Long term Road Skid resistance: How to choose aggregates for the wearing course

Abstract*– This work focuses on the relation between the mineralogical composition of aggregates and their capacity to generate adequate friction between the road surface and the tyre after the polishing action of traffic. Three different types of aggregate namely Greywacke, Granite and Limestone were used in the study. Petrographic examination of the aggregates was carried out using optical microscopy. The Wehner-Schulze apparatus was used to determine the evolution of friction with polishing cycles of both aggregates and asphalt specimens. A new aggregate hardness parameter was introduced based on the mineralogical composition and the hardness of the individual minerals. This hardness parameter was then related to friction coefficients measured on aggregate specimens after 180.000 polishing cycles. Initial results indicated that this new aggregate hardness parameter is a good indicator of the capacity of an aggregate to retain good friction levels.

Keywords—Skid resistance, road surface, polishing, Traffic, Wehner-Schulze machine

I. INTRODUCTION

A. Evolution of skid resistance

Skid resistance indicates the contribution of the road surface to the generation of friction between the tyre and the road surface and is one the most important surface properties with regard to safety. It is, for instance, one of the factors that determine braking distance and sliding forces in a sharp bend. However, due to the polishing action of the traffic, the skid resistance of an asphalt surfacing decreases continuously with time. Figure 1 shows how the skid resistance changes with time [Kane et al, 2010].

B. Surface texture and skid resistance

Skid resistance is primarily related to the road surface texture. Texture is characterized at two scale levels, namely, microtexture and macrotexture. The microtexture corresponds to surface irregularities whose dimensions range from 0.001mm to 0.5mm vertically and less than 0.5mm horizontally [ISO 13473-1]. It is generally an aggregate surface characteristic that provides small irregularities that disrupt the continuity of the water film and produces frictional resistance between the tyre and the pavement. The magnitude of microtexture depends on the initial roughness of the aggregate surface and the ability of the aggregate to retain this roughness inspite the polishing action of traffic [Do et al, 2009, Kane et al, 2010]. The macrotexture, on the other hand, corresponds to surface irregularities whose dimensions range between 0.1mm and 20mm vertically and between 0.5mm and 50mm horizontally [ISO 13473-1]. It is an overall asphalt mixture characteristic and its role is to provide surface drainage paths for water to evacuate from the contact area between the tyre and pavement and to prevent hydroplaning at high speeds. It also contributes to skid resistance by means of energy dissipation due to the deformation of the tyre rubber. [Villani et al, 2011].

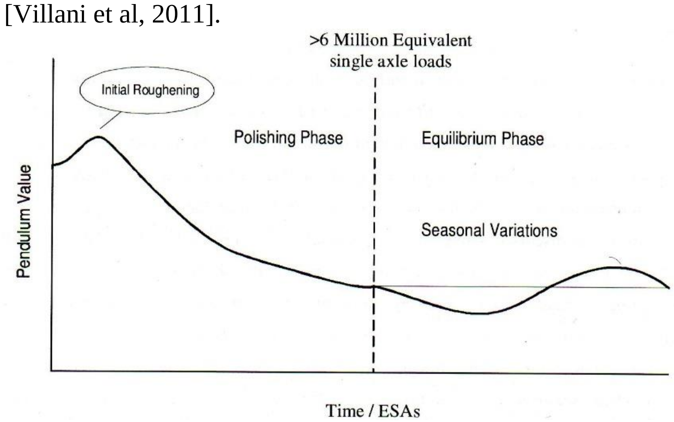


Figure 1 : Simplified general pavement polishing model

C. Aggregate and resistance to polishing

The small irregularities of the aggregate surface corresponding to the microtexture disrupt the continuity of the water film between the tire and road surface and produce frictional resistance. The initial aggregate microtexture and its evolution as a result of the polishing effect of traffic depends primarily on the type of aggregate i.e. its mineralogical composition.

Tourenq showed two mechanisms regarding polishing of aggregates : “general” polishing that tends to smooth off the coarse aggregate edges, and “differential” polishing that tends to create additional roughness on the aggregate faces [Tourenq et al., 1971]. The creation of new rough textures during polishing is only possible on aggregates originating from multi-mineral rocks, where polished soft minerals form "valleys", while hard minerals, less affected by polishing, constitute the "peaks".

Aggregates composed of single minerals of relatively low hardness, such as limestones, have a very low resistance to polishing. On the other hand, sandstones, composed primarily of hard quartz mineral particles cemented together with a softer mineral matrix, have good frictional properties because of the differential wear and debonding of individual particles under traffic [Masad et al, 2009].

