On rolling resistance of bicycle tyres with ambient temperature in focus

Malte Rothhämel

KTH Vehicle Dynamics,
Royal Institute of Technology,
100 44, Stockholm, Sweden
Email: malter@kth.se

Abstract: Two sets of bicycle tyres were tested with a one-degree-of-freedom two-wheeled pendulum, a portable rolling resistance test bed. Vertical load affected the rolling resistance coefficient only in a minor matter. The wider tyre showed an about 10% lower rolling resistance coefficient in comparison to a narrow tyre of the same type. Tyre inflation pressure and temperature are the major influence factors for rolling resistance. Both of them affect with factor two to three in the relevant range. Based on the data about temperature and inflation pressure a simple model is suggested.

Keywords: rolling resistance; tyres; bicycle; ambient temperature; tyre width; vertical load.

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Biographical notes: Malte Rothhämel received his PhD in Vehicle Engineering at the Royal Institute of Technology, KTH Stockholm. After an industrial PostDoc at Volkswagen Global Research, he developed fault-tolerant chassis systems for autonomous heavy trucks at Scania. He is an Assistant Professor at the Department of Technical Mechanics, KTH. His research interests include next to earlier research issues related to longitudinal bicycle dynamics.

1 Introduction

"Experto credite!" ("Believe someone who has tried it!", Vergil, Aeneis 11, 283)

Bicycle driving resistance is closely related to sustainable mobility, as the problem of low-emission and (sub-)urban mobility is often planned to be solved through an increased use of bicycles. At the same time bicycle as mode of transportation is more and more in focus even for simulation tools supporting planning of infrastructure. So, there is need for empirical data for the simulation of bicycles as means of transport. Moreover, in the significant fraction of pedelecs, driving resistances are a question of battery size, which further raises the question on sustainability, weight, total cost of ownership and range.

On a bicycle where traction power is much more limited than in a car, the driving resistances affect the driving performance significantly. Considering that time and energy people are willing to spend on utility trips is limited, and that travel time (under given conditions) is one of the main drivers for the choice (not) to cycle, it becomes clear that driving resistances on bicycles are a question to cope with in order to secure the extended use of bicycles. Hence, it is apparent that bicycle driving resistances are an important research topic.

Rolling resistance is one of the main driving resistances for bicycles next to acceleration, aerodynamic drag and road inclination (Wilson, 2004). The distribution of these resistances varies, of course, depending on the application (racing vs. utility cycling), the driving style (acceleration and speed), the topology, the traffic situation and the wind conditions. For a utility cyclist at a constant speed of 15 km/h with rough estimated parameters the distribution of power needed to overcome air drag and rolling resistance is 45% and 55% respectively (Grappe et al., 1997; Tengattini and Bigazzi, 2018).

However, while the power needed to overcome the rolling resistance increases nearly linearly with vehicle speed, the power to overcome the aerodynamic drag increases with vehicle speed with an exponent of three. This shows that the rolling resistance is more important at low vehicle speed – meaning in the speed range of utility cyclists – while the aerodynamic resistance is more important at higher vehicle speed, e.g., in the range of racing cyclists.

This paper presents an analysis of bicycle tyre rolling resistance measurements using a one-degree-of-freedom two-wheeled pendulum. The current research contributes to the literature on bicycle tyre rolling resistance through measurements with an angle velocity sensor on the pendulum with parameter variation in inflation pressure, vertical load, and ambient temperature. The paper is organised as follows: Section 2 gives an overview over related research; Section 3 illustrates the data and the methodology; Section 4 presents the experimental results, completed by Section 5 where a model is suggested based on the measurements. The results are discussed in Sections 6 and 7 extracts the conclusions of this work.

