# A Pin-on-disc Study of the Rusts on Wheel Rail Material and its influence on the friction coefficient


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Control of the friction coefficient

Maintenance of the wheel-rail interface

Vehicle operation

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- Importance
- Influential factors: environment; third-body; material properties…
- Measures: friction modifier; lubricant; grinding

Rust and oxide layers

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# What is rust?

Rust is hydrated iron oxides.
Iron oxides refer to anhydrous iron oxides.

TABLE 1—PROPERTIES OF IRON OXIDES AND RUSTS

| TYPE | MINERAL NAME | CHEMICAL NAME | FORMULA | COLOR |
|---|---|---|---|---|
| Anhydrous | Wustite | Ferrous oxide | FeO | Black |
| | Magnetite | Ferrosoferric | $Fe_3O_4$ | Black |
| | Martite | Ferric oxide | $Fe_2O_3$ | Black |
| | Hematite | Ferric oxide | alpha-$Fe_2O_3$ | Orange Red |
| | Maghemite | Ferric oxide | gamma-$Fe_2O_3$ | Reddish Brown |
| Hydrated (RUSTS) | Goethite | Ferric hydroxide | alpha-$Fe_2O_3.H_2O$ | Red-brown |
| | Akaganeite | Ferric hydroxide | beta-$Fe_2O_3.H_2O$ | Red-brown |
| | Lepidocrocite | Ferric hydroxide | gamma-$Fe_2O_3.H_2O$ | Yellowish-Red-brown |
| | Feroxyhyte | Ferric hydroxide | delta-$Fe_2O_3.H_2O$ | Red-brown |
| | Xanthosiderite | Ferric hydroxide | $Fe_2O_3.2H_2O$ | Red-brown |
| | Esmeraldite | Ferric hydroxide | $Fe_2O_3.4H_2O$ | Red-brown |
| | Turgite | Ferric hydroxide | $2Fe_2O_3.H_2O$ | Red-brown |
| | Limonite | Ferric hydroxide | $2Fe_2O_3.3H_2O$ | Yellow to reddish |
| | Hydrogoethite | Ferric hydroxide | $3Fe_2O_3.4H_2O$ | Red-brown |
| | Ferrihydrite | Ferric hydroxide | $5Fe_2O_3.9H_2O$ | Yellow-brown |

----D. Godfrey, ”Iron oxides and rust in tribology”, Technical paper, Journal of the society of tribologists and lubrication engineers 1999; 55(2); 33-37

# Rusts on rails:

Different rusts and iron oxides on the rail can result in various friction coefficient causing stick-slip which leads to rail corrugations.

---M. Ishida, et. al, ”Rail corrugations caused by low coefficient of friction in a submarine railway tunnel”.


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It was reported that β- $Fe_2O_3 \cdot H_2O$ which is generated under the moist environment with the presence of chloride (Cl) has a great impact on reducing friction coefficient. A detailed surface treatment was also suggested.

---J. Suzumura, et. al, ”In situ X-ray analytical study on the alteration process of iron oxide layers at the railhead surface while under railway traffic”, Wear 271 (2011) 47-53

Two exposures:(pins and discs are made of wheel rail materials)

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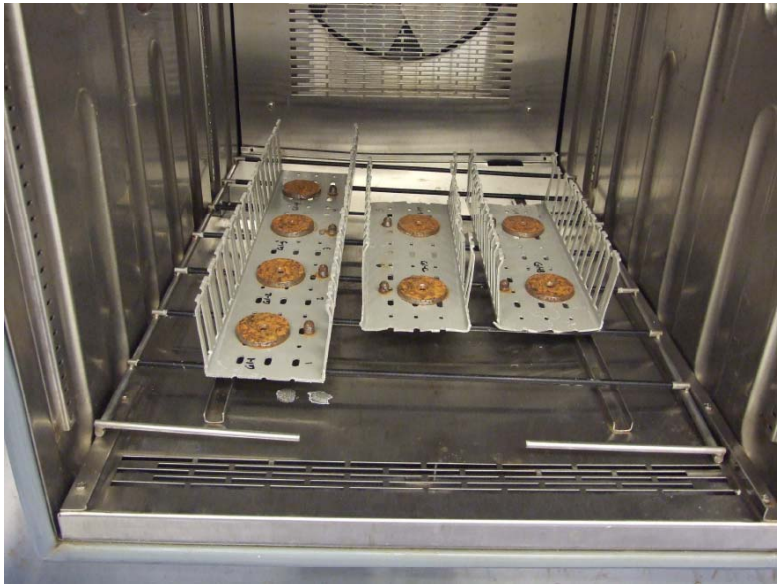
| | Group1 G1 (five cycles) | Group 2 for comparison G2 (five cycles) |
|---|---|---|
| **Step 1** | exposure in air for 0.5 h at 40 ◦C and RH> 90% | exposure in air for 2 hours at 40 ◦C and RH > 90% |
| **Step 2** | exposure in air for 0.5 h with 1% NaCl solution spray at 40 ◦C and RH> 90% | exposure in air for 6 hours at 40 ◦C and RH< 30% |
| **Step 3** | exposure in air for 1 h at 40 ◦C and RH> 90% | |
| **Step 4** | exposure in air for 6 h at 40 ◦C and RH< 30% | |