So, while the microtexture evolves continuously due to the polishing effect of traffic, analyzing the mineralogical composition can give a quantitative evaluation of an aggregate's ability to retain its microtexture.

D. Polishing tests

To forecast the capacity of an aggregate to resist polishing, various tests have been proposed in the past, Tests to estimate the polishing resistance of aggregates were first developed in the 1950's by TRRL. The method has since been standardized and is now widely known as "PSV test" (Polished Stone Value) [NF EN 1097-8]. Despite its popularity, the PSV test cannot be adapted to asphalt mixes because of the curved shape of the aggregate specimens. Furthermore, it has been shown that the PSV test is just a ranking tool for a given set of laboratory conditions that offers limited prediction of the complex development of skid resistance of asphalt surfacings [Woodward et al, 2005]. Wilson and Dunn [Wilson & Dunn, 2005] discuss the results of a large study conducted at the University of Auckland which shows the use of the PSV approach. They conclude that the PSV test is not necessarily a good indicator of the equilibrium level of skid resistance.

Another test named CPA test (accelerated polishing coefficient), developed in France to simulate polishing, uses of a jet projection containing a mix of water and abrasive onto the pavement [Lédée et al, 2005]. The polishing action of the water jet is, however, very different to the polishing effect of a rubber tyre on a road surface. Tourenq proposed and validated a relationship between this CPA and the mineralogical composition of the aggregates [Tourenq et al, 1971]. Unfortunately the CPA test is no longer used as the polishing action is not representative of polishing effect induced by traffic.

Alternatively, the Wehner-Schulze (WS) apparatus developed in Germany can be used to assess polishing and friction properties of aggregates and asphalt mixtures. The tests reproduce well the polishing effect of traffic and the variation of the friction of the surface [Do et al, 2009, 2009, Kane et al, 2010]. Furthermore, a correlation coefficient has been found between the number of polishing cycles in the WS apparatus and the cumulated road traffic [Do et al, 2007]. Also, it has been shown that the long term friction coefficient (180.000 polishing cycles) is related to the PSV of the aggregates used in the asphalt surfacing [Do et al, 2009, Kane et al, 2010]. However, Arampamoorthy and Patrick [Arampamoorthy and Patrick, 2011] argue that there is no sufficient evidence to favour the WS test or the PSV approach as both measures correlate to each other. The test results showed that PSV and WS test results on the hand-placed samples were highly correlated. Therefore, in this form the WS test is not a better predictor of on-road friction than the PSV test.

E. Aims of the work

The objective of this work is to correlate the long term skid resistance of a road surfacing as measured in the laboratory to the mineralogical properties of aggregates. Three different types of aggregates namely greywacke, granite and limestone typically used in asphalt surfacings were studied. Petrographic analyses were carried out in an attempt to correlate aggregate mineralogy to aggregate polishing and consequently to friction and skid resistance.

The first part of the paper describes the mineralogy of the aggregates. The second part analyzes friction and texture characteristics before and after the polishing process using the WS test. The third part focuses on the correlation between an aggregate hardness parameter determined from the petrographic analyses and friction measured after polishing. Furthermore, analyses of the textures of the aggregate specimens using an optical method before and after polishing are also included.

II. AGGREGATES

A. Selected types of aggregates

Three different types of aggregates namely, greywacke, granite and limestone commonly used in asphalt surfacings were used in the study. The selection of aggregates was based on the mineralogy and their PSVs. Greywacke is a type of sedimentary rock belonging to the sandstone group. 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. Limestone is also a sedimentary rock formed in a marine environment from the precipitation of calcium carbonate and compressed to form a solid rock. PSV values for the three aggregates were 60 for greywacke, 58 for the granite and 32 for the limestone.

B. Petrographic examination

Petrographic examination of aggregate samples was carried out in accordance with BS EN 932-3: 1997. The general characteristics of the aggregate samples including maximum particle size, texture and shape were first examined and recorded. The main rock types were then identified and the relative proportions of the constituents were estimated using a light (optical) microscope. Colour, grain size and degree of weathering were also recorded.

For quantitative examination, aggregate samples were first sieved into separate size fractions and the mass of each size fraction determined. Each size fraction was then examined and the petrological composition was determined by hand separation and weighting. The method employed required two representative samples to be tested and the result was the mean of the two measurements.

