contact area is usually between the wheel tread and railhead, as shown by contact point 1 in Fig. 1. Thus, in this research, the test rigs were made to have 1 cm width to simulate the railhead-wheel tread contact.

Causes of low adhesion

Based on the literatures reviewed, adhesion losses were seen as serious incidents of accidents and, most of the time, are caused by the different contaminants as in [3, 8, and 21]

- Light rain or drizzle, dew, snow, ice on the rail, generally due to humidity; and crashed damp leaves,
- Damp rust,
- Solid particles like rust or coal dust,
- Spilled diesel fuel, lubricating oil from vehicles, leaking hydraulic fluid from track machines, oil/grease from defective rail mounted flange lubricators
- Chemicals from washing or near industrial sites.

These conditions are often combined with weather conditions such as air and ground temperature, relative humidity and atmospheric pressure, which are difficult to predict. Measurements of adhesion, however, although not perfect, can give some prediction or indication of low adhesion sites.

Contamination of contact surface

As a rolling-sliding contact, a wheel-rail contact is similar to a rolling ball bearing or gears [13, 14], though these are mostly closed systems with comparatively good lubricating conditions. The wheel-rail contact is an open system, which makes it extremely difficult to transfer knowledge from other well-studied but closed systems. For example, the friction coefficient on the railhead is high on a sunny day but decreases on a rainy day. Even on a sunny day, the friction coefficient can differ depending on the humidity and temperature. In addition, foreign substances, such as sand, dust, leaves, oil or grease, can also be present on the rail. All these factors will influence the friction coefficient/adhesion coefficient, resulting in excessive or insufficient wheel-rail adhesion.

Table 1 shows the friction coefficient measured using a hand-push tribometer in [2, 10] and even though other current rail adhesion measurement methods exist as discussed in [11]. The friction coefficient varies depending on the conditions, and is generally reduced by water, oil/grease, and wet leaves as discussed in [2, 1, 10, 6, 3, and 12]. Moreover, temperature and humidity can also change the friction coefficient [4, 8]. A typical available friction, i.e., adhesion coefficient, is seen under various conditions in Table 1.

Table 1 Friction coefficients measured on metro lines using a hand-pushed tribometer [1].

Conditions	Temperatures	Friction coefficients
Sunshine ,Dry Rail	19	0.6-0.7
Recent Rain on rail	5	0.2-0.5
A lot of grease on rail	8	0.05-0.1
Damp Leaf film on rail	8	0.05-0.1

For the steel-steel contact under dry, clean conditions, the coefficient of friction is approximately 0.6, which obviously fulfils all adhesion requirements. However, the wheel-rail interface is an open system, meaning that contaminants can enter as the third-body layer between the bulk materials in the wheel-rail contact as shown in **Fig. 2** and affect the friction levels, making the wheel-rail adhesion too high or too low.

Contamination can be divided into solid contamination, such as sand, dust, leaves, and debris, and liquid contamination, such as water, oil or grease as discussed in [8]. Liquid contaminants and leaves can reduce adhesion, especially when the rolling speed is increasing. Dust or debris could reduce the adhesion by mixing with liquids [2, 10]. As a result, the dominant problem is too low adhesion in the wheel tread-railhead contact. This work focuses mainly on low adhesion in the wheel tread-rail head contact caused by water, oil, grease, mud and leaf-formed blackish layer on the wheel tread and rail head.

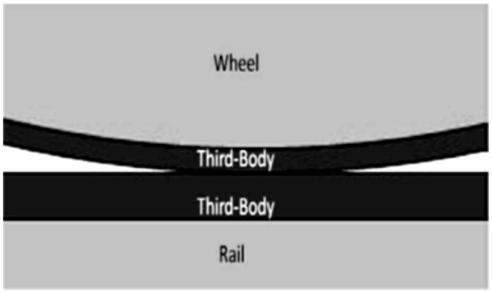


Figure 2 The third-body layer between the bulk materials in the wheel-rail contact [1]

Twin-disc Test Apparatus

There are two main types of laboratory test rigs detailed in [3, 7, 12, 13, 15, 16,17,19,20 and 22]; the full size wheel-on-rail test rig and twin disc machines as described below. In addition, there are a number of similar devices that may be useful for simulating low adhesion conditions:

- Independently motor controlled twin disc machine (Sheffield University)
- 1/3 scale twin disc machine (Manchester Metropolitan University)
- 1/5 scale roller rig (Manchester Metropolitan University)
- Pin-on-disc machine.

