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Texture characteristics of unpolished and polished aggregate surfaces

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ABSTRACT

In order to investigate evolution of polishing aggregate surfaces on an aggregate wear index (AWI) wear track specimen, experimental texture measurements and data dependent system (DDS) approach were utilized to model and analyze elevation profiles collected from unpolished and polished aggregate surfaces. It was found that the DDS approach was able to characterize the evolved macrotexture and microtexture. The polishing effect induced by the interaction between tire tread and aggregate surfaces was found to reduce the microtexture roughness significantly, but showed little influence on the macrotexture. This does not imply that the macrotexture plays little role in tire tread friction. It was also found that polishing effect presented a strong relationship with grain size existing on aggregate surfaces.

1. Introduction

Pavement texture measurements, modeling and analysis are a great challenge and have attracted considerable interest over the past several decades. Pavement texture profiles generally present many of the statistical properties of random signals. It is very difficult to make a distinguishing between different surfaces using either experimental or theoretical methods. However, it is well recognized that pavement texture plays a vital role in the development of both pavement friction and tire wear. In general, pavement texture has traditionally been grouped into two classes, i.e., micro- and macrotexture. Based on ASTM E 867, the two textures can be characterized using characteristic dimension of wavelength and amplitude existing on pavement surfaces, for microtexture the characteristic value is defined less than 0.5 mm and for macrotexture it is defined larger than 0.5 mm. Pavement macrotexture has been found to play a substantial influence on the interaction between tire and road surfaces, especially at high speeds and in wet pavement conditions. Kokkalis [1] has shown a relationship between wet pavement accident rate and pavement macrotexture. As might be expected, the accident rate was shown to decrease as macrotexture increase. Gunaratne et al. [2] used an electro-mechanical profilometer to record the surface profiles of both asphalt and concrete pavements. The data were later modeled using auto regressive (AR) models, where a fast Fourier transform (FFT) technique was used to graphically regenerate the pavement surface. Since the order of the models used in the studies was very low (AR(3)), the models were only able to model macrotexture and could not capture the characteristics of microtexture. Fülöp et al. [3] investigated the relationship between international friction index (IFI) and skid resistance, as well as the relationship of IFI with surface macrotexture. The hysteresis effect was found to result from macrotexture on the tire tread rubber. Hence, they concluded that macrotexture had a direct effect on skid resistance. Liu et al. [4] confirmed the direct effect of macrotexture on skid resistance by finding an optimum gap distance between aggregates at which skid resistance was at maximum.

Due to advances in measurement technology, both micro- and macrotexture profile can now be obtained easily by setting a collecting step size using profilometer. Based on the apparent polishing phenomenon, more and more researchers have focused on the microtexture to search for friction contribution in terms of tire and road interaction. The investigations by Kokkalis [1] classified the microtexture and macrotexture as the first and second order of pavement surface irregularities, respectively. Rohde [5] developed a model to simulate a tread element descending on pavement microtexture. His model revealed the importance of microtexture pattern as well as the influence of its amplitude on the descent time of the tread element. Taneerananon and Yandell [6] developed a model to simulate a rigid tread element sinking onto portion of a road surface and studied the effect of microtexture roughness on braking force coefficient. They found that microtexture roughness became more important when the pavement surface was wet. Persson and Tosatti [7] presented a comprehensive treatment of the hysteric contribution to the friction for viscoelastic solids sliding on hard substrates with different types of (idealized) surface roughness. They discussed qualitatively how the resulting friction force depended on the

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nature of the surface roughness. When rubber was slowly sliding on the surface, at a velocity less than 1 cm/s (as in the case to ABS—braking of automotive tires), the rubber would deform and fill out the nanoscale cavities associated with the short-ranged surface roughness and this gave an additional contribution to the sliding friction. Recently, Luce et al. [8] utilized micro-Deval test and aggregate imaging system (AIMS) to investigate the influence of polishing on texture. But due to the influence of image noise, the AIMS texture analysis was just able to correlate skid friction with average aggregate texture. Slimane et al. [9] adopted the similar image technique to characterize microtexture of road surfaces and the maximum image resolution was about 50 μm.