G1 exposure

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G2 exposure

# XRD X-ray diffraction analysis

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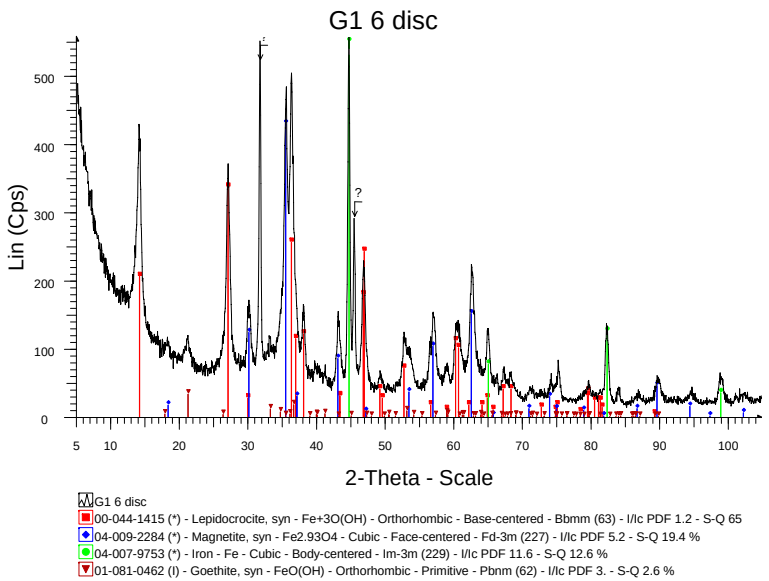
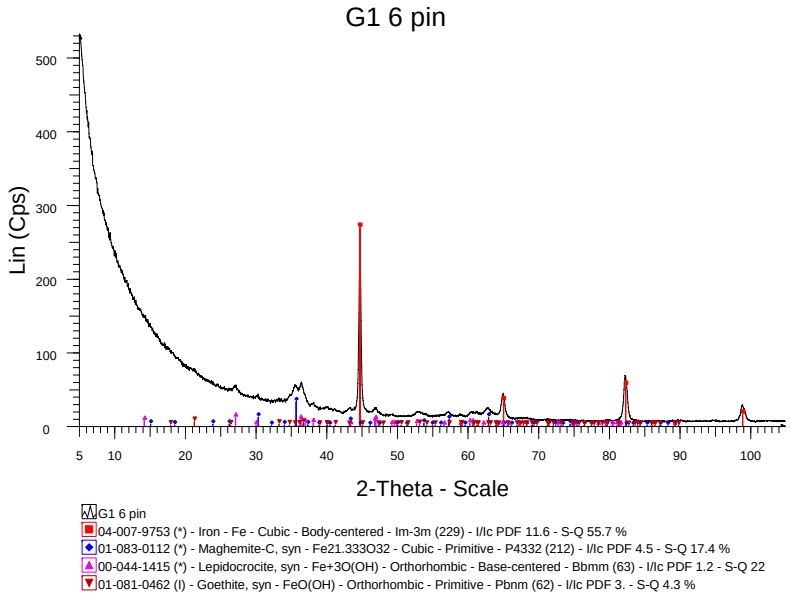
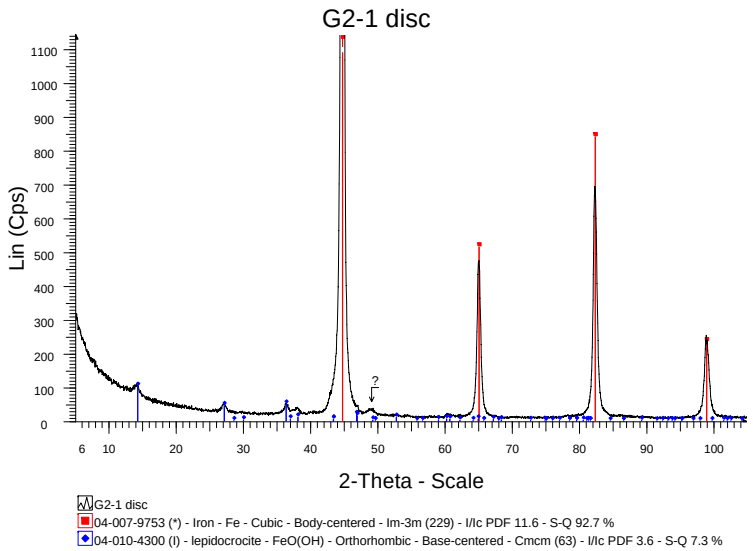
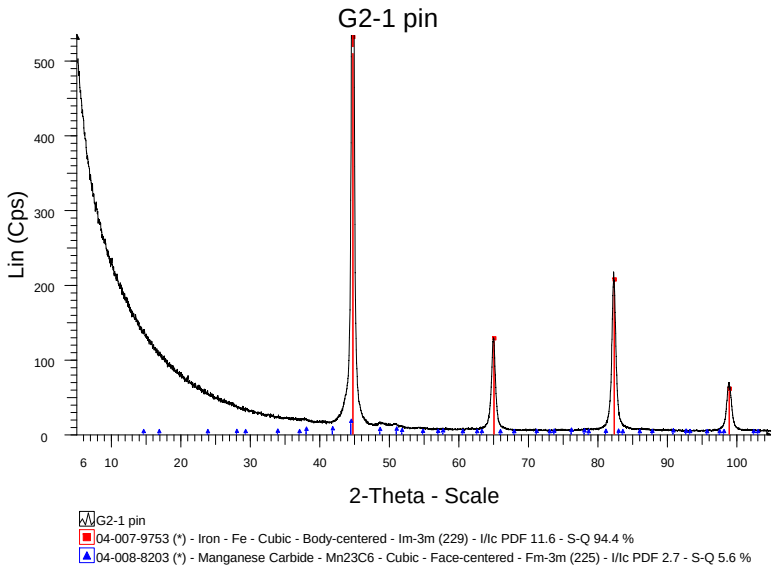