The twin disc machine which is described by Kenza Ikoubel [12] is connected to a computer where the “tribosoft” software can be started. The software consists of two windows (Measurement and Setup). The setup window allows the change of the test parameters. The diameter of the test samples, the suited load, the desired velocity in rpm or m/s are inserted. When the rolling option is selected, both discs rotate at the same speed. It is possible to select a slip percentage or to enter directly the velocity of the 2nd disk if the gliding option is selected. The software makes a file of each current test. Once the modules are confirmed, the machine is set up. The machine is mainly composed of two servo-motors, a torque transducer, load counterweights, a thermo-couple, an oil pump and two samples rolling against each other. Each of them is driven by a motor [12].

Twin disc machines of Amsler machine [16] are commonly used as research tools by industry and academia and provide a laboratory method of testing for friction, wear and lubrication. These machines use discs of approximately 40 mm diameter and can be loaded to reproduce wheel/rail maximum contact pressures.

Parameters in lab test with twin disc test machine

As to Oscar Arias-Cuevas, Lewis and Gallardo-Hernandez [3, 17], the slip ratio between the discs was prescribed by setting different rotational speed of the shafts and maintained constant throughout each test with a controller. The slip ratio is defined in Eq.1 where ω and r are the rotational speed and rolling radius of the discs, respectively. The adhesion coefficient was calculated with the readings of the torque transducer and the load cell T and F_N respectively as in Eq. 2.

$$Slip = \frac{\omega_{wheel} * r_{wheel} - w_{rail} r_{rail}}{\omega_{wheel} * r_{wheel} + \omega_{rail} r_{rail}} * 200\% \qquad (1)$$

$$= \frac{V^{rel}}{V^{mean}}$$

Where V^{rel} relative velocity and V^{mean} mean velocity of the two discs

$$\mu_{adhesion} = \frac{T}{F_N * r_{rail}} \qquad (2)$$

Where $\mu_{adhesion}$ adhesion coefficient, F_N applied force read from force cell and T torque read from torque transducer.

Specimen/Test Discs

In many research works, discs to be used during the testing were cut from R8T wheel rims and UIC60 900A rail sections or close to this European standard and machined to a diameter of 47mm with a contact width of 10 mm. The contact surfaces were ground to a roughness of 1 micron as indicated in [7]. As discussed by [1, 2 and 7] rail material designated by UIC 900A in Table 2 does have a hardness of 300 HB and a minimum tensile strength of 863 N/mm^2. R7 wheel material is a little softer, in the hardness range of 229–277 HB, with tensile strength in the range of 730–890 N/mm2. Wheel specimens were drawn from the wheel rim parallel and as close as possible to the outer surface as discussed in [3, 8, 17].

EXPERIMENTAL INVESTIGTIONS

Material of the Test Rigs/Specimen

As investigated in different literature, there are several wheel and rail standards and are closely similar in their properties. In all standards wheel steel material is a little softer than that of the rail differing slightly in the amounts of carbon, silica, and manganese in the steels used. For Addis Ababa light rail train (AA LRT), the rail standard used is Chinese National Railways standard. Materials chosen to represent this standard as depicted in Table 3 the chemical compositions and Table 4 mechanical property of wheel and rail specimens.

Feature and Dimension of the test rigs/Specimen

As discussed in most research papers, the maximum outer diameter of the specimens are limited by the maximum diameter that can be extracted from the section of the rail head; the contact width being 10 mm to represent the wheel thread and rail top contact. Unfortunately, the unavailability of plasma cutting machine to cut from rim of the wheel was a must finding an alternative way of preparing the specimens with material composition close to the standard wheel rail material which was chosen CSN 12051(in Czech standard) for wheel disc and CSN 12071 for rail as depicted in Table 3.

