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# Application of fractal analysis for measuring the effects of rubber polishing on the friction of asphalt concrete mixtures

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ABSTRACT

Skid-resistance is one of the most important pavement surface properties with respect to driver safety. For example, the friction of asphalt concrete mixtures continuously evolves because the aggregates are subjected to polishing by rubber tires.

Currently available tests for mix design optimization are focused primarily on evaluating the polishing characteristics of aggregate surfaces rather than actual AC mixtures. Factors such as aggregate gradation cannot directly be taken into account in aggregate polishing tests, and hence its effects on the friction of the overall mix are not accounted for when mixes are being designed.

Using the Skid Resistance Interface Testing Device (SR-ITD®), developed for laboratory use during the European project SKIDSAFE, the evolving frictional properties of asphalt concrete mixes containing any desired combination of aggregate type, maximum size and gradation can be evaluated. The effects of the number of wheel passes and combinations of contact pressure and speed are documented.

During SR-ITD testing, evolution of the surface morphology is recorded using a laser profilometer. Post-processing of the results by means of fractal analysis enables the characterization of the surface texture on the basis of three unique descriptors.

By combining the variation of surface descriptors with the friction coefficient, the influence of aggregate type and gradation on the frictional response of asphalt concrete mixes can usefully be determined.



## 1. Introduction

Pavement texture is of fundamental importance for the road network since it influences road users' safety [1]. The surface characteristics vary during the pavement lifecycle accordingly to continuous abrasion of small aggregate asperities resulted from the rubbing action due to the tire passing and the presence of fine road detritus (polishing) and environmental factors such as freezing/thawing, wetting/drying and oxidation (wearing). Both phenomena involve similar processes driven by the strength and the durability of the aggregate/s composing the mixture, which vary only in the degree and the rate of material loss.

The role of the aggregate is twofold: the mineralogical and chemical characteristics influence the microtextural wavelengths (ranging from 0.1 to 0.5 mm) while the granulometric curve composition designed at mix design influences the macrotextural wavelengths (ranging from 0.5 to 50 mm).

In order to make sure that the aggregates selected by the asphalt producer are characterized by good mechanical and/or chemical characteristics, satisfactory performance are often required with respect to a set of tests [2]. These tests are performed on single aggregates or on group of aggregates. Several studies [3–5] have shown that the result of these tests don't always provide reliable indications.

In the last years, a lot of research effort [6–9] has been spent in developing laboratory procedures and methods focused on the evolution of friction and texture with progressive polishing of the aggregates embedded in the asphalt concrete matrix. These studies are possible thanks to the availability of optical or laser devices, technologies nowadays very accurate, economically affordable and easy to carry.

At the moment, the Mean Profile Depth (MPD) and the Root Mean Square (RMS) are the most popular parameters to characterize the macro textural properties of AC profiles and to compare them with the frictional response obtained by means of laboratory devices [10–12]. The main limitation of these parameters is related

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to the limited range of texture lengths taken into account for its evaluation.

Another similar approach for surface characterization has been developed by Do et al. [13]. They consider three roughness parameters characterizing asperity height and sharpness and compare them with skid resistance.

In order to have a more physical based surface characterization of asphalt concrete mixture, able to take into account all the different scales influencing friction, a more comprehensive multi-scale approach, based on the self-affine properties of asphalt surfaces is used often by the rubber community [14,15]. Only lately this methodology has been introduced in research studies focused on the comparison between different types of stone/asphalt concrete/concrete surfaces [16–18]. An attempt in aggregates (mosaics) surface characterization using different multiscale approaches (fractal and spectral approach) has been described in a paper of Chen and Wang [18].

In this paper, fractals parameters of different asphalt concrete mixes made of different aggregate types and sizes are deduced from measured height profiles accordingly to the method of Kluppel and Heinrich [14].

By means of the newly developed Skid Resistance Interface Testing Device (SR-ITD®), texture evolution due to progressive polishing can be monitored and fractal surface descriptors can be obtained. Since this device is also able to perform friction tests, the fractal surface descriptors can be coupled with the frictional response. In this way, a robust methodology for inspection of the changes in asphalt concrete surface texture as they undergo to progressive polishing action is presented.

The surface and frictional characteristics for the different mixes are compared with the results of the experimental testing performed on the composing stones to investigate the influence of the stone types in the surface characteristics of the different mixes.