Thin sections were also used for examination using a high power petrographical microscope. The aggregate particles were first washed in order to remove any finer grains and then ground down to a thickness of 30 microns. The ground material was finally embedded in a resin for examination. High-power microscopic examination was conducted using a polarizing microscope (Reichert petrographic microscope) capable of magnification of up to x600. Thin sections were examined in plane-polarized transmitted light. Photomicrographs of representative coarse and fine aggregate test samples were also taken.

Greywacke aggregate

Petrographic examination showed that greywacke aggregate comprised of several mineral grains namely quartz, feldspars, chlorite and biotite. Quartz and feldspars grains are angular and relatively coarse with grain sizes ranging from 100 to 300 μm. Chlorite and biotite mineral grains, on the other hand, are elongated and smaller in size. Moreover, in the greywacke, coarse angular quartz and feldspar grains are cemented by the much finer matrix of chlorite and biotite minerals. Furthermore, the poor sorting of the different minerals grains and differences in size and shape between them create an irregular and fairly harsh rock surface microtexture. Mineral composition of the greywacke aggregate is presented in Table 1.

Typical hardness of the different mineral grains based on Moh's scale is also presented in Table 1. It can be seen that quartz and feldspars grains are relatively hard with typical hardness values of 7 and 6 respectively. Chlorite and biotite grains are, on the other hand, much softer with hardness values of between 2 and 3 approximately. For the greywacke, high concentration (> 60 %) of hard quartz and feldspars grains gives the rock good resistance to polishing. Moreover, variations in hardness between mineral grains causes differential wear and material removal which helps to maintain the hardest and roughest grains in contact with the polishing medium, in this case the rubber tyre.

Table 1. Mineral composition of greywacke aggregates

Phase	% by weight	Moh's scale
Quartz	52	7
Feldspar	16	6
Chlorite	22	2.5
Biotite	10	3

A typical reflected light photomicrograph of a greywacke aggregate sample is presented in Figure 2. Coarse angular quartz and feldspar grains were evident in the sample. These grains were cemented by a much finer matrix of chlorite and biotite minerals. The smallest grains observed are mono-mineralic grains of either quartz or feldspar that have been plucked from the sedimentary matrix. Iron has been leached from the mafic chlorite and biotite minerals.

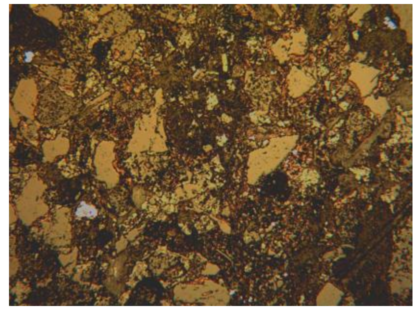


Figure 1: Microstructure of greywacke aggregate (coarse)

Granite aggregate

Petrographic examination of the granite showed that the rock comprised mainly of quartz, feldspars (orthoclase), amphibole and biotite. Feldspars and amphibole grains are angular and coarse with grain sizes ranging from 100 to 2000 μm. These minerals have well developed crystal faces (euhedral). Quartz grains are finer (50 – 200 μm) and rounded with no crystal faces (anhedral). Biotite grains, on the other hand, are elongated and smaller than the feldspars.

Furthermore, quartz and orthoclase feldspars grains are relatively hard with typical hardness values of 7 and 6, respectively. Amphibole grains are also hard with typical values of 6. Biotite grains are, on the other hand, much softer with hardness values of between 2 and 3 approximately, Table 2.

Table 2: Mineral composition of granite aggregates

Phase	% by weight	Moh's scale
Quartz	27	7
Orthoclase felspar	49	6
Amphibole	19	6
Biotite	5	3

A typical photomicrograph of the granite aggregate is presented in Figure 3. Coarse, well formed feldspar and quartz grains are clearly visible at the centre of the micrograph. The more angular grains are indicative of euhedral feldspars which crystallised earlier in the cooling history of the melt. The smaller anhedral crystals of quartz are indicative of quartz crystallising at later stages in the history of the melt. The amphibole minerals top left and top right of the micrograph show considerable weathering, ultimately breaking down to chlorite and iron oxides.

