Road surface friction and motorcycling

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Introduction

Friction force, or skid resistance, is important to avoid the wheels of a vehicle losing grip on the road surface which increase the risk of crashing. Friction is crucial for the safety of all road users. The skid resistance is related to many factors, and it is known to be a function of pavement construction materials[1 2], pavement roughnes[3], and surface conditions[4]. The friction is determined by adhesion (created by intermolecular binding or adherence at the surface level) and hysteresis grip.

For motorcycles this is even more important than for two-track vehicles, because loss of grip may lead to loss of balance and crashes. Present ways to measure friction are developed for cars and do not consider that motorcyclists use the whole lane and try to stay out of the ruts that are caused by the wheels of cars and trucks. Also, in current measure methods and protocols, as well as in the follow-up, it is not considered that a tiny slippery patch is enough to cause loss of balance for a motorcycle.

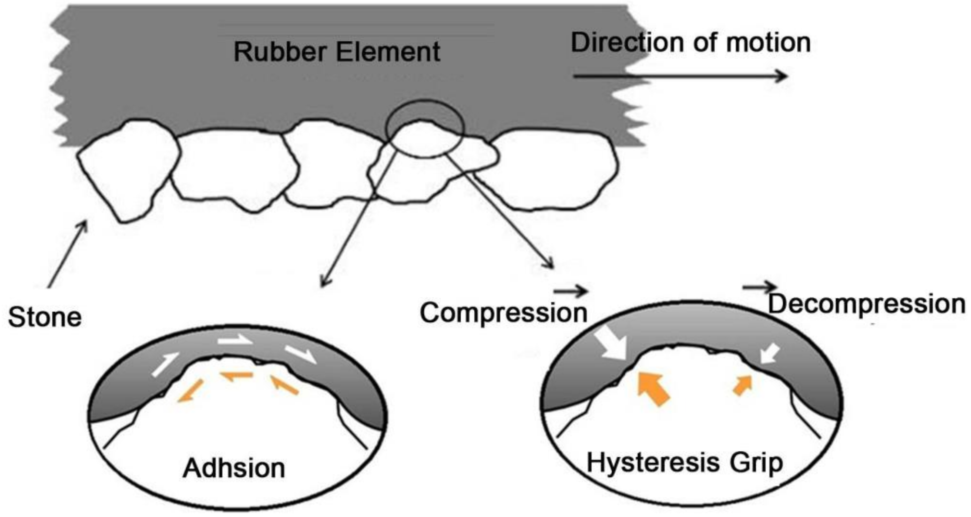

Figure 1. Schematic plot of hysteresis and adhesion, source: Choubane, B., Holzschuher, C. and Gokhale, S. (2004) Precision of Locked-Wheel Testers for Measurement of Roadway Surface Friction Characteristics. Transportation Research Record: Journal of the Transportation Research Board, 1869, 145-151 (23).

Motorcyclists must be aware of dangerous surface conditions, how to detect them and to ride in an appropriate speed. This means that riders are obliged to maintain the ability of either stopping in advance or swerving around low-friction areas at any time. However, poor friction cannot always be detected by visual scanning. There is no possibility of a correct estimation of a wet road's friction coefficient with the eyes only. Underneath modern high-friction road markings, old material may reappear by wear suddenly. Even "normal" road surface may have much lower friction than the visual impression suggests. Thus, it is inappropriate to always blame a rider for a crash.

Loss of friction causes crashes

Loss of grip can occur when a road surface has lost some of its friction because of wear, because of the weather (water, snow, ice) and because of bitumen bleeding, badly executed repairs, manhole covers, road markings, wrong choice of aggregate, gravel, spillage and similar. Uncontrolled skidding due to inadequate surface friction and poor visibility due to splash and spray have been found to be the two primary causes of wet weather crashes with skidding alone contributing to 15% to 35% of all wet weather crashes[5].

The MAIDS report[6] shows that 29.7% of the single two-wheel vehicle crashes happen because of sliding. The Riderscan report[7] found that 88.5% of the surveyed riders saw road maintenance as the main infrastructure problem for sliding and 79.6% saw the road surface as an infrastructure problem.

