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Research Article

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Characterization of Semi-Graded Bituminous Concrete (SGBC) and Graded Bitumen (GB) Based on Bakel Quartzite Aggregates

Mory Coulibaly*, Makhaly Ba, Bibalo Ida Josiane Ki

Laboratoire de Mécaniqueet Modélisation (L2M), UFR Sciences de l'Ingénieur, Université de Thiès, Thiès, Sénégal
*e-mail: mory.coulibaly@univ-thies.sn

Abstract The tests carried out in this laboratory study on Bakel quartzite for use as an aggregate in the manufacture of SGBC 0/14 and GB 0/14 give PCG compaction values for SGBC equal to 16 % void at 10 gyrations and 8.3 % void at 80 gyrations and for GB, 11 % void at 10 gyrations and 5.2 % void at 100 gyrations. These values are acceptable and comply with the required specifications. The results of the water resistance tests (Duriez test) on the SGBC and GB formulations comply with the current specifications. Indeed, the values of the Rh/RS ratio for the SGBC and GB are respectively 0.82 and 0.83 and are higher than the minimum value required by the standard which is 0.75. The rutting tests carried out for the SGBC and the GB give rut depths respectively equal to 4,5 % at 30 000 cycles at 60° C and 8,67 % at 10 000 cycles at 60° C. These rut depths obtained are in accordance with the required specifications (rut depth ≤ 5% for SGBC and rut depth ≤ 10% for GB). Complex modulus test results give stiffness modulus values for SGBC and GB that meet specifications. Indeed, the stiffness modulus values obtained for SGBC (7115 MPa) and GB (11637 MPa) are higher than the minimum required which are equal to 7000 MPa for SGBC and 9000 MPa for GB. The results of the fatigue test give a value of the deformationε_6 equal to 90 µdef under the following conditions 10° C and 25 Hz. This value complies with the specifications as it is equal to the minimum required value.

Keywords quartzite, bitumen, formulation, semi-graded bituminous concrete, graded bitumen, fatigue

Introduction

By land, roads play a major role in traffic. It must ensure that people and goods on the move are in optimum conditions of safety and comfort. To this end, the materials that make up the structure of the road pavement must meet a number of quality and cost requirements. Among these roads, some are made with hydrocarbon materials, i.e. a mixture of aggregates and bitumen, the first of which occupies 95% of the total weight, while the second occupies the remaining 5%.

In Senegal, basalt is used as an aggregate in these types of pavements while it is mainly exploited in Diack in the Thiès region (main basalt quarry). This source of supply of aggregates raises two major concerns. The first is that it is finite and the others that exist are very distant (Kédougou region in Mako) from the rest of the country where their exploitation is prohibited (Dakar) [1]. The second concern is related to its position, the supply of aggregates to large construction sites in certain areas of the country contributes substantially to the increase in the cost of construction. Faced with this situation, it is necessary to diversify the aggregates quarries and to reduce the distances for supplying worksites.

Since 2013, the Mapathé DIOUCK company has been mining Bakelquartzites in the Tambacounda region with a very important investment [2]. Studies were undertaken on the characterization of Bakel quartzite for use as a substitute aggregate for basalt aggregate.

Tested Materials

The aggregates used in this study are Bakelquartzites, which is located in eastern Senegal on the border between Mali and Mauritania, 687 km from Dakar. They generally present an outcrop in the form of small mounds of up to 10 m in height [3].

Observations carried out on thin sample slides make it possible to distinguish three sub-facies in quartzites: horthoquartzites, micaceous quartzites and ferruginous quartzites. The study zone is essentially detrital and consists of massive quartzite and quartzite associated with schists. [2]has carried out facies recognition operations and identified high-extension facies of black quartzite sandstones and red to whitish quartzite friezes. These facies outcrop not far from the city of Bakel and are mainly in the form of large hills.

Methodology

This study deals with aggregate identification tests on granular classes 0/3, 3/8 and 8/14, bitumen characteristics and finally the evaluation of the performance of the selected formula. The identification tests on aggregates relate to the granulometric analysis [4], the density [5]equivalent to 10% fine sand [6], the value in blue [7], superficial cleanliness [8], resistance to impact fragmentation [9], wear resistance brittleness [10], the flattening coefficient [11], and the flow coefficient [12] on class 0.063/2.