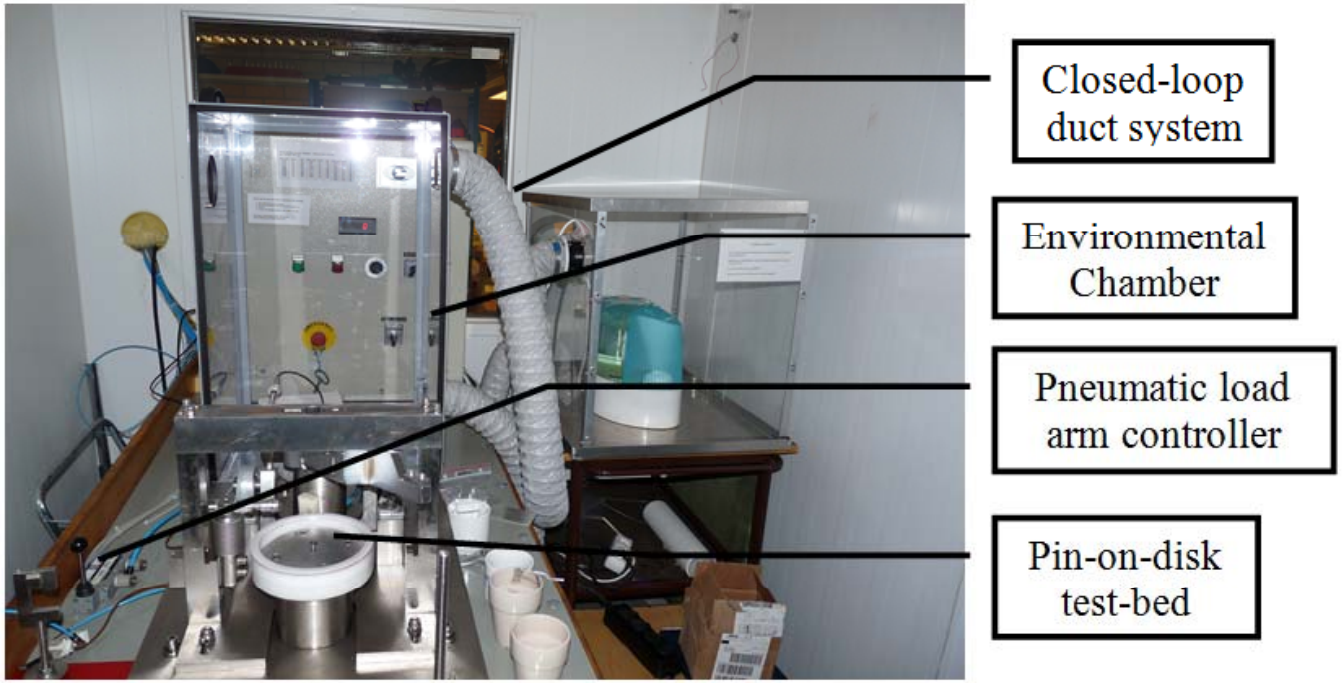



| Treatment | Conditions | Generated | Generated from ref. |
|---|---|---|---|
| Sprayed salt solution (1%) for half an hour | 40°C, 2 hours with high humidity, 6 hours with low humidity. 5 cycles | $\alpha$-$Fe_2O_3 \cdot H_2O$<br>$\gamma$- $Fe_2O_3 \cdot H_2O$<br>$Fe_3O_4$<br>$\gamma$- $Fe_2O_3$ | $\alpha$-$Fe_2O_3 \cdot H_2O$<br>$\beta$-$Fe_2O_3 \cdot H_2O$<br>$\gamma$- $Fe_2O_3 \cdot H_2O$<br>$Fe_3O_4$ |
| No salt solution | | $\gamma$- $Fe_2O_3 \cdot H_2O$ | $\alpha$-$Fe_2O_3 \cdot H_2O$<br>$\gamma$- $Fe_2O_3 \cdot H_2O$<br>$Fe_3O_4$ |

| 環境 | 条件 | 発生さび | | |
|---|---|---|---|---|
| 純水噴霧 ($H_2O$) | 短時間 4.5hr (short) | — | — | γFeOOH |
| | | — | — | — |
| | 長時間 20d (long) | αFeOOH | — | γFeOOH |
| | | $Fe_3O_4$ | — | — |
| | 長時間噴霧後加熱 (heat) | — | — | — |
| | | $Fe_3O_4$ | αFe2O3 | — |
| 3%NaCl 水溶液噴霧 ($NaCl$) | 短時間 4.5hr (short) | — | βFeOOH | γFeOOH |
| | | — | — | — |
| | 長時間 20d (long) | αFeOOH | βFeOOH | γFeOOH |
| | | — | — | am.FeOOH |
| | 長時間噴霧後加熱 (heat) | — | — | — |
| | | $Fe_3O_4$ | αFe2O3 | — |