The NCHRP Guide for Pavement Friction[15] mentions several sources that indicate a direct relation between road surface frictions and crashes. One of them is a research report from Wallman and Åstrom. In this research, a comprehensive evaluation of friction measurements and crash rates revealed that increasing pavement friction does reduce crash rates significantly, as summarized in table 1.

Friction Interval	Crash Rate (injuries per million vehicle km)
< 0.15	0.80
0.15 – 0.24	0.55
0.25 – 0.34	0.25
0.35 – 0.44	0.20

Table 1: Correlation between friction and crashes

However, recognition of the issue is not universal. In other publications, for example, the DEKRA Motorcycle Road Safety Report of 2010[8], the issue of friction and road surface is ignored.

Friction coefficient

The Coefficient of Friction (COF) is the relationship between the force required to move the surfaces against each other and the pressure to stay in contact while in motion[9]. It defines the slipperiness of a road surface.

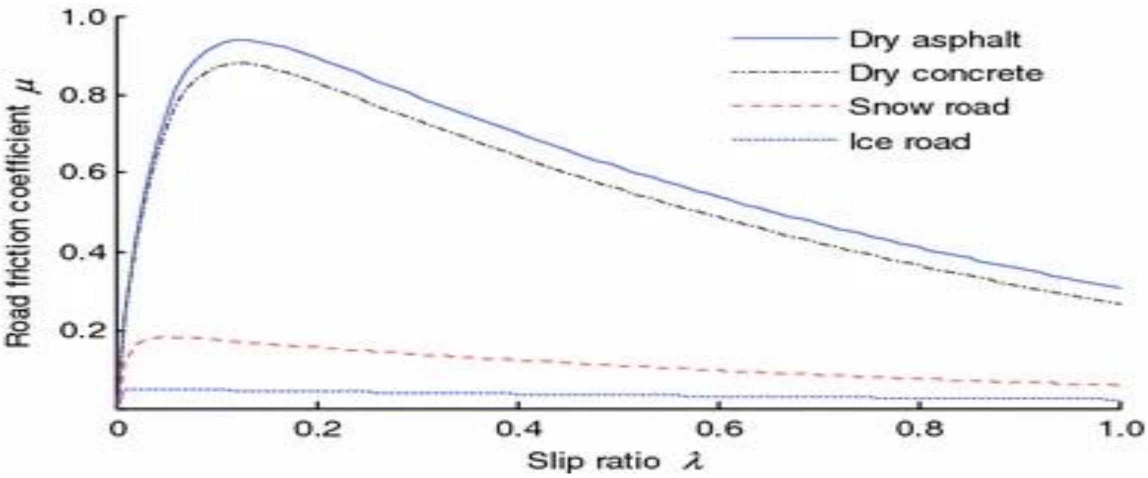

Figure 2, Relationship COF vs. slip ratio (source: Zhao et.al., Estimation of Road Friction Coefficient in Different Road Conditions Based on Vehicle Braking Dynamics).

In the context of motorcycles, it is the relationship between the force required to get the tire into a slip on the road and the skid resistance of the road surface. The higher the friction coefficient is, the more force is required to get the tire into a slip. The value of the friction coefficient depends on the micro- and macrostructure of the road surface and of the quality of the tire. Zhao et.al.[10] shows us the correlation between COF and slip ratio (Figure 2).

Pavement skid resistance is primarily a function of the surface macro texture and micro texture. There is a definition for both macro and micro texture on the wavelengths range in ISO standards.
Micro texture refers to small irregularities on the pavement surface (fine-scale texture), and it is related mostly to aggregate surface texture and the ability of the aggregate to maintain this texture against the polishing action of traffic and environmental factors. The friction coefficient decreases with skid speed, which in turn depends on the speed of vehicle and degree of brake application or the brake efficiency. The friction coefficient also decreases slightly with increase in pavement temperature and tyre/wheel pressure. Contrary to what many motorcyclists think, the lean angel of the wheel is not relevant here[14].

