INFLUENCE OF RAP's AGGREGATE HETEROGENEITY ON RECYCLED HOT MIX SKID RESISTANCE

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ABSTRACT

Hot-mix recycling techniques have been developed for many years. In the present sustainable development context, the re-use of old mix asphalt called RAP (Reclaimed Asphalt Pavement) is becoming a priority for the road industry. Their aim is to optimize the use of these RAP in various layers of roads. According to their role in the structure, these layers contain materials with more or less high quality. This article aims at evaluating intrinsic characteristics of the mix of two aggregates used in a recycled bituminous mix (an aggregate commonly used on surface course and another in base layer). These materials have been mixed in different proportions in order to simulate low and high percentage of recycling. Traditional normalized tests (fragmentation, wear and skid resistance) have been realized, completed by the skid resistance tests with the Wehner & Schulze machine. The elaboration of mixed samples have been studied and planned. The results show the influence of the characteristics of each material on the final mixture.

KEY WORDS: RAP, skid resistance, aggregates, recycling, wearing course.

1. INTRODUCTION

Bituminous mixes recycling has become a necessity for the protection of the environment. It allows on the one hand, to preserve natural resources which are aggregates and oil, and on the other hand to limit the cost due to production and transport of materials.

Each year, many millions tons of bituminous mixes are removed from roads in order to be replaced. Theses mixes, after have been crushed, are named reclaimed asphalt pavement (RAP). It constitutes significant reserves of raw materials which can be useful in the construction of new roads.

In France, hot-mix techniques appeared in the 1970's but their development was slowed because there were many quarries and hot-mix plants. However, in 1990, a law for the limitation of quarries and more recently the Grenelle de l'Environnement (2008), contributed to change that tendency. This one imposes to add systematically 10 to 20% of RAP in new roads. In February 2009, the principal actors of road industry engaged themselves to reuse 60% of RAP in 2012. We estimate that 23% were used to build new bituminous mixes in 2009, against more than 80% in Germany and USA [1]. In Holland, that rate is almost 100%.

Most of the studies and researches on RAP have been made on the bituminous binder because its properties can considerably evolve with time [2 and 3]. These studies aimed, firstly to find the characteristics of the RAP binder [4, 5 and 6], and secondly to evaluate the effects of the old binder on the blend with a new one [7, 8 and 9].

Another important parameter which is often studied in the problematic of recycling is the rate of RAP and its influence on the hot-mixes performances in terms of resistance to fatigue, rutting, creep, moisture sensibility [10, 11, and 12]. Studies tend to show a significant decrease of those performances from 25 to 30% of RAP, except for the resistance to rutting which is better with RAP.

In all those studies, the aggregates which represent approximately 95% of the RAP mass are characterized as new homogeneous materials while they are often constituted of heterogeneous materials stemming from many layers.

The great thickness of the base courses allows to bring an important quantity of recyclable materials; however, we must notify that the rate of replacement of the surface courses is often more important base layers one (in general, from 7 to 10 years for the first ones against 20 to 25 for the second ones). So, the use of RAP in the surface courses is possible if we can assure the surface performances which are normally attended. The skid resistance is a determinant property for a use in a surface layer and is directly linked to the choice of aggregates which are composing it. The heterogeneity of the RAP could influence the skid resistance of a surface course.

Our study aims to quantify the effect of theses RAP aggregates on skid resistance of a hot-mix designed for a surface layer. For that layer, the exigencies on the materials in terms of quality are higher. So, we characterized very meticulously different blendings of aggregates which can be used in the design of surface course mix, by fragmentation, wear and skid resistance tests.

2. MATERIALS AND EXPERIMENTAL DESIGN

We chose to work with new aggregates because we supposed that intrinsic characteristics of aggregates don't change, even after their use in road layers. In fact, the figure 1 shows the similitude of the behavior to polishing between new aggregates and aggregates of the same nature extracted from a wearing course (type BBTM 0/10) twelve years old. The daily traffic was 17600 including all types of vehicles. That choice also guaranties us a constant control of constancy and the homogeneity of the studied materials.

