R&T UPDATE
Concrete Pavement Research & Technology

Current Perspectives on Pavement Surface Characteristics

***NOTE**: Much of this Issue was excerpted from the ACPA publication EB235P “Pavement Surface Characteristics: A Synthesis and Guide” by Mark B. Snyder.*

The Surface Texture Continuum

Pavement surface texture influences many aspects of tire-pavement interaction, including wet-weather friction, tire-pavement noise, splash and spray, rolling resistance and tire wear.[1] Overall pavement surface texture includes contributions from features such as aggregate texture, aggregate gradation, pavement finishing techniques and pavement wear. Different texture characteristics [i.e. combinations of feature depth (amplitude) and feature length (wavelength)] have different effects on tire-pavement interactions. Therefore, it is important to be able to classify pavement texture in a way that is useful to interpreting the effect of the texture on pavement performance characteristics.

In 1987 the Permanent International Association of Road Congresses (PIARC) proposed four categories for classifying pavement surface characteristics based on the amplitude and wavelength of the feature: *microtexture*, *macrotexture*, *megatexture* and *unevenness* (roughness).[2] Each of these categories is described in subsequent sections, and the specific influence of each category on tire-pavement interaction is illustrated in Figure 1.

Microtexture has wavelengths from 0.00004 in. to 0.02 in. (1 µm to 0.5 mm) and vertical amplitudes less than 0.008 in. (0.2 mm).[2] Good microtexture is usually all that is necessary to provide adequate stopping on dry pavements at typical vehicle operational speeds and on wet (but not flooded) pavements when vehicle speeds are less than 50 mph (80 kph). When higher vehicle speeds are expected, good microtexture and macrotexture are generally required to provide adequate wet-pavement friction.[4] Microtexture is not generally considered to be a factor in the development of pavement noise or splash and spray.

Macrotexture has wavelengths from 0.02 in. to 2 in. (0.5 mm to 50 mm) and vertical amplitudes ranging from 0.004 in. to 0.8 in. (0.1 mm to 20 mm).[2] Macrotexture plays a major role in wet weather friction characteristics of pavement surfaces, especially at high vehicle speeds. Therefore, pavements that are constructed to accommodate vehicles traveling at speeds of 50 mph (80 kph) or greater require good macrotexture to help prevent hydroplaning.[4] In addition to providing wet weather friction, macrotexture is the pavement surface characteristic with the strongest impact on tire-pavement noise and splash and spray (see Figure 1).

Megatexture has wavelengths from 2 in. to 20 in. (50 mm to 500 mm) and vertical amplitudes ranging from 0.004 in. to 2 in. (0.1 mm to 50 mm).[2] This level of texture is typically the result of poor construction practices, local settlements or surface deterioration. Megatexture can cause vibration in tire walls, resulting in in-vehicle noise and some external noise. It also adversely affects pavement ride quality and can produce premature wear of vehicle suspensions (e.g. tires, shock absorbers and struts).[5]

Unevenness (roughness) has wavelengths longer than the upper limit of megatexture (> 20 in. [500 mm]).[2] Any surface irregularity that has a wavelength in this range has an impact on vehicle dynamics, ride quality and surface drainage.[5] Unevenness does not significantly affect tire-pavement noise.

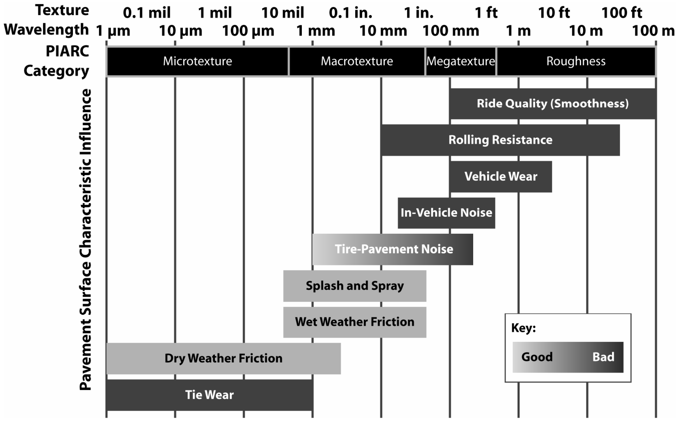

Figure 1. Illustration of PIARC Pavement Surface Characteristics (after reference 3).

