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The Effect of Surface Conditions on Wear of a Railway Wheel and Rail

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***Abstract*—**Understanding the nature of wheel and rail wear in the railway field is of fundamental importance to the safe and cost effective operation of the railways. Twin disc wear testing is used extensively for studying wear of wheel and rail materials. The University of Huddersfield twin disc rig was used in this paper to examine the effect of surface conditions on wheel and rail wear measurement under a range of wheel/rail contact conditions, with and without contaminants. This work focuses on an investigation of the effect of dry, wet, and lubricated conditions and the effect of contaminants such as sand on wheel and rail wear. The wheel and rail wear measurements were carried out by using a replica material and an optical profilometer that allows measurement of wear in difficult location with high accuracy. The results have demonstrated the rate at which both water and oil reduce wheel and rail wear. Scratches and other damage were seen on the wheel and rail surfaces after the addition of sand and consequently both wheel and rail wear damage rates increased under these conditions. This work introduced the replica material and an optical instrument as effective tools to study the effect of surface conditions on wheel and rail wear.

***Keywords*—**Railway wheel/rail wear, surface conditions, twin disc test rig, replica material, Alicona profilometer.

I. Introduction

WEAR can be defined as the removal of material from solid surfaces by mechanical action [1]. The steel wheel rolling on a steel rail is the basis of almost all railway systems. Wheel and rail meet at a contact patch that sees severe stresses. These conditions lead to wheel wear and rail wear [2]. A number of different techniques have been used for studying wear of railway wheels, but the twin disc approach has been used more than most because it offers greater control over experimental variables as well as the ability to test a wide range of materials at lower cost [3].

The aim of this work was to study wheel wear and rail wear under several surface conditions using a twin disc test machine and an optical profilometer.

II. Background

Wear transitions in the wheel/rail contact area are of increasing interest since the general trend in railway traffic is toward increased velocities and higher axle loads. Transition to severe or catastrophic wear can occur if the contact is improperly lubricated [4]. In sharp curves, the lubrication reduces rail and wheel wear [5].

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Sanding is used in train operation to improve adhesion at the wheel/rail interface during both traction and braking. An experimental study has been carried out to determine the effect of sanding on the wheel and rail materials using a twin disc rig with and without sand [6].

The most used method for increasing levels of adhesion is sand application between wheel and rail. In braking, sand is used to reduce the distance to stop the train. In traction sand helps decrease sliding thereby enabling transfer of more power from wheel to rail. Sand can increase the adhesion coefficient but can also cause damage to the wheel/rail surfaces. Sand can significantly increase the degree of wear which is dependent on the slip. Lubrication decreases adhesion in comparison with water and dry conditions [7].

Fig. 1 shows an example of wheel wear and rail wear. Flange wear can be reduced by a factor of 4.5 for the wheels equipped with lubrication [8].

Fig. 1 Wheel wear and rail wear [8]

In the following section, the effect of dry, wet, lubricated, and sand conditions on wheel/rail wear were investigated using a twin disc test rig.

III. Twin Disc Test

The twin disc rig at the University of Huddersfield is shown in Figs. 2 and 3. The rig consists of a steel wheel of 310 mm diameter, the wheel roller, which is driven at a constant speed, in contact with a similar wheel of slightly smaller diameter of 290 mm that is free to rotate in its bearings. The wheel roller is mounted on a stub shaft supported in self-aligning bearings mounted at the middle of a lever arm pivoted at one end onto a rigid frame. The shafts of the rollers are made of EN24T steel and have a larger diameter at the hub. The lever arm provides the vertical force acting on the rollers through the jacking mechanism at the end of the arm. A vertical force of up to 4 kN can be applied to the rollers through a jacking mechanism. A rotary table on which the self-aligning bearings of the lower shaft are rigidly mounted allows a relative yaw angle between the rollers. This yaw angle is indicated by markings on the handle of the rotary table.

IV. Replica Material and an Alicona Profilometer

Fig. 4 shows the replica material and the Alicona profilometer (an optical profilometer) which were used in this work for wheel wear and rail wear measurements.