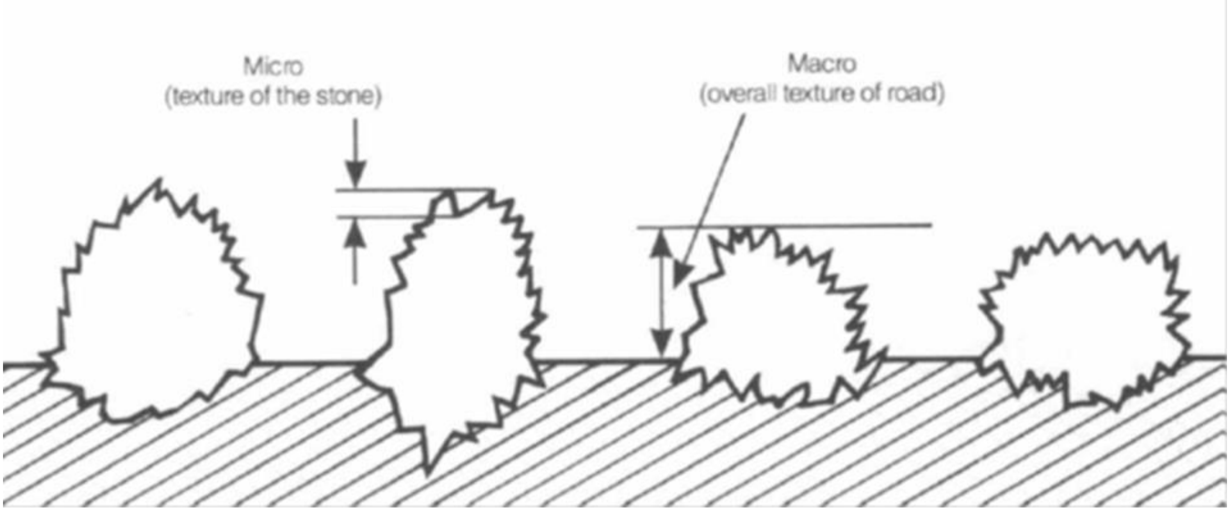

Figure 3. Micro- and macro texture. Source: Umair, report on basis skid resistance test

Macro texture refers to the large irregularities on the road surface (coarse-scale texture) that are associated with voids between aggregate particles. The magnitude of the macrotexture depends on the size, shape, and distribution of coarse aggregates used in pavement construction as well as the construction techniques used in the placement of the pavement surface layer. In wet circumstances both the micro-texture and the macro-texture are important. Micro-texture plays a considerable role in the road-tire contact in wet surfaces. The size of micro asperities has a significant trace in overcoming the thin water film.

Squeezing and overcoming the thin water film present in the pavement-tire contact area and generating friction forces requires the existence of micro-texture[15]. Moreover, to maintain a confident contact between tire and pavement, the micro-texture has a great role to penetrate thin water film present on the surface of the pavement. The shape of micro asperities controls the drainage process.

Macro-texture is important for the drainage of water at higher speed. Too little macro-texture may cause a too thick water film, which the tyre cannot force away. In time, because of the wear by the tires, the aggregate in the pavement that provides the structure get polished in the direction of the traffic and gradually loses its skid resistance.

Cause for poor friction

Poor friction can be caused by wear (aggregate becomes polished, less micro-structure), weather (water, snow, ice), use of bad materials, bitumen bleeding, badly executed repairs, manhole covers, (rubber or metal) speed bumps, road markings, loose grid, gravel, and sand, oil or diesel leakage and manhole covers. The location of manholes is a matter of design, and they should be in the footway and not in the carriageway. When this is unavoidable (or in existing situations) the manhole covers should have an ant-skid treatment on top. As is mentioned before, the need of predictable friction is crucial among all motorcyclists.