This approach combined with this device or used with other polishing and friction devices could help practitioners in identifying the optimum mix and in monitoring asphalt concrete surfaces.

## 2. Research methodology

At the beginning of this research, granite and greywacke aggregates, which are commonly used for wearing courses in asphalt pavements, have been characterized by means of well-known aggregate tests.

At the same time, three different asphalt concrete mixes, also commonly used for wearing courses have been designed. All the mixes are characterized by the same maximum aggregate size. Granite aggregate was selected for the skeleton of Stone Mastic Asphalt (SMA) and Dense Graded Mix (AC10) while, for the Porous Asphalt (PA) mix, greywacke aggregate was utilized. Stone types and the most common ways to characterize them are discussed in Section 3.

Asphalt slabs have been manufactured in the lab and tested with an innovative polishing and friction testing device (described in Section 4) obtaining an evaluation of friction for different polishing levels. The surface texture evolution with polishing has also been recorded by means of a laser profilometer and the profiles have been post processed in order to obtain surface parameters accordingly to the method described in Section 5. The results are presented in three different steps. In Section 6, the surface descriptors for different asphalt types are discussed. In Section 7, the variation in the surface descriptors and the friction coefficient for different asphalt types due to the polishing action is considered. Finally, in Section 8, the results in term of asphalt concrete are compared with those of the composing stones in order to investigate the influence of the stone type on the mix.

## 3. Materials

The section materials is divided in three different parts. In the first part, the stone petrographic characterization is discussed. In a follow up sub-section, the results of mechanical aggregate tests are discussed and, finally, the composition of the mixes composed of the studied aggregates is discussed.

### *3.1. Aggregate selection*

In this paragraph, petrographic analysis is discussed for a more comprehensive characterization of greywacke and granite stones.

Greywacke is a type of sedimentary rock belonging to the sandstone group. The following mineral grains are part of its matrix: quartz, feldspars, chlorite and biotite. Petrographic examination shows that quartz and feldspars are angular and relatively coarse with grain sizes ranging from 100 to 300 μm, while chlorite and biotite mineral grains are elongated and smaller in size. They are cemented by the much finer matrix of chlorite and biotite minerals. Chemical analysis indicates relatively high silica content (66%). Quartz is composed of pure silica. The silica combines with the main oxides (Iron, Magnesia, Calcium, Sodium and Potassium oxide) to form the silicates. Feldspars are aluminosilicates containing potassium, sodium and calcium. Chlorite and biotite are phyllosilicate minerals, i.e. with a tendency to split along defined crystallographic structural planes, rich in iron and magnesium.

On the basis of this preliminary analysis, the frictional performance for this aggregate is expected to be high due to the angular shape of the coarse quartz and feldspars grains. The poor sorting of the different mineral grains and differences in size and shape between them create an irregular and fairly harsh rock surface microtexture which provide high friction and high polishing resistance.

Granites are intrusive igneous rocks composed of interlocking crystals. They are usually coarse grained, often with similar sized individual crystals which are generally randomly arranged. Petrographic examination shows the presence of orthoclase feldspars as the main component (46%) but also quartz, amphibole and biotite.

Regarding the grain characteristics, feldspars and amphibole grains are angular (grain sizes ranging from 100 to 2000 μm) with well-developed crystal faces. Quartz grains are finer (50–200 μm), rounded with no crystal faces. Biotite grains have an elongated shape. Also in this case, the chemical analysis indicates relatively high silica content (64%). All grains contain silicates. Quartz is composed of pure silica. Orthoclase feldspars are aluminosilicates containing potassium. Amphibole is an inosilicate or chain silicate containing iron and magnesium in its structure and trace of sodium and calcium. Biotite is a phyllosilicate (sheet silicate) mineral rich in iron and magnesium.

Also for this type of aggregate, the frictional performance is expected to be good due to the angular shape of the coarse interlocking feldspars and amphibole grains. The crystalline structure of these minerals and the random distribution of the crystals creates a rough surface microtexture which provide high friction and therefore good skid resistance. For this stone, good resistance to polishing is ensured by high concentration of feldspars grains ( $>$ 40%) plus the contribution of the amphibole and quartz.

Comparing the two aggregates with respect to the chemical composition, no clear ranking can be made. The amount of silica is comparable for the two aggregates. Only some hypothesis can be made in relation to the structure and the grains bonding, in relation to resistance to polish and friction characteristics.