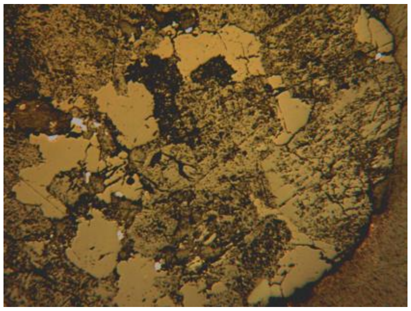


Figure 2 : Microstructure of granite aggregate (coarse)

Limestone aggregate

Petrographic examination of the limestone showed an almost single mineral phase nature of the aggregate. There was evidence of different types of limestone, namely, sparite, ooid and micrite, Figure 4. Sparite calcite showed angular rhomboid-like grains between 100 microns and 1.1 mm in size. Oolithic limestone showed rounded ooids with a diameter of 300 microns. Micrite, on the other hand, was composed of very small crystals (< 5 µm). As regards polishing, the single nature of the mineral grains and their low hardness, typically around 3 in the Moh's scale, Table 3, make this type of rock very susceptible to polishing.

Table 3: Mineral composition of limestone aggregate

Phase	% by weight	Moh's scale
Calcite	100	3

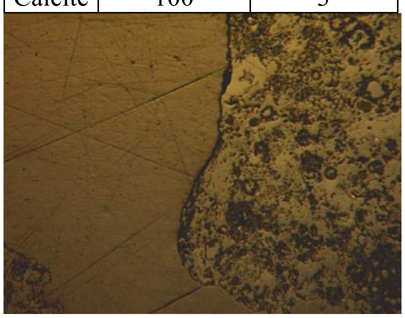


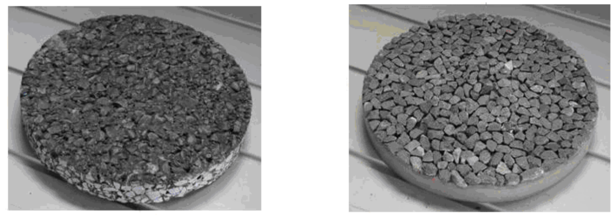
Figure 3 : Microstructure of limestone aggregate (coarse)

III. Wehner-Schulz test

A. Specimens preparation

Circular aggregate mosaic specimens of 22.5 cm in diameter were prepared using the 7.2-10 mm aggregate size fraction (see Figure 1). The mosaics were fabricated by placing manually the aggregates in a single layer as closely as possible, with their flattest faces lying on the bottom of a mould and then filling the mould with a resin [Do et al., 2007]. For each aggregate type one mosaic was prepared.

Asphalt specimens, on the other hand, were first mixed in the laboratory and then compacted to 300 x 300 x 50 mm3 slabs using a laboratory roller compactor. Cores of 225 mm diameter were then taken from the slabs. Four asphalt surfacings were used in the study, SMA with granite aggregate, Porous Asphalt (PA) with greywacke, and two Asphalt Concretes (AC) with granite and limestone aggregates.



Asphalt Mosaic

Figure 1 : Example of circular specimen (22.5 cm of diameter). Left – Core of extracted from asphalt slabs fabricated in the laboratory; Right - Mosaics of aggregates prepared from the size 7.2/10 mm of aggregates are used for this study.

B. Test procedure

Friction and polishing tests were performed with the WS machine (see Figures 6 and 7). This machine contains two stations, one for polishing and one for measuring of friction.

The polishing station contains three rubber cones mounted on a rotary disc and rolling on the specimen surface with a given load. To accelerate the polishing process, a mix of 5% quartz powder (< 0.06mm) in 95% water is sprinkled during the rotation of the cones. The surface is polished on a ring. The machine can be programmed to stop after a given number of rotations. At each stop, water is projected on the specimen to wash all debris.

After the washing period, the specimen is moved manually to the friction measuring station. This station is composed of three small rubber pads (4 cm^2 area for each pad) disposed at 120° on a rotary disc. The contact load between the rubber pads and the specimen surface is approximately 0.2 N/mm^2. For the friction measurement, the disc is accelerated until a speed of 100 km/h is reached. When the speed reaches 90 km/h, water is projected on the specimen surface. At 100 km/h, the motor is stopped and the disc is dropped until the rubber pads touch the specimen surface. The rotation is stopped by friction between the rubber pads and the specimen surface; the friction–time curve is recorded. The friction value at 60 km/h is taken into consideration for analyses.

IV. Analysis and discussion

A. Analyzing the friction and texture evolutions against polishing

Erreur ! Source du renvoi introuvable. (a, b and c) shows the evolution of the friction coefficients against polishing cycles for the three mosaics of aggregates and the four asphalt mixes. The friction curves of asphalts show two phases:

A first phase, where the friction coefficient increases to its maximum. This increase corresponds to the stripping of the binder film that masked the microtexture of aggregates (**Erreur ! Source du renvoi introuvable.**). The duration of that phase depends on the binder type and its adhesiveness on the surface of the aggregates.