A study of WSP[16] in 2017 commissioned by the Sveriges MotorCyclister (SMC) showed that loose gravel leads to a reduction of friction from 0.8 to 0.35, while with diesel spills the friction went from 0.8 to 0.3. One common denominator for poor friction are failures in the maintenance process. This is the case in Sweden where gravel, mainly from road repair, is the most common cause for single vehicle crashes according to the leading insurance company Svedea. A recent study based on seriously injured vulnerable road users registered in the crash database Strada (Swedish Traffic Accident Data Acquisition) for the years 2014–2019 shows that loose grit was the most common cause for crashes among moped riders and motorcyclists. 21 percent of the motorcyclists and 22 percent of the moped riders were seriously injured due to a crash caused by gravel. These crashes were mainly an effect of poor maintenance. Uneven surface/potholes were also common, between 9 and 17 percent depending on the road user category (22).

Measuring the friction coefficient

There are several ways to measure the friction coefficient of the road surface. Skid resistance (friction) on road sections is usually measured by moving a (partially) braked wheel along the pavement, either fitted on a trailer or to a truck. In Europe braked-wheel or fixed-slip testing methods are still standard (described in CEN/TS 13036-2). The average skid resistance is calculated on road sections of 20 to 100 metres and most of them have the measuring wheel located in the right wheel track or both wheel tracks. For wet road surfaces the loss of skid resistance tends to increase progressively with increasing speed. Statistics show that the risk of crash is much higher on wet roads. Therefore, the measurements are done on wet roads. To this aim water is sprayed before the testing wheel to simulate a wet road.

COF is an empirical measure, a result of practical experiments and comparisons rather than theoretical calculations. As far as we can find, there is currently no standardized scale for road friction.

In general, it can be said that asphalt and concrete roads in dry condition have a COF of 0.7 to 0.8 and with a wet surface from 0.4 to 0.5, With snow the COF drops to 0.2 to 0.3 and icy roads have a COF from 0.1 to 0.212. The World Road Association indicates that the friction coefficient decreased on the road below 0.45 will increase the risk of crashes 20 times; when it goes below 0.30 the risk is 300 times higher (13). There are several methods to measure the friction.

Skid resistance can be measured in a stationary way with pendulums and in a dynamic way, usually with a trailer with a wheel that is attached to a truck or a trailer in a predetermined (15^o -**2**0^o) to the direction of the vehicle (Sideway Force Friction Coefficient, SFC) or is attached in the direction of travel (Longitudinal Friction Coefficient, LFC). The way this is executed divers in kind, pattern and size of tyre, inflation pressure, vertical load, slip ratio, angle of the tire to the direction of the vehicle (with

SFC). AIT[24] found that an angle of 18º with the RoadSTAR measures resembles best the braking of a passenger car with ABS.

Figure 4 illustrates the large variety of vehicles in use in Europe. It is outside the scope of this document to go further into the differences of measuring. There as also differences in the stretches of road that are used for calculating the skid resistance and the way these values are reported. The UK standard CS228 prescribes a length of 10 metres for bends and roundabouts or where the surface material is known to be variable.

Figure 4. Participants of European Friction Workshop 2019 / Nantes. Photo courtesy of AIT

There is a need of a defined standard with minimum demands for asphalt and concrete roads. Note that this is for the whole road pavement including manhole covers, sealings, road markings, road surface repairs and joint transitions.

The car-trailer combination drives to the upmost right side of the lane the test wheel is effectively situated in the track that is closest to the roadside. The outcomes consist of measurement results of 5-10 cm road lengths that are added to calculate an average on a length of the road between 20 and 100+ metres. However, tracks of 5 metres or less that have a skid resistance that is below the standard can also be reported to the client. The tests can be measured in tracks of 2 meters. This is important since a small section with poor friction can cause loss of control and end with serious crashes for a motorcyclist even if the average on 20 meters is above the required limit.

Road repairs that have become slippery, or other surface issues such as bitumen bleeding, manhole covers or road markings, can be over the width of the road and between the wheel tracks of cars and trucks. These tracks are often not measured using current methods. Sealings between the lanes can also be very slippery and have caused several severe and fatal crashes. In Sweden, this led to new regulations and demands on the width of the sealing as well as measures to minimize overflow of bitumen and instant sanding if this is the case.