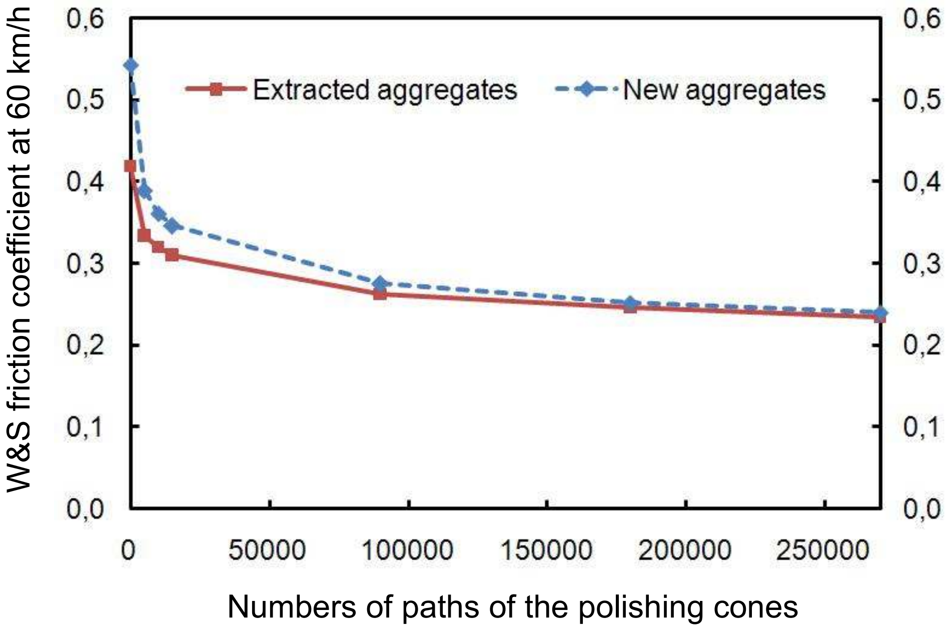


Figure 1 – Behavior to polishing of new and recycled aggregates.

The materials used are two aggregates with different mechanical intrinsic properties. The first one is commonly used in surface course whereas the second one is used in base layer according to the specifications given by the quarries and also the French normalization [13]. Then, each material answers to the specifications required for its utilization in the corresponding layer. These requirements which are principally defined in terms of fragmentation, wear and polishing resistances are notified in the tables 1 and 2. The table 3 which was given by the quarries shows the characteristics of the materials.

All the analysis had been made on the fraction 6/10 of the aggregates.

Table 1 – Intrinsic characteristics of the gravels and of the gravels fraction of the graves for a use in wearing course (according to the French norm XP P 18-545).

Code	Los Angeles	Micro-Deval	Polished Stone Value
A	≤ 20	≤ 15	≥56
B	≤ 20	≤ 15	≥50
C	≤ 25	≤ 20	≥50

Table 2 – Intrinsic characteristics of the gravels and of the gravels fraction of the graves for a use in binder and base layers (according to the French norm XP P 18-545).

Code	Los Angeles	Micro-Deval
B	≤ 20	≤ 15
C	≤ 25	≤ 20
D	≤ 30	≤ 25
E	≤ 40	≤ 35

Table 3 – Characteristics of the 6/10 sized aggregates used (found in the laboratory).

Designations	Type	Los Angeles	Micro-Deval	Polished Stone Value
Aggregate 1 (G1)	Diorite	12.44	8.48	50
Aggregate 2 (G2)	Limestone	23.5	13.3	36

These aggregates had been mixed in different mass proportions (table 4) and characterized with different tests which we will explain in the following parts. The aim is to be able to predict the mix characteristics from its components ones. We worked on intrinsic properties and particularly on aggregates skid resistance which are essential for bituminous mixes skid resistance.

Table 4 – Mass composition of the granular blends.

Blendings	Aggregate 1 (G1) (%)	Aggregate 2 (G2) (%)
1	100	0
2	75	25
3	50	50
4	25	75
5	0	100

2.1. Los Angeles test (EN NF 1097-2)

It is used to find the fragmentation resistance of aggregates [14]. We introduce a sample of 5000 g ± 5 g heavy in a cylindrical drum with an internal diameter of 711 mm and 508 mm of length. We also add a ball load, consisting in spherical steel balls. The aggregates size is 6/10. The drum turns around its axis at approximately 32 rotations per minute during 15 minutes. Afterwards, we can calculate the Los Angeles coefficient with the mass m retained on the 1.6 mm sieve by the following equation:

$$\text{LA} = \frac{5000 - m}{50}$$

2.2. Micro-Deval test (EN NF 1097-1/A1)

This test allows us to work out the wear resistance of the aggregates [15]. A sample of aggregates sized 6/10 and of a mass of 500 g ± 5 g is placed in a drum (internal diameter of 200 mm) with 2,5 liters of water and a load of approximately 4500 g constituted by steel balls. The drum spins at 100 tours per minute.