A second phase, where the friction coefficient decreases first and stabilizes after. This decrease is caused by polishing of the aggregate microtexture already stripped of their protective layer of bitumen (**Erreur ! Source du renvoi introuvable.**). The evolution of the friction coefficient in this second phase is very close to that of aggregates of mosaics, whatever the asphalt design.

These findings confirm well that the skid resistance of roads after a long term of use is mainly driven by the characteristics of the aggregates in the asphalt. Indeed, it was actually from the same observation that an evolution model of skid resistance has been proposed by Kane et al. [Kane et al., 2012; Kane et al.,2010]. The model in question uncouples bitumen and aggregates by weighting their contributions in the generated tire-road friction. The weight factor tends toward one when the number of polishing cycles increases, giving therefore to aggregates to drive the global behaviour of the whole mix.

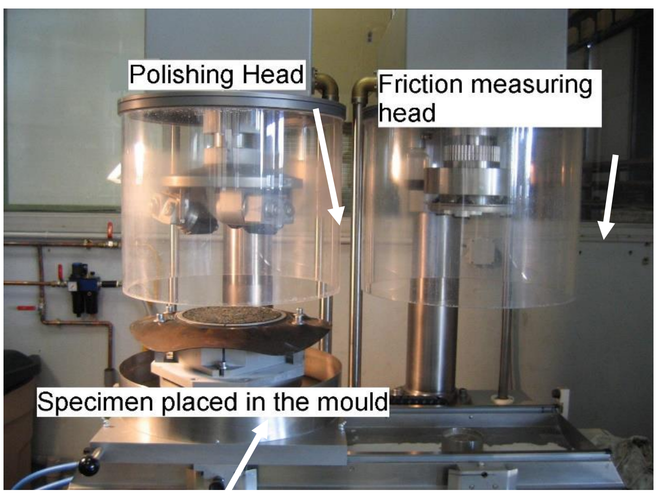


Figure 2 : Overall view of the machine with two heads for respectively polishing and friction measurement

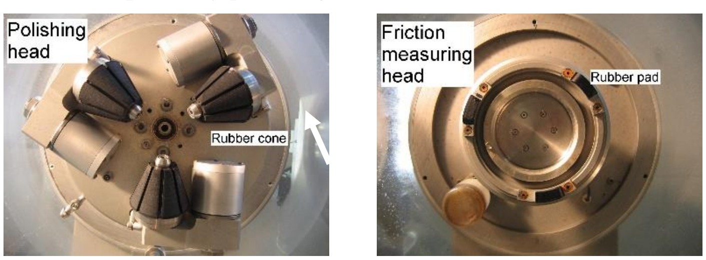


Figure 3 : The two heads of the Wehner-Schulze machine for respectively polishing (left) and friction measurement (right)

