A Criterion for Optimizing Surface Characteristics

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Requirements for road pavement performance were long centered on safety but are currently being extended to such concerns as the environment, comfort, and costs. The following aspects must now be considered: (1) for safety: skid resistance, road-holding qualities, splash and spray reduction, and visibility of the road and road markings; (2) for economy: reduction of fuel consumption, tire and vehicle wear, and dynamic extra loads that may shorten the life of road (and engineering) structures; and (3) for user comfort and the environment of roadside residents: reduction of noise and vibrations inside and outside vehicles. Each feature of pavement performance is chiefly or partly determined by surface irregularities on different scales. Traditionally, three ranges of irregularities have been considered: microtexture, macrotexture, and roughness. Recent research into the relations between performance and pavement characteristics has revealed the part played by a hitherto unchecked range of irregularities: the so-called megatexture, with wavelengths between 50 and 500 mm, the adverse effects of which (noise, vibrations, and extra rolling resistance) used to be attributed to macrotexture. Megatexture is out of the measuring range of conventional test methods and devices but can now be checked with the new generation of contactless profilometers, such as laser profilometers. Thus it is possible, in principle, to optimize road pavement performance while meeting most of the requirements, even minor ones, by considering that some surface characteristics must be present (micro- and macrotexture) and that others are undesirable (megatexture and roughness).

Traditionally, road surface requirements and specifications are intended to ensure, first, the safety of road users and, second, their comfort. At present, constantly increasing road traffic has a considerable impact on the environment and the economy. Recent awareness of the influence of surface characteristics has extended the performance requirements for road pavements, resulting in conflicts between apparently contradictory requirements. This paper reviews the main performance requirements for road pavements as well as the surface characteristics that determine performance; it shows that it is possible, in principle, to meet most if not all requirements without compromising any. The key to the problem lies in investigating the part played by a characteristic that the PIARC Technical Committee on Surface Characteristics has termed "megatexture" (*1*).

MEGATEXTURE

Figure 1 shows the deformation of a tire traveling over various road profiles with irregularities of the same amplitude but different wavelengths. This deformation results from two components: a stationary component (broken line), which does not depend on the shape of the profile and corresponds to the deformation that the tire would have undergone on a rectilinear profile (i.e., a flat surface); and an alternate component that varies with the shape of the profile. It can be seen that the second component is maximized on a profile whose wavelength (λ) approaches the footprint length (*a*) of the tire. More exactly, it can be shown that this critical wavelength equals *a*/2 (*2*), which generally is about 50 to 100 mm, both for passenger cars and for trucks.

Such surface irregularities are bound to cause dynamic effects that generate vibrations inside vehicles, tire/road contact noise inside and outside vehicles, and extra fuel consumption from rolling resistance (*3, 4*). Even though they seem to match the definition of roughness (ASTM E867) and could be thought of as small-scale roughness, this range of irregularities is out of the span of the various roughness measuring devices; and they cannot be detected from sand patch tests, either. Moreover, because of the specific nature of their effects, they should be distinguished from the ranges of irregularities hitherto considered by road engineers. That is why the scale of relevant wavelengths (λ) has now been divided as follows by the PIARC Technical Committee on Surface Characteristics (*1*):

Microtexture: $\lambda < 0.5$ mm,
Macrotexture: $0.5 \text{ mm} < \lambda < 50$ mm,
Megatexture: $50 \text{ mm} < \lambda < 500$ mm, and
Roughness: $0.5 \text{ m} < \lambda < 50$ m.

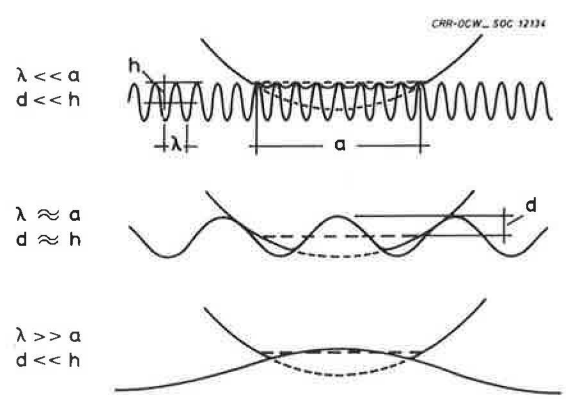

FIGURE 1 Deformation of tire when rolling on a profile with undulations of variable wavelength (*d*: alternate component of tire deformation; *a*: length of tire footprint; *h*: mean profile depth; λ: profile wavelength).