The dimensions were modified as in **Figure 4** because no dimension limitation as it would have been taken from the rail section. As the name implies, Twin Discs, both the wheel disc and the rail disc have the same dimensions and shape. The effective diameter of both rigs were made 100 mm while the contact width is made 10 mm to represent the contact width of the wheel thread and rail top.

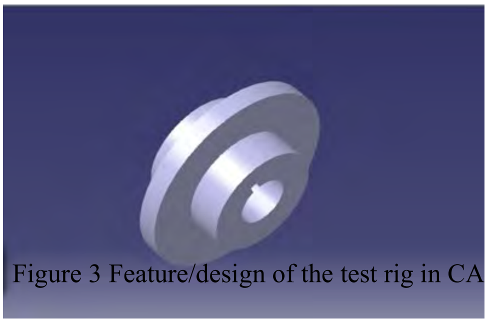


Figure 3 Feature/design of the test rig in CATIA V5.

Table 2 Wheel and rail material composition from Yi Zhu [1, 2]

Chemical composition (wt. %)	C	Si	Mn	P	Ni	Cr
UIC60 900A rail	0.6-0.8	0.15-0.5	0.8-1.3			
R7 wheel	0.52	0.4	0.8	0.035	0.3	0.3

Table 3 Materials selected for the wheel and rail rigs/specimen

Chemical composition (wt. %)	C	Si	Mn	P	Ni	Cr
CSN 12071(rail) (AISI/SAE 1070	0.6-0.7	0.37	0.6-,8			
CSN 12051(wheel) (AISI/SAE 1050	0.47-.55	0.17-0.37	0.5-0.8	0.035	0.3	0.25

Table 4 Mechanical properties of the selected materials for both the wheel and rail disc samples

Material Type	Brunel hardness (HRC)	Yield strength (M Pa)	Tensile strength (M Pa)
CSN 12051(wheel) (AISI/SAE 1050)	270-286 (28-30)	460	700-850
CSN 12071(rail) (AISI/SAE 1070)	282-330 (30-35)	470	750-900

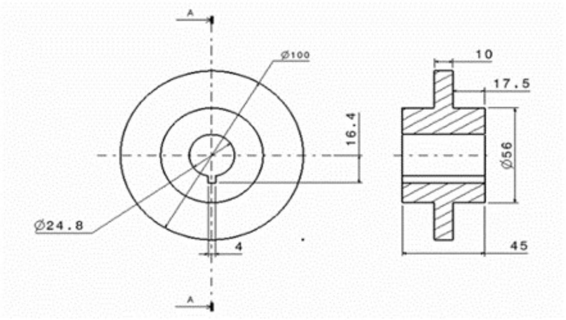


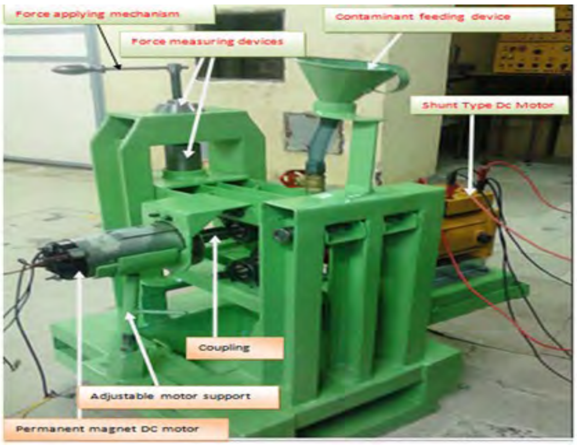
Figure 4 Dimension of the Test rig

Figure 5 Photograph of test rigs manufactured for this work

Twin disc Test Machine

The machine used to investigate the extent of adhesion loss due to the different contaminants is a twin disc machine. This machine is designed and constructed here as part of this work as shown in **Figure 6**. Two independent motors (shunt type with capacity of 0.3 KW and Permanent magnet DC motor with 2.65 HP) each of which is capable of transmitting the torque to couple the twin discs each other so as to rotate them to the required speed creating an intended slip velocities. A speed is read with a speed sensing speedometer and torque is calculated from the armature voltage and current read from the ammeter and voltmeter respectively at each application of the contaminant.