The Micro-Deval coefficient is given by:

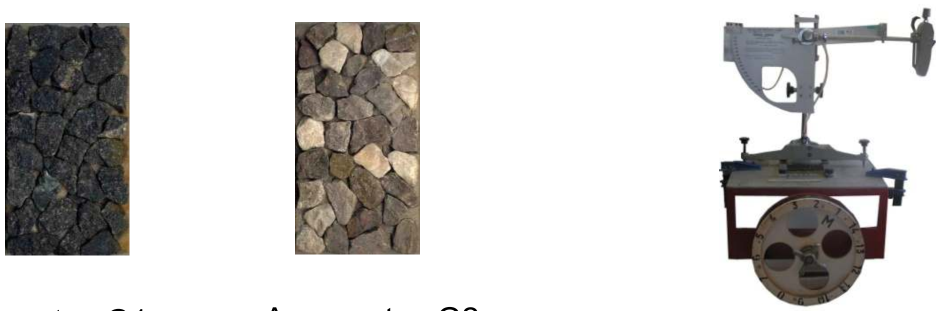
$$MDE = \frac{500 - m}{5}$$

Where m is the mass retained on the 1.6 mm sieve (in grams).

2.3. PSV test (Polished Stone Value) (EN 1097-8)

It’s only used on surface layers aggregates, in order to evaluate the skid resistance coefficient [16]. The test is carried out on aggregate passing a 10 mm sieve and retained on a 7.2 mm grid sieve. The aggregates are cautiously arranged in a mould, like a puzzle, and fixed with a synthetic resin to make a test specimen (figure 1). These specimens are arranged on wheel named “road wheel”. That wheel spins around it axis at 320 rotations per minute and receives a weight of 725 N by the way of a solid rubber-tyred wheel. A feed mechanism spreads a blend of water and abrasive substance on the aggregates during 6 hours.

Then the measure with the SRT pendulum (“Skid Resistance Tester”), in the opposite sense of polishing process, gives the polishing resistance value.



Aggregates G1 Aggregates G2

a) Glimpse of the PSV samples b) SRT pendulum and PSV wheel

Figure 2 – Measurement system for the PSV test.

2.4. Wehner & Schulze test

It’s another way to find the skid resistance. It can be done on aggregates or hot-mixes samples. It hasn’t been normalized yet, and is the object of many studies which can serve to the elaboration of a European norm [17].

The machine is composed of two parts (fig. 1): a polishing part which simulates the action of the road traffic and a measure part which imitates the braking of a vehicle when having water [18].