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In that definition, megatexture extends beyond the above-mentioned critical domain and reaches up to the lower wavelength cutoff of the response of the conventional roughness-measuring devices.

Megatexture can be produced by deterioration of the road surface: alligator cracks and spalling, small potholes, plucking, and scabbing. It also exists, however, on roads in good condition or those newly built. It can be a byproduct of the way macrotexture is achieved: a surface dressing with two chipping sizes, a chipped bituminous or cement concrete, or a stripped concrete (a technique for exposing the aggregates) can present the tire with an irregular contact area because of a lack of homogeneity of macrotexture. Or it can originate from the laying process: corrugation and other kinds of "waviness" sometimes show up on top of cement concrete layers and could be due to vibrations of the paving machine, the action of the smoothing beam, and other possible factors or circumstances.

PERFORMANCE FOR SAFETY

Skid Resistance

Wet road skid resistance is achieved (provided there is also good transverse evenness) by the presence of two ranges of surface irregularities (*5*): (1) microtexture, which ensures preservation of a high friction coefficient by breaking the water film on the asperity tips of the pavement that remain in contact with the tire, and (2) macrotexture, which drains away the water at the tire/pavement interface, preventing the buildup of hydrodynamic pressure that may induce aquaplaning. In this way, macrotexture helps keep a high coefficient of friction at high speeds.

When related to profilometric measurements on dozens of road sections with varying pavement characteristics (*2*), sideway force coefficient (SFC) measurements indicate that the drop in SFC between 20 and 80 km/h presents a maximum correlation with the surface irregularities of 20 mm in wavelength (Figure 2). This finding agrees well with the theoretical and experimental study of Bond et al. (*6*), which pointed out that, other things being equal, maximum effectiveness of drainage at tire/pavement contact is achieved where irregularities have wavelengths of 8 to 16 mm.

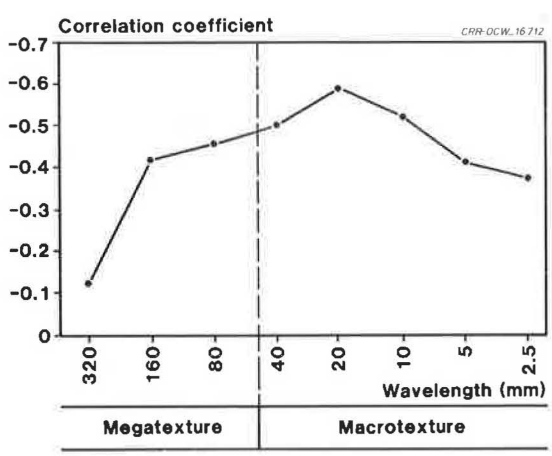

FIGURE 2 Correlation coefficient between drop in SFC from 20 to 80 km/h and amplitude of surface irregularities in relation to their wavelength (number of road sections = 36).

Splash and Spray

Studies have not quantitatively associated splash and spray with a given range of irregularities. Nevertheless, it may reasonably be assumed that splash and spray will be lessened as the surface characteristics of the pavement allow more effective drainage and minimize the thickness of the water film. Apart from cross slope and the absence of ruts, macrotexture should also have a favorable effect.

Optical Properties

The synthesis recently published jointly by the International Commission on Illumination and PIARC (*7*) defines three optical properties of road surfaces beneficial to safety:

1. The average dry-weather luminance coefficient, which must be high to ensure that the road contrasts well with the surrounding landscape both in daylight and under public lighting at night;
2. The luminance coefficient for grazing illumination, which must be high to ensure effective retroreflection of road illumination from car headlights; and
3. The specular factor, which must be as low as possible to avoid glare being produced by the headlights of opposing cars on the wet pavement at night.

These three conditions will be fulfilled all the better as the surface has a marked macrotexture. Moreover, the latter helps to improve the visibility of road markings on wet pavement (*8*).

Road-Hold

To allow maximum tire grip, the vertical action on the wheel must be as constant as possible. Critical frequencies in this respect range from 5 to 20 Hz, which approximately corresponds to the roughness of wavelengths of 0.5 to 8.0 m (*9*). It should be remembered that transverse irregularities (ruts and asymmetry between left- and right-hand longitudinal profiles) must also be avoided.