Measuring Surface Texture

There are several different methods for quantifying surface texture, but the results of these methods are sometimes difficult to compare directly (although correlations and conversion equations have been developed). Two commonly used methods are the mean texture depth (MTD) and the mean profile depth (MPD). The MTD is determined using the traditional volumetric method (commonly referred to as the “sand patch test” or ASTM E965) whereas the MPD is determined using laser technology at highway speeds (ASTM E1845).

Common equipment used to measure the MPD includes the C.T. Meter, inertial profilers and the RoboTex. The C.T. Meter is a static measurement device, while the RoboTex is a slow-speed, remote-controlled robotic device. Inertial profilers are typically operated at highway speeds.

Measuring Roadway Friction

Four basic types of full-scale devices are commonly used to obtain direct measurements of pavement surface friction: *locked-wheel, side force, fixed slip* and *variable slip* testers. All of these devices can be equipped with tires featuring either a “ribbed” tread (longitudinal grooves on the tread surface) tire (ASTM E201) or a “blank” tread (smooth) tire (ASTM E524). However, measurements obtained using ribbed tires are somewhat insensitive to macrotexture and are mainly influenced by microtexture.[6]

Locked-wheel testers simulate emergency braking conditions for vehicles without anti-lock brakes by dragging a locked wheel on a pavement wetted with a specified amount of water. When the brake is applied, the force is measured and averaged over the one second after the test wheel is fully locked. Locked-wheel testers are usually fitted with a self-watering system for wet testing; a nominal water film thickness of 0.02 in. (0.5 mm) is commonly used. An example of this is the ASTM locked-wheel tester (ASTM E274).

Side force testers simulate a vehicle traveling though a curve. They function by maintaining a test wheel in a plane at an angle to the direction of motion (the yaw angle) while the wheel is allowed to roll freely.[1] Side force is measured perpendicularly to the plane of rotation. The main advantage of this method is that it can measure friction continuously through a test section. Examples of specific side force testing equipment include the Mu Meter and the Sideways-Force Coefficient Routine Investigation Machine (SCRIM), both of which originated in the United Kingdom.

Fixed and variable slip testers simulate a vehicle’s ability to brake while using antilock brakes by attempting to detect the peak friction level. Fixed slip devices operate at a constant slip (usually between 10 and 20 percent slip) by driving the test wheel at a lower angular velocity than its free rolling velocity whereas variable slip devices sweep through a predetermined set of slip ratios (in accordance with ASTM E1859).[1,7] Examples of fixed slip devices include the Grip tester and SAAB Friction Tester and an example of a variable slip device is the Norsemeter Road Analyzer and Recorder (ROAR). There is currently no ASTM standard for fixed slip testing due to its lack of use on highway pavements in the United States.

Measuring Roadway Noise

Many sources of sound contribute to the overall level of sound that is generated in the highway environment, including:

- Pure vehicular sources (e.g. mechanical sounds from the engine, drive train and exhaust, as well as onboard equipment, such as refrigeration units in heavy trucks).
- Aerodynamic effects, such as those that result from the passage of air around the vehicle and through the vehicle (e.g. into radiator and engine air intakes).
- The interaction of vehicle tires and the pavement over which they travel.

The noise produced from tire-pavement interaction is generally the largest individual source at vehicle speeds of more than 20 mph (32 kph) for cars and more than 30 mph (48 kph) for trucks. Many factors are involved in tire-pavement interaction and the resulting generation of sound, including tire design, size, condition and loading, vehicle speed and pavement texture. If all other factors are held constant, traffic noise levels will vary mainly with the different physical characteristics of the pavement surface, such as porosity, texture, etc. In other words, pavements constructed using different materials but with identical surface texture characteristics will generate nearly identical sounds when subjected to identical traffic streams.

Outside of vehicles, overall sound levels depend upon the distance to the source, the presence of blocking barriers and reflecting surfaces, environmental conditions (e.g. wind direction and speed, temperature, etc.) and many other factors. Inside any given vehicle, overall sound levels depend upon on the frequencies and levels of sound generated by the different sources and the ability of the vehicle to filter, block or “cancel” those sounds (though insulation, suspension characteristics, etc.).