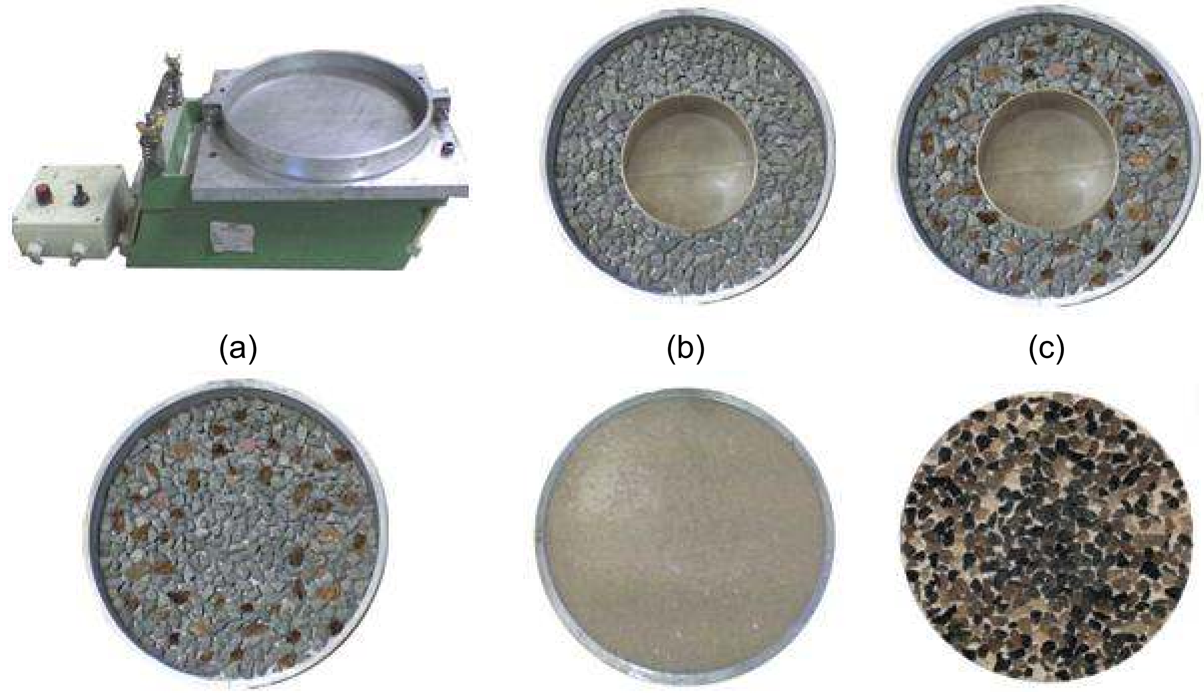
		
	b- The three cylindrical rubber cones which provide the polishing function.	c- Geometry of the cone
		
a- The compartments of the machine.	d- Rubber sliders which provide the measure function	e- Geometry of the rubber sliders

Figure 3 – Wehner & Schulze machine.

The realization of the aggregates samples is done manually. Aggregates sized 7.2/10 are used (like in the PSV test). The aggregates are arranged in one layer in a 225 mm internal diameter mould sized. The voids between the aggregates must be reduced to the minimum. To facilitate that proceeding, the mould is put on a vibrant table. Then, the aggregates are fixed with a synthetic resin (fig. 4 e). In the case of blending samples, it is essential to remain homogeneous in the entire polishing zone. So, we elaborate the following protocol: firstly, fill up the mould with a single type of aggregates, afterwards replace the aggregates we previously selected, one after another, in order to obtain the expected mass proportions. Due to the difference of form and volumetric mass of the aggregates, that replacement is a long and delicate proceeding.

The polishing process is made with rubber cones and with an abrasive solution composed of silica and water. The measurement of the friction's coefficient is done through rubber sliders on a ring 14.5 mm large (figure 3 e).

Contrary to the PSV test, the measure of the coefficient is an automatic process that allows eliminating the effect of the operator. A measure at 60 km/h is done at different levels of polishing: 0, 5000, 10000, 15000, 90000 and 180000 passes of cones following a procedure developed jointly and severally by the four French users of the machine (LCPC, LRPC - Angers, Colas and Eurovia) [17]. The test gives the evolution of the friction coefficient.



(a) (b) (c)

(d) (e) (f)

Figure 4 – Fabrication protocol of a Wehner & Schulze aggregates sample.

3. RESULTS

The results obtained allow following the evolution of the characteristics of the blending in function of the percentage of each type of aggregates. Table 5 shows the coefficients of resistance to fragmentation (Los Angeles) and wear (Micro-Deval). For each blending, the tests have been made twice for the Los Angeles' and three times for the Micro-Deval's.

Table 5 – Fragmentation and wear resistance coefficients (Los Angeles and Micro-Deval) of the different granular blendings.

%* of aggregates G2	Los Angeles			Micro-Deval		
	Min	Average	Max	Min	Average	Max
0	10.26	10.68	11.10	9.56	9.66	9.76
25	12.70	14.00	15.30	11.01	11.14	11.28
50	17.36	18.05	18.75	10.95	11.64	12.33
75	21.05	20.87	20.69	13.07	13.43	13.80
100	24.11	24.55	25.00	14.39	14.30	14.22

* mass percentage

As illustrated with the figures 4a and 4b, these coefficients rise proportionally to the fraction of aggregates G2. The fragmentation and wear resistance evolve linearly:

$$LA(\alpha G1+\beta G2) = \alpha LA(G1) + \beta LA(G2)$$
$$MDE(\alpha G1+\beta G2) = \alpha MDE(G1) + \beta MDE(G2)$$

where α and β represent respectively the proportions of the materials G1 and G2 our blending.