V. Test Results

The twin disc test machine was used to investigate the effect of several surface conditions on the wheel/rail wear. The replica material was used to make a copy of the surfaces of the two rollers before and after each test. The wheel sample dimensions were 5 mm in width and 35 mm in length, and the rail sample dimensions were 5 mm in width and 20 mm in length. The speed of the rail wheel was 960 rpm, the test time was 10 min, the yaw angle was 0.5°, the distance was 9600 m, and the load was varied from 1000 N to 2200 N in six steps.

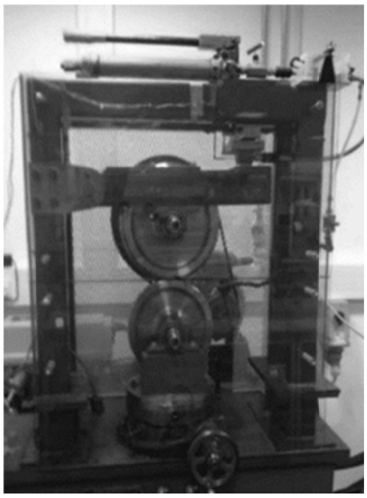


Fig. 2 The twin disc rig

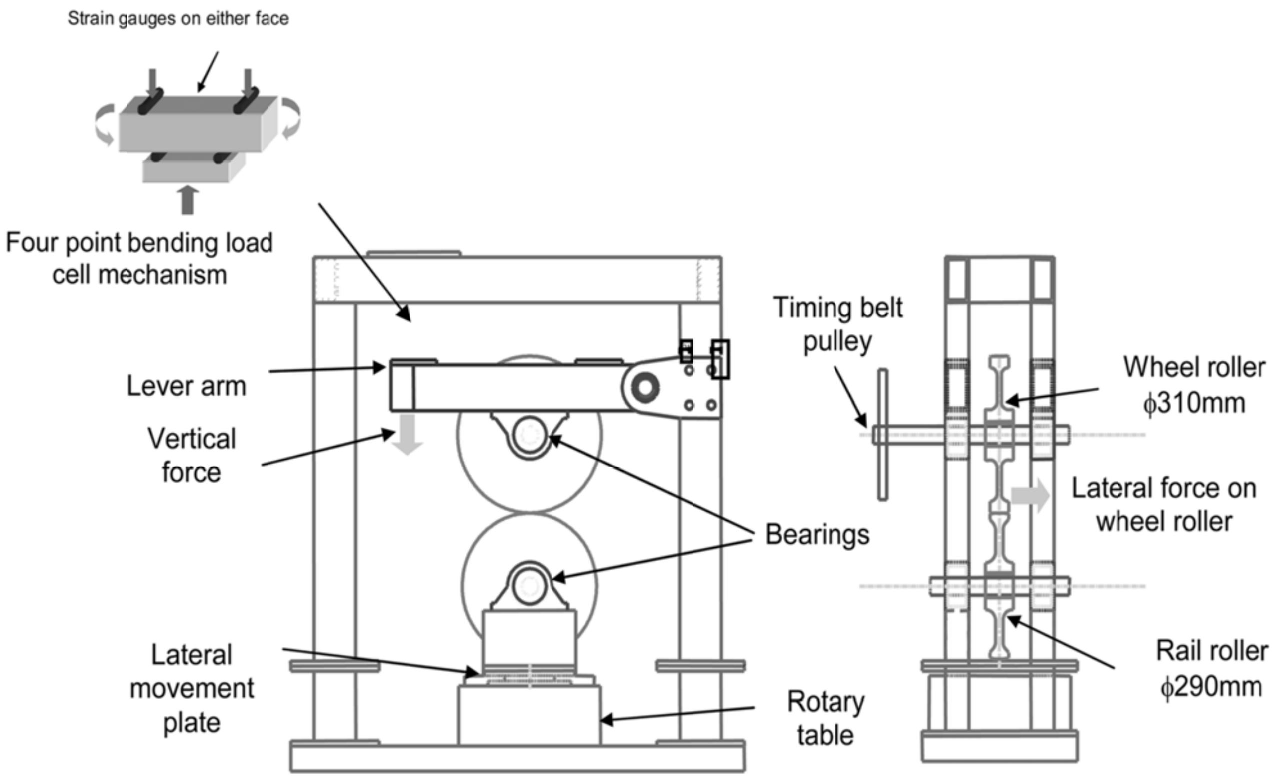


Fig. 3 Schematic of the twin disc rig [9]