The NCHRP Guide for Pavement Friction recommends a visual assessment of the rest of the area: "*Is the rest of the area of the maintained pavement surface visually consistent with the measured path, or are there any localized areas of polished surfacing, low texture depth, patching, or areas otherwise likely to give rise to uneven friction (i.e., is it likely that the friction of other lanes could be lower than the lane tested)?*"

As addition to regular inspections, a semi-automatic inspection can be done, using a specific motorcycle for safety inspections, for example the Austrian MoProVe motorcycle[25]. The MoProVe is a sensor-equipped motorcycle, that is used for risk analyses and safety inspections, based on collected vehicle dynamics data. The MoProVe is a rolling road infrastructure laboratory which makes it possible to create risk maps and risk models, based on processed data. It can also deliver objective and comparable observations of safety relevant parameters. The integrated use of AI-methods opens the field for data cross-validation, big data analytics and risk prediction models (Motorcycle probe vehicle, AIT Austrian Institute of Technology GMBH). This needs to be further investigated.

Data availability and multiple data sources for traffic safety research

Highly relevant for further steps within road safety research and the increase of the state of the art, as well as opportunities developing new, innovative safety measures, are the possibility to use existing data (public or stakeholder-owned). Road authorities, road operators, service providers, infrastructure and vehicle industry are collecting large amounts of various data on a regular basis, for example about friction, potholes, crashes, and roadside environment.

Data, which feed their own systems, models, and investigations – e. g. predictive road maintenance systems, using road surface condition data; or map /navigation system providers, collecting route and vehicle dynamics data of the road users; can be used to identify new patterns and relevant safety trends for different stakeholders dealing with different part of the transport system. A smart correlation, joint analytics and interfaces between different data bases and sources, will open new opportunities for predictive safety systems, that integrate safety forecasts such as assistant systems, that include road, traffic, and weather information. When using multiple data sources, it is possible to provide a completer and more accurate picture of road safety issues. Each data source has its strengths and weaknesses and combining them can help compensate for any limitations and provide a more comprehensive understanding of road safety issues. Using different data sources also allows cross-validation of results, which helps to ensure that findings are robust and reliable. If multiple data sources are showing similar results, it increases confidence in the findings. Any cross-link of different parameters enhances the chance to calculate or simulate new interrelations, dependencies, and potential risk causal correlations, which are the baseline for future risk mitigation measures. Floating vehicle data, cloud-based information, netwide measurement data, and others must be made available for road safety experts and research purposes, to develop smart safety systems and solutions, e. g., working in real-time or to be used as training material for self-learning (AI) systems. The overlaying of data sets helps to improve the quality of the data itself, due to identifying inconsistencies and errors in data sets. The overall benefit of using multiple data sources, is the possibility to provide a more robust evidence base to support cost-efficient, eco-efficient and sustainable decisions, while improving road safety.

Summary and conclusions

Motorcyclists use the whole width of the road, depending on the circumstances. The commonly used devices measure the skid resistance on the part of the road where usually the right wheels (or left wheels in countries where traffic keep to the left) of the vehicles are that drive in the most outside lane of the road in case there is more than one lane each direction. This place is chosen because the wear is strongest there, but this is not where motorcycles ride. Thus, it is important to measure the entire road. It is also important to measure and report the entire road section instead of an average of 20 meters since a tiny section with low friction can lead to serious crashes. The problem with the above-described measure methods is that only part of the road is measured and not necessarily the part that is used by motorcycles.

There is a need for new and improved methods to measure the road surface skid resistance. Partially, and in the future perhaps entirely, this could be solved by making use of camera- and lidar techniques (3-D scan) as are already used in small scale in several countries. Current laser profilers can measure with resolutions smaller than 0.1 mm.

Inspection, management, and enforcement

Regular inspections, maintenance, and enforcement of maintenance was found to be scarce. The EU Road Infrastructure Safety Management (RISM) Directive[1] (Directive 2008/96/EC) was revised in 2019. It mentions maintenance of pavement defects and pavement skid resistance as indicated elements of network-wide road safety assessments, but it gives no other guidance. It does not contain minimum standards for road surface friction, and it is not mentioned in relation to motorcyclists. National regulations about skid resistance and maintenance often exist, but not in the form of a law. Nevertheless, the regulations are often, but not always, legally binding or represent the state of the art and are therefore important in lawsuits when crashes happen.