2 Literature review

A number of factors affect the rolling resistance of a pneumatic tyre and comprehensive research has been done about them. Most of the investigations focus on tyres for passenger cars or sometimes for heavy vehicles. Popov et al. (2003) performed experiments with truck tyres on a drum rig. In addition to the vertical force amplitude a dynamic amplitude of 50% was added with different frequencies. The main observation was that there was no significant effect of dynamic load on mean rolling resistance. Taghavifar and Mardani (2013) investigated the effect of velocity, inflation pressure, and vertical load on rolling resistance of a radial ply tyre on an agriculture tractor on loose ground. Vertical load caused the major resisting force, however, the correlation seemed to be linear according to the definition of rolling resistance coefficient, i.e., C_r was constant over varying vertical load. In addition, rolling resistance increased with ground deformation, anyhow, lower tyre inflation pressure caused higher rolling resistance in this special context. Eckert et al. (2014) confirmed the increased rolling resistance of passenger car tyres with decreasing inflation pressure by means of measurements.

Even temperature as a parameter affecting the rolling resistance of tyres is known. Bode (2016) measured the temperature increase during warm-up phase in parallel to the rolling resistance on heavy truck tyres. In an ambient temperature of about 20°C the tyre belt temperature increased by 50 K and the gas temperature inside the tyre increased by 40 K while the rolling resistance coefficient decreased from 6.5% to 4.5% . On the simulation side Greiner et al. (2018) modelled the viscoelastic behaviour of car tyres predicting the rolling resistant as function of the tyre temperature.

In the domain of bicycles, Bulsink et al. (2015) tested the rolling resistance torque of bicycle tyres (size 37-622) with constant vertical load but varied inflation pressure and measured decreasing rolling resistance torque with increasing inflation pressure. Nilges (2004) performed comprehensive bicycle experiments comparing nine different tyres on three different types of surface (asphalt, gravel, grassland) with focus on the effect of tyre inflations pressure levels (150 kPa to 400 kPa). While the rolling resistance on asphalt decreased with increasing tyre inflation pressure, the opposite effect arised on gravel and grassland. Nilges explained the effect with higher amount of energy dissipation by means of churning within the grassland ground below the tyre at higher pressure. On gravel Nilges stated that the system bicycle-driver loses energy during the system getting lifted when rolling over unevenness with high tyre pressure. Hölzel et al. (2012) measured rolling resistance of a set of bicycle tyres by means of a pendulum and inspired that way to this measurement method. Bertucci et al. (2013) investigated aero and rolling resistance of a mountain bike with different drivers on a slope consisting of asphalt, hard sand and grass varying tyres and tyre pressure. The numbers for the nobby tyre on grass showed hardly any difference (with a slight advantage for lower pressure), the numbers for the Randonneur tyre on dry grass indicated a 10% higher rolling resistance for the 200 kPa inflated pressure against the 400 kPa inflated tyre. Reiser II et al. (2003) investigated bicycles on a roller rig. The well known effect of tyre inflation pressure on rolling resistance on hard ground could be shown even there. However, different tyre widths could hardly be distinguished, on parallel real-road-experiments it was impossible to distinguish tyre width. Whitt and Wilson (2004) found that pressure had an exponential effect on rolling resistance as pressure approached zero. However, once pressure reached approximately 500 kPa, rolling resistance levelled out with little to no change as tyre pressure was increased further. Grappe et al. (1999) investigated that additional weight (realised by a mass of 15 kg increased the rolling resistance coefficient and approximated this behaviour with a second order polynomial.

2.1 Literature summary and scope of current study

From literature it can be summarised that on hard ground increasing tyre inflation pressure leads to lower rolling resistance while the results on soft ground are not that clear. Tyre width could not be distinguished significantly in rolling resistance experiments. In contrast, for bicycle tyres the rolling resistance coefficient seems not to be independent of vertical load. No laboratory measurements of bicycle tyre rolling resistance under controlled temperature variation have been reported until recently according to the authors knowledge.

So, the scope of this study was to gain knowledge about changes in rolling resistance coefficient with regards to various factors through experiments. In this direction, this paper presents an analysis of bicycle tyre rolling resistance measurements using a one-degree-of-freedom two-wheeled pendulum. The measurements are conducted with an angle velocity sensor on the pendulum with parameter variation in inflation pressure, vertical load, and ambient temperature.