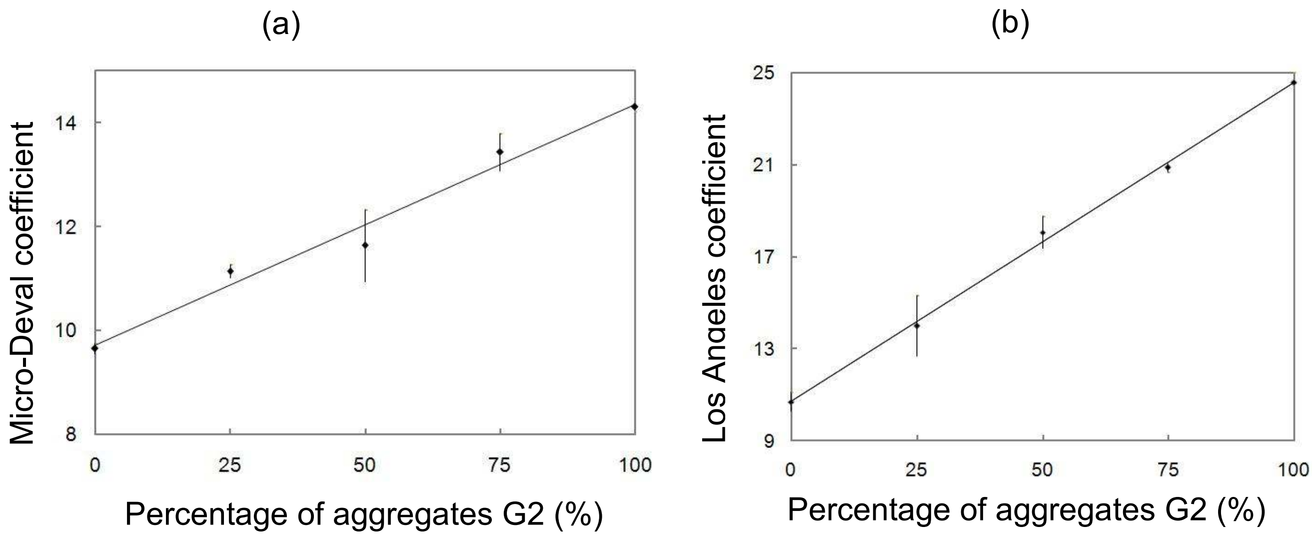


Figure 5 - Evolution of the wear (a) and fragmentation (b) resistance of the granular blendings in function of the fraction of aggregates G2.

The Wehner & Schulze tests were made respecting the mass proportions in the granular blendings. However, the friction coefficient depends on the surface distribution of each type of aggregates (G1 and G2) in the measured zone. The surface distribution has been precisely found in the measured zone using image processing. This analysis consisted in isolating a single type of aggregates (we chose G1 which is easier to identify) and in calculating the surface occupied by the aggregate in the measured zone (fig. 6) with the software Matlab. Then, we can describe the evolution of the friction coefficient for each blending (table 6).

			
Blending N° 1	90 %	Blending N° 2	51 %
			
Blending N° 3	33 %	Blending N° 4	21 %
			
	Blending N° 5	83 %	

Figure 6 – Surface distribution of the aggregates G1 in the measure zone by image processing.

*There are only aggregates G2 in the sample n°5. So, the figure 6 shows the surface distribution of aggregates G2 in the measure zone.

For each sample, we can see a decrease in the friction coefficient during the test. The results we obtained also show a decrease in the skid resistance levels. That decrease is proportional to the increase of the fraction of aggregates G2. We also studied the evolution of the friction coefficients for each polishing step and we noticed that the coefficients are regulated by linear rules. The initial state of polishing is illustrated by figure 7. We recalculated all the friction coefficients by using those linear rules. We found a good correlation between the experimental and the calculated coefficients (fig. 8). So, like in the previous cases, we can find the friction coefficients of a blending from the initial materials by using the following rule:

$$\mu_{WS}(\alpha G1+\beta G) = \alpha\mu_{WS}(G1) + \beta\mu_{WS}(G2)$$

where μ_{WS} is the skid resistance coefficient at 60 km/h obtained with the Wehner & Schulze machine.

Table 6 - Skid resistance coefficients by the Wehner & Schulze test for the different granular blendings.