Figure 6 Constructed Twin disc Machine



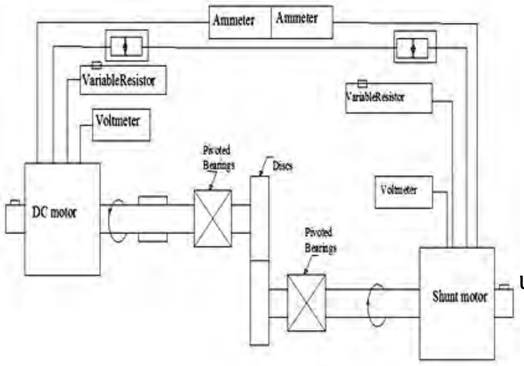
Test Set-up and Conditions

The adhesion test was carried out under the conditions of different wheel/rail contacts, such as various speeds of the wheel disc while rail disc made constant throughout the tests, contact load of 400 N at dry and contamination situation (water, mud, leaves, oil and grease.). In order to generate slip, we adapt a method by presetting the two motors' speeds which the rotation speed of the braking motor .

In order to generate slip, we adapt a method by presetting the two motors' speeds which the rotation speed of the braking motor i.e. the rail disc motor made 400 rpm throughout while wheel disc motor speeds are varied from 400 rpm to 442 rpm so as to create slip values of 0 to 10% calculated from Eq.3.3, In this process, the torques induced were calculated as in Eq. 3.1 from the armature voltage and armature current of the motors read form the voltmeter and ammeterat loaded-state. So that all data: speed, voltage and current were taken from the shunt type motor to calculate the torques to corresponding slips of 0 to 10% at each contaminant application. The Schematic representation of the setup is shown in Figure 7 and the apparatus as shown in Figure 8 includes vacuum cleaner to prevent the environmental chamber clogging. For determination of adhesion coefficients at each application of the contaminant, the friction characteristics of contact bodies should be considered by taking into account the roll mode with a slip parameters considered in calculating adhesion coefficients:

- Normal contact load of 400 N due to the applied load of 120 N through the T-bolt beneath with force measuring mechanism;
- Dimensions of each wheel roller is 100 mm as depicted in Figure 4;
- The wheel disc is a little softer than the rail disc to represent the real situation of wheel-rail contact
- Angular speeds of the wheel roller were preset 400 to 442 rpm so as to create slip value/relative slips of 0 to 10% respectively;
- Torques due to the influences of the contaminants could have been read directly from a torque transducers had it been fitted on the shaft of the motor but it was calculated from the induced armature voltages and currents and the corresponding, rotational speeds as in Eq. 1.

$$T_i = \frac{60(E_a I_a)_i}{2\pi N_i} \tag{1}$$



up

$$= \frac{9.55(E_a I_a)_i}{N_i}$$

Where T_i, E_a, I_a and N_i are Torques, armature voltage, armature current and rotational speed from 0 to 10% slips at each contaminant application respectively.

- The corresponding adhesion coefficients are calculated as in Eq. 2.

$$\mu_i = \frac{T_i}{T_{const}} \tag{2}$$

Where μ_i and T_{const} are adhesion coefficients at each slip values and constant toque due to the applied load respectively.

- Preset slip values are calculated with formula [Eq. 3] below.

$$Slip = \frac{\omega_{wheel} * r_{wheel} - w_{rail} r_{rail}}{\omega_{wheel} * r_{wheel} + \omega_{rail} r_{rail}} * 200\% \tag{3}$$

Figure 8 Photo-

graph of the set-up

Tested Contaminants

As shown in Figure 9, five contaminants were considered to test to represent adhesion conditions of wheel rail contact. These were mainly chosen because they are intentionally or unintentionally inevitable to occur as contaminants in the wheel-rail contact.