Regardless of the noise level measurement approach used, sound measurements must be objective (i.e. measurement must be accomplished with a machine rather than by the subjective human ear) because traffic noise that is very irritating to someone might not bother someone else at all. Furthermore, an environment with an overall lower level of sound might be perceived to be louder or more irritating to someone than an environment with a higher overall level of sound if the lower level contains high pitch frequencies. Therefore, to determine the “less noisy” of two pavement textures, frequency content and other factors must also be considered when quantifying the noise level, a difficult task for even the most trained human ear.

Measuring Roadway Profile

Roadway profile measurements are obtained using both low-speed and high-speed equipment. In the late 1950s, the California Highway Department developed a profilograph to evaluate pavement smoothness during the construction process. A pavement index, Profile Index (PI), was established so that different roads could be compared and new construction specifications could be developed. The PI was established by conducting a network survey of both flexible and rigid pavements and establishing the “threshold” PI value of a good pavement, considered to be seven inches per mile. This specification is still widely used in the construction industry for both flexible and rigid pavements.

In the 1960s, General Motors developed an inertial profiler, which could measure the true profile of a pavement at a speed of approximately 25 mph (40 kph). With time, technology allowed for the development of non-contact profilers, which allowed for testing at higher speeds.

In 1990, the Federal Highway Administration (FHWA) began promoting the use of a standard roughness statistic, the International Roughness Index (IRI), developed by the World Bank. This statistic was established so a common metric is available to evaluate ride quality from cradle to grave.

Current Practices in the U.S.

Safety and Friction – Most agencies in the United States currently measure pavement friction using an ASTM locked-wheel trailer with either a standard ribbed or smooth tire.[1,8] Testing is typically conducted at discrete intervals, such as mile post locations, and at some designated time interval, such as annually. Test results go into a pavement management system (PMS) to determine necessary intervention times for safety purposes (e.g. inadequate friction).

In 1980, the FHWA provided guidance to state and local highway agencies in establishing skid accident reduction programs via Technical Advisory T 5040.17, entitled "*Skid Accident Reduction Program.*"[9]. This advisory is currently under revision.

In practice, friction numbers from 30 to 40, measured at 40 mph (64 kph) using a ribbed tire, have generally been considered acceptable for interstate highways or other roads with design speeds greater than 40 mph (64 kph). Lower friction numbers have generally been accepted for pavements with low traffic volumes (e.g. ADT less than 3,000 vehicles) and traffic speeds less than 40 mph (64 kph).

Noise – In May of 2005, the FHWA began requiring the use of a new traffic noise modeling procedure called Traffic Noise Model 2.5 (TNM 2.5). Agencies are required to use this software to analyze data and consider potential noise mitigation methods during preparation of the environmental impact assessment on federally funded projects. The new methodology replaced the older software, called STAMINA, which was developed in the early 1970s in a four-state study. Since the development of STAMINA, many changes have occurred, including fleet changes on the highways and significant improvements in both software and noise modeling, enabling a more sophisticated approach to be taken. The new study began by developing a national Reference Energy Mean Emission Level (REMEL) database.

TNM 2.5 has many advantages over the previous software. For one, it can evaluate the effect of four different pavement categories: average (75% dense-graded asphalt pavement and 25% concrete), dense-graded AC, open-graded AC and concrete. Currently, the average pavement category is the only approved surface type that can be used in modeling.

Roughness – Roughness measurements are typically obtained for two purposes: construction acceptance and system monitoring. For system monitoring, such as with a PMS, high-speed profilers are almost exclusively used, with measurements taken at highway speeds. The measurements are typically obtained continuously over some finite length, such as a mile, and assigned to a locator, such as a milepost location. This allows a PMS system to evaluate the change in properties over time; the IRI is almost exclusively used for this evaluation. The data is also obtained to support the FHWA Highway Performance and Monitoring Systems (e.g. HPMS) and the required input for this is the IRI statistic.

Newly constructed pavements are evaluated with both low-speed and high-speed measurement devices. For concrete pavements, the profilograph device and profile index (PI) statistic are most common. An increasing number of agencies are replacing the profilograph equipment with lightweight profilers, but they generally still require the measurement index to be the PI.

