STATE OF THE ART ON FRICTION AND TEXTURE MEASUREMENTS

ir. T.A. Bennis & ing. L.B. de Wit
Ministry of Transport, Public Works and Water Management
Road and Hydraulic Engineering Institute
P.O. Box 5044, NL-2600 GA Delft, The Netherlands
Tel. +31 15 2518518, fax +31 15 2518555
e-mail t.bennis@dww.rws.minvenw.nl & l.b.dwit@dww.rws.minvenw.nl

ABSTRACT

This paper describes the state of the art on friction and texture. After an introduction (paragraph 1) paragraph 2 describes the importance of regular friction measurements. Paragraph 3 will describe existing problems related to the current practice, like the comparability of different devices and influences of temperature, road pollution and ageing of tyres. Then, in paragraph 4, a categorisation will be given of friction and texture measurement devices currently used around the world. Next new developments as the IFI, EFI, HERMES, the calibration of devices and other new developments are discussed. This paper will end with conclusions and recommendations.

KEY WORDS

PAVEMENT / SKID RESISTANCE / TEXTURE / MEASUREMENT

1. INTRODUCTION

This paper presents the state of the art on friction and texture measurements.

Friction is an important property of a road surface. An adequate friction between the tyres of a vehicle and the road is necessary to make the desired movements (accelerating, steering and braking) possible. Insufficient friction may cause loss of vehicle control, which might result in accidents.

It is important for a road authority to ensure that roads have adequate friction properties. So a regular monitoring of the actual friction properties is necessary. Friction measurements are performed for several reasons, that will be described in paragraph 2. To establish intervention levels, studies have been made into the relation between friction and traffic safety (risk of accidents involving lack of friction). As the properties of roads and cars change in time and some studies have been made decades ago, some countries decided to establish new intervention levels in the near future.

The measured actual friction value of a certain road is not constant in time, but is influenced by external factors like temperature, road pollution and ageing of tyres that change the road properties and the measurement conditions. These factors will be dealt with in more detail in paragraph 3.

As the need for friction measurements did not emerge at the same time in different countries, the measurement devices and conditions are developed nationally. The differences between devices and conditions make direct comparisons impossible. These differences also led to different intervention levels per country that may cause changes in allowed friction level between countries. A number of different categories of measurement types will be described in paragraph 4.

In the last ten years many efforts have been made to make friction results of different devices comparable. New developments to enhance the comparability of devices are the International PIARC experiment (which produced an International Friction Index, IFI) and European harmonization (EFI), followed by a European study (HERMES). The different studies (see paragraph 5) showed that to improve the comparability a measurement of macrotexture is desirable. This type of measurement is traditionally done with a sand patch test. In the last ten years (laser) texture devices that can measure statically or dynamically (at normal traffic speeds) replace the sand patch test more and more. The different types of (laser) texture measurement devices will be described as well.

Other new developments that will be described in paragraph 6 are the following.

- Measurement of the whole slip – friction curve, which gives more information about the friction properties of a road.
- A study into the relation between longitudinal and transverse friction, which is especially important in curves. A Dutch study showed that situations might exist with a poor transverse friction but a good longitudinal friction. In such a situation a measurement of longitudinal friction only is not sufficient to assure that the necessary friction is available.
- The replacement of the rubber of the tyre (the source of much variation in friction) by a polymer or another type of rubber with less variation in properties.
- A measurement of the combination of microtexture and macrotexture (with a texture device) as a replacement for a friction measurement. With the increasing accuracy of (laser) texture devices the measurement of microtexture with normal traffic speeds may become possible within several years.
- Plans in France and the United Kingdom (within the framework of the HERMES project) to develop a reference device and reference surfaces to decrease the amount of variation when making comparative measurements.

The paper ends with conclusions and recommendations (paragraph 7).

2. WHY TO MEASURE FRICTION?

2.1. General

It is important for a road authority to ensure that roads have adequate friction properties. A road authority is liable for the results of accidents involving lack of friction. So a regular monitoring of the actual friction properties is necessary. This is usually done by a periodic monitoring of all roads in a network, by quality control of new roads (to assure that the initial friction is adequate) and measurements after accidents.

