# Accurate rolling resistance

## Rolling resistance measurements can be influenced by a number of factors

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Tire rolling resistance is one of the most difficult-to-measure parameters of the tire/pavement interface, especially if road measurements are required. First of all, it is necessary to measure a fairly small force in the system that is heavily loaded by other forces and subjected to many adverse effects causing measurement errors. The second problem is related to the fact that tire rolling resistance depends on many factors, such as temperature, which are difficult to control outside the laboratory.

The Technical University of Gdańsk (TUG) performs tire rolling resistance measurements both in the laboratory using the drum method and on the road using the $R^2$ Mk.2 test trailer.

Typical laboratory measurements (for example, measurements performed according to ISO standards) are executed on smooth steel drums or on drums covered with Safety Walk material, which has a very fine texture. This is the most important drawback of the drum method as deflections of the tread elements are very different on smooth steel than they are on typical, 'real' road surfaces such as SMA or PCC. On top of this, the curvature of the drum makes the footprint of the tire and deflection of its elements very different from that on a typical flat road.

At TUG, all drums are covered with replica road surfaces that replicate the texture of selected real road pavements. The replicas can be seen in Figure 1. There is also one special replica with smooth texture that imitates very uneven pavements with unevenness in the form of a sinusoidal wave of 800mm length and 20mm peak to peak amplitude (Figure 2).

Table 1 describes replicas that were used to perform the measurements reported in this