Fig. 5 shows the replica sample for wheel and rail surfaces. The replica samples were scanned by using the Alicona profilometer, and the results processed to establish wheel wear and rail wear.

A. *Effect of Dry Conditions on Wheel and Rail Wear*

The variation of wheel and rail wear under dry conditions after a distance of 9600 m is shown in Table I.

Fig. 6 shows the variation of wheel/rail wear with different values of load under dry conditions.

Fig. 4 Alicona profilometer and replica material

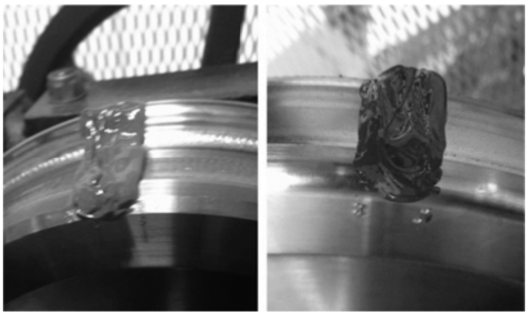


Fig. 5 Replica sample for wheel and rail surfaces

TABLE I
WHEEL/RAIL WEAR UNDER DRY CONDITIONS

Test No	Load (**N**)	Wheel wear (mm^3/mm^2)	Rail wear (mm^3/mm^2)
1	1000	0.0023	0.0031
2	1200	0.0030	0.0045
3	1400	0.0072	0.0097
4	1600	0.0098	0.0126
5	1800	0.0140	0.0168
6	2000	0.0178	0.0245
7	2200	0.0258	0.0333

B. Effect of Wet Conditions on Wheel and Rail Wear

The variation of wheel and rail wear under wet conditions after a distance of 9600 m is shown in Table II.

TABLE II
WHEEL/RAIL WEAR UNDER WET CONDITIONS

Test No	Load (**N**)	Wheel wear (mm^3/mm^2)	Rail wear (mm^3/mm^2)
1	1000	0.0017	0.0025
2	1200	0.0024	0.0038
3	1400	0.0054	0.0084
4	1600	0.0078	0.0102
5	1800	0.0100	0.0142
6	2000	0.0144	0.0204
7	2200	0.0165	0.0257

Fig. 7 shows the variation of wheel/rail wear with different values of load under wet conditions.

C. Effect of Lubricated Conditions on Wheel and Rail Wear

The variation of wheel and rail wear under lubricated conditions after a distance of 9600 m is shown in Table III.

TABLE III
WHEEL/RAIL WEAR UNDER LUBRICATED CONDITIONS

Test No	Load (**N**)	Wheel wear (mm^3/mm^2)	Rail wear (mm^3/mm^2)
1	1000	0.0012	0.0017
2	1200	0.0018	0.0026
3	1400	0.0041	0.0062
4	1600	0.0057	0.0093
5	1800	0.0071	0.0115
6	2000	0.0093	0.0144
7	2200	0.0130	0.0185

Fig. 8 shows the variation of wheel/rail wear with different values of load under lubricated conditions.

D. Effect of Sanded Conditions on Wheel and Rail Wear

The variation of wheel and rail wear under sanded conditions after a distance of 9600 m is shown in Table IV.