2.2. Measurement purposes

Monitoring for PMS
In several countries a periodic monitoring of all roads in a network is performed. Usually besides friction several other parameters are measured like longitudinal and transverse evenness and visual damage (cracks, ravelling, etc.). All the measurement data can be entered into a PMS (Pavement Management System). Based on historical data and knowledge of deterioration over time, the system can predict for some parameters when

intervention levels will be exceeded. With this information a maintenance program can be drawn up.

Quality control of new roads
To assure an adequate friction during the whole lifetime of a pavement, the initial friction has to be sufficiently high. Many countries have formulated minimum friction values for new pavements. Before being accepted, measurements must prove that the standards are met.

Measurements after accidents
It can happen that several accidents possibly involving lack of friction happen at the same spot on a road. This can lead to doubts whether the friction intervention level is still met. This can be a reason to perform additional measurements on that spot. If the friction is insufficient, measures can be taken on a short term to bring the friction to an acceptable level.

2.3. Friction and safety

An important aspect of friction evaluation is the establishing of intervention levels. Without sensible intervention levels a friction measurement is useless. The most practical way to determine intervention levels is by making a comparison between friction and traffic safety. This has been done in several countries e.g. the United Kingdom and The Netherlands.

The United Kingdom has a long tradition with research into the relation between friction and safety (Hosking, 1992). Already in 1956 Giles proposed friction standards, based on four categories of roads. The requirements ranged from 0.6 for category A (most difficult sites) to no requirement for category D (proved sites), based on a SCRIM measurement at 30 mile/h. The proposals were formulated after comprehensive studies of tyre/road adhesion during braking and manoeuvring, together with studies at accident black spots. These recommendations, with some changes (among other things the omission of category D), were included in a report of the Ministry of Transport's Marshall Committee on Highway Maintenance in 1970.

In 1970 the Transport and Road Research Laboratory started to make standards acceptable for all parties. The standards were based on Giles's and Marshall's recommendations, but were improved by incorporating the results of further research. Category A was divided into two categories A1 and A2. For each category, the minimum value of SFC required (measured with 50 km/h) should additionally be dependent on a risk rating, which was to be determined locally by the accident potential of the site. Recommendations for texture were included as well: 2.0 mm for new bituminous surfacings and 0.8 mm for new concrete surfacings. To limit the drop in friction with increase of speed, maintenance was required at 1.0 mm and 0.5 mm respectively.

The first mandatory skidding standards for in-service roads in the United Kindom were those published by the Department of Transport in 1988 in Departmental Standard HD 15/87 and Advice Note HA 36/87. These apply to in-service trunk roads. These standards require that one third of the trunk road network is tested for skid resistance each year and the full network over a three-year period. Investigatory levels are prescribed, based on 13 categories. 11 Categories need to be measured with the SCRIM at 50 km/h, 2 categories (sharp curves, roundabouts) at 20 km/h.

In The Netherlands a safety study was done in the late sixties of the last century. All accident data of some years were analysed. Only accidents involving lack of friction were selected. The friction values on these road sections were compared with those on road sections without accidents. Based on the distribution of friction values in both groups an intervention level for in-service roads has been chosen. Acceptance levels for new roads have been chosen accordingly in such a way that it is not likely that the intervention level will be exceeded during the lifetime of the pavement.

This study has been done several decades ago. Since then a lot has been changed in the traffic: there are new pavement types like porous asphalt, roads are busier then before, cars have changed (many cars have ABS nowadays) and also the tyres have been developed. For these reasons, a new study will be executed the coming years.

In (Wallman and Åström, 2001) a German regression analysis between friction numbers and accidents is described, based on the proportion of wet road accidents. On most road sections this proportion varies between zero per cent and approximately 50% and averages about 33%. If on any particular section of road the proportion significantly exceeds this range, this may be a sign of reduced traffic safety under wet conditions.

3. PROBLEMS RELATED TO THE CURRENT PRACTICE

3.1. Influence of temperature

The temperature of the air, road and tyre has influence on the measured friction: friction decreases when temperature increases. It is therefore that some countries restrict the air temperature or the period of the year in which measurements may be done. Sometimes values measured during several months are averaged to obtain a mean summer value. Another solution is to find a relation between temperature and friction. In that case measured values can be corrected to a ‘standard’ temperature. Several studies showed a sinusoidal form of the friction variation within a year. The implementation of a correction model is underway (see paragraph 3.3).