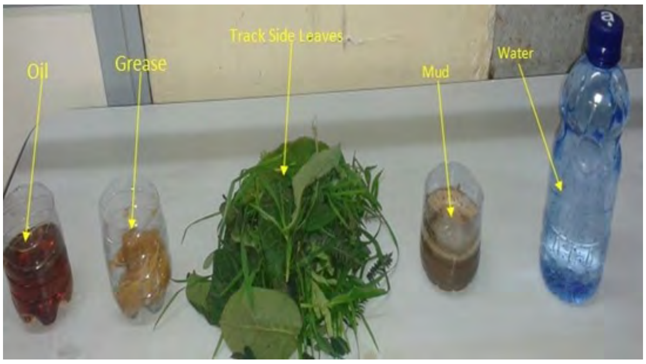


Figure 9 Photographs of the contaminants considered for adhesion loss testing

Test Procedure

The tests were carried out using the wheel disc as the driving disc and the rail disc as the braking disc. The rail disc rotational speed of 400 rpm was made constant throughout the tests and force of 400 N at the two rigs contact. The tests were carried out at slips of 0, 0,25, 0.5%, 1%, 2%, 3% up to 10% re. For tests with water and oil the supply of liquid was started prior to loading the then the whole test was run lubricated. The mud test was run in a similar fashion. For tests with leaves, the discs were run dry until the traction coefficient stabilized and then the leaves were added. Suction was applied to draw the leaves through the contact and prevent them clogging the environment chamber. Leaves were fed through a chute as in Figure 10 at a rate sufficient to ensure a continuous supply to the contact. Lastly, of course, the oil and grease test were performed respectively.

Dry Test

Tests were initially run dry with no contamination i.e. dry test. This test was performed from 0% to10% slips. Test one of the dry test, at 0% slip, the rotational speed of each motor was adjusted to 400 rpm prior to loading each disks together. Then the upper disk was lowered by releasing the load arm lock from its rest pivot and made to meet to the lower disk as in Figure 10. Insuring the two discs are perfectly aligned at their 10 mm contact width and seen run smooth, a force of 120 N is applied through T- bolt compressing the spring 6 mm through the guide yielding force of 400 N at the disks contact thus creating constant torque of 6 Nm. Data were collected i.e. speed with speed sensor/ speedometer, armature voltage from the voltmeter and current from ammeter. Similarly the corresponding data were collected for the rest of slip values of the dry test as depicted in Table 4.1.

Water and Mud Test

Next to dry test the test was carried with water. Water was poured by a plastic bottle enough to keep the discs completely wetted for each slip value and data were collected as were done in dry test. After finalizing the test with water, the test was performed with mud the same fashion as water was poured at the top of rail disk and data were collected as the same scenario shown in Table 4.

Leaves Test

The leaves used in this experiment were taken from main road sides, 5 kilo to Meskel Square which also likely to exist along the track sides of railways in the future. Once they were picked up, they were rinsed in water to remove dust particles and made ready for use.

Prior to leaves testing, the disks and surrounding were cleaned well so as to avoid the effects of previous contaminants other than the leaves. As was done in the preceding tests starting with zero slip the tests were strictly done for all of the slip values. Since the cylindrical disks were used in the experiment, a line contact of 10 mm width was present. Prior to application, the leaves were cut into pieces smaller than the disk contact width to ease their entrapment into the disks interface. They were manually fed through a chute to the disks interface as in Figure 10 and being drawn through by a suction system, vacuum cleaner located on the other side of the disks as depicted in Figure 11.