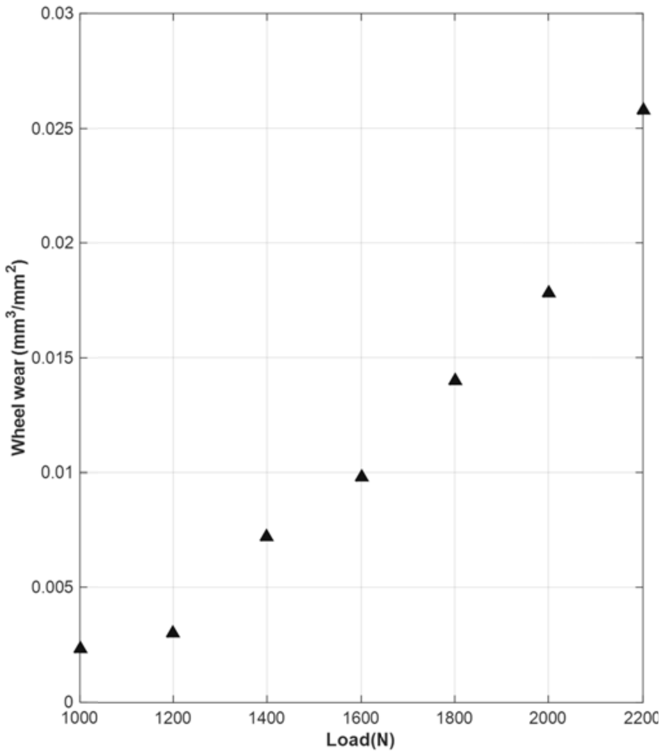
TABLE IV
WHEEL/RAIL WEAR UNDER DRY CONDITIONS

Test No	Load (**N**)	Wheel wear (mm^3/mm^2)	Rail wear (mm^3/mm^2)
1	1000	0.0032	0.0052
2	1200	0.0041	0.0073
3	1400	0.0088	0.0141
4	1600	0.0112	0.0175
5	1800	0.0169	0.0269
6	2000	0.0236	0.0377
7	2200	0.0341	0.0584

Fig. 9 shows the variation of wheel/rail wear with different values of load under sanded conditions.

E. Comparison between Wheel/Rail Wear under Dry, Wet, Lubricated, and Sand Conditions

Fig. 10 shows comparison between wheel/rail wear under dry, wet, lubricated, and sanded conditions.



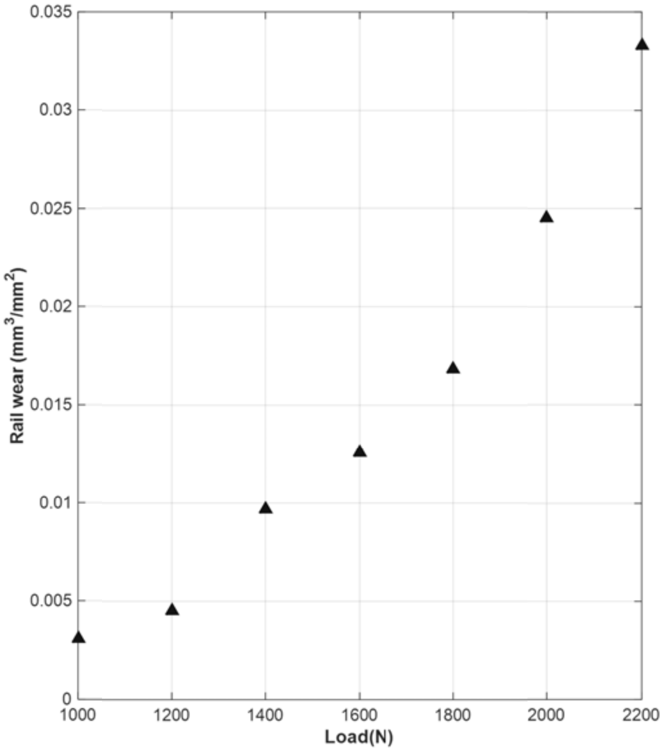


Fig. 6 Variation of wheel/rail wear with different values of load under dry conditions