3.2. Influence of road pollution

During long dry periods the surface of a road may become polluted with rubber and oil. During the first rain after such a period the rubber and oil will be loosed from the road and the friction will drop considerably to a value lower then usual during rain (see the example in Figure 1). If a wet friction measurement is made in such a period the friction values, although representative for the actual friction, will not be representative for the condition of the pavement. The possible presence of this influence needs always been taken into account when making measurements.

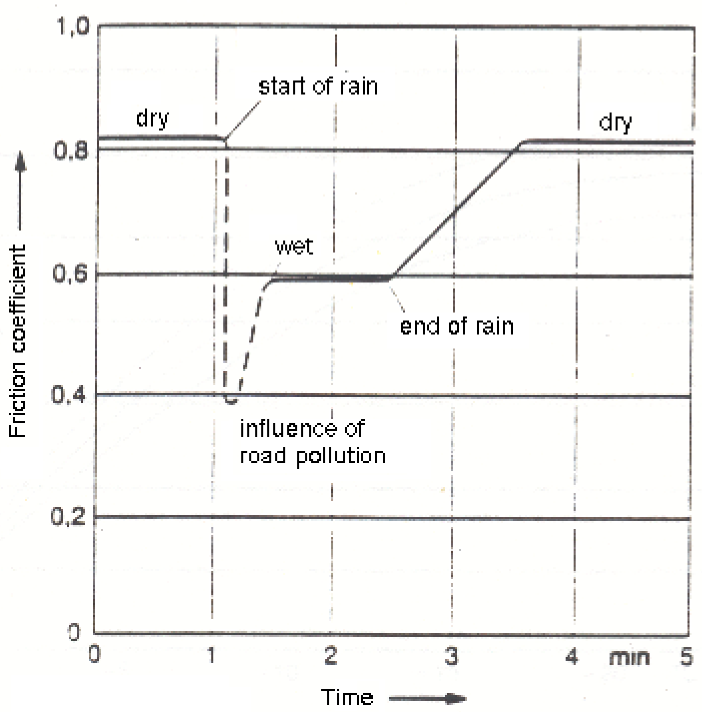

Figure 1 – Influence of road pollution on friction

3.3. Influence of ageing of tyres

Measurement tyres are only produced on request of the users. Due to the high costs this is only done once every five or ten years for many users together. That means that tyres are kept in stock for a long period. During these years the hardness of the tyres will increase due to ageing. This increased hardness has influence on the measured friction. Figure 2 shows the differences in friction between an old series of PIARC tyres (manufactured in 1990) and a new series (manufactured in 1998). The differences are caused by ageing of the tyres and slight differences in the rubber composition of both series. It is clear that special attention with respect to the storage of tyres and/or a correction for the hardness is necessary. It can be seen that the friction differences are not the same for all pavement types.

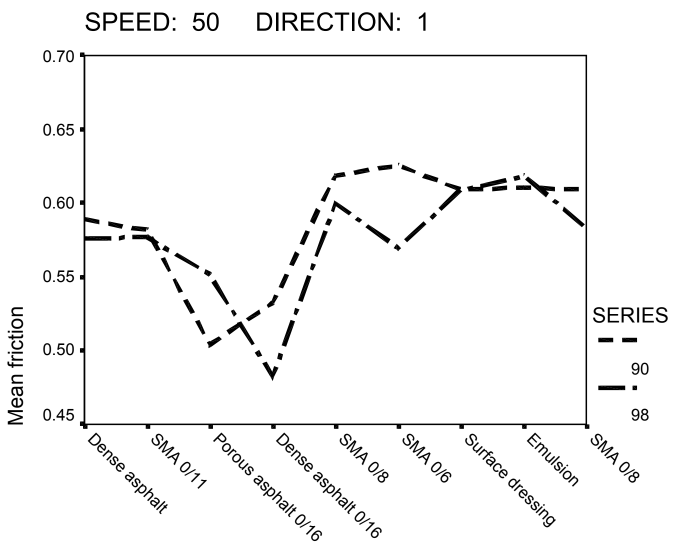

Figure 2 – Friction differences between different series of PIARC tyres

A Dutch study (Schoen and Bakker, 2001) showed that the differences between tyres and the influence of temperature and speed could be described with the macrotexture of the road, the hardness and the temperature of the tyre. So a correction should be dependent of the macrotexture. The usefulness of this model will be tested in the coming period. If successful, implementation will follow.