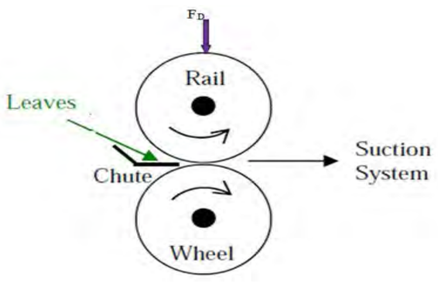


Figure 10 Test rigs set up and leaves feeding through chute [20]

In each test, equal amount of wet leaves were fed enough to create a relatively hard, durable leaf layer on the disk surface. At the beginning of each test, the disks were run at 0% slip for 2 minutes to condition the surface; then 5-10 minutes were required to apply the necessary amount of leaves. Thus the leaf layer generation as in Figure 11 simulated what happens in the real situation, in which repeated wheel passages compact and shear leaves on the top of the rail. As has been done in the preceding tests, data were collected at the end of each leaves test where it was believed the readings in the instrument were somewhat stable.

Figure 11 Rail and Wheel discs after leaf test with blackish leaf layers

Test with Oil and Grease

Before staring the test with oil, the leaf layer was removed from both discs by rotating against each other dry until the contact surfaces were barely clean. Oil tested was standard 15W40 engine oil. For tests with oil, two drops per interval was entertained; the supply was started prior to loading the discs together so that the whole test was run lubricated. The test was competed with all the slip values and data were collected as depicted in Table 4.

To start with grease test, the oily surfaces were first cleaned well with a clean rag. Then at some interval, a paint of grease was applied at the top of rail disc; so grease layer was seen to transfer to the wheel disc. At each slip value data were collected to calculate adhesion coefficients as depicted in Table 4.

Experimental Results

Dry Tests

The adhesions results for 0, 0.25, 0.5, 1, and 2 to 10% slip in dry conditions are given in Figure 12 The dry test gave the largest adhesion coefficient of 0.58 for the slip value of 3%, while in most research works, it was found to be 0.6 at 2-3% slip. However, this is in good agreement with previous research [3, 12, and 15]. In many research works the test investigated with dry test at zero slip was seen to be almost zero adhesion i.e. indication of pure rolling ; but in this particular test it has come to be 0.1.This could be due to the resistance torque of bearing and some misalignment of couplings due to imprecision of the test machine and other factors.

Water and Mud Test

Figure 12 shows the adhesion results obtained for the tests with water. As water was entrained in the contact, the adhesion coefficient seen to rise to pick of 0.29 at 2% slip and started to decrease after wards as the slip further increased. Mud mixed water entertained in the running discs and data was collected to calculate adhesion coefficients as depicted in Table 4.

EXPERIMENTAL RESULTS AND DISCUSSION

Leaf Test

During wet leaf tests separate tests at different slip values were run so that a soft dark layer was apparent on the disc surfaces immediately after 5 to 10 minutes (with visible wrinkles), as shown in Figure 11; this layer was responsible for the adhesion loss seen in Figure 12. As shown in the graph, at zero slip 0.07adhesion was registered and picked 0.43 at slip of 3% and afterwards was seen to decrease its slop.

Test with Oil

Similarly, tests with oil were performed with all the slip values and at zero slip 0.03, and 0.09 at 0.5 -1% slip values. The curve was seen less steep and smooth afterwards.

Test with Grease

With similar fashion as oil test, the curve was seen quite similar with a little shift up in the adhesion coefficients compared to oil as seen in the Figure 12.

Discussion

The highest adhesion levels are obtained in dry, without contaminant, pick at 3% slip i.e. 0.58. Leaves show the next highest adhesion coefficient with pick value 0.43. This is contrary to the research made so far. As investigated in the literatures [3, 12, 16 and 18] the adhesion due to leaf was found to be lesser than even that of oil. But in this particular paper work it was found higher than that of water's.

When water was applied to the discs contact, the adhesion coefficient drops to 0.29 peaks at 2% slip faster recovery than that of mud and dry test. The mud test came to peak higher than that of water at 3% slip beneath that of leaf. The largest drop in adhesion was seen with both oil and greases. The adhesion requirements differ for traction and braking operations and they also depend on the type of vehicle under consideration. Based on the discussion in [20], low level of adhesion found with oil and grease may primarily lead to traction problems.