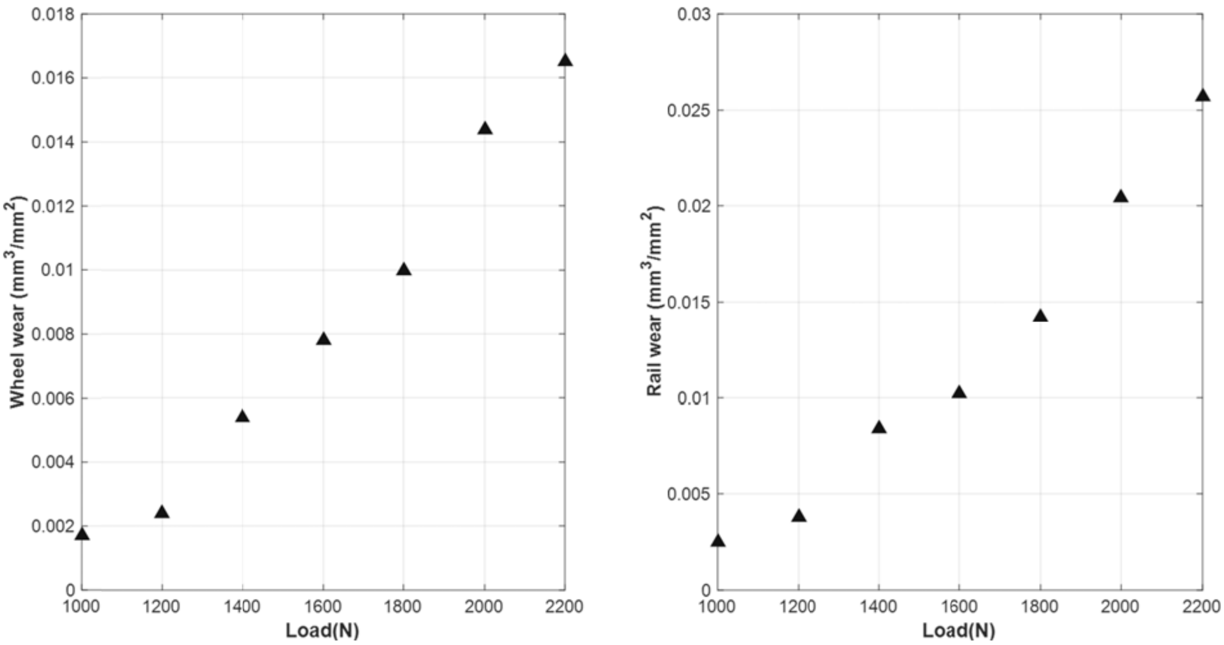


Fig. 7 Variation of wheel/rail wear with different values of load under wet conditions