Bitumen characteristics and specifications [13] are summarized in Table 2. These are the softening point determination tests [14], needle penetrability [15], the relative density [16] from the point of light [17], ductility [18] the increase in TBA after RTFOT [19] of the residual penetration after RTFOT [19] and the adhesiveness of pure bitumen [20].

The performance evaluation is done on:

- bitumen concrete according to three formation levels : PCG test (Rotating Shear Press) [21], Duriez test [22], rutting test [23] and complex modulus test (two-point bending test on trapezoidal shaped specimens) [24] ;
- bitumen concrete according to three formation levels : PCG test [21], Duriez trial [22], rutting test [23] and complex modulus test (two-point bending test on trapezoidal specimens) [24] and the fatigue test [25].

Formulation of Semi-Grained Asphalt Concrete and Gravel Bitumen

The formulation of hydrocarbon compounds is a complex exercise based on technical, normative, economic and even ecological criteria (research on innovative binders and granular materials).

Identification of Mineral Constituents

The results of the identification tests on aggregates are summarized in Figure 1 and

Table 1. The results obtained indicate that the manufacturing characteristics are in compliance with the requirements [26]. Thus, the granularity is of category Gc85/20, the cleanliness is less than 1 and the flattening coefficient is of category FI25. The test of resistance to fragmentation indicates that the class 8/14 quartzite is of category LA20 according to [26]. The same standard indicates, according to the results of the wear resistance test, that class 8/14 quartzite is of the MDE10 category.

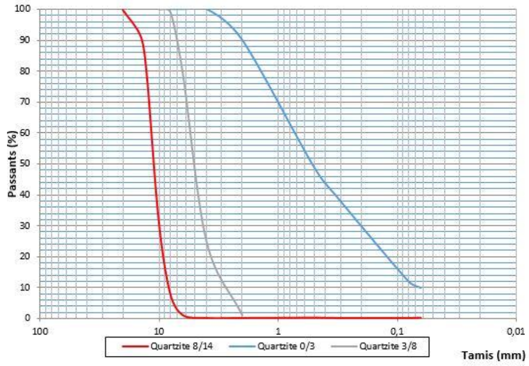

Figure 1: Particle size curve of quartzite samples

Table 1: Identification test results for quartzite samples

Physical-mechanical characteristics	Granular classes		
	0.3.	**3.8.**	**8.14.**
Density (g/m^3)	2.557	2.594	2.615
Flattening coefficient A (%)		21	8
Micro-Deval (%)			8
Los Angeles (%)			18
Friability Fs (fraction 0/2) (%)	40		
Surface cleanliness (%)		0.4	0.2
Flow coefficient of sands Ecs (s)	33		
Methylene Blue value (fraction 0/2) (g/kg)	0.3		
Sand equivalent (%)	72		

Table 2: Bitumen Test Results

Test	Bitumen 35/50	Specifications (NF EN 12591)
Softening temperature ball ring (°C)	52	50 à 58
Penetrability at 25°C (1/10mm)	38	35 à 50
Relative density at 25°C (%)	1.04	1.00 à 1.10
Flash point (°C)	312	> 240
Ductility at 25°C in cm	>150	> 25
TBA increase after RTFOT (°C)	6.2	≤ 8
Residual penetration after RTFOT (°C)	65	≥ 53
Adhesion pure bitumen G4/10 (°C)	50 à 75%	

Choice of the Mineral Composition of the Semi-Grained Asphalt Concrete

The choice of the granular mixture curve is made taking into account the targeted granular characteristics. The theoretical mixture selected from the different granular classes is as follows: 23% of 0/3, 32% of 3/8, 41% of 8/14 and 4% of 0/0.125. The dosage of bitumen contained in the granular mixture is: 5.1%, 5.3% and 5.5%.

To evaluate the formula, the following tests are carried out:

- In the CGP test, the different percentages of voids obtained at 10 and 80 gyrations are recorded in the Table 3. The percentages of voids obtained are consistent for the different bitumen grades.

Table 3: Percentage of voids at 10 and 80 gyrations

Dosing in total binding agent	Wealth Module	% empty at 10 gyrations	% empty at 80 gyrations
5.10 %	3.23	17.3	9.7
5.30 %	3.36	16	8.3
5.50 %	3.48	14.4	6.3
Required values	≥ 3.2	> 11%	4 à 9 %

- In the Duriez test, the results (Table 4) of the water and compressive strength tests are in accordance with the specifications [27]. The formula with a dosage of 5.3% was chosen for the rest.

