Measuring Rolling Resistance
Properties of Pavements

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What is rolling resistance?

Coefficient of rolling resistance = $C_R = \frac{P_f}{F_z}$

Direction of travel

Coeficient of rolling resistance = $C_R$
Components of driving resistance of a road vehicle

(Vehicle) Driving resistance

(Vehicle) Propulsion resistance

- Inertial resistance
- Gravitational resistance
- Engine resistance
- Auxiliary equipment resistance

(Vehicle) Aerodynamic resistance

- Body air resistance
- Tyre air resistance

Vehicle rolling resistance

- Tyre/road rolling resistance
- Bearing resistance
- Transmission resist. (churning & mech.)
- Suspension resistance
How pavement characteristics create rolling resistance energy losses

- Deformation in suspension and friction in damper
- Unevenness
- Megatexture
- Macrotexture
- Microtexture
- Tire/rim & suspension assembly
- Deformation in tire/road contact patch
- Hysteresis in pavement deformation
- Stick-slip (friction)
Main methods:

**Coasting tire** -- Rolling resistance: Lab. meas. on drum (e.g. ISO 28580)

**Cruising vehicle** -- Fuel consumption: Meas. of fuel flow with instrumented car

  **Cruising vehicle** – Rolling resistance: Measurement of torque on axle

  **Coasting vehicle** -- Rolling resistance: Coast-down with car or truck

**Coasting tire** -- Rolling resistance: Measurement with test tire on trailer
  (three sub-methods)
Measurement of rolling resistance according to ISO 18164 or 28580 .... intended mainly for tire testing

Facility at the Technical University of Gdansk (TUG), Poland
Statistical distribution of measured CR values

Safety Walk surface on drum

Rolling resistance coefficient

Number of tested tyres

- **Summer tyres**
- **Winter tyres**

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+ 70 % for worst vs best tyres
.... but one can put replicas of pavements on the drum, or even real pavements
New RR facility recently constructed at TUG designed for truck tires
Two ref (replica) surfaces on the drum
Test car used for fuel consumption (FC) measurements on various pavements in 1982 by this author and colleague.
Relation between fuel consumption and road surface macrotexture recorded by VTI in 1982

Range of Swedish road surface textures

+ 7.5 % FC
(+40 % RR)
VTI’s truck “RDT” performing coast-down measurements
Coast-down – Speed vs position

Road number=9 Västerlösa1

Velocity [km/h] vs Position [m]
How to measure rolling resistance with special trailer?

Three ways:

Pulling force in towing link --- by force transducer

Torque on wheel axle --- by torque transducer

Deflection angle --- by angle transducer
Car at Opel/GM in Germany in the 1980’s

Force measurement at this link

- tracking is done by a Watt’s linkage
- RR of two identical rear axle tyres is measured
- car was wrecked several years ago
Trailer at IPW in Germany, based on principle by Opel/GM in Germany in the 1980’s

Force measurement at this link
How to measure rolling resistance?

\[ C_R = \frac{P_f}{F_z} = \tan \Theta \approx \Theta \]
Pilot tests in 2007, using new trailer from the Technical University of Gdansk in Poland

Measurements in Sweden on 5 pavements for 5 tires at 50, 70 and 90 km/h
Four of the five pavements

SMA 0/8

DAC 0/8

Surface dressing 8/20

SMA 0/16
Correlation between rolling resistance and road surface texture

\[ y = 0.0024x + 0.0083 \]

\[ R^2 = 0.988 \]
Trailer constructed at TUG used for measurements at VTI in Sweden
Compensation for effect of gradients/slopes by "counterweight system" (to be patented)

Compensation for acceleration/deceleration by same system
Reference tires?

Experience of this only since 3 years

ASTM (SRTT)  Repr. light vehicles
Avon AV4  Repr. heavy vehicles
Michelin Primacy  Tyre used "from the beginning"
RRC versus texture – Data by VTI

Results of all RR measurements in 2009 by TUG/VTI
Average for 3 tires, normalized to 80 km/h
Round Robin Test (RRT) at IFSTTAR in Nantes

BRRC (Belgium)

TUG = Techn Univ of Gdansk (Poland)

BASt (Germany)
Repeatability of the TUG trailer in 2007

The diagram shows the repeatability of the TUG trailer with two different tires, W6c and W3c, at 50 km/h. The data is presented in two runs for each tire type:

- Tyre W6c 50km/h 1st run
- Tyre W6c 50km/h 2nd run
- Tyre W3c 50km/h 1st run
- Tyre W3c 50km/h 2nd run

The y-axis represents the RR coefficient [-], while the x-axis represents time [ms].

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### Within-day repeatability

Standard deviation between tests made a few hours apart
Expressed as % of measured rolling resistance coefficient

<table>
<thead>
<tr>
<th>Speed</th>
<th>BRRC</th>
<th>BASt</th>
<th>TUG</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 km/h</td>
<td>2.2</td>
<td>2.1</td>
<td>1.0</td>
</tr>
<tr>
<td>80 km/h</td>
<td>3.1</td>
<td>3.3</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Day-to-day repeatability

Rolling resistance coefficient measured in two days by the same trailer (BASt)

Overall (rms) difference: Stand. dev. between the two days = 7 %
Reproducibility
Rolling resistance coefficient measured by BASt and TUG trailers (3 tires)
Influence of speed

RRC measured by TUG and BRRC for one tire at 2 speeds on 10 pavements

BRRC at 80 km/h
BRRC at 50 km/h

Broken lines = TUG at 50 and 80 km/h
Comparison of BRRC and TUG trailers

Note that BRRC has no wheel cover
The major 3 test tires used in the RRT

- SRTT (ASTM std ref tire)
  P225/60 R16

- AAV4
  Avon AV4 Supervan
  (Light truck tire)
  195 R14 C

- ES16
  Michelin Energy Saver
  225/60 R16
Pavement classification by different tires
Rolling resistance coefficient measured by TUG for 3 tires on 10 pavements
Effect of temperature

Black = data measured on-road in 1986 for one tire (includes effect of inflation pressure)

Red = temp. corr. in ISO 28580 for drum measurements and ambient air temp. (car tires)
Conclusions:

RR vs pavement is a research area still in its infancy; especially measurement technology

Presently best method for measuring pavement properties is the trailer method

Three trailers studied in Round Robin Test ("Rodeo")

Test tires include SRTT, Michelin Energy Saver, and Avon AV4 (light truck tire)

Repeatability is very good for one trailer, barely acceptable for the other two

Day-to-day variability is poor, hardly acceptable (partly due to temperature)

Reproducibility is very poor – totally unacceptable (calibration problem?)

Trailers must have test tyres properly protected from ambient air flow & wind

Different tires classify pavements in similar way

Temperature is a very important factor
State-of-the-Art report, June 2011

Rolling Resistance – Basic Information and State-of-the-Art on Measurement methods

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Models for rolling resistance In Road Infrastructure Asset Management systems
Rolling Resistance – Measurement Methods for Studies of Road Surface Effects

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RR = \frac{P_f}{F_z}