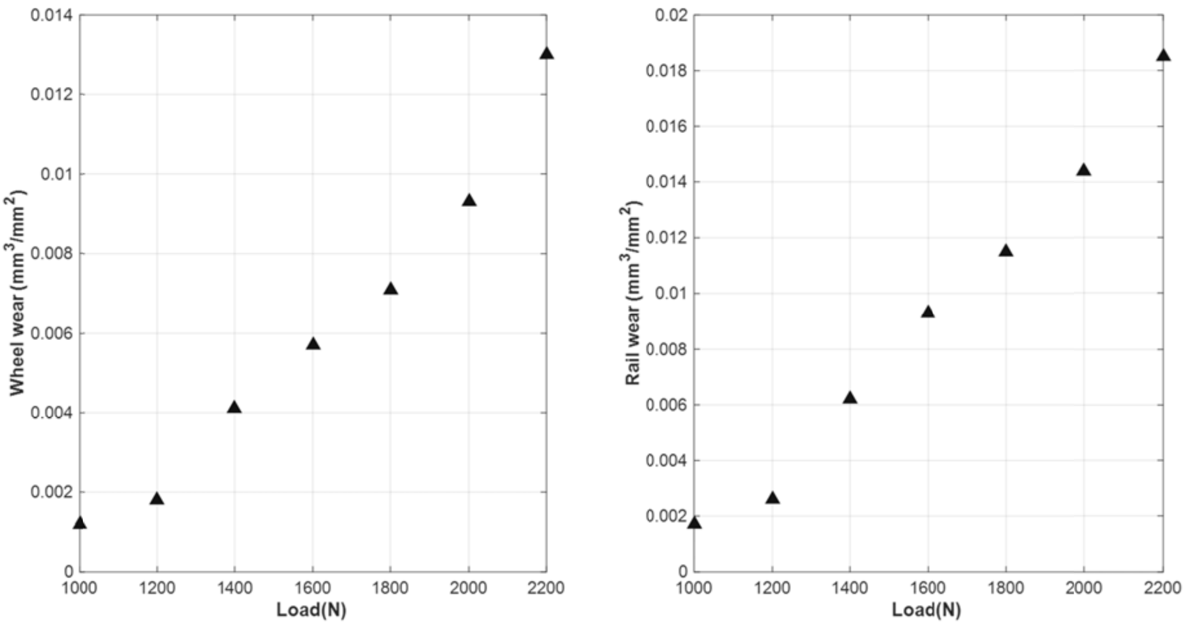


Fig. 8 Variation of wheel/rail wear with different values of load under lubricated conditions

Tests results shown in Tables I-IV were used to find the results which are shown in Table V. Table V shows the effect of wet, lubricated, and sanded conditions on wheel/rail wear. As an example: With an applied load of 1000 N, the wheel wear decreased by a factor of 1.3 and the rail wear decreased by a factor of 1.2 under wet conditions; the wheel wear decreased by a factor of 1.9 and the rail wear decreased by a factor of 1.8 under lubricated conditions; and the wheel wear increased by a factor of 1.3 and the rail wear increased by a factor of 1.6 under sanded conditions.

VI. Discussion

Fig. 6 and Table I show the wheel wear and rail wear under dry conditions. The wheel wear increased from 0.0012 mm^3/mm^2 at load of 1000 N to 0.0258 mm^3/mm^2 at load of 2200N. The rail wear increased from 0.0031 mm^3/mm^2 at load of 1000 N to 0.0033 mm^3/mm^2 at load of 2200 N.

Fig. 7 and Table II show the wheel wear and rail wear under wet conditions. The wheel wear from 0.0017 mm^3/mm^2 at load of 1000 N to 0.0165 mm^3/mm^2 at load of 2200 N. The rail wear increased from 0.0020 mm^3/mm^2 at load of 1000 N to 0.0257 mm^3/mm^2 at load of 2200 N.