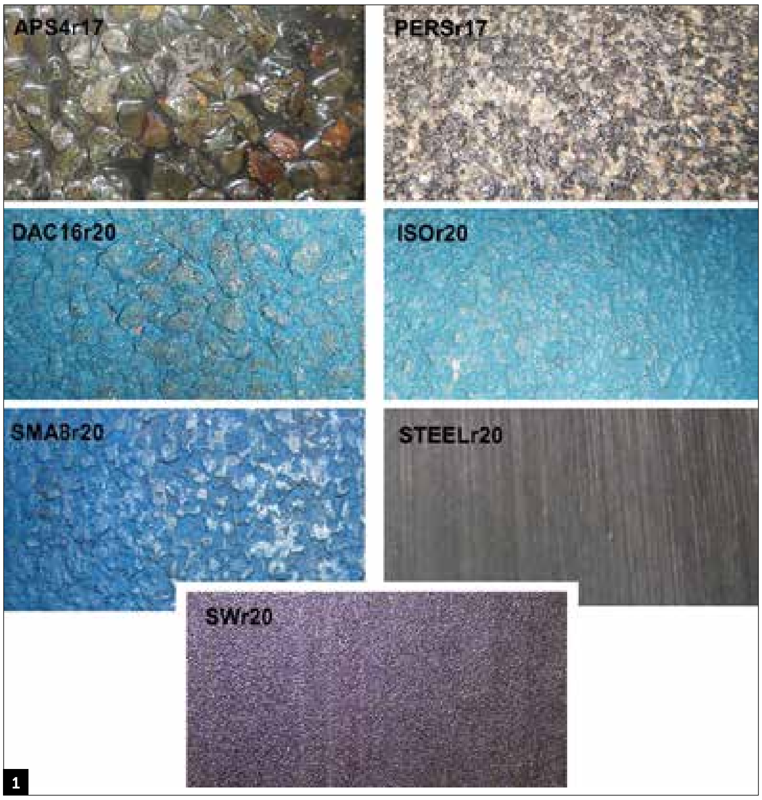



**Figure 1:** Replica road surfaces used at TUG

**Table 1: Description of replica road surfaces**

| Designation | Description | Placement | MPD [mm] |
|---|---|---|---|
| **APS4r17** | Replica of surface dressing 8/10mm aggregate. Mineral chippings connected to the polyurethane base layer by the polyurethane resin | Roadwheel facility 1.7m | 4.75 |
| **PERSr17** | Poroelastic road surface (mineral and rubber aggregate glued by polyurethane resin), 4mm chipping size | Roadwheel facility 1.7m | 1.53 |
| **DAC16r20** | Replica of dense asphalt concrete with 16mm aggregate made as an epoxy laminate | Roadwheel facility 2.0m | 1.33 |
| **ISOr20** | Replica of ISO reference road surface made as an epoxy laminate | Roadwheel facility 2.0m | 1.06 |
| **SMA8r20** | Replica of Stone Mastic Asphalt with 8mm chipping size, made as an epoxy laminate | Roadwheel facility 2.0m | 1.31 |
| **STEELr20** | Smooth steel surface of the drum | Roadwheel facility 2.0m | 0.42 |
| **SWr20** | Safety Walk anti-slip self-adhesive surfacing with grit size "80" made by 3M | Roadwheel facility 2.0m | 0.84 |

Figure 2: Sinusoidal replica that imitates extremely uneven pavement

article. The table also contains information about mean profile depth (MPD) values that are commonly used by road engineers to describe the texture of road pavements.

In the opinion of the authors, road measurements are, by far, more representative for estimation of tire rolling resistance as they are performed on real road surfaces, so the tire/pavement interface is not spoiled by drum curvature and atypical texture. Unfortunately, road measurements are much more difficult to perform, and generally, there are three main methods for taking these measurements: the classic one – coast-down; the trailer method; and the fuel consumption method.

TUG developed and built a special trailer for rolling resistance measurements, named $R^2$ Mk.2, that is frequently used all over Europe and in the USA to make rolling resistance measurements (see Figure 3). TUG believes it to be the most advanced trailer of its type in the world, although this is a specialized field with few competitors. The trailer is based on the 'vertical arm' principle[1] and equipped with sophisticated systems to compensate for the influence of acceleration, road grade and ruts. In Figure 4, some of the details are shown, including a patented system for the correction of road grade and vehicle acceleration.

In order to perform reliable measurements of tire rolling resistance, it is necessary to ascertain realistic and stable measuring conditions such as speed, load, inflation, temperature, pavement texture and pavement conditions.


Figure 3: $R^2$ Mk.2 trailer for tire rolling resistance measurements

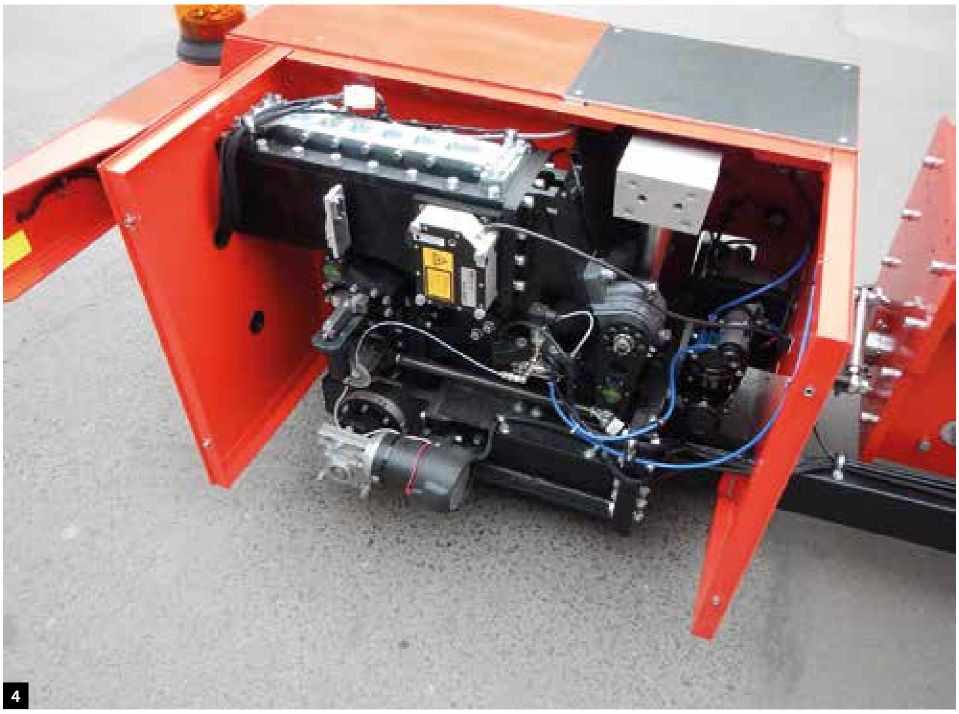


Figure 4: Details of the R² Mk.2 trailer

A full discussion of these conditions follows in the sections below.