Table 4 All contaminants' slip versus adhesion data

Slip (%)	μa dry	μa (water)	μa (mud)	μa wet (leaves)	μa (oil)	μa (grease)
0	0.10	0.06	0.05	0.07	0.03	0.05
0.25	0.11	0.09	0.09	0.09	0.07	0.08
0.5	0.15	0.15	0.15	0.16	0.09	0.09
1	0.25	0.20	0.25	0.23	0.09	0.10
2	0.48	0.29	0.28	0.34	0.09	0.09
3	0.58	0.29	0.31	0.43	0.08	0.09
4	0.56	0.28	0.29	0.39	0.08	0.09
5	0.56	0.25	0.28	0.40	0.08	0.09
6	0.57	0.25	0.30	0.37	0.08	0.09
7	0.57	0.22	0.27	0.34	0.08	0.09
8	0.55	0.21	0.31	0.32	0.08	0.08
9	0.54	0.20	0.28	0.28	0.07	0.07
10	0.53	0.19	0.28	0.28	0.07	0.07

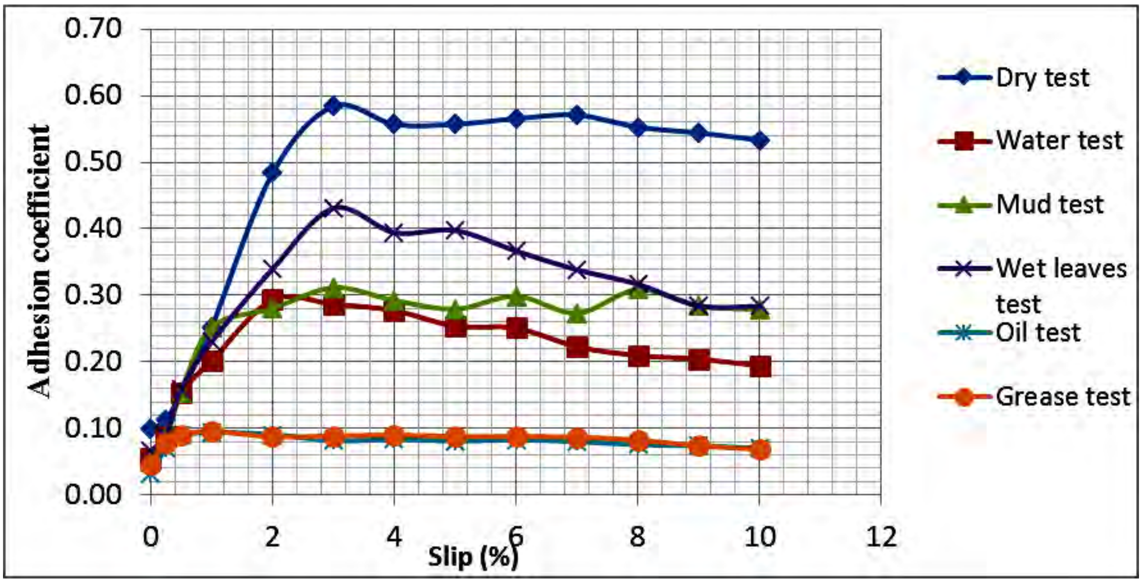


Figure 12 Slip/Creep Curves for the various Test Conditions

On the other hand, the moderate adhesion level reached with water would be advantageous to reduce wear and the occurrence of rolling contact fatigue defects in rails subject to high tangential forces, like in accelerating/braking sections and short-radius curves. However, it has to be acknowledged that the adhesion coefficients obtained in this testing may not be completely in agreement with the actual wheel-rail adhesion, because of the differences between the actual and laboratory testing conditions as already pointed out. Therefore, the results presented in this work can only be taken as qualitative of the actual wheel-rail situation to be used for comparisons between the contaminants and the dry test. The influence of water is one of the most important factors to investigate further, as it is recurring in the regular rainy seasons of Ethiopia in which the rainy water is to rainy seasons of Ethiopia in which the rainy water is to exert influences on adhesion. In this work, however, wear and indentations are present in both wheel and rail disks, which can be attributed to the small difference in hardness of the wheel and rail steel. The wear debris in water test was also seen reduced compared to dry test. These facts would be more beneficial from the railway maintenance point of view if appropriate friction modifiers are applied on the contact surface where the rails experience high tangential forces.