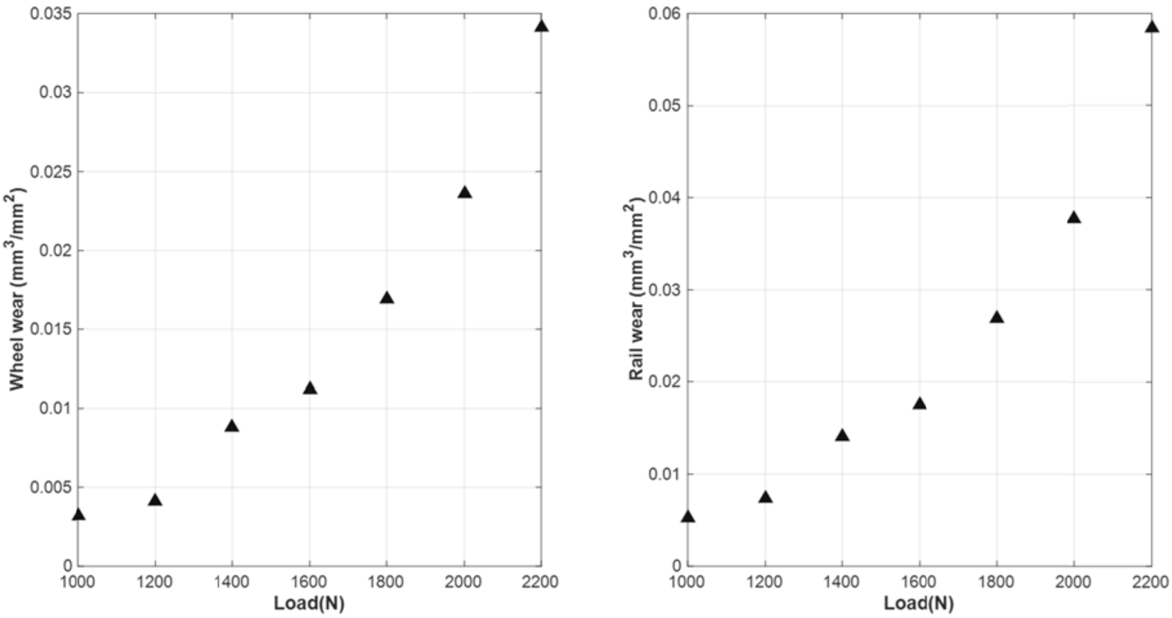


Fig. 9 Variation of wheel/rail wear with different values of load under sanded conditions

TABLE V
EFFECT OF SURFACE CONDITIONS ON WHEEL/RAIL WEAR

Test No	Load (N)	Wheel wear (−)Wet	Rail wear (−) Wet	Wheel wear (−) Lubricated	Rail wear (−) Lubricated	Wheel wear (−) Sanded	Rail wear (−) Sanded
1	1000	↓ 1.3	↓ 1.2	↓ 1.9	↓ 1.8	↑ 1.3	↑ 1.6
2	1200	↓ 1.2	↓ 1.1	↓ 1.6	↓ 1.7	↑ 1.3	↑ 1.6
3	1400	↓ 1.3	↓ 1.1	↓ 1.7	↓ 1.5	↑ 1.2	↑ 1.4
4	1600	↓ 1.2	↓ 1.2	↓ 1.7	↓ 1.4	↑ 1.1	↑ 1.3
5	1800	↓ 1.4	↓ 1.1	↓ 1.9	↓ 1.4	↑ 1.2	↑ 1.6
6	2000	↓ 1.2	↓ 1.2	↓ 1.9	↓ 1.7	↑ 1.3	↑ 1.5
7	2200	↓ 1.5	↓ 1.2	↓ 1.9	↓ 1.8	↑ 1.3	↑ 1.7
Average	--	↓ 1.3	↓ 1.1	↓ 1.8	↓ 1.6	↑ 1.2	↑ 1.5

Fig. 8 and Table III show the effect of lubricated conditions on the wheel/rail wear. The wheel wear increased from 0.0012 mm^3/mm^2 at load of 1000 N to 0.0130 mm^3/mm^2 at load of 2200 N. The rail wear increased from 0.0017mm^3/mm^2 at load of 1000 N to 0.0185 mm^3/mm^2 at load of 2200 N.

Fig. 9 and Table IV show the wheel wear and rail wear under sanded conditions. The wheel wear increased from 0.0032 mm^3/mm^2 at load of 1000 N to 0.0341 mm^3/mm^2 at load of 2200 N. The rail wear increased from 0.0052 mm^3/mm^2 at load of 1000 N to 0.0584 mm^3/mm^2 at load of 2200 N.

Fig. 10 shows comparison between the effects of the four surface conditions on wheel/rail wear. With an applied load of 2200 N, the wheel wear was 0.0258 mm^3/mm^2 under dry conditions, and it decreased 0.0165 mm^3/mm^2 under wet conditions, and decreased to 0.0130 mm^3/mm^2 under lubricated conditions, while it was increased to 0.0341 mm^3/mm^2 under sanded conditions. The rail wear was 0.0333 mm^3/mm^2 under dry conditions, and it decreased to 0.0257 mm^3/mm^2 under wet conditions, and decreased to 0.0185 mm^3/mm^2 to 0.0584 mm^3/mm^2 under sanded conditions. The wet conditions decreased the wheel wear by a factor of 1.5; the lubricated conditions decreased the wheel wear by a factor of 1.9, while the sanded conditions increased the wheel wear by a factor of 1.3. The wet conditions decreased the rail wear by a factor of 1.2; the lubricated conditions decreased the rail wear by a factor of 1.8, while the sanded conditions increased the rail wear by a factor of 1.7.