---K. Ohno, Y. Ogawa, RTRI Rep., No. A-83-70, 1983

# Pin-on-disc testing:

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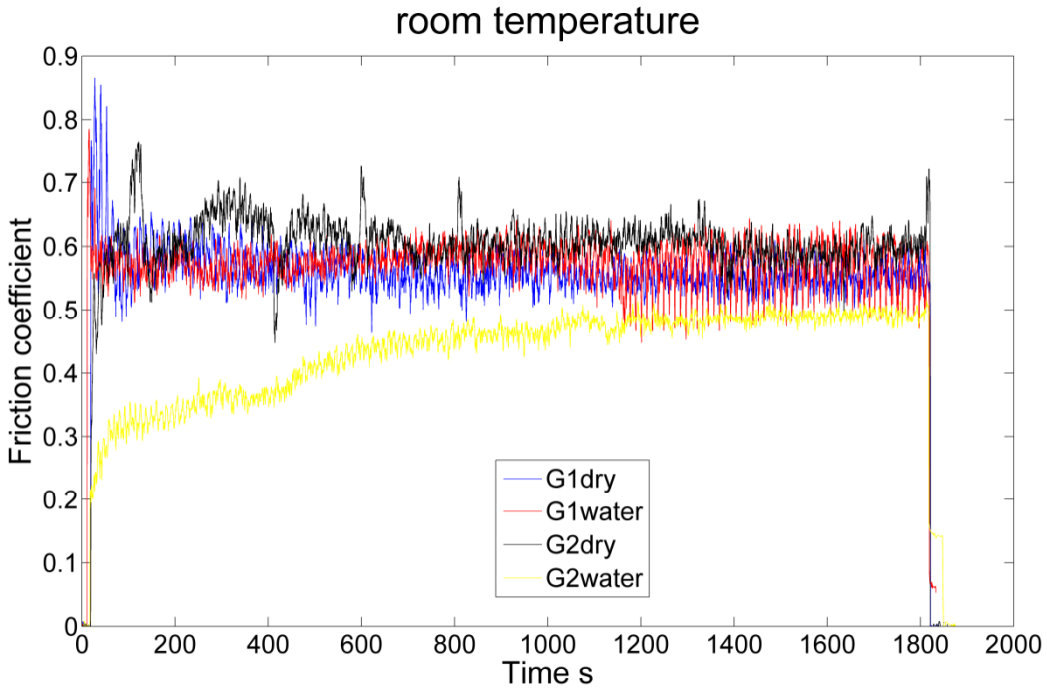
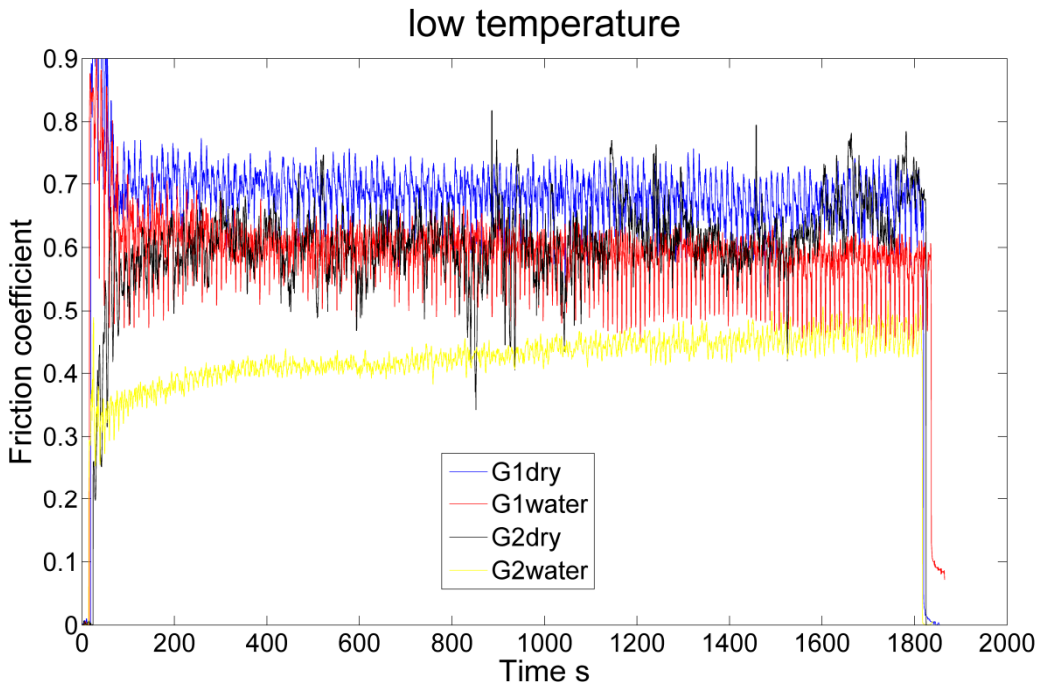
Contact pressure: 900MPa;
Sliding speed: 0.01m/s
Pin-on-disc testing with two temperature 20°C (+) and 10°C (-) with RH 40%±5%; with water (w) and dry (d)
Test duration: 30min
Sliding distance: 18m

# Friction results:



In one of the tests, interesting results are observed!