3 Data and methodology

3.1 Test equipment

For this investigation the approach presented by Hölzel et al. (2012) was adopted. An eccentric weight was attached to a pipe connecting two bicycle wheels rigidly, which made these four parts to one mechanical body, called a one-degree-of-freedom pendulum. There are no bearings or other friction out of the tyre-road interaction. The basic experimental setup is explained in detail in a previous conference contribution (Rothhämel, 2021). For better understanding the most important facts are repeated here. The only modification was that the eccentric weight was reduced to 20 kg causing the oscillation, and a centred weight was added to adjust the vertical load without affecting the oscillation characteristics. This resulted in the same system weight as before, but reduced the dynamic vertical load peaks during oscillations.

The rims had an ERTRO size 19-559, i.e., a rim inner width of 19 mm and a diameter of 559 mm, which corresponds to 26" wheels. They were built with hubs and 36 spokes as standard wheels for bicycles, while a pipe connected the hubs. Moreover, an eccentric weight was attached to the pipe and additional weight was arranged symmetrically around the pipe. The eccentric weight had a dimension of 25 cm length, 25 cm width and 4 cm thickness, was made of steel and had a weight of 20 kg. By adding pairwise additional similar steel plates with a thickness of 2 cm and a weight of 10 kg each, the total vertical load could be increased stepwise. The whole device had a track width of 62 cm and a total weight of 23 kg, including tyres and tubes.

3.2 Basic test operation

By deflecting the pendulum with about 90°, the eccentric weight (m_{weight}) was lifted, which was a supply of potential energy (E_{pot}). When releasing, the pendulum was oscillating. The rolling resistance was the only significant resisting force braking the pendulum to zero over time. During the oscillation the potential energy will be converted into rolling resistance energy (E_{roll}), see equation (1). To reduce potential measurement errors, the first half oscillation was discarded. Thereafter, three full oscillations where used for the evaluation. In equation (2) the normal fraction of the centrifugal force is added, since the oscillating weight of the pendulum adds an additional vertical force that cannot be neglected. In the present study the centrifugal force was calculated for each oscillation by means of the known eccentric mass and the measured angular velocity in each time step. Then the vertical fractions were extracted based on the angle derived from the gyro since only the vertical force affected the rolling resistance force. The characteristics of the vertical fraction of the centrifugal force varies over time. However, since the rolling resistance was calculated by the evaluation of whole pendulum oscillations, the variation of vertical force during one oscillation could not be considered. Instead it was simplified to an average of this force over time and added to the vertical force caused by the weight of the pendulum for the corresponding oscillation. Adding this term made a difference of about 1% in the resulting rolling resistance coefficient.

$$\Delta E_{pot} = m_{weight} \cdot g \cdot \Delta h = C_r \cdot m_{total} \cdot g \cdot x = E_{roll} \tag{1}$$

$$\Delta E_{pot} = m_{weight} \cdot g \cdot \Delta h = C_r \cdot (m_{total} \cdot g + F_{centrifugal,normal}) \cdot x = E_{roll} \tag{2}$$

with

x:	Distance travelled
C_r:	Rolling resistance coefficient
m_{total}:	Total mass taking effect on the tyres
g:	Gravity acceleration
m_{weight}:	Mass eccentric weight
Δh:	Height difference of the eccentric weight.