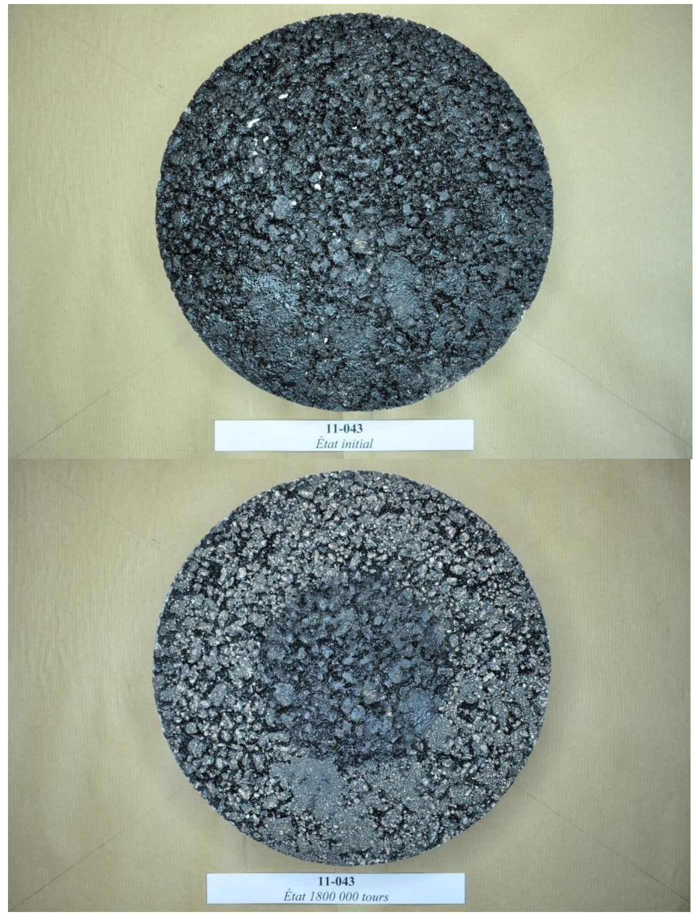
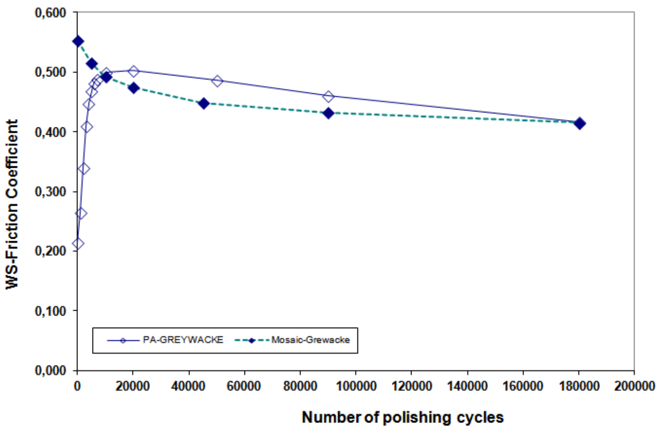


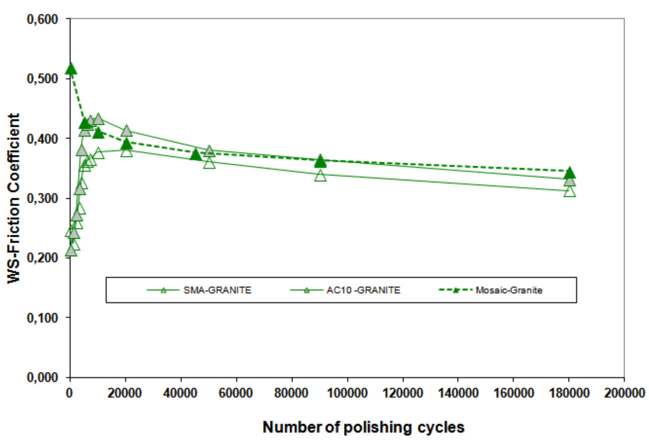
Figure 4 : Photos one of the asphalt samples before (up) and after (down) polishing

It can be seen that for the aggregate specimens (**Erreur ! Source du renvoi introuvable.** – d), the friction coefficients decreased with polishing cycles and tended towards an equilibrium (or final) value. Results showed a higher friction value after 180,000 cycles for the greywacke than those for granite and limestone. Furthermore, friction values for the limestone were very low indicating the poor resistance to polishing of this type of aggregate (The values of the data shown in **Erreur ! Source du renvoi introuvable.** are given in a data-table in the Appendix).

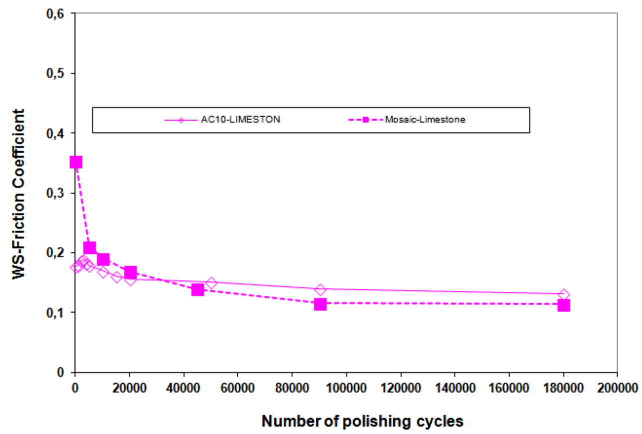
These observations are in agreement with the PSV of the aggregates. Work by Kane et al has shown that aggregates with high PSV have better resistance to polishing as seen by the friction values obtained in the WS test [Kane et al, 2010]. In a recent publication however, Artamendi et al showed that WS test results for mixtures produced with a 55 PSV aggregate had higher friction than those produced with a 60 PSV aggregate [Artamendi et al, 2012]. This was also observed from in situ measurements of skid resistance using both SCRIM and GripTester which suggests that the WS test is a more reliable tool to characterise the skid resistance of asphalt mixtures in the laboratory than the traditional PSV test.



