TIREE / ROAD FRICTION – ASSESSMENT OF THE POLISHING OF ROAD AGGREGATES

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SUMMARY
This paper dealt with a laboratory study on the effect of the polishing process on the road aggregate micro texture. The polishing action was simulated by the projection of a water and fine abrasive mix under pressure. Evolution of the aggregate micro texture with the polishing time was assessed by profile analyses and Scanning Electron Microscope (SEM) observations. The profile analyses were based on a method developed at LCPC for characterizing the asperity shape and relief. The SEM observations were done at different magnification levels. Results from the profile analyses showed that polishing involves two micro texture scales: the “roughness” scale, composed of few ten microns asperities, and the “undulation” scale, composed of few hundred microns asperities. Evolutions of the asperity shape and relief at these two scales depended on the rock nature. SEM observations supported these results and gave a better insight into the evolution of the mineral surfaces, related to the rock properties.

Keywords: Polishing, Micro texture, Relief, Shape, Petrography.

1 INTRODUCTION
The tire/road friction, which is essential for the safety of road users, decreases when the road surface is worn. Wear of road surfaces involves mainly the polishing of the micro texture of aggregates due to the repeated actions of traffic. The micro texture is defined as surface asperities whose height is less than 0.2 mm and width is less than 0.5 mm.

Currently, the phenomena involved in wear are not well understood and therefore no satisfactory model is available to predict wear. Previous studies reported the evolution of friction measured on road surfaces with the polishing time. However, this knowledge does not give a good insight into the polishing process. Particularly less is known about the effect of polishing on the characteristics of micro texture asperities such as their shape, size and density.

Recent results obtained at LCPC [1] showed that the tire/wet road friction at low speeds is greatly influenced by two angular parameters characterizing the shape and relief of micro texture asperities. It was shown also that at least two micro texture scales contribute to the generation of friction. Asperity size is respectively in the order of 10 µm and 100 µm for these two scales, called “the roughness scale” and “the undulation scale”.

The aim of the study dealt with in this paper was to assess the evolution of the micro texture with polishing by means of the two angular parameters mentioned above, and to relate this evolution to the aggregate petrography.

2 EXPERIMENTAL PROGRAM
2.1 Materials
Aggregates from three stones were used: a limestone, a sandstone and a diorite.

2.2 Devices
The polishing actions were simulated in laboratory by means of a mlpc® equipment called “GRAP”, which was developed in France by the LPC network (Public Works Regional Laboratories) as an alternative to the well known British PSV test method [2]. Results from [2] showed also that the limit polishing states, assessed by means of friction measurements, of both methods are quite comparable. GRAP polishing is achieved by the projection of a water and very fine abrasive mix under pressure by means of a nozzle with a given incidence angle (Fig. 1). The surface is swept by the displacements of the projection nozzle. Twenty sweep cycles are necessary to obtain a conventional limit state. The test method is well described in [2].

Friction was measured by means of a Pendulum Tester (Fig. 2). This device is widely used in order to assess the skid resistance properties at low speeds of a surface either in the field or in the laboratory. The tester incorporates a spring-loaded slider made of a standard rubber attached to the end of a pendulum. On releasing the pendulum from a horizontal position, the loss of energy as the slider passes over the test surface is
measured by the reduction in length of the upswing using a calibrated scale.

![Figure 2: Pendulum Tester](image)

Micro texture profiles were measured by means of high resolution laser sensor. Petrography examinations were done by means of pictures taken from a Scanning Electron Microscope (SEM).

### 2.3 Specimens

Specimens used for the GRAP polishing are 100 mm × 150 mm rectangular plates. They are composed of coarse aggregates of similar sizes and fixed in a resin matrix (Fig. 3).

![Figure 3: GRAP specimen](image)

### 2.4 Polishing states

Analyses and observations were done at the initial (without polishing) and four polishing states, expressed as the number (n) of sweep cycles of the GRAP nozzle: 1 – 5 – 10 – 20 cycles. The initial state was considered as the 0-cycle polishing state. Five series of specimens were made, each being used for the study of a polishing state. At every selected n-cycle polishing state, the GRAP machine was stopped after n sweep cycles and the specimens were taken out for observations and measurements.