VII. CONCLUSIONS

This paper investigated the effect of wheel/rail surface conditions on wheel/rail wear. Twin disc rig tests results shown in Table V reveal that the wheel and rail wear was influenced by wet, lubricated, and sanded conditions. Key findings are:

- The wet conditions decreased the wheel wear by a factor of 1.3, the lubricated conditions decreased the wheel wear by a factor of 1.8, while the sanded conditions increased the wheel wear by a factor of 1.2.

- The wet conditions decreased the rail wear by a factor of 1.1, the lubricated conditions decreased the rail wear by a factor of 1.6, while the sanded conditions increased the rail wear by a factor of 1.5.

The replica material and the Alicona profilometer can be used to study the effect of surface conditions on wheel wear and rail wear. The advantage of the use of the replica material that it is a permanent record of the wheel and rail surface, while the advantage of the Alicona profilometer is that it can measure the wheel and rail wear at high resolution.

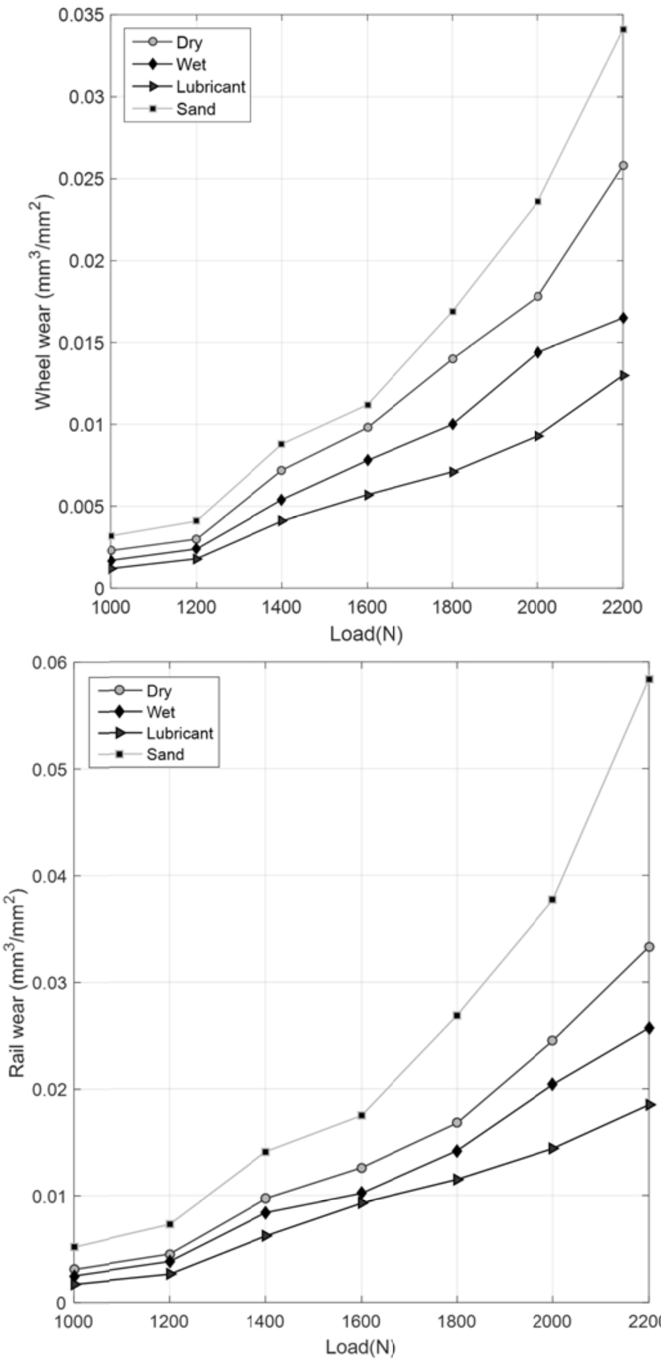


Fig. 10 Wheel/rail wear under dry, wet, lubricated, and sanded conditions

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