PIARC Committee C1 (Surface Characteristics) is investigating the problems due to ageing of tyres, in order to reach a uniform solution for Europe. The solution will include recommendations for the short, medium and long term. Short-term recommendations include the determination of correlations between different series of tyres and the draft of a document with the exact properties of the tyres combined with specifications for storage and use. Medium term recommendations are the gathering of knowledge about the PIARC tyres and commercial tyres and the investigation of the 1992 test results between the PIARC tyre and the Specialty tyre. Long-term recommendations include the performing of comparative tests with PIARC tyres and ASTM tyres and idem with PIARC tyres and commercial tyres.

4. SYSTEMS CURRENTLY USED

4.1. General

As the need for friction measurements did not emerge at the same time in different countries, the measurement devices and conditions are developed nationally. Therefore a wide variety of measurement devices has been developed. Due to the differences in devices and measurement conditions, a direct comparison between different devices is not possible.

In a PIARC-publication (PIARC Inventory, 1995), an overview is given of measurement devices currently used. Friction measurement devices can be divided into four groups. Texture measurement devices can be divided into two groups of mobile devices and two separate static devices.

4.2. Friction measurement devices

Side force friction measurement devices
This type of device uses a wheel that is placed under an angle with the direction of travel. The force that is exerted on the wheel to turn it back in the direction of travel is measured. So this type of device measures the transverse friction. A much-used system in this group is the SCRIM[1] that measures with a special type of wheel (brand: AVON) that is placed under an angle of 20° (see Photo 1).

[1] Sideway force Coefficient Routine Investigation Machine

Photo 1 – SCRIM (Spain)

Locked wheel friction measurement devices
This type of devices uses a free rolling wheel that is locked for a short time. In this way an emergency brake is simulated. The force acting on the wheel when it is locked is measured. Disadvantage of this method is that no continuous measurement is possible: the wheel can only be locked for a short time to avoid damage to the tyre.

Fixed slip measurement devices
This type of devices uses a wheel that is pulled over the road while slipping with a certain slip ratio. The slip ratio is the difference in angular velocity between the measurement wheel and a free rolling wheel. 0% slip means that the wheel is free rolling, 100% means that the wheel is fully locked. Most devices of this type try to measure the peak friction, therefore they have slip ratios between 15 and 25%.

Multiple slip friction measurement devices
New developments in measurement control made it possible to develop measurement devices that can measure under several conditions, like one or more fixed slip ratios, locked wheel and/or measurement of the whole slip – friction curve. It is clear that with this type of devices more information can be gathered which offers advantages for research projects. An example of this type of equipment is the ROAR[2] (see Photo 2).

[2] Road Analyser and Recorder

Photo 2 – ROAR (The Netherlands)

4.3. Texture measurement devices

Mobile devices based on the laser triangulation principle
Most mobile devices use the laser triangulation principle. A laser beam is emitted perpendicular to the road and reflected under an angle. The reflected light is received on a position detector. A difference in height is detected as a difference in position on the position detector. The output is a digital signal corresponding to the texture profile.

Mobile devices based on the light sectioning method
Visible light is projected perpendicular to the road. A camera, mounted under an angle, records the profile. Differences in height will be reflected as position differences on the recorded images. The output is a digital profile, statistical profile information and images on videotape.

Sand patch test (static)
This measurement method consists of the spreading of a known volume of sand or glass spheres on the road. The sand must be spread in a circle as great as possible, filling up the texture with sand. The diameter of the sand circle is a measure for the texture.

Outflow meter (static)
A tube is placed upward on the road. Between the bottom opening of the tube and the road is a rubber ring with a certain weight on it, that closes the gaps between the tube and the road. The tube is filled with water, the time that the water level needs to decline between two markings is a measure for the water drainability of the road. This measure is related to texture as well.