Number of passes of cones	Wehner & Schulze friction coefficient at 60 km/h				
	Mélange 1	Mélange 2	Mélange 3	Mélange 4	Mélange 5
0	0.527	0.410	0.390	0.375	0.322
5 000	0.437	0.356	0.321	0.303	0.249
10 000	0.410	0.336	0.301	0.286	0.231
15 000	0.396	0.325	0.292	0.272	0.218
90 000	0.353	0.276	0.247	0.223	0.162
180 000	0,330	0,262	0,234	0,205	0,138

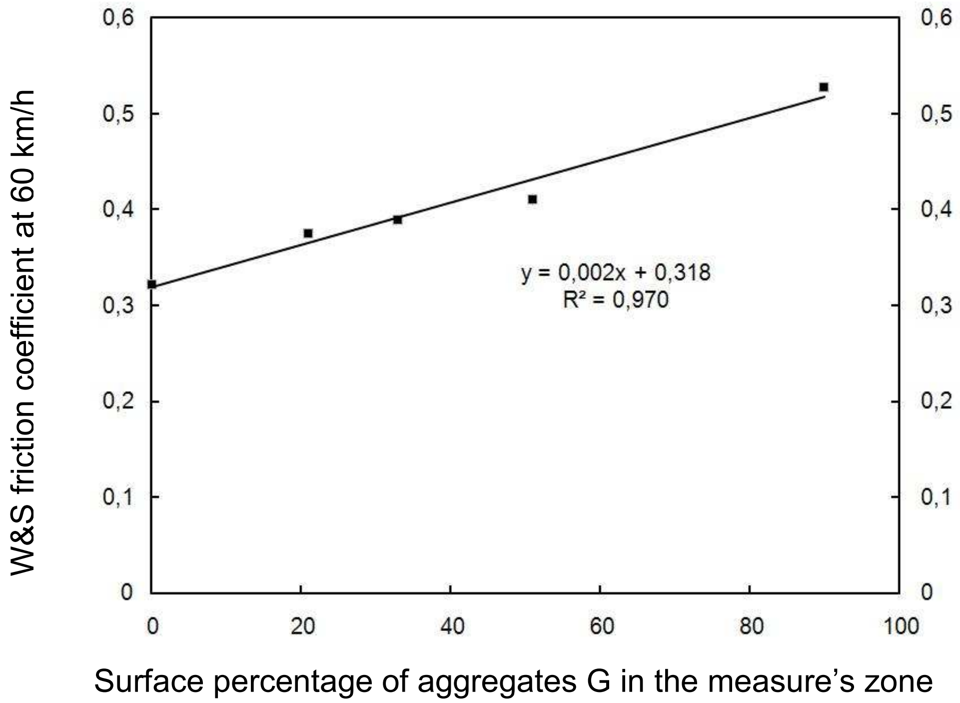


Figure 7 – Correlation of the W&S friction's coefficient in function of the percentage of aggregates G1 in the measure zone for the initial step.