3.3 Test procedure

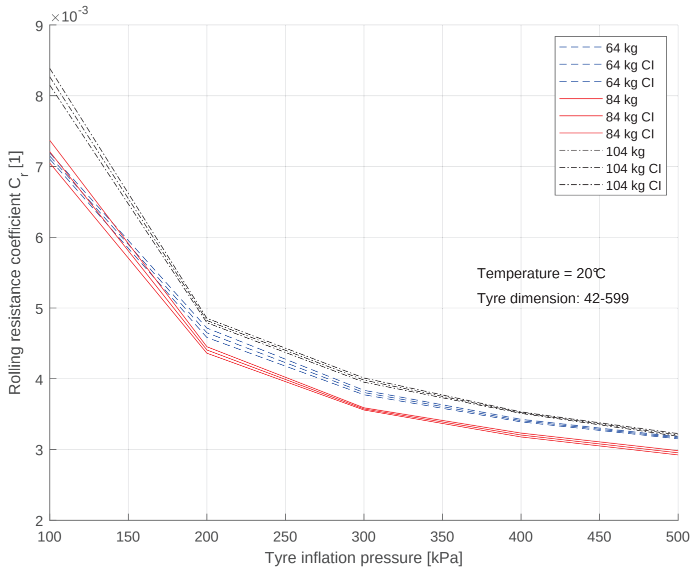
The static wheel radius was measured for each combination of tyre, vertical load and inflation pressure. This was performed on the pendulum with the mounted tyre by means of a bubble level and a yards stick between ground and the centre of the hub. If left and right wheel differed, the mean value was calculated. This method was already used before and showed very good repeatability in the range of the possible accuracy (1 mm). This static wheel radius was used as effective radius in the algorithm. Before and after each set of measurements, the tyre pressure was measured with an air pressure maximum was accepted. This gauge is known for high precision, however, there was no possibility for calibration. Repeated tests showed reasonable values, anyhow, the inflation pressure values were in the end accepted as displayed. Each measurement was performed eleven times (one set) to avoid the effect of random disturbances. The parameters were varied as specified in Table 1.

Table 1 Varied parameters in this experiments

Tyre inflation pressure	(50); 100; 200; 300; 400; 500	kPa
Vertical load	(432); 628; 824; 1020	N
Tyre width	42; 50	mm
Temperature	–30; -15; 5; 25	°C

For different temperature measurements, the equipment was acclimated at least 1 h including air movement. For larger temperature differences, acclimatisation was performed over at least 8 h. Before testing at a new temperature, the tyre temperature was measured with an infra-red camera. The temperature named for the test was the ambient temperature in the climate chamber. The tyre pressure was adjusted at each temperature level. However, it must be considered that values with variation of temperature cannot directly be compared to other values since the experiments in the climate chamber (variation of temperature) were performed on steel while the reference experiments were performed on a fine concrete surface (see Figure 1).

Figure 1 Rolling resistance coefficient over tyre inflation pressure for a narrow tyre (42-599) (see online version for colours)



CI = Confidence Interval.

4 Experimental results

This section presents the experimental results of the bicycle tyre rolling resistance measurements for each of the varied parameters.

4.1 Vertical load

The rolling resistance coefficient (C_r) is defined as the rolling resistance force divided by the normal force based on the experience of a linear relation (Pacejka, 2006), see equation (3). So, for variation of vertical load no differences in the rolling resistance coefficient were expected.

$$R_r = C_r \cdot N \tag{3}$$

with

R_r Rolling resistance force

C_r Rolling resistance coefficient

N Normal force.

Figure 1 visualises the results of rolling resistance coefficient on fine concrete surface from the experiments over tyre inflation pressure with vertical load as parameter including the confidence intervals. The confidence intervals are quite narrow, which indicates that the measurements of the same setting are quite similar. Also the curves for different vertical load are quite near to each other, partially intersecting. For the narrow tyre (42-599) the inflation pressure of 50 kPa was not tested to avoid damages to the tube at high vertical load. The test series with 432 N vertical load was omitted by error.

4.2 Tyre width

The influence of tyre width on rolling resistance of bicycle tyres is not that clear in contrast to e.g., car tyres. The contact patch size is defined by the tyre pressure and the vertical load (Maier et al., 2018). However, the contact patch shape varies depending on the outer diameter and the tyre width. A wider tyre usually results in a wider contact patch. Compared to a slim tyre, the contact patch length decreases. The centre of the contact patch area might move closer to the projected axle and decrease the lever arm of the rolling resisting force.