5. COMPARABILITY OF DIFFERENT DEVICES

5.1. General

As can be seen in the previous paragraph, there are large differences in equipment used over the world. As friction is dependent of variable parameters like slip ratio, measurement speed, vertical load, tyre type (rubber composition, with or without tread) and water amount between tyre and road, different types of devices will not give comparable friction values. The influence of the parameters mentioned on friction is so complex that the relation between two devices can usually not be described with a simple linear regression. Therefore international studies have been carried out with the goal to describe the relation between different devices in a general way.

5.2. International harmonization (IFI)

In September and October 1992 the PIARC Committee on Surface Characteristics (C1) organised an international experiment to compare and harmonise skid resistance and texture measurements (PIARC Experiment, 1995). The overall objective of this experiment was to harmonise the many different pavement friction measurement methods used in different countries around the world. For this, the following objectives have been defined:

- develop relationships between friction and texture measurements obtained with different devices as a function of texture, speed, slip angle, test tyre, climate and materials;
- quantify relationships between standard measures of friction and texture obtained with different devices under specified conditions;
- quantify the repeatability for each device and establish a sampling rate required by each device;
- develop an International Friction Index (IFI) that all equipment can report.

The expected benefits of this experiment are:

- road and airport authorities can report to an international standard without having to replace their existing measurement method, their experience and historical data;
- intervention levels are interchangeable;
- suppliers can extend their area of distribution to other countries;
- contractors can work abroad because they can adapt to specifications based on local control methods;
- test equipment manufacturers can supply to wider markets;
- researchers can acquire better knowledge of skid resistance and the relation with texture.

From this experiment a model has been developed to correct friction measurements made with different devices for differences in speed and type of device (see Figure 3).

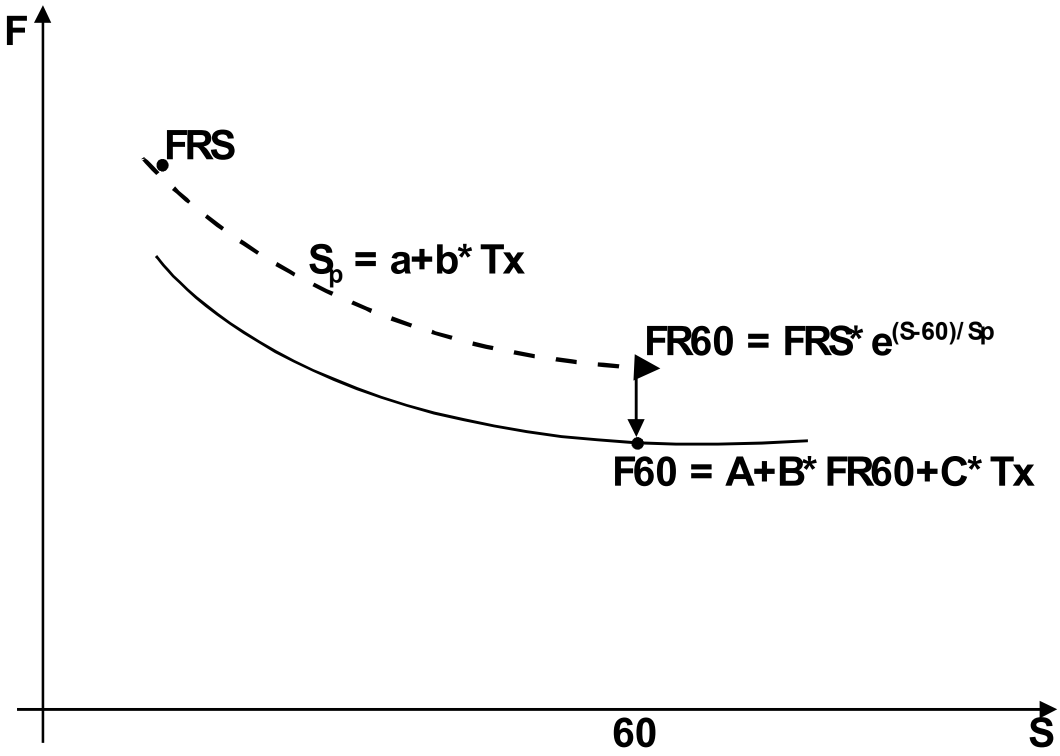

Figure 3 – Calculation of IFI

5.3. European harmonization (EFI)

In a Belgian research project (Descornet, 1998) pre-normative research for European normalisation was done. The study was based on the data of the PIARC experiment and data from an additional experiment in Belgium.