CONCLUSIONS AND RECOMMENDATIONS

A twin-disk roller rig is used to simulate the wheel-rail contact in somewhat controlled laboratory conditions so as to study the influence of contaminants in consideration and compare with dry contact. These contaminants have been used or tested in several railway networks as adhesion depriving agents. In this work, tests with these contaminants and dry condition were carried out at different slip Values.

Due to the early establishment of railway engineering sector in Ethiopia no experimental research has been so far made on adhesion losses with any of the contaminants in consideration; thus this work is the first of its kind to attempt to investigate the influences of the contaminants considered and, of course, with its own limitations but also does have uniqueness in its load application, speed control, environmental conditions, kinds of leaves used, Method of acquiring torque and Test rigs' dimension compared to the research works done so far. Though the results from the experiment do have limitations, they can be used for further improvement through well-developed twin disc test machines.

Conclusions drawn from the test results:

a. In dry conditions the highest adhesion coefficients are obtained at 3% slip value i.e. 0.58 which is in good agreement with previous research works. In this test as was expected higher debris was collected - indication of high wear.

b. Water test seen moderate at lower slip but declined after peak has been reached, indication of significant adhesion loss at higher slip; this will be even worse combined with other contaminants.

c. The blackish leaf layer generation indicates what happens in the real situation, in which repeated wheel passages compact and shear leaves on the top of the rail. In the presence of water the adhesion coefficient is reduced to 0.29, whereas 0.31 is for mud. The later may primarily lead to a conclusion that it was higher because the mud may contain fine sand particles that enhanced the adhesion coefficient.

d. Mud and leaves were seen to have the same effect at higher slip by filling the grooves in between asperities. As the slip increased further the effect of mud was seen to be in line with that of leaves as seen in the curve figure 4.1. As discussed in the discussion part of this paper, the adhesion loss caused in leaf test was due to the blackish leaf layer adhered on the contact surface filling the grooves of the asperities, likely due to the contact temperature the dried mud adhered in between asperities causing the same effect like those of leaves.

e. Both the oil and grease leads to a faster recovery time and lowest adhesion of all the contaminants for all the slip values considered. The increase in slip led to a stable adhesion loss declining rather significantly. Therefore, the use of more adequate track side lubrications, oil leaking from gear box and shock absorbers may lead to an undesirable adhesion loss extent to the wheel rail contacts.

f. In the investigations made so far, at the start of the μ VS slip curve the curves start from origin but in this work, due to the inherited resistance of bearing, misalignment, vibration, etc. of test, the machine exerts initial torques other than zero values as seen in Figure 12.

Recommendations

⇒ From the result found, experimental method of assessing adhesion loss is the best way with twin disc test machine. The test results would have been in best agreement with previous investigations had servo-motors and measuring devices been fitted to the test machine.

⇒ Had the shunt motor been in good capacity, it could have been possible to simulate the contact pressure close to the real situation of the railway system

⇒ According to the experiment, oil and grease were seen to produce the lowest extent of adhesion. Thus, malfunctioning of rail edge and wheel flange lubrication mechanisms, oil leaking from gear-boxes and shock absorbers may cause adhesion loss problems due to the migration of this lubrication to the rail head. Therefore, internal mechanisms and track side lubrication appliances should be frequently checked for their proper functioning.

⇒ In this particular experiment, wet test result seemed moderate for both traction and braking. But as to the real situation of the rail-wheel contact condition the result triggers this could be even least if all the conditions were fulfilled. Therefore, in the rainy seasons, train should be equipped with adhesion enhancer or modifier so as to ensure safety and full utilization of the capacity of the rolling stock. For safe and reliable operation of the rolling stock, rail head should often be clear of mud and leaves because there is an indication that these contaminants can cause adhesion problems. Thus train operators and maintainers should be aware of the effects of contaminants and measures to be taken.

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