PERFORMANCE FOR ECONOMY

Dynamic Loads

Irregularities in the road profile subject the sprung and unsprung masses of vehicles to vertical oscillations that cause the loads exerted on the pavement to vary by as much as 10 to 20 percent with respect to their static values. Since the relations between loads and their damaging effects are strongly nonlinear, this fluctuation is equivalent to a 30 to 40 percent increase in the number of equivalent standard axles (*10*) and thus results in accelerated deterioration of the pavement. The ranges of wavelengths involved are those that correspond to the resonant frequencies of the tires (about 1 Hz) and the body (about 15 Hz) and to medium or high speeds (15 to 30 m/s), which virtually cover the whole range of roughness (1 to 30 m).

Vehicle Wear

Studies conducted by the World Bank in Brazil (*11*) have made it possible to establish significant correlations between the consumption of spare parts and an overall assessment (QI) of the roughness of roads considered in the statistical analysis. Under the worst conditions, maintenance costs may be up to 20 percent higher.

More specific studies on tire wear have shown a strong dependence on texture. For example, tires were found to wear down three times more rapidly on a surface that was both harsh and rough than on another that was merely rough (*12*). Observations clearly point to microtexture as the determining factor (*6*).

Rolling Resistance

Using an apparatus developed at the Belgian Road Research Centre, measurements of rolling resistance were performed on paved roads and related to surface irregularities. Rolling resistance was 47 percent higher on the worst surface than on the best. This amounts to potential fuel savings of up to 9 percent. Various ranges of surface irregularities seem to contribute to the higher rolling resistances observed, but megatexture appears to be the most important factor. The rolling resistance coefficient of a car tire at 50 km/h presents a maximum correlation with the level of the irregularities of 80 mm in wavelength (Figure 3) (*4*).

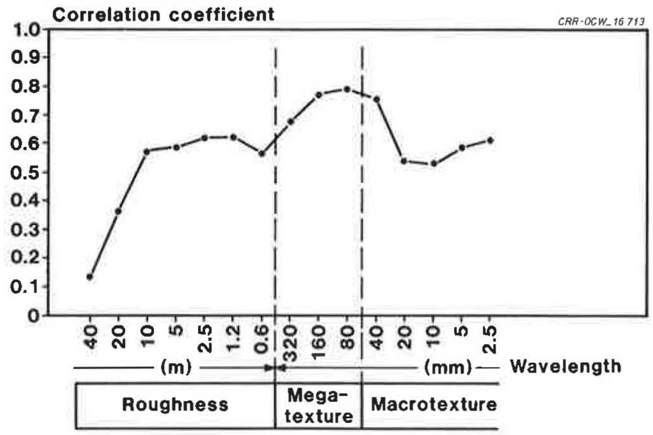

FIGURE 3 Correlation between rolling resistance coefficient and amplitude of surface irregularities in relation to their wavelength (number of road sections = 37).

PERFORMANCE FOR COMFORT AND THE ENVIRONMENT

Traffic Noise

One of the major, often dominant sources of noise emitted by vehicles turns out to be tire/road interaction (*1*). Tire/road contact noise varies greatly (more than 10 dB[A]) with certain surface characteristics. By studying the relations between the spectrum of the profile irregularities of closed-textured pavements and the spectrum of the tire/road contact noise generated by a test car, it has been possible to establish the following (*13, 14*) (see Figure 4):

1. When surface irregularities with wavelengths close to 80 mm increase in amplitude, the level of tire noise increases; this effect is apparent mainly in the low-frequency part (< 1 kHz) of the sound spectrum.
2. On the other hand, when surface irregularities with wavelengths close to 3 mm increase, the level of tire noise decreases; this effect is apparent mainly in the high-frequency part (> 1 kHz) of the sound spectrum.

The first effect results from tire vibrations induced by megatexture. The second is most generally assumed to be connected with suction noise ("air pumping") that can be reduced by the presence of irregularities on the scale of the width of the grooves in the tire tread, which would explain the beneficial effect of a fine macrotexture. This air-pumping abatement effect is also obtained by open-textured surfaces.

Noise Inside Vehicles

Noise inside vehicles not only causes discomfort but also affects safety by contributing to the fatigue of drivers and consequently impairing their performance. Moreover, this aspect may be expected to gain importance with the extension of verbal communication in vehicles (e.g., radio guidance, vocal commands). Noise levels inside medium-sized passenger cars are determined mainly by tire/road contact noise. Variations observed between different pavements may exceed 15 dB(A) (*3*). Studies by the author have revealed the predominant influence of megatexture, as shown in Figure 5.