In this experiment, two sets of tyres of the same type (Schwalbe Marathon Supreme Evolution) were used that differed only in their width (50 mm vs. 42 mm according to size label). The actual width is shown in Table 2. Anyhow, in this paper the tyres will always be identified by means of their labelled width.

Table 2 Actual width of the tyres tested, mounted on a rim with ERTRO size 19-559

Tyre inflation pressure	*50-559*	*42-559*
50 kPa	44.5 mm	37.0 mm
100 kPa	45.0 mm	37.5 mm
200 kPa	46.5 mm	38.0 mm
300 kPa	47.0 mm	39.0 mm
400 kPa	47.5 mm	39.0 mm

Table 3 shows the differences of rolling resistance from a 42 mm tyre against the 50 mm tyre as a reference. According to the results, the 42 mm tyre has in nearly all settings a higher rolling resistance than the 50 mm tyre. In average, the difference is about 10%, while at higher inflation pressure the difference increases.

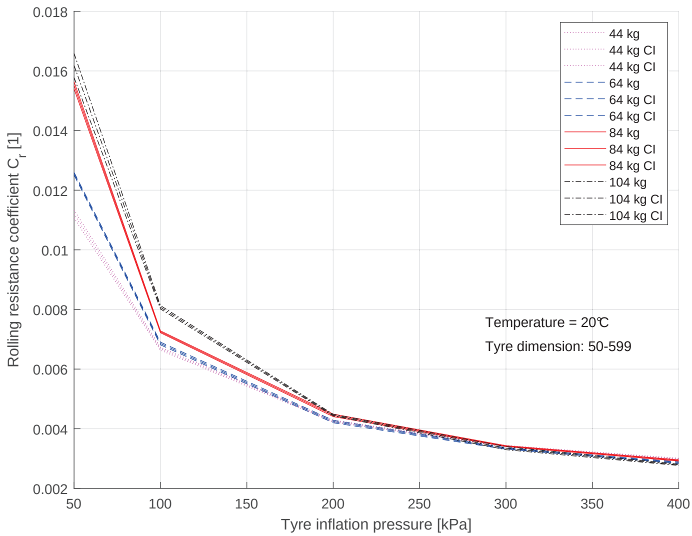
Table 3 Difference in rolling resistance of the 42 mm tyre against the 50 mm tyre (reference)

Tyre inflation	*Vertical load*		
pressure	*64* kg	*84* kg	*104* kg
100 kPa	4%	–0.6%	2%
200 kPa	10%	–0.9%	8%
300 kPa	14%	5%	19%
400 kPa	19%	9%	26%

4.3 Tyre inflation pressure

Tyre inflation pressure is probably the most well known influence factor for rolling resistance even outside the scientific community. The contact patch increases and the tyre's sidewalls are chunked during rolling where energy is dissipated as heat. Figure 1 shows the non-liner relation of increasing rolling resistance coefficient over decreasing inflation pressure for an 42 mm tyre, nearly independent of vertical load. For the wider tyre (50 mm) Figure 2 shows a similar behaviour.

Figure 2 Rolling resistance coefficient over tyre inflation pressure for a wide tyre (50-599) (see online version for colours)



CI = Confidence Interval.

4.4 Temperature

Rubber properties are temperature dependent (Strobl, 2007). However, rolling resistance experiments with controlled or measured temperature are quite seldom. For this investigation the pendulum was situated in a climate chamber where the temperature could be controlled. Rolling resistance was measured at a temperature range of –30°C to +25°C and with relevant inflation pressure of 200 kPa to 500 kPa. At lower inflation pressure the measuring method collapsed because of a too low number of oscillations, jeopardising the comparability of the results. The results are shown in Figure 3.