As part of a long-term effort to understand and improve pavement friction, the Michigan Department of Transportation (MDOT) has developed an aggregate wear track to quantify the tendency of individual coarse aggregate sources to polish under the action of traffic as shown in Fig. 1. The wear track consists of a pair of diametrically opposite rubber tire wheels attached to a common center pivot point. An electric motor is used to apply a driving force to the wheels through the center pivot point. Uniformly graded aggregates are used to make trapezoidal shaped test specimens for the wear track. To make the test specimens, aggregates are placed directly against a mold and then covered by Portland cement mortar. Placing 16 of the test specimen end to end forms a circular path about 2.13 m in diameter. The wear track specimens are subjected to four million wheel passes with the surface friction of each specimen measured at regular intervals. Based on these friction measurements, an aggregate wear index (AWI) (the AWI represents the average initial peak force measurement determined on duplicate test slabs after four million wheel passes of wear track polishing) is calculated for each aggregate source. Minimum required AWI values have been established by MDOT for coarse aggregates used in the wear courses of HMA pavements.

To understand the generation mechanism of friction, it is necessary to establish a robust correlation between aggregate properties and laboratory measures of friction and texture. As the first research step, a methodology is developed to characterize texture on an AWI wear track specimen. Through the texture analysis, it is highly expected that mechanisms of pavement friction related to characteristics of surface texture could be essentially revealed, because tire tread friction has been recognized to mainly result from hysteresis effects generated by surface asperity [7,10]. Fig. 2 shows several polished aggregates from the specimen used in this study. The limestone aggregates are around 10 mm in size. A laser sensor was used to collect elevation profiles from unpolished aggregate surfaces and polished aggregate surfaces with four million wheel passes separately. The significantly different surfaces might have made it easier to investigate the evolution process of tire polish. Data dependent systems (DDS) methodology [11] was employed to model the elevation profiles. This approach models the trends in the data to capture the dominant frequencies (or wavelengths), their damping characteristics quantifying the regularity with which they repeat, and their contributions to variance quantifying the roughness magnitude, so that the surfaces could be distinguishingly characterized in both directions of length and height.

Fig. 1. AWI circular wear track assembly (the wheel tire is 578 mm in diameter and rotates around the center pivot point at a speed of 25 rpm).

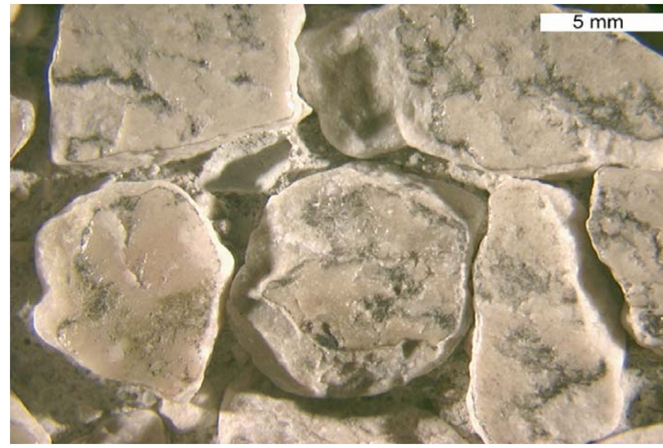

Fig. 2. Aggregates on polished AWI wear track surface.

2. Surface texture measurements

Under interaction of tire and pavement surface, the mechanism of pavement texture to generate friction remains unclear. As described in the introduction, it is generally accepted that macrotexture and microtexture play a significant role in generation of tire–road friction. Persson et al. [10] considered that rubber friction was mainly induced by surface roughness that generated pulsating forces on rubber surface. They used power spectrum of surface texture to calculate the hysteric friction. Limited by the texture region they studied (1 cm order of length), it seemed to be impossible to consider the effect of macrotexture on the hysteric friction. In 1980s, Spectral techniques were introduced into pavement roughness analysis, a series of spectral functions describing power spectral density (PSD) of pavement profiles were developed [12–15]. It has been found that various pavement profiles have shown many similarities in spectral characteristics and a single parameter known as the roughness index can shift the PSD level up or down, depending on the roughness [14]. Some authors even suggested dividing the PSD curves into two families, one used for rigid pavements and the other one used for flexible pavements. Because pavement profiles usually appear in random signals and present stochastically statistical properties, it seems to be difficult to distinguish different pavement profiles using spectral techniques.

The purpose of this paper is to characterize the macrotexture and the microtexture presented on both the unpolished and polished wear track aggregate surfaces as an effort to explain the influence of the aggregate texture on generated friction. A high resolution laser profilometer was used to collect the elevation profiles on the surfaces. The laser sensor of the profilometer has a maximum 1 μm resolution. Due to a restriction on the number of data points that can be effectively used in the subsequent DDS