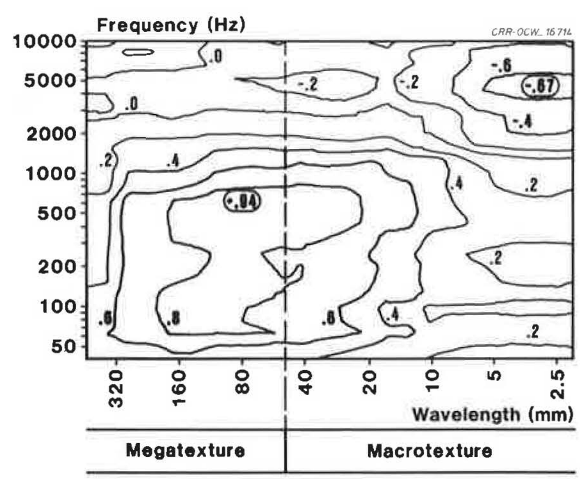

FIGURE 4 Contour lines representing correlation coefficient between spectrum of tire/road contact noise (outside the vehicle) and power spectrum of longitudinal profile of pavement (number of road sections = 33). The two extreme values of the correlation coefficient are denoted by circles.

Vibrations Inside Vehicles

The influence of surface irregularities on comfort levels has been subjectively evaluated by panels of drivers in many studies, which have established the relations between various overall measurements of roughness spanning a wide range of wavelengths approximately contained between 0.5 m and 50 m. A recent investigation (*15*) to define better the wavelengths that are critical in this respect has pointed out, using correlations established between the power spectrum of the road profile and the mean comfort rating by a panel, that short-range roughness ($0.5 < \lambda < 3$ m) is determinant. Below 0.5 m, the drop in the correlation coefficient could either actually reflect a smaller contribution of the shorter wavelengths to the feeling of discomfort or be caused by the proximity of the cutoff frequency of the profilometer used. If it were confirmed that megatexture contributes to the feeling of discomfort, it would be difficult to discriminate between the part of the vibrations and that of the noise, the two phenomena being connected, as shown in some studies published by manufacturers (*16*).

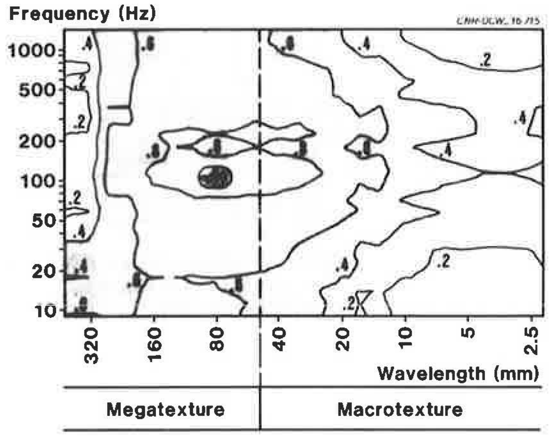

FIGURE 5 Contour lines representing correlation coefficient between spectrum of tire/road contact noise (inside vehicle) and power spectrum of longitudinal profile of pavement (number of road sections = 33). The maximum value of the correlation coefficient is denoted by a circle.

CONCLUSIONS

A review has been presented of various features of road pavement performance that may need to be considered; the critical range of wavelengths of longitudinal profile irregularities that determine these features has been indicated for each. An overview is presented in Figures 6 and 7. This approach is based on the results of recent studies that, using modern profilometric methods and spectrum analysis, have revealed the hitherto ignored role of megatexture. It makes it possible, in principle, to solve apparent conflicts between certain