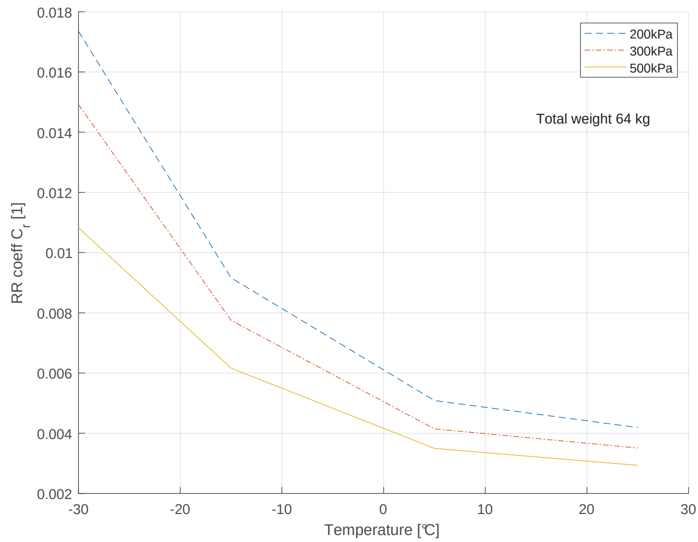
Next to the well known tyre inflation pressure dependency, a clear non-linear behaviour is observable with a strong increase in rolling resistance coefficient with decreasing temperature. In addition, the increase characteristics is stronger with decreasing tyre inflation pressure. Table 4 shows the gradient of C_r over temperature in the range of +5°C to +25°C. The gradient is more steep at lower inflation pressure. For bicycle energy simulations in a medium temperature range only, this might be the easiest adaptation to temperature.

Table 4 Linearised gradient of C_r over temperature in the range of +5°C to +25°C for the narrow tyre (42-559)

Tyre inflation pressure	*Gradient over temperature*
200 kPa	$-44.8 \cdot 10^{-6}\text{K}^{-1}$
300 kPa	$-31.8 \cdot 10^{-6}\text{K}^{-1}$
500 kPa	$-28.1 \cdot 10^{-6}\text{K}^{-1}$

It must be observed that the baseline at standard tyre testing temperature (+25°C) is at a very low level since the tyre rolls on a smoothed steel surface, which results in a very low rolling resistance ($C_r = 0.0029$ at 500 kPa). A parallel conducted experiment with the same equipment on chequer plate resulted in a similar curve with a slightly higher shifted graph. Because of time limitations in the climate chamber only one set of vertical load (628 N) was tested.

Figure 3 Rolling resistance coefficient of a narrow tyre (42-559) over temperature on smoothed steel surface (see online version for colours)



5 Temperature data fitting and model

As far as known the rolling resistance data over that wide temperature range was not reported for bicycle tyres before. To make these data more applicable in other context, a model was fitted and evaluated. ISO 28580 (2018) suggests a linear temperature correction in the range of ± 5 K around the proposed ambient temperature of +25°C. However, next to the presented data here, both Neubeck et al. (2017) and Hyttinen (2022) showed non-linear correlations in the shape of a hyperbola. Therefore, a corresponding basic formula was chosen, see equation (4). This is limited to the range of measurements. An extrapolation to lower or higher temperature might be feasible as long as there is a safe margin to the glass transition or the decomposition temperature, where the rubber is expected to show a different characteristic.

$$C_r = b_1 + \frac{b_2}{T + b_3} \tag{4}$$

with

C_r	[1]	Rolling resistance coefficient
T	[°C]	Ambient temperature
b_n	[1]	Hyperbola coefficients

The results for the coefficients characterising the shape of each hyperbola based on the measurements are listed in Table 5. b_1, which moves the graph along the ordinate, is always close to zero. b_2, which stretches the graph along the ordinate, is in the range of 0.2 to 0.3. b_3, which moves the graph along the abscissa, is between 44 and 49. Since the optimiser did not converge with the data collected on chequer plate with a tyre inflation pressure of 200 kPa, b_3 was after a few iterations set to 40 manually.