Perspectives on Current Practice

Safety – Pavement texture plays an important role in roadway safety issues. There are more than one million deaths and 50 million injuries annually on highways and roads all over the world, with more than 40,000 deaths and 3 million injuries annually in the U.S. alone.[10] Research indicates that about 14 percent of all crashes occur in wet weather, and that 70 percent of these crashes are preventable with improved pavement texture/friction.[11,12] Two primary causes of wet weather crashes are 1) uncontrolled skidding due to inadequate surface friction in the presence of water (hydroplaning) and 2) poor visibility due to splash and spray. Pavement surface texture characteristics play an important role in both of these safety-related phenomena. Inadequate friction contributes to accidents in dry weather as well, especially in work zones and intersections, where unusual traffic movements and braking action are common.

It has been reported that 10 percent of wet weather accidents are caused by reduced visibility due to splash and spray (especially at night) and that 15 to 35 percent of wet weather crashes involve skidding.[4] If wet weather crashes account for about 19 percent of all fatal crashes, improved pavement texture/friction could reduce overall highway crash, fatality and injury rates by 13 percent (i.e. 5,600 fewer deaths; 390,000 fewer injuries; and 3.25 million fewer accidents in the U.S. each year).

It is important to understand that hydroplaning is different than skidding on wet pavement. When hydroplaning occurs, the entire tire footprint is separated (i.e. complete loss of contact) from the pavement by a thin layer of water and the pavement surface texture no longer plays a role in the friction process. When a rolling tire encounters a film of water on the roadway, the water is channeled through the tire tread pattern and through the surface texture of the pavement. Hydroplaning occurs when the drainage capacity of the tire tread pattern and pavement surface is exceeded and the water begins to build up in front of the tire, creating a wedge of water that lifts the tire off the pavement surface.

In a 2004 Australian study, macrotexture levels were strongly correlated with crash rates for most pavement locations and categories that were studied, particularly at intersections. The lower limits of satisfactory surface texture were determined to be 0.016 and 0.020 in. (0.4 and 0.5 mm) (measured using laser-based devices), respectively, for two different highways. Crash risks were determined to be 1.8 and 1.9 times higher, respectively, when the average macrotexture dropped below these critical values.[13] The authors estimated that 13 to 17 percent of all crashes on the two study highways could be prevented by improving all low macrotexture sites.[13,14]

A 1999 survey of U.S. highway agencies revealed that only 11 of 42 responding agencies had published minimum acceptable levels for skid resistance.[1] It appears that many highway agencies are reluctant to assign minimum acceptable friction levels for highway pavements because of liability concerns.

It follows that good surface texture can prevent many accidents, thereby reducing the number of deaths and serious injuries. Pavement engineers must select surface textures that reduce the potential for hydroplaning at higher speeds while also providing sufficient surface drainage so that splash and spray are minimized.[4]

Noise – Current noise mitigation procedures require the use of wayside noise measurement equipment. This testing is both time-consuming and expensive to conduct. As such, there has been recent interest in near-field noise measurement techniques such as On-Board Sound Intensity (e.g. OBSI). Unfortunately, there are no current standards addressing this technique, although the FHWA and ASTM are both working on standards for this.

The TNM 2.5 does not allow the designer the ability to use pavement surface type as a noise mitigation strategy. The reason the FHWA does not provide this capability is due to the changing acoustic properties over time. Many pavements become noisier over time as a result of surface attrition. The change in acoustic properties makes it necessary to establish what those changes are and how best to measure them. Currently, the OBSI technique is the *de facto* standard for measuring acoustic changes over time in the U.S. However, with no established test procedure and no standard test tire, there is concern as to the viability of this test. In addition, there is presently no way to use OBSI data to modify the TNM REMEL database, which would be necessary to allow pavement surface type as a variable.

Current noise mitigation requirements only involve the dBA level of the noise source. Consumer annoyance is not exclusively related to level alone and a need exists to establish a better annoyance metric than dBA level.

Roughness – While the profilograph has served the industry well over the past 50 years, new profiling technology and equipment have evolved such that more meaningful measurement statistics, particularly IRI, are fast becoming the choice of US road agencies. With encouragement from the ACPA, profile equipment manufacturers have been improving their equipment for construction acceptance and performance monitoring, even on coarse-textured concrete surfaces.

For more information on these topics, refer to ACPA Publication EB235P "Pavement Surface Characteristics: A Synthesis and Guide." To obtain a copy, visit our on-line bookstore at: http://www.pavement.com/Bookstore/

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