### 2.5 Observations and measurements

SEM observations were done at two stages:

- identification of the minerals from the SEM pictures by comparison with the results from a preliminary petrographic study;
- examination of the effect of polishing on the minerals.

For the second stage, three magnification levels were used: ×30, ×300 and ×3000. By this way, the effect of polishing at different scales could be observed and related to the profile analyses. On every specimen, profile measurements were carried out on about 15 aggregates. The sampling interval was of 1 µm. Profile lengths varied between 6 mm and 12 mm, the total length varying between 120 and 150 mm.

### 3 RESULTS

#### 3.1 Effect of polishing on the micro texture

##### 3.1.1 Definition of the angular parameters

The angular parameters were calculated from the micro texture profiles (Fig. 4). Profile indenters were first defined as being composed of a profile peak and its two neighboring left-right valleys. Indenter shape was defined locally as the cotangent of the indenter summit semi-angle α. Indenter relief was defined locally as the angle θ between the segment connecting the summits of two consecutive indenters and the horizontal.

![Figure 4: Definition of the shape and relief](image)

Beside the shape and relief, density could be defined as the number of indenters per unit length. Indenter width could also be calculated.

Peaks and valleys were defined as points respectively higher and lower than their neighboring left and right points. Formulae for calculating the shape and relief are the following:

\[
\theta = \tan^{-1} \left( \frac{z_{p+1} - z_p}{x_{p+1} - x_p} \right)
\]

(1)

where \( z_p, x_p \) : height and abscissa of the \( p \)th peak.

\[
\alpha = \frac{1}{2} \left[ \tan^{-1} \left( \frac{x_e - x_{e-1}}{z_e - z_{e-1}} \right) + \tan^{-1} \left( \frac{x_{e+1} - x_e}{z_{e+1} - z_e} \right) \right]
\]

(2)

where \( z_e, x_e \) : height and abscissa of the \( e \)th extremum.

##### 3.1.2 Definition of the micro texture scales

Indenters could be detected from two profiles: the measured profile, defining the “roughness scale”, and the envelope profile composed of segments connecting
every peak of the measured profile, defining the “undulation scale”.

Profile analyses were performed by means of a Matlab® program developed at LCPC. The measured profiles were re-sampled at respectively 5 µm and 50 µm sampling intervals for the analyses of the roughness and undulation scales.

On every specimen, mean values of the shape and relief were calculated from the profiles. Evolution of the micro texture with the polishing time was then studied by means of these values.

3.1.2 Evolution with the polishing time

Evolutions of the shape and relief were presented on figures 5a, b and c for respectively the limestone, diorite and sandstone. Evolutions of the friction were also shown. Values at n-cycle polishing states were normalized by the values at the initial state.

It was noted that the indenter width stayed almost constant with the polishing time, and the width difference between the three stones was small. The mean width was respectively about 20 µm and 200 µm at the roughness and undulation scales.

On the limestone (Fig. 5a), shape and relief values at the roughness and undulation scales decreased continuously with the polishing time, meaning that indenter summits were progressively rounded off and indenters were lined up. There was less evolution at the undulation scale then at the roughness scale. It was noted that friction values decreased in the same way as the shape and relief did at the roughness scale. Polishing of the limestone seemed then depend almost on the evolution of small asperities, the mean size of which was about 20 µm.

On the diorite (Fig. 5b), evolutions of the shape and relief values at the roughness and undulation scales were different. Variation of the indenter geometry at the roughness scale was similar to what could be observed on the limestone, meaning that polishing smoothed off the small asperities. At the undulation scale, there was first an increase of the shape and relief values, then a slight decrease with the polishing time. This result could mean that polishing created first sharp and coarse asperities. These asperities were then slightly rounded off with the polishing time. Variation of friction values seemed to be governed solely by the undulation scale after the first polishing cycle and by both the roughness and undulation scales in the subsequent cycles.