Table 5 Hyperbola coefficients b_n for rolling resistance coefficient model over temperature fitted in the range of –30 °C to +25°C

		Smoothed steel surface	
	500 kPa	*300* kPa	*200* kPa
b_1	$-1.399 \cdot 10^{-6}$	$-49.90 \cdot 10^{-6}$	$31.46 \cdot 10^{-6}$
b_2	0.204	0.233	0.278
b_3	48.80	45.55	46.04
		Chequer plate surface	
b_1	$546.8 \cdot 10^{-6}$	$-33.70 \cdot 10^{-6}$	$783.7 \cdot 10^{-6}$
b_2	0.217	0.274	0.235
b_3	44.42	46.01	40.0

For the investigated tyre, the values for b_1 were assumed to be close enough to zero to be neglected. An adaptation to inflation pressure could have been expected but cannot be supported with the present data. The values for b_2 seemed to be of largest importance with an increase of 36% over the investigated space of variables. Since b_2 stretches the characteristics and the inflation pressure dependency depends obviously on the temperature, this is a reasonable meaning of the coefficient. b_3 seems to be significant but its range covers only 11%. An adaptation to inflation pressure cannot either be supported by the present data. Instead, it can be understood as a form factor similar to those in the Magic Formular tyre model. For a simplified model b_1 was set to zero, b_3 was set to 46.8, which is the mean value of the found range of b_3. The values for b_2 were taken from the curve fitting (Table 5) corresponding to a certain pressure. This simplified model is expressed in equation (5) based on curve fitting of available measurements.

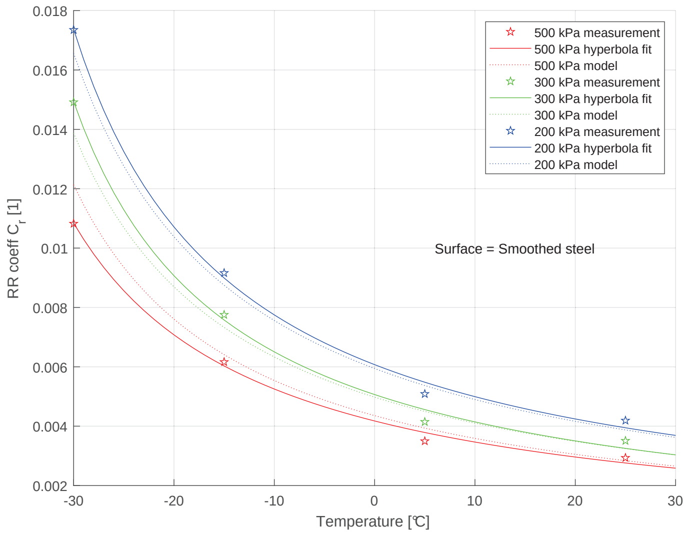
Figure 4 shows the measured data (stars) as well as the corresponding hyperbola fitted for each set of data. In addition, the dotted line shows the results of the simplified model.

$$C_r = \frac{b_2}{T + 46.8} \tag{5}$$

6 Discussion

Regarding the vertical load, even if the confidence intervals do not overlap all over the plot, it can be concluded that the difference in load hardly affects the rolling resistance coefficient. Large differences as shown in Figure 2 in combination with extremely low tyre inflation pressure might affect the rolling resistance coefficient significantly, but the load range is limited on a bicycle.

Figure 4 Rolling resistance coefficient of a 42-559 bicycle tyre over temperature on smoothed steel surface: Measured values (stars), fitted hyperbola curve based on each set of data and general simplified model (dotted lines) (see online version for colours)



Comparing tyres of different width is in general difficult because wider tyres are usually made for bicycles with higher comfort requirements operated with lower inflation pressure. Furthermore, tyres with different width own a different range of recommended inflation pressure, see Table 6. A reasonable comparison might be at 90% of their maximum recommended inflation pressure.