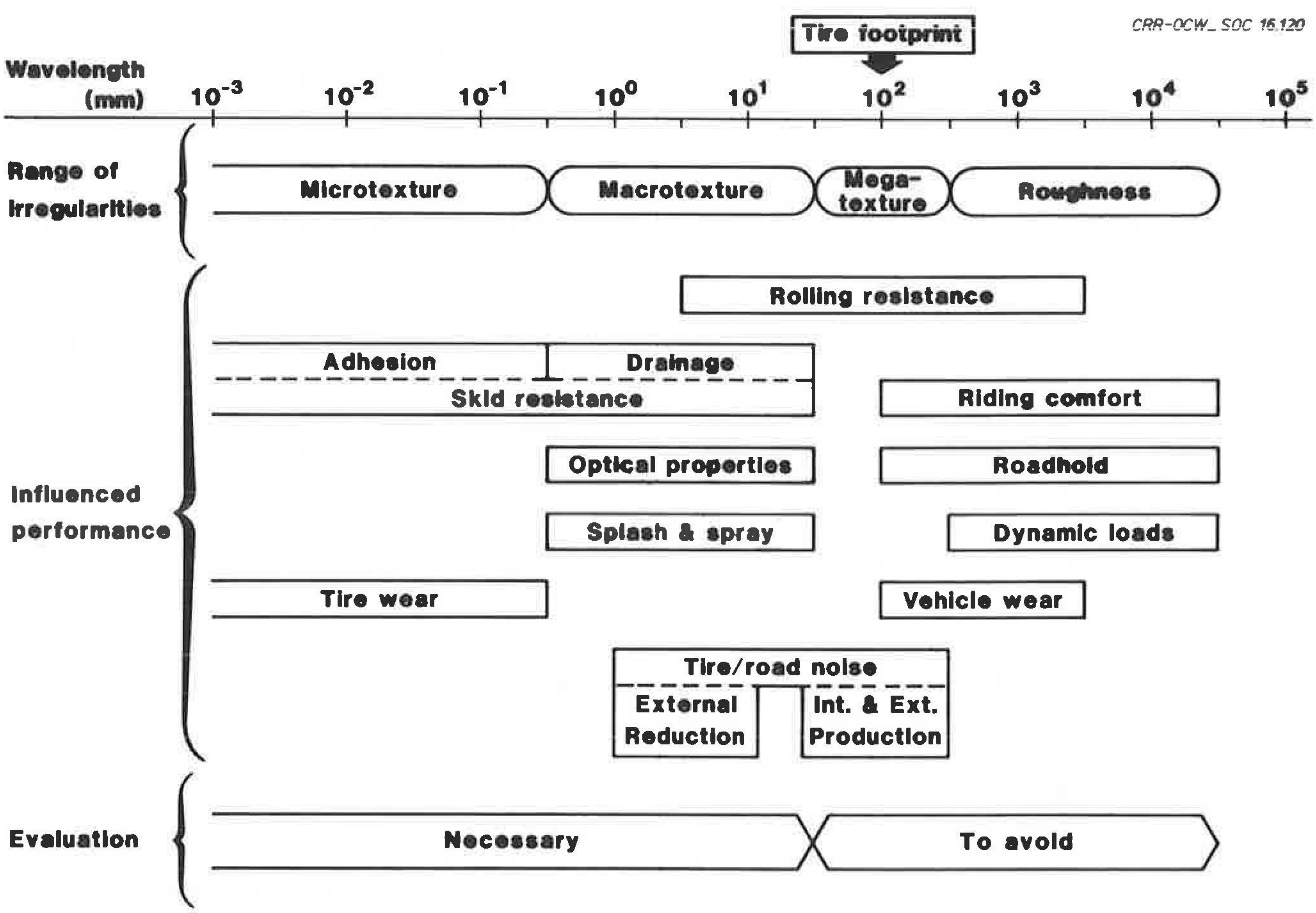

FIGURE 6 Performance features of road pavements against wavelength ranges of surface irregularities that influence them.

	Texture			Roughness
	Micro	Macro	Mega	
Skid resistance	+	+		
Roadhold				-
Splash & Spray		+		
Reflectance		+		
Dynamic loads				-
Vehicle wear				-
Tire wear	-			
Rolling resistance			-	
Vibrations (inside)			-	-
Noise (inside)			-	
Noise (outside)	+	+	-	

FIGURE 7 Relations between performance features and surface characteristics. Beneficial and adverse effects are denoted by + and −, respectively.

requirements, such as skid resistance on one hand and low tire noise and low rolling resistance on the other hand, which seemed to dictate contradictory specifications for macrotexture. Figure 7 shows that the undesirable effects that are often attributed to macrotexture are actually due to megatexture. This clears the way for optimizing surface characteristics by setting a simple criterion that should make it possible to maximize compliance with virtually all performance requirements (even minor ones, with the exception of tire wear) without compromising any. It consists of recognizing that there are two categories of irregularities: one that must be present (micro- and macrotexture) and another whose presence is undesirable (megatexture and roughness). The limit between the two is at approximately 50 mm of wavelength. Porous asphalt surfaces may be included in the overview provided it is considered that the macrotexture function is performed by porosity, which may be viewed as a negative, or inversed, macrotexture.

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