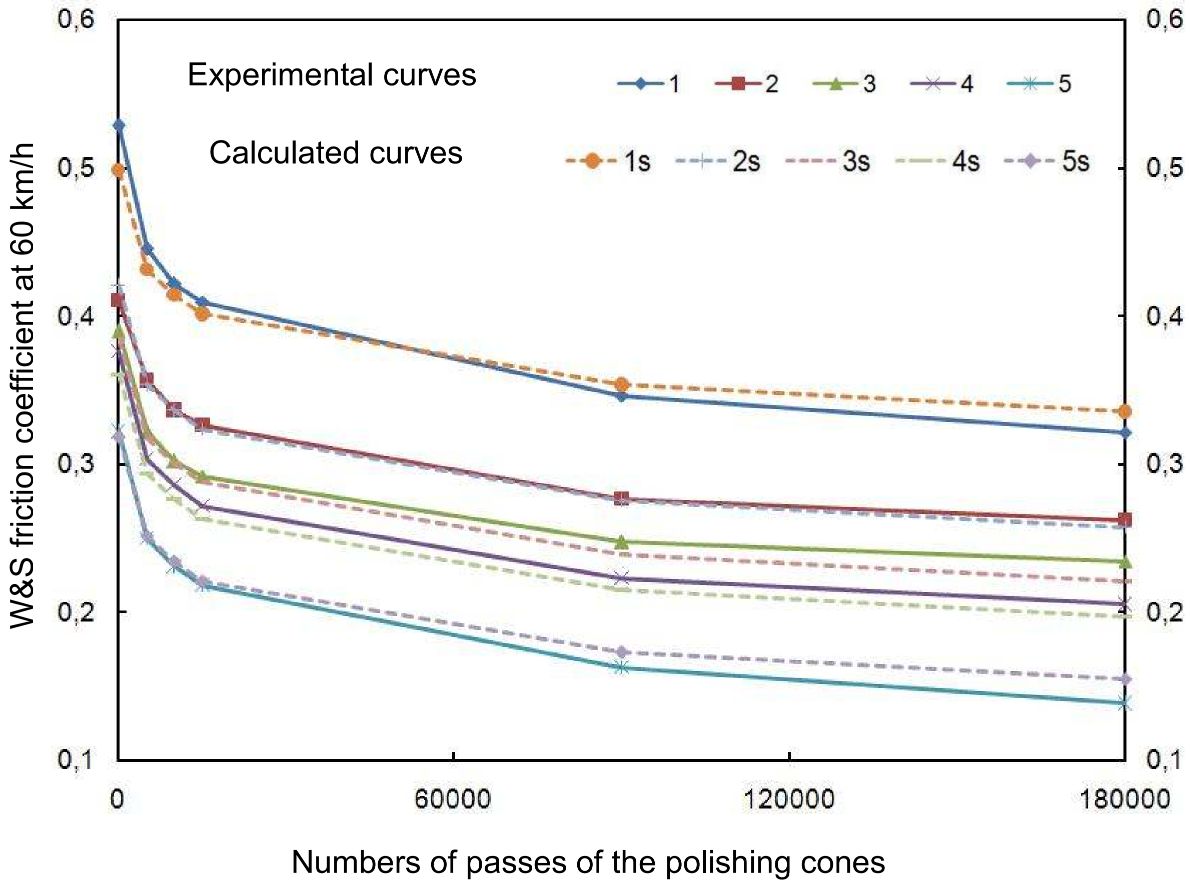


Figure 8 - Evolution of the WS friction coefficient at 60 km/h as a function of the number of paths of polishing cones.

4. DISCUSSIONS

According to the different results about the fragmentation and wear tests, we can suggest that a granular blending behaves like a material whose properties could be simply obtained using a rule of mixture (balancing the properties of the aggregates which compose the blending). Then, it is possible to obtain several blendings responding to the normative requirements for road layers for example, from the two materials getting opposed characteristics. This result which seems trivial has been verified and brings to question ourselves about the protocol of the used tests like the choice of the sieve 1.6 mm sized and its influence on the results. Complementary tests will be done in order to answer to those questions.

The results of the Wehner & Schulze tests consolidate this hypothesis of balancing of the characteristics in function of the proportions of the aggregates: the skid resistance coefficient of a blending constituted of heterogeneous aggregates would be directly proportional to the coefficient of each aggregate.

But, the arrangement of the aggregates in hot-mix asphalt is unpredictable. The levels of skid resistance depend on the surface proportion of the aggregates which are in contact with the wheels. Our fabrication's protocol for the aggregates' samples recommends placing the aggregates in order to perform the measure on their planest face. Finally the proportions of materials for a hot-mix fabrication are calculated in mass fraction and not in surface fraction. Nevertheless, the results we obtained for the granular blendings could be used to predict a minimum and a maximum of skid resistance for the corresponding hot-mix asphalts.

The Wehner & Schulze test gives some information about the evolution of the friction coefficient but isn't normalized. The Polished Stone Value test remains the reference for the road profession about skid resistance value. So, we are studying the PSV of our granular blendings. The results should bring additional information about the applicability of our method by correlation between the two tests.

5. CONCLUSION

During that study, we characterized granular blendings in being interested by the intrinsic properties required for a use in a surface course. We showed that the properties of a blending can be predicted from those of its components. Those properties obey to linear rules. Thus, we confirm the use of the characteristic tests of homogeneous granular materials for blendings of granular materials. The results also show the possibility to compensate, at some extend, the bad qualities of an aggregate by adding another aggregate with better properties, encouraging the use of local materials in some regions.

However, in spite of the fact that the skid resistance of hot-mix asphalt is deeply influenced by the mineral nature of its aggregates [19], we must also consider some other parameters like the formulation [20], the texture [20], the parameters of fabrication and the nature of the binder. Our study must be completed by some tests on bituminous mixes in order to verify our hypothesis.

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