Table 6 Recommended tyre inflation pressure for the tyres used

Tyre size		*Recommended inflation pressure*	
42-559	350	...	550 kPa
50-559	250	...	450 kPa

The results in this study show that rolling resistance is higher for the 42 mm tyre compared to the 50 mm tyre under similar conditions. In average, the increase in rolling resistance is at 10%, whereby the difference increases with increasing tyre pressure (Table 3). However, even if the tyres are compared at 90% of their maximum recommended inflation pressure, the 42 mm tyre still has an 8% higher rolling resistance coefficient than the 50 mm tyre. The influence of an adapted rim width and aerodynamic (dis)advantages are not considered here. Though, this is in contradiction to the findings of Henchoz et al. (2010) who tested racing bike tyres on a treadmill. In Henchoz's experiments the 28 mm tyre had an offset of about 0.002 higher rolling resistance coefficient against a 22 mm tyre.

As far as the tyre inflation pressure is concerned, the results about rolling resistance as function of tyre inflation pressure are not surprising, confirming previous results from e.g., Henchoz et al. (2010), Nilges (2004), Reiser II et al. (2003), Wilson (2004) and Grappe et al. (1999). On solid ground higher inflation pressure leads to a lower rolling resistance coefficient. The correlation is non-linear with strong decrease at low inflation pressure and flattens out at higher inflation pressure (Figures 1 and 2). In addition, the findings about lower rolling resistance on finer road roughness (Rothhämel, 2021) are confirmed.

Finally, the rolling resistance coefficient characteristics over temperature for bicycle tyres has according to the author's knowledge not yet been reported. The characteristic is clearly non-linear increasing with decreasing temperature with a similar shape as rolling resistance coefficient over inflation pressure. Already during 'normal' ambient temperature for usual cycling (above 5°C), there is a significant difference observable that needs to be taken into consideration when performing field measurements or when modelling bicycle tyre behaviour. However, even the curve below the freezing point is of interest where winter cycling is investigated and/or promoted. The coefficients chosen here are valid for the tyres chosen for this investigation. Other tyres might own different characteristics. However, the qualitative non-linear characteristics was seen in other tyre applications, too. Whether b_1 must be adjusted for tyres with generally higher rolling resistance and whether b_3 must be adjusted for tyres with another glass transition temperature such as typical for winter tyres as mentioned by Vennebörger et al. (2013) must be shown in further investigations. Even the influence on road roughness in combination with low ambient temperature is not finally clear.

7 Summary and conclusion

This paper presented measurements of bicycle tyre rolling resistance coefficient with regards to various parameters (i.e., tyre inflation pressure, vertical load, tyre width and ambient temperature). The applied method was a one-degree-of-freedom two-wheeled pendulum, a rigid body, consisting of two bicycle wheels, connected to a pipe that has an attached eccentric weight (pendulum) and additional centred weight to vary the vertical load. The analysis of the results provided various insights regarding the interaction of the various parameters, while an empirical model based on curve fitting of the available data has been presented. The main outcomes of this work can be summarised:

- Vertical load has hardly a specific influence on rolling resistance coefficient but is covered by the definition of the coefficient.
- The wider tyre has less rolling resistance. The difference increases with increasing tyre pressure.
- The well-known influence of tyre inflation pressure on rolling resistance has been confirmed.
- The ambient temperature affects the rolling resistance with a similar characteristics as known from tyre inflation pressure: With decreasing temperature the rolling resistance coefficient increases above average. This is already significant in the temperature range above freeze point.

Most important seems to be the temperature dependency e.g., for tests in the field. The experiments were mainly performed at room temperature on a fine concrete surface and in a climate chamber on smoothed steel and chequer plate as ground surface. The analysis was always based on eleven measurements with the same setting calculating mean values to avoid random errors. An extension on other tyres and possibly other ground surfaces is necessary and suggested for future work.

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Disclosure statement

No potential conflict of interest was reported by the author.

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