The NCHRP Guide for Pavement Friction defines three basic elements that are considered vital to any successful pavement friction management (PFM) program:

- A system for evaluating in-service pavements for friction (Collect and analyse friction data of representative pavement sections a network to develop an understanding of how effective pavement design, construction, and maintenance practices are in providing good friction characteristics).
- A system for correlating available friction with wet-weather crashes (Develop an understanding of how pavement friction properties impact crash risk).
- Guidance on the design, construction, and maintenance of pavement surfaces with adequate surface friction throughout the pavement design life (Utilize pavement design, construction, and maintenance practices that result in good friction characteristics to minimize wet weather crashes).

Regular or mandatory inspections also means that there is a need for standards. These can be found in the CEN Technical Specification 13036-2:2010 “Assessment of the skid resistance of a road pavement surface by the use of dynamic measuring systems”, see above.

[1] Directive 2008/96/EC on road infrastructure safety management amended on 23 October 2019 by Directive EU/2019/1936.

Conclusion

One important issue is the responsibility for the road inspections and what party that will perform it. This could be the road authority itself or a subsidiary organisation. It could also be the private road operator who is responsible for the maintenance of the road or an independent third party. Examples of the last are AIT in Austria, Kiwa KOAC in the Netherlands. In Sweden the maintenance inspections are done by the private road operator who at the same time is in charge of the maintenance of the road. In the Netherlands, maintaining road surface quality is part of the road maintenance plans of the road authorities, like the Multi-Year Road Maintenance Plan (MJPV) of Rijkswaterstaat, the Dutch highway authority[20]. Like the United Kingdom, the Dutch road authorities are liable for the condition of the roads.

Friction testing and motorcycles

There is very little information available about friction testing in relation to motorcycles, although both the importance to test the friction on the entire road as well as reporting on smaller sections than 20 meters are important to ensure that a road in this respect is safe for all road users, including motorcycles, as is shown in the Swedish tests by the WSP Group.[16]

Costs and benefits of friction testing

The road authority may be confronted with extra costs when testing and following up on the testing. This may include:

- Additional design and engineering costs.
- Aggregate materials with required frictional properties.
- Additives, including polymers, to improve surface properties and performance.
- Frequency/duration of restoration activities may also impact costs. Factors to be considered are:
    - Design strategies involving frequent maintenance and repair are typically more costly overall because of the effects of highway user delay costs, traffic control, and so on.
    - Timing of maintenance and repair can significantly escalate costs if maintenance and repair to restore surface friction does not coincide with maintenance and repair to restore structural capacity.

However, there are clear benefits associated with maintenance of good road pavement friction, namely improving road safety, and reducing the number of people killed and seriously injured due to motorcycle crashes. These benefits can be quantified in terms of:

- Reduction in crash costs.
    - Value of lives saved.
    - Value of injuries avoided (medical, loss income, psychological damage).
    - Savings in pain and suffering of crash victims and their families due to a reduction in crashes, and
    - Reductions in property damage due to reduction in crashes.

- Non-monetary benefits associated with improved pavement friction include:
    - Reduced pavement–tire noise.
    - Reduced splash and spray (and thus improved sight distance in wet conditions)
    - Reduced fuel consumption/rolling resistance.
    - Reduced tire wear, and
    - Reduced reflectance and glare.

Available resources

The report Quantifying the Costs and Benefits of Pavement Retexturing as a Pavement Preservation Tool of the e University of Oklahoma[20] provides tools to calculate the best ways to make informed engineering and management decision to preserve the pavement. Skid testing is part of this toolbox.

The iRAP Road Safety Toolkit provides guidance for road managers on the importance of maintaining good skid resistance, including case studies and quantification of the benefits. Skid resistance is described as having low-medium cost, with a life of 5-10 years and 25-40% effectiveness in terms of crash reduction.

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