The first goal was to optimise the parameters in the IFI definition and to focus more on the results of the devices in use in Europe.

The second objective was to validate the extension of the IFI to surfacings which were not or insufficiently adopted in the PIARC experiment as there are porous asphalt, stone mastic asphalt, surface dressings etc.

The last goal was to make a proposal for calibration of skid resistance and texture devices based on the IFI. By periodically convening small subsets of devices the device coefficients can be secured. Certain criteria have to be involved for minimising the danger of drifting away of coefficients of the different subsets. A method was proposed to the working group of the Technical Committee on Road materials of the CEN[3].

Based on this analysis a European Friction Index (EFI) could be defined with the profit of a lower reference speed (30 km/h) which made the correction for the speed influence the smallest and no necessity of a separate texture term for devices with profiled tyres.

The main profit is that this EFI minimises the systematic differences of skid resistance values of different devices and so approaches the goal of harmonisation but at the expense of a lower reproducibility than between devices of the same type.

---

3 European Committee for Standardisation

5.4. HERMES[4]

The FEHRL[5] members have drawn the conclusion from previous studies that the use of IFI (or EFI in Europe) is not yet possible due to a great uncertainty in the predictions and lack of experience with the proposed calibration procedure. For these reasons a calibration exercise is executed three times until the end of 2002 in several European countries. Objective is to get acquaintance with the calibration procedure, to adopt it if necessary and to decrease the uncertainty in the predictions by improving the model.

As the project is still in progress at this moment, no conclusions can be drawn yet.

5.5. Calibration

As shown before many factors influence the measurement results. Some factors, like the effect of temperature, are the same when more than one device of a type makes a measurement at the same time. However, factors related to the tyre used can differ between devices. It is therefore that in some countries comparative calibration measurements are made on a regular basis, even when the types of device are the same. For instance in The Netherlands the three devices of the type DWW-trailer are compared on a monthly basis. In the United Kingdom all SCRIMs are compared regularly as well. The results show that these comparisons are not useless.

A new type of calibration is the Europe wide calibration of different types of devices. The proposed procedure is based on the EFI model (see paragraph 5.3). Objective of such a calibration is to establish the parameters in the friction model and through that offering the possibility to contractors to work abroad as all devices can report a common value.

6. OTHER NEW DEVELOPMENTS

6.1. General

Besides studies to improve the comparability of devices (see paragraph 5), there is also research ongoing to improve the friction measurement. Some interesting studies will be dealt with in this paragraph.

6.2. Measurement of whole slip – friction curve

New measurement devices make it possible to measure the whole slip – friction curve. This gives additional information, for instance about the location of the peak value and the ratio between peak value and locked wheel value. The shape of the curve can differ much between different types of pavement. More knowledge needs to be gathered on this issue. Then it can be used to determine better intervention levels and to improve friction models.

6.3. Relation between longitudinal and transverse friction

Dutch experiences sometimes show strange effects in curves. It can happen that cars loose control in narrow curves that are used in junctions. However, a friction measurement with the DWW-trailer (86% longitudinal slip) sometimes shows that the friction is above the intervention level. This gave cause for a research project (Hogt, 2001) in which measurements have been made with a tyre test vehicle that can measure longitudinal and

---

4 Harmonisation of European Routine and Research Measuring Equipment for Skid Resistance of Roads and Runways

5 Forum of European Highway Research Laboratories

transverse friction. The results showed that there is no unique relation between longitudinal and transverse friction. Especially in the curve, the transverse friction was low and the longitudinal friction was high. The transverse friction even differed according to the turning direction of the measurement wheel: the lowest values were found when the measurement wheel was turned in the direction of the curve. So it seems that a measurement of longitudinal slip only is not under all conditions sufficient.