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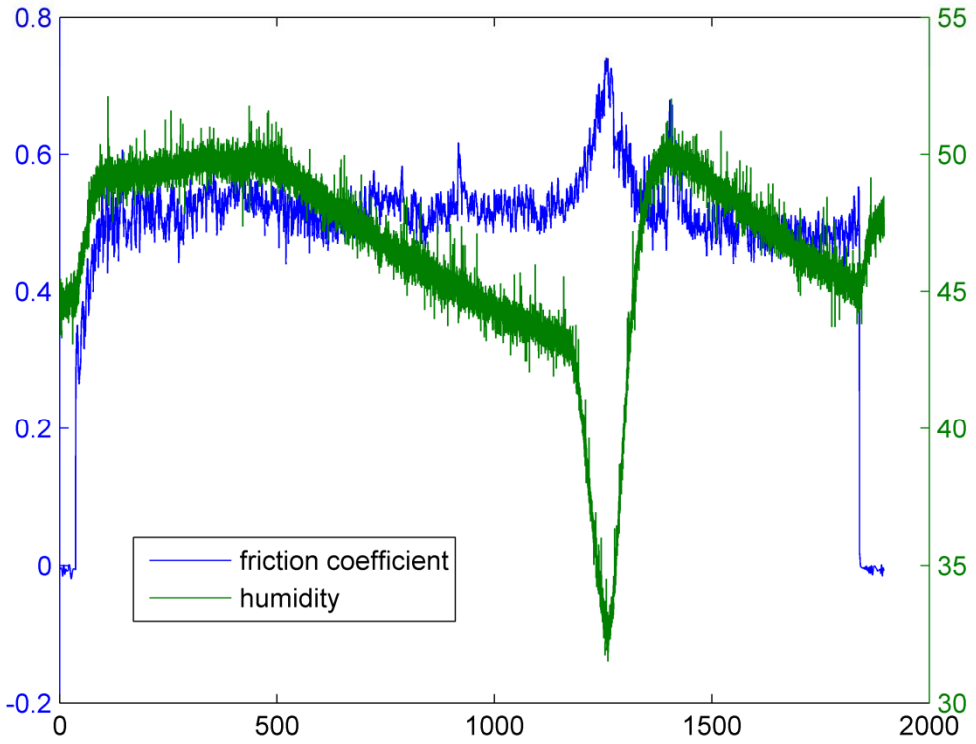
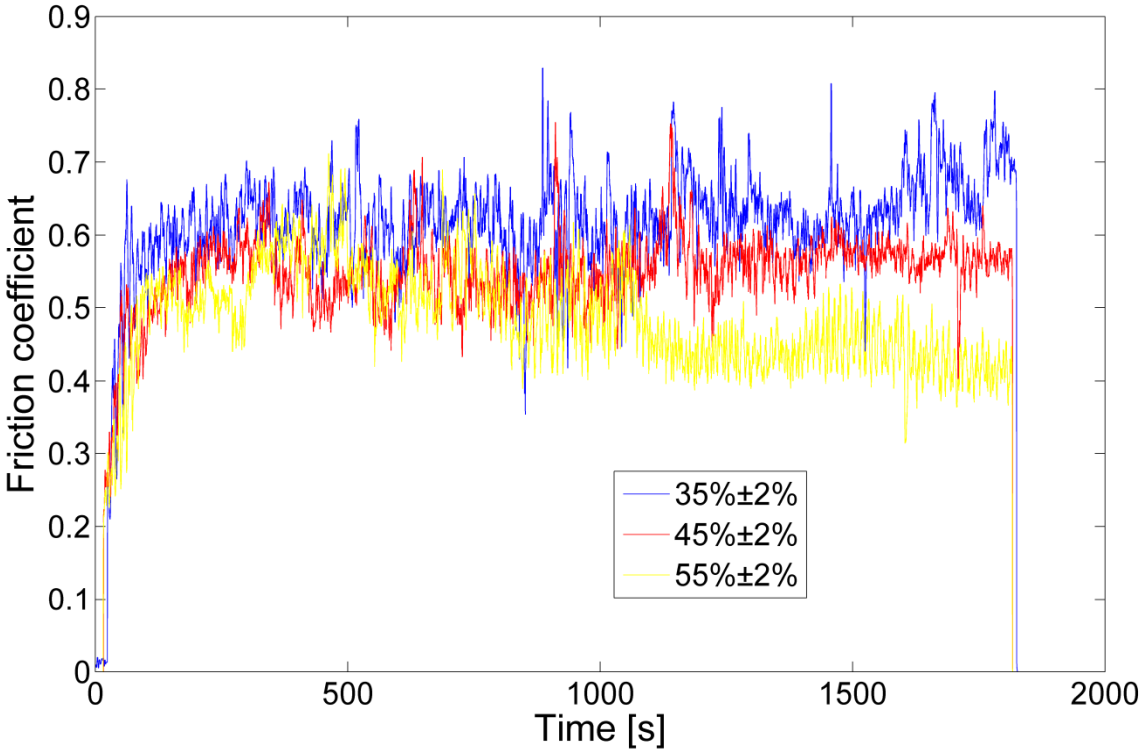