On the sandstone (Fig. 5c), evolution of the indenter geometry was similar to what could be observed on the diorite. However, friction values varied in the same way as the shape and relief did at the undulation scale, meaning that the polishing of the sandstone depended almost on the evolution of coarse asperities, the mean size of which was about 200 µm.

3.2 Visual examinations from SEM pictures

Evolution of the aggregate micro texture depends on the nature of the rock, and mainly on its mineralogical composition.

3.2.1 The limestone aggregates

The limestone is made of calcite, the hardness of which is far below that of the silica abrasive. The crystal sizes are mainly between 1 and 5 µm. Few crystals exceed 50 µm and can be seen with sharp edges (cleavage plans).

SEM observations showed that the important decrease of the friction values at the beginning of the polishing is correlated with the wearing away of the few micrometer high crystals (Fig. 6). Then, the following lighter decrease was due to the removal of the residual micro-asperities, as well as the rounding off of the edges of the few coarser crystals.
3.2.2 The diorite aggregates

Diorite is made of an imbrications of crystals from different minerals: amphibole, feldspar, and quartz to a lesser extent. Silica is harder than feldspar, and much harder than amphibole. Crystal sizes are in the order of 300 µm to 500 µm.

The increase of friction values after the first cycle of polishing could not be observed by means of SEM pictures. From the fifth cycle, the decrease of friction values might be related mainly to the rounding off of the crystal edges. In the same time, the medium-sized asperities (due to cleavage plans or fractures edges), which were located at the surface of each crystal, seemed to get gradually smooth.

The final friction value is due to the contrast between mineral hardness [3]. The final figures were rounded crystal-sized asperities.

3.2.3 The sandstone aggregates

The tested sandstone is made of 50 - 300 µm quartz particles strongly linked to each other by a matrix. The particle hardness is similar to that of the abrasive. The matrix is mainly made of needles-like or sheets-like soft clay minerals.

The first increase of the friction values could be explained (×30 scale) by the digging of the softer matrix. The quartz grains were then put into relief. Asperities could reach few tens of micrometers high, with various shapes including sharp conchoidal fractured edges.

Then, shocks on the quartz grains caused fractures on the smooth surfaces and on the sharp edges. This involved a pricked appearance of the grains, with 1 µm high asperities, and the edges gradually rounded off. After the 10th polishing cycle, the small asperities were removed but the few tens micrometers high relief remained. This observation might explain the high level of the residual friction value of this rock.

3.3 Corroboration between profile analyses and petrography observations

SEM observations showed that polishing involved on the limestone the evolution of small crystals (a few micrometers) and on the diorite and the sandstone mainly the evolution of coarse crystals (a few hundred micrometers). These observations confirmed the respective roles of the roughness and undulation scales as assumed by the profile analyses (§ 3.1.2).

The observed crystal evolutions might also be related to the graphs showing the variations of the indenter shape and relief (Figs. 5a, b, c). It should be emphasized that the interpretation of profile analyses should be supported by petrography observations, which give a better insight into the mechanisms involved in the polishing process.

4 CONCLUSIONS

In this paper, the effect of polishing on the road aggregate micro texture was investigated. Evolution of the micro texture asperities with the polishing time was studied by means of a profile analysis method, which is based on the description of the asperity shape and relief. Results were compared to visual observations of SEM pictures.

Analyses of profiles measured on three rocks whose mineralogical compositions were different showed that polishing involved two micro texture scales: the roughness scale, composed of a few micrometers size asperities, and the undulation scale, composed of a few ten to hundred micrometers size asperities. These scales were in fact related to the rock crystal sizes.

Satisfactory corroboration was found between profile analyses and petrography analyses via SEM pictures. The shape and relief parameters used in this paper could then be a reliable index to quantify the aggregate micro texture. However, petrography analysis remains a precious tool for a good understanding of the phenomena.

5 REFERENCES