Table 4: Results of Duriez tests on SGBC specimens

Dosage in binder	HR/RS resistance ratio
5.30%	0.82
5.50%	0.83
Specifications	≥ 0.75

- In the rutting test, the results obtained with this test show a rut depth equal to 4.45 % at 30 000 cycles at 60 °C. This value of rut depth is in accordance with the SGBC specifications [27] (≤ 5 %);

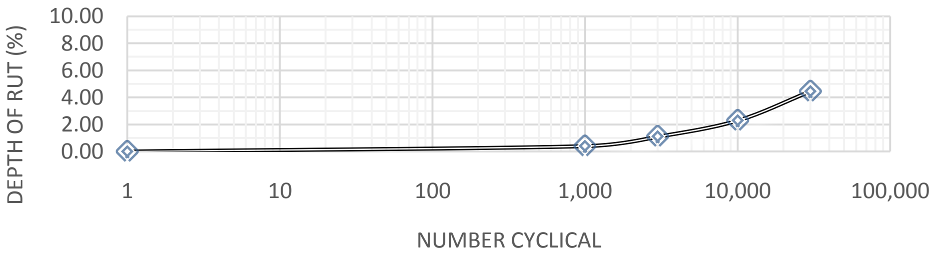

***Figure 2:** Rut depth as a function of the number of cycles at 60°C*

- The complex modulus test is carried out by means of the two-point bending test on trapezoidal shaped specimens. The test was carried out on four test pieces (Table 5) at a temperature of 15 °C and a frequency of 10 Hz.

Table 5: Modulus of rigidity measurement at 15 °C with a frequency of 10 Hz

Test tube reference	Age (day)	Density (T/m^3)	Deformation (µDef)	Module E1 (Mpa)	Module E2 (Mpa)	Modulus of rigidity (Mpa)	Specifications
SGBC_1		2.212	31.32	6769	2047	7071	
SGBC_2	14	2.217	31.19	6839	1986	7122	
SGBC_3		2.261	32.15	6701	1935	6975	
SGBC_4		2.255	32.41	7015	1987	7291	
Average (Mpa)						7115	≥ 7000

Choice of the Granular Composition of Bitumen Gravel

The choice of the granular mixture curve is made taking into account the targeted granular characteristics. The theoretical mixture selected from the different granular classes is as follows: 50% of 0/2, 25% of 3/8 and 25% of 8/14. Taking into account the modulus of richness set by the GB3 product standard, the bitumen dosages retained in the granular mixture are: 4.6 %, 4.8 % and 5 %.

To evaluate the formula, the following tests are carried out:

- In the CGP test, the different percentages of voids obtained at 10 and 100 gyrations are recorded in the Table 6. The percent voids at 100 gyrations meet the specifications for the different bitumen grades. The percentage voids at 10 spins are slightly less than the required value but may still be acceptable based on the rutting test results. A void percentage value of around 14% for base course materials can result in an excessive workability of the mix, making it difficult to compact without excessive deformation. This would lead to an unstable material under the effect of traffic.

Table 6: Percentage of voids at 10 and 100 gyrations

Dosing in total binding agent	Wealth Module	% empty at 10 gyrations	% empty at 100 gyrations
4.60%	2.81	11.7	6.1
4.80%	2.93	11.8	5.2
5.00%	3.06	9.9	3.8

Required values	≥ 2.8	> 14%	10%

- The Duriez test was conducted with bitumen grades of 4.8% and 5% Table 7. Water resistance and compressive strength test results are in accordance with the specifications of the standard [27]. The formula with a dosage of 4.8 % was chosen for the rest.

Table 7: Results of Duriez tests carried out on GB specimens

Dosage in binder	HR/RS resistance ratio
4.80 %	0.83
5.00 %	0.84
Specifications	≥ 0.70

- In the rutting test, the results obtained with this test show a rut depth equal to 8.67 % at 10 000 cycles at 60° C (Figure 3). This value of rut depth is in accordance with the SGBC specifications [28] (≤ 10 %);