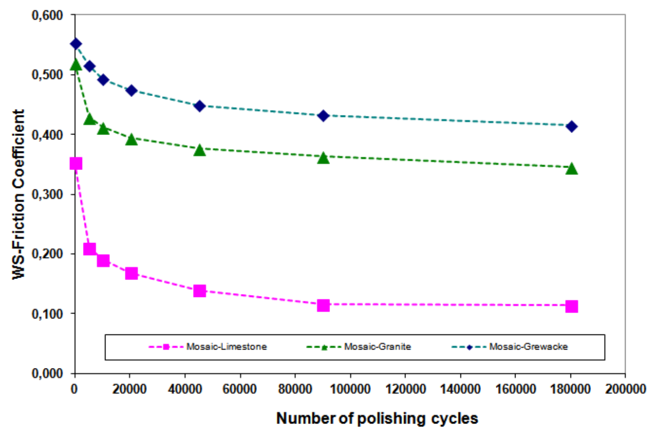
(a)



(b)



(c)



(d)

Figure 5 : WS-friction coefficient versus polishing of the three aggregates, comparison between asphalts and mosaics of aggregates (a, b and c), comparison between types of aggregates (d)

B. Correlation of mineralogical composition and long term skid resistance

Tourenq et al. defined two physical quantities from petrographic examination in order to quantify the capability of aggregates to maintain good skid resistance under polishing: the average hardness (dmp) and the contrast of hardness (Cd), as follows [Tourenq et al, 1971]:

$$dmp = \sum_i dv_i \cdot p_i \quad (1)$$

$$Cd = \sum_i |dv_i - dv_b| \quad (2)$$

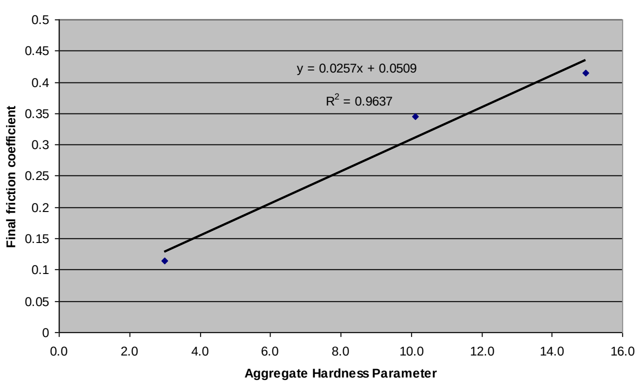
where:

dmp is defined as the “average hardness” of the aggregate, dvi is the Vicker’s hardness of each mineral constituting the aggregate and pi is the percentage by mass of each mineral constituting the aggregate. Cd is defined as the "contrast of hardness" of the aggregate and dvp is the Vicker's hardness of the most abundant mineral constituting the aggregate.

To correlate the aggregates' mineralogical composition and their capability to maintain their friction capacity, the two parameters defined by Tourenq "average hardness" and "contrast of hardness" have been redefined by replacing the "Vicker's hardness" by the "Moh's scale hardness value" of the minerals. So, an index "M" is added to their names to differentiate with those proposed by Tourenq. The Aggregate Hardness Parameter (AHP) has then been defined as the sum of these two aggregate hardness parameters (dmpM + cdM). **Erreur ! Source du renvoi introuvable.** shows the data of Aggregate Hardness Parameter plotted against the corresponding value of friction values at 180,000 polishing cycles. Only three aggregates were tested.

Table 4: Aggregate Hardness Parameter and WS-Final Friction Coefficient of all aggregates

Aggregate type	Mineral type	Mineral composition (%)	Mineral Hardness Moh's scale (1 - 10)	dmp_M	cd_M	*AHP*	*μ (180.kcycles)*
Greywacke	Quartz	52	7	5.5	9.5	15.0	0.415
	Feldspar	16	6				
	Chlorite	22	2.5				
	Biotite	10	3				
Granite	Quartz	27	7	6.1	4	10.1	0.345
	Feldspar	49	6				
	Amphibole	19	6				
	Biotite	5	3				
Limestone	Calcite	100	3	3.0	0	3.0	0.114



C. Discussion

Of significance to practitioners are the following observations:

When choosing the aggregate, the mere knowledge of the mineralogical composition of aggregates is enough to estimate the final skid resistance that will offered be the road. This information may be sufficient to predict the lifetime of the wearing course, duration beyond which the layer must be renewed;

When controlling the road, the implementation of this information would allow the laboratory in charge of this control to understand the origin of its measures, and interpret the differences, accounting of course for the inevitable seasonal variations.