## Speed

Speed is one of the easiest parameters to control during laboratory measurements, but it may be somewhat difficult to control during road measurements, especially if the measurements are performed on trafficked road. Although speed does not have much of an influence on rolling resistance in typical driving conditions (50-120km/h), the deviation of the speed (acceleration/deceleration) induces substantial inertia forces in the elements of measuring system and thus may influence results considerably, especially if measurements are made on short test sections.

Experiments performed by TUG show that the best way to eliminate the influence of inertia forces is to use a specially designed mechanical system that creates exactly the same force as the one affecting the measuring system – but acting in the opposite direction. This solution works better than complicated electronic corrections, and what is more, it also corrects road-grade influence.

During typical measurements performed on roads, the exact longitudinal profile of the road is usually unknown, so this is a very welcome feature of the mechanical system used in the R² Mk.2 trailer.

If not corrected, errors caused by road grade and acceleration/deceleration of the test vehicle can easily reach a magnitude higher than the rolling resistance force itself.

## Load and inflation pressure

Load and inflation influence rolling resistance in a very complicated way and this subject has been covered in detail.[2] Tire load increase (for given tire, road pavement and speed) always leads to increase in rolling resistance force at constant inflation pressure. Changes of the coefficients of rolling resistance (CRR) are, however, specific to the tire and pavement combination; thus CRR may decrease, increase or stay fairly constant. Changes of CRR due to load changes can be substantial.

Inflation pressure increase (at constant load) always reduces CRR, but the rate of decrease is very much dependent on the 'absolute level' of rolling resistance. Tires with higher values of CRR are more sensitive to inflation changes than low rolling resistance tires. For low-resistance tires, precision of inflation pressure adjustment is not critical, but for tires with high rolling resistance, even small inflation pressure changes can lead to substantial changes of rolling resistance – up to 3.5% for a 10kPa change of inflation pressure.

So in order to assure good precision of on-road rolling resistance measurements, it is better to regulate inflation pressure in warm conditions, as tires that have capped inflation pressure may reach different final inflation pressure during tests due to different cooling conditions. The R² Mk.2 trailer is designed in such a way that tire inflation pressure can be adjusted in cold conditions (capped inflation pressure), or it can be stabilized at a certain value during the measurements (regulated inflation pressure).

## Temperature

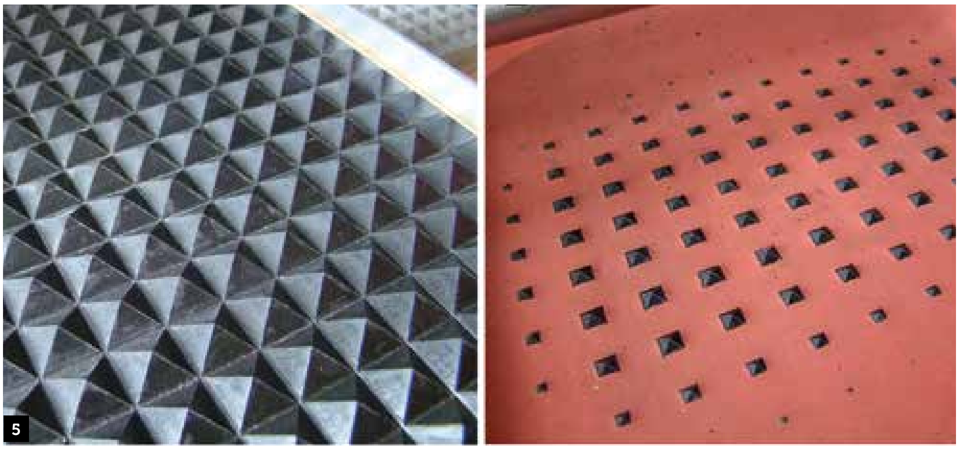
Temperature is a very important factor in the rolling resistance of tires. There are at least three different temperatures that may be considered as important factors controlling the thermal conditions of the rolling tire. The most common measure of the thermal conditions during tire rolling is ambient air temperature; the other two are pavement temperature and tire temperature. Tire temperature is the most difficult to establish, as temperatures of different parts of rolling tires differ considerably, thus it is difficult to obtain representative values.