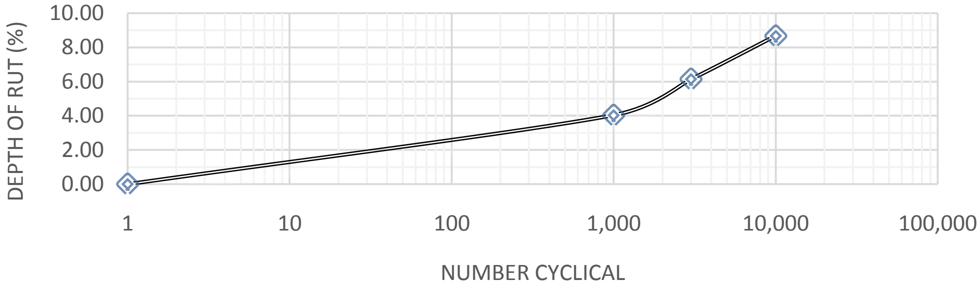

Figure 3: Rut depth as a function of the number of cycles at 60°C

- The complex modulus test is carried out by means of the two-point bending test on trapezoidal shaped specimens. The test was carried out on four specimens (Table 8) at a temperature of 15 °C and a frequency of 10 Hz.

Table 8: Modulus of rigidity measurement at 15 °C with a frequency of 10 Hz

Test tube reference	Age (day)	Density (T/m^3)	Deformation (μDef)	Module E1 (Mpa)	Module E2 (Mpa)	Modulus of rigidity (Mpa)	Specifications
GB_1	14	2.242	33.7	11322	2671	11633	
GB_2		2.218	32.2	11398	2703	11714	
GB_3		2.244	32.75	11487	2724	11806	
GB_4		2.238	31.53	11070	2700	11395	
Average (Mpa)						11637	≥ 9,000

- The fatigue test was carried out on the GB with a bitumen content of 4.8 %. The results of the test give a value of the deformation ε_6 i.e. the deformation corresponding to the lifetime at one million cycles under the following conditions 10° C and 25 Hz, equal to 90 μdef (Figure 4).

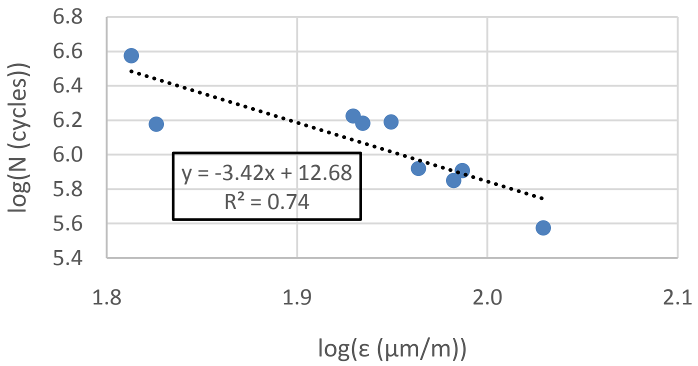

Figure 4: Wohler Curve of the UK

Conclusion

The study carried out on the formulation of semi-graded asphalt concrete (SGBC 0/14) and graded asphalt concrete (GB 0/14) based on Bakel quartzite aggregates is carried out up to level 3 for the former and level 2 for the latter. This study was carried out without additives in the laboratory using standardised tests. The results of the identification tests on the materials (bitumen and quartzite) show that they meet the specifications in force. The PCG compaction test performed on the SGBC (16% void at 10 gyrations and 8.3% void at 80 gyrations) and the GB (11% void at 10 gyrations and 5.2% void at 100 gyrations) gave acceptable values that meet specifications. The results of the water resistance tests (Duriez test) on the SGBC and GB formulations comply with the current specifications. The RH/RS ratio values for the SGBC and GB are 0.82 and 0.83 respectively and are higher than the minimum value required by the standard, which is 0.75. The rutting tests carried out for the SGBC and the GB give rut depths respectively equal to 4,5 % at 30 000 cycles at 60° C and 8,67 % at 10 000 cycles at 60° C. These rut depths obtained are in accordance with the required specifications (rut depth ≤ 5% for SGBC and rut depth ≤ 10% for GB). Complex modulus test results give stiffness modulus values for SGBC and GB that meet specifications. Indeed, the stiffness modulus values obtained for SGBC (7115 MPa) and GB (11637 MPa) are higher than the minimum required which are equal to 7000 MPa for SGBC and 9000 MPa for GB. The results of the fatigue test give a value of the deformation ε_6 equal to 90 µdef under the following conditions 10° C and 25 Hz. This value complies with the specifications as it is equal to the minimum required value. The results obtained in this study show that Bakel quartzite can be used as a wearing course and base course in road works.

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