However, it should be noted that in most cases, the skid resistance is measured in-situ using SCRIM, ADHERA, Grip Tester and others. So, the establishment of strong relationships between laboratory tests such as the WS and others together with mineralogical and texture characteristics of the aggregates and the in-situ monitoring techniques is more important than ever to predict the evolution of the skid resistance of an asphalt surface in-service.

V. CONCLUSION

An aggregate hardness parameter was defined based on the mineralogical composition of the aggregates and the hardness of the individual mineral grains. This parameter was then correlated to the WS-friction coefficient values. It was found that the aggregate hardness parameter gives a good indication of the ability of an aggregate to retain its microtexture and consequently its friction properties.

REFERENCES

[1] Arampamoorthy H., Patrick J., Comparison of the Weiner-Schulze and PSV test for estimating the polishing resistance of New-Zealand Chip Seal Aggregate, In Proceedings: 3rd International Surface Friction Conference, Safer Road Surfaces - Saving Lives, Gold Coast, Australia, 2011

[2] Tourenq C., Fourmaintraux D., Propriétés des granulats et glissance routières, Bulletin de Liaison des Laboratoires des Ponts et Chaussées, 51, pp. 61-69, 1971

[3] ISO 12473-1, Characterization of pavement texture by use of surface profiles. Part 1: Determination of mean profile depth, 1997

[4] NF EN 1097-8, Essais sur les propriétés mécaniques et physiques des granulats – Partie 8 : Détermination du coefficient de polissage accéléré, 2000

[5] Lédée V., Delalande G., Dupont P., Ganga Y., Adhérence et Granulats, Bulletin des Laboratoires des Ponts et Chaussées, 255, Pages 91-116, 2005

[6] Moore D. F., Friction of Pneumatic Tyres, Elsevier Ed, 1975

[7] Do Minh-Tan; Tang Zhenzhong; Kane Malal; Delarrard François, Pavement polishing - Development of a dedicated laboratory test and its correlation with road results, WEAR, Volume: 263, Special Issue: SI Pages: 36-42, 2007

[8] Do Minh-Tan; Tang Zhenzhong; Kane Malal; Delarrard François, Evolution of road-surface skid-resistance and texture due to polishing, WEAR, Volume: 266 Issue: 5-6 Pages: 574-577, 2009

[9] Masad Eyad, Rezaei Arash, ChowdhuryC Arif, Harris Pat, Predicting Asphalt Mixture Skid Resistance Based on Aggregate Characteristics, Report no. fhwa/tx-09/0-5627-1, Texas Transportation Institute, 226 p, August 2009

[10] Kane, Malal; Zhao, Dan; De-Larrard, Francois, Laboratory evaluation of aggregate polishing as a function of load and velocity. Application to the

prediction of damages on skid resistance of road surfaces due to trucks and passenger cars, ROAD MATERIALS AND PAVEMENT DESIGN, Volume: 13, Issue: 2, Pages: 312-326, 2012
[11] Kane Malal; Do Minh Tan; Piau Jean Michel, On the Study of Polishing of Road Surface under Traffic Load, JOURNAL OF TRANSPORTATION ENGINEERING-ASCE Volume: 136, Issue: 1, Pages: 45-51, 2010
[12] Villani M. M.; Artamendi I.; Kane M.; Tom Scarpas, Contribution of Hysteresis Component of Tire Rubber Friction on Stone Surfaces, TRANSPORTATION RESEARCH RECORD, and Issue: 2227, Pages: 153-162, 2011
[13] Woodward W. D. H., Woodside A. R; Jellie J. H 2005, 'Higher PSV and other aggregate properties', 1st International surface friction conference, Christchurch, New Zealand, Transit New Zealand, Wellington, NZ, 12p.
[14] Artamendi, I., Phillips, P., Allen, B. and Woodward, W.D.H, 2012, An assessment of the evolution of the skid resistance of proprietary asphalt surfacings in the UK. 5Th Euroasphalt & Eurobitume Congress, Istanbul, 12-15 June.
[15] Wilson & Dunn (2005) Polishing aggregates to equilibrium skid resistance. Road and Transport Research, 14(2) 55-71.
[16]