G2 exposure (thin oxide, 10˚C):

# More tests are done with regard to different levels of humidity:

## On the thin oxide specimens at 10˚C

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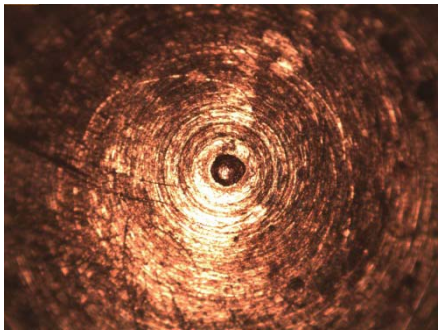
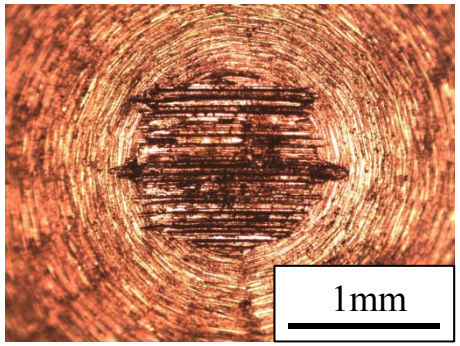
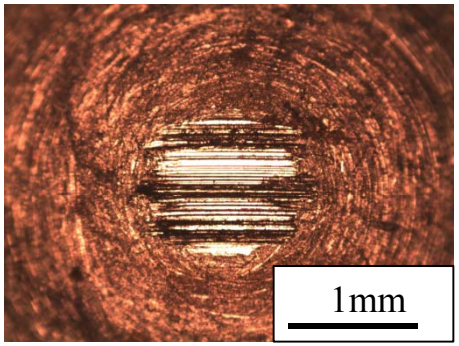


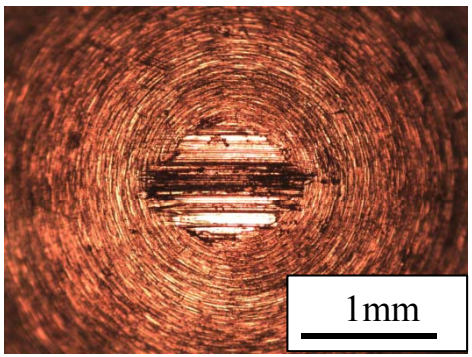
Water lubricated




35%




45%




55%

| Specimens | Height [mm] | Width [mm] |
|---|---|---|
| 35% | 1.2 | 1.5 |
| 45% | 0.97 | 1.1 |
| 55% | 0.79 | 1.1 |

[Ref] O. Hayashi et. al, Influence of atmospheric conditions upon adhesion between rails and running wheels, Nippon Kikai Gakkai Ronbunshu, C Hen/ Transactions of Japan Society of Mechanical Engineers, Part C 63 (606), pp. 566-571

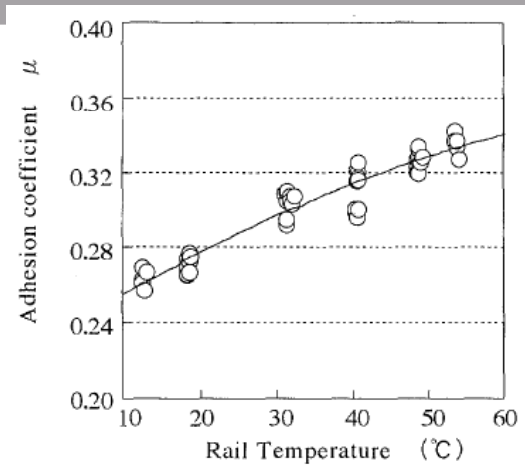



Fig.3 Reference Rail Temperature with $\mu$
( Atmosphere Temp. 14℃, Humidity 70% )