All measurements performed in 'non standard' temperatures must be corrected to the standard temperature (usually 25°C) using a procedure described elsewhere.[3] The warming-up process of the tire must be carefully monitored and must be performed in exactly the same conditions as subsequent measurements. The measurements can start only if tire temperature stabilizes for the given test conditions. The typical warming-up period for passenger car tires is 20-30 minutes.

All abnormal thermal conditions (for example, very hot or cold pavement) have an adverse effect on the precision of the correction, so it is not recommended that you perform standard road measurements of tire rolling resistance if the temperature differs more than 5°C from the reference temperature of 25°C and if the road pavement has atypical thermal conditions (after cold rain or during strong sunshine).

## Pavement texture

Tire performance is strongly related to the road surface characteristics, most notably to the pavement texture. Mean profile depth (MPD) is one of the most common descriptors of road surface texture and in many studies it is correlated with tire rolling



interference of tire tread with typical textured pavement. In comparison with real road surfaces, the curved, smooth steel drum induces greater deflections of tire sidewalls while it doesn't create local deflections of the tread elements that are penetrated by the protruding chippings of the road pavement. Deflections of the tire elements (especially sidewalls, belt and tread elements) are directly responsible for energy losses and thus create rolling resistance.

In the opinion of the authors, bad correlation between tire-label energy-efficiency data and real-life performance is primarily caused by the inadequate method that is used to establish the rolling resistance of tires during standard laboratory measurements. **tire**

resistance. Results of measurements performed by the TUG show that although the correlation exists, it is not very strong and regression between MPD and rolling resistance is not linear.[4] The key reason for this is partial enveloping of the tire tread. This phenomenon is presented in Figure 5. In the left part of the picture, a very simple geometrical texture (6mm-high pyramids) is presented, while in the right part, it shows which part of this texture has real contact with smooth tire tread. It shows that only the summits of pyramids interface tire tread and the depth of the local tread deflections is only 2mm (in comparison with the pyramids' height of 6mm). This explains why MPD that is based on the texture shape from the very top of 'summits' to the very bottom of 'valleys' doesn't correlate well with rolling resistance that is influenced only by the texture contacting (penetrating) tread elements.

Many sources state that MPD correlates well with rolling resistance and shows correlation as high as $R^2$=0.90 or even more. This is true only if very rough pavements (for example surface dressing) with an MPD about 4mm are included (see Figure 6). When correlation is based on more common pavements with an MPD between 0.5mm and 1.5mm (the cluster of results in the lower left corner of Figure 6) it drops down to about $R^2$ = 0.4.

A similar situation is seen during laboratory drum measurements of rolling resistance. In Figure 7, the CRR obtained for selected tires and data averaged for 40 tires is shown. The measurements were performed on replica road surfaces as described in Table 1. It is clearly visible that good correlation is obtained only because of replica APS4r17 that has MPD = 4.75 mm. Results obtained on more common surfaces with an MPD <1.5mm have a very much worse correlation with texture.

**Figure 5:** Experimental surface with uniformly spaced 6mm-high pyramids (a) and the same surface covered by silicone resin that was formed by enveloping tread of smooth tire (b)

**Figure 6:** Results of rolling resistance measurements on test sections at IFSTTAR test track (France) at speeds of 50km/h and 80km/h averaged for four tires (including tire for electric cars)

**Figure 7:** Rolling resistance coefficients $C_{RR}$ for selected tires and data averaged for 40 tires

## Conclusion

Most tire industry rolling resistance measurements are performed by the laboratory method on smooth steel drums according to ISO standards. Interference of the tire tread with ultra-smooth steel is different to

## References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