A continuation of this research is desirable to draw more firm conclusions, for instance about the desirability to measure transverse friction as well.

6.4. New tyre material

The rubber of the measurement tyre causes much variation in friction values measured. Rubber is a material that is very sensitive to temperature. During storage and use the hardness of the rubber may increase due to ageing. This also influences the friction values measured. In The Netherlands a study is underway to examine the possibilities of another type of rubber or a polymer that is less sensitive to temperature and ageing. If such a material exists, it is worthwhile to make a tyre out of this material and make comparative tests.

6.5. Measurement of friction with a texture device

Micro- and macrotexture are responsible for the amount of friction between a tyre and the road. So if a direct measurement of micro- and macrotexture is possible, it may become possible to develop a new measurement method without a tyre. Texture can be measured with a laser texture device. However, at this moment a measurement of microtexture at normal traffic speeds is not possible. Should such a measurement method become possible in the future, an experiment is worthwhile.

6.6. Reference device and reference surfaces

Within the framework of the HERMES project initiatives have emerged to develop a reference device and reference surfaces.

LCPC (France) is looking into the possibilities for developing a reference device that, in due course, can replace the different existing devices throughout Europe. The replacement of different types of devices by one type will of course increase the comparability.

TRL (United Kingdom) is exploring the possibilities of reference surfaces with friction and texture properties that will not, or only slightly, change in time. If these surfaces can be constructed in a reproducible way, they can be constructed throughout Europe. This will ease the Europe wide calibration of devices, as travel times will be reduced. If a reproducible construction is not possible, surfaces will be constructed at one place in Europe. The benefit of a surface with constant friction and texture properties will remain.

7. CONCLUSIONS AND RECOMMENDATIONS

- Friction and texture are important road surface characteristics to maintain the road safety on a high level. Especially friction is an important indicator that is measured on a regular basis and used in Pavement Management Systems (PMS). Most countries have minimum friction values for new roads as well for in-service roads.

It is desirable to develop models describing the deterioration of friction with time in order to predict when a pavement needs maintenance, enabling a long-term planning of maintenance.

- In some countries the intervention levels are based upon studies into the relation between friction and safety.
  As types of road pavements and traffic situations change in time, such studies need to be repeated after several time.

- Measurement results are influenced by many factors, like temperature, hardness of the tyre (related to age) and road pollution.
  To improve the accuracy of measurements, correction formula or measurement procedures need to be established.

- Large differences exist between different types of equipment. Harmonization studies are made to improve the comparability of measurement results. Indices like IFI and EFI have been developed. However, the accuracy of these indices is not yet sufficient.
  Harmonization studies need to be continued in order to improve the existing models and therewith the accuracy of the indices.

- Continuous developments take place regarding the measurement devices, for instance the possibility to measure the whole slip – friction curve or to measure texture with normal traffic speeds.
  New developments in measurement technology need to be used for friction measurements to improve the current measurement practice (e.g. less impediment for other traffic) and to collect other useful data (whole slip – friction curve, transverse friction).

REFERENCES

Descornet, G.: Proposal for a European standard in relation with the skid resistance of road surfacings. Final report Research contract NO/C3/004. Belgian Road Research Centre, Brussels, 1998.

Hogt, R.M.M.: Verkennend onderzoek naar de relatie tussen stroefheid en lateraal voertuiggedrag. TNO-rapport 01.OR.VD.034.1/RMH. Delft, 23 November 2001.

Hosking, R.: State-of-the-Art Review 4: Road Aggregates and Skidding. ISBN 0-11-551115-6. HMSO, London, 1992.

PIARC: Inventory of Road Surface Characteristics Measuring Equipment. PIARC-publication 01.03.B. Paris, 1995.

PIARC: International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements. PIARC-report 01.04.T. Paris, 1995.

Schoen, dr. E.D. and Bakker, drs.ing. M.: Correction of Skid Resistance Measurements Obtained under Non-Standard Conditions – Revised Version. TNO-report FSP-RPT-010008. Delft, 27 April 2001.

Wallman, Carl-Gustaf and Åström, Henrik: Friction measurement methods and the correlation between road friction and traffic safety. A literature review. VTI meddelande 911A. Linköping, 2001.