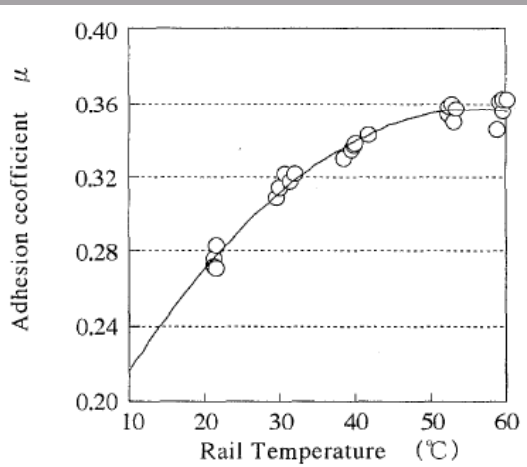



Fig.4 Reference Rail Temperature with $\mu$
( Atmosphere Temp. 20℃, Humidity 55% )

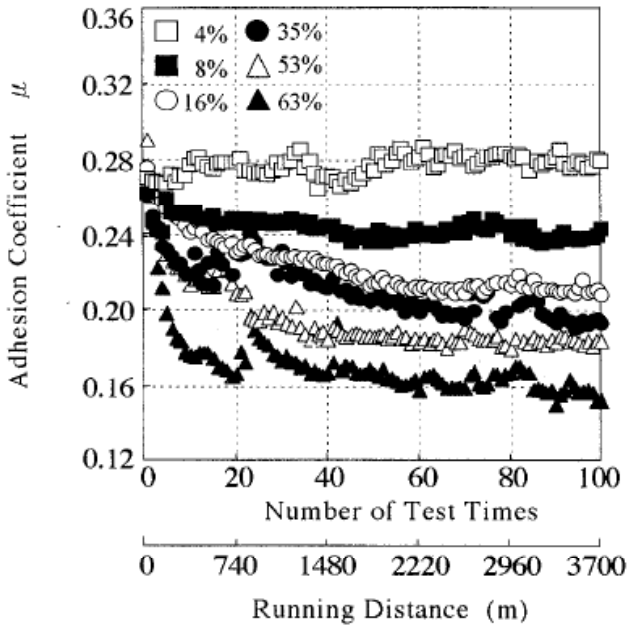



Fig.5 Behavior of $\mu$ changed with the Running Distance of Test Truck under Various Humidity of the Atmosphere around the Running Surface of Rail
( Atmosphere Temp. 15℃ )

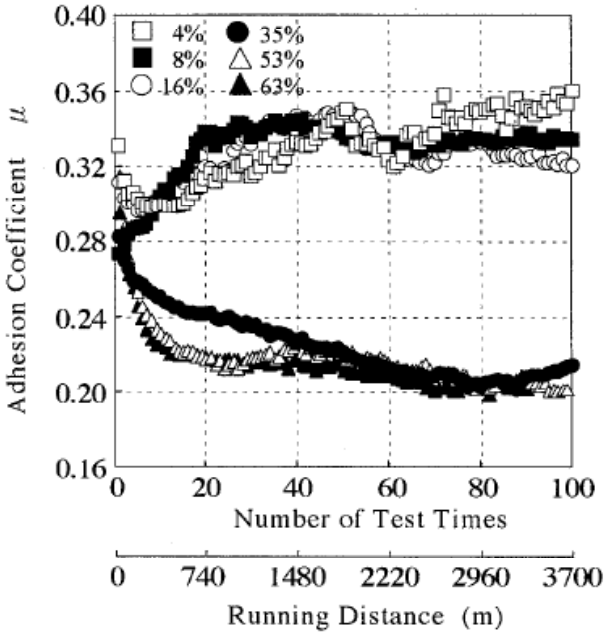



Fig.6 Behavior of $\mu$ changed with the Running Distance of Test Truck under Various Humidity of the Atmosphere around the Running Surface of Rail
( Atmosphere Temp. 28℃ )

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## Discussion

1 for thick oxide specimens, μ is almost independent of lubricants (dry or water), especially at room temperature. The running-in process is also independent of the environmental conditions. These phenomenons are probably due to the extremely rough surface topography.

2 for thin oxide specimens, the running-in process lasts only for a very short while (< 2min, sliding distance around 1 meter) under dry condition. However, under wet condition, the running-in process lasts long.

3 thin oxide specimens are very sensitive to relative humidity.

Future work:

1 more tests will be done for thin oxide specimens at various humidity levels; temperature levels.
2 surface analysis

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Thank you for your attention!

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