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Study of the formulation of a 0/10 Semi-Grained Bituminous Concrete from basaltic crushed rock of Diack (Senegal) for use in wearing course

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Abstract The work presented in this paper made it possible to determine a composition satisfying the requirements of compactibility PCG and resistance to rutting of the standard NF EN 13108-1 for a BBSG 0/10 of class 1, 2 and 3. The obtained material, for use in wearing course, is composed of 49% of basaltic sand 0/4, 10% of basaltic gravel 4/6.3, 38.5% of basaltic gravel 6.3/10, 2.5% of cement CEM II/B - LL 32.5 R and 5.1% of bitumen 35/50.

The tests conducted on this composition allowed to highlight the very rubbing character of the basaltic aggregates of Diack. This very rubbing character observed was then confirmed by the results of Duriez and rutting tests conducted on this composition, showing respectively an insufficient resistance to water and an excellent resistance to rutting.

Keywords use, basalt, wearing course, 0/10 semi-mixed asphalt concrete

1. Introduction

Basalt is the most widely used material in Senegal for the manufacture of bituminous mixes used in road engineering. This rock, of acidic volcanic origin, is essentially composed of plagioclase and pyroxene **[1]**.

In Senegal, this material comes mainly, following the 1972 presidential ban on aggregate mining in Dakar, from the Diack massive rock deposit located 30 km from Thies **[2]**.

Its use has shown that this material has excellent intrinsic characteristics, in terms of hardness, for the manufacture of bituminous mixes. On the other hand, a low polishing resistance (PSV) and a poor adhesiveness with bitumen due to their chemical nature is noted.

This work presents the results of characterization of this material and determination of a formula respecting the rules and standards in force in Senegal for use in pavement.

2. Materials and Methods

2.1. Origin of the components of the studied formula

The formulation constituents used in this work consist of the following materials:

- a gravel 6.3/10 of basalt crushed stone;
- a gravel 4/6.3 of basalt crushed stone;
- a sand 0/4 of basalt crushed stone;
- a road bitumen of class 35/50 and
- an “addition of Portland” cement of type CEM II/B - LL 32,5 R as an addition filler coming from the “Société Commerciale du Ciment (SOCOCIM-Industries)”

The gravel and sand used come from the volcanic deposit of Diack. This deposit is located at the eastern end of the Thies plateau, 30 km from Thies. It lies between meridians 16°43' and 16°45' West longitude and parallels 14°40' and 14°41' North latitude **[3]**.

From these studies, Dia (1982) distinguishes the presence of 3 facies at the Diack deposit:

- fine-grained facies corresponding to a fine-grained gray-black generally phanitic rock sometimes containing olivine crystals visible to the naked eye in an interstitial mesostasis. The dense, compact rock has a conchoidal fracture;
- medium-grained facies corresponding to a rock is grey-black and slightly lighter than the very fine-grained one. It is compact, dense and almost entirely crystalline;
- coarse-grained facies represented by a fully crystallized gritty rock, without interstitial mesostasis. The texture is of the pegmatitoide grey type containing numerous plagioclase laths and pyroxene crystals.

The figure below shows an overview of the location of this deposit in the Thies region.

Figure 1: Location of the Diack basalt quarry (Thies, Senegal)

The geological map shows that this region (Thies) is essentially marked by the presence of materials, the oldest of which date from the secondary era, others from the tertiary era and others from the quaternary period. Diack basalt, a material of volcanic origin, is one of the Tertiary rocks (Figure 2).

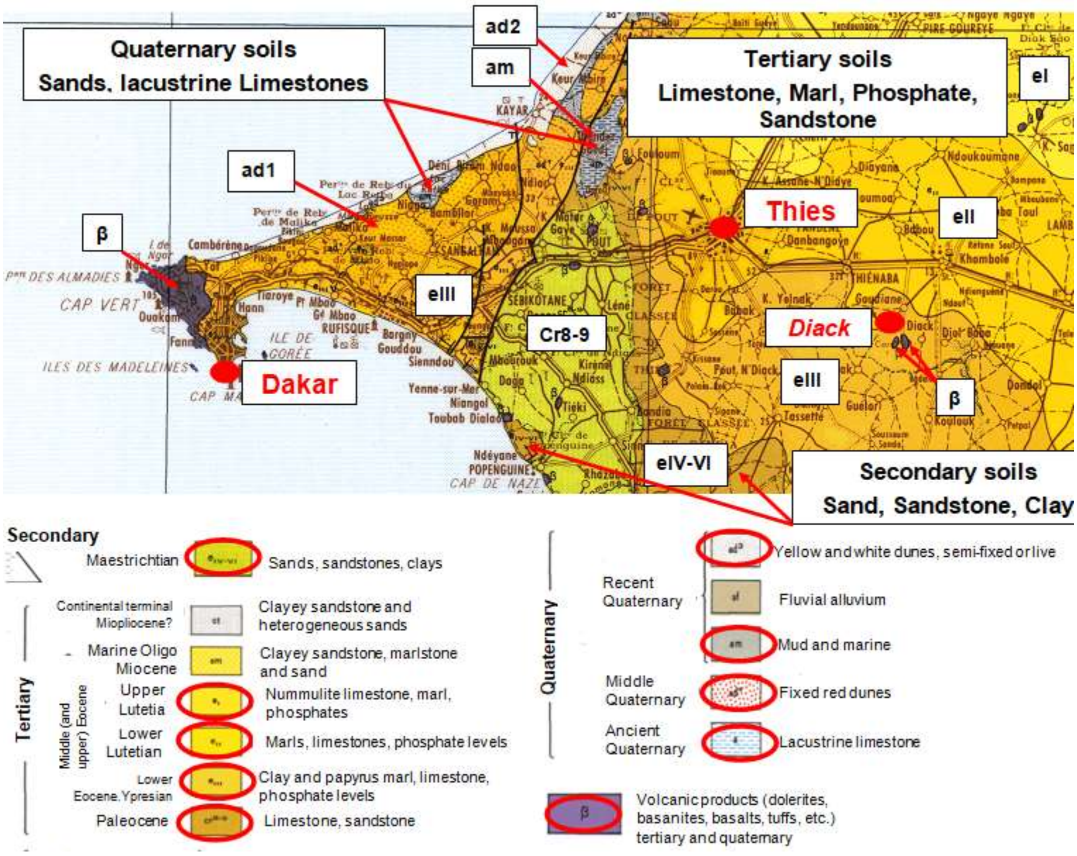

Figure 2: Overview of the geological formations in the Thies region (extract from the geological map of Senegal established by BRGM in 1962 [4])

2.2. Determination of the formulation level of the studied formula with the basaltic crushed rocks of Diack (Thies, Senegal)

In Senegal, the formulation of bituminous materials is dictated by the « catalog of new pavement structures and pavement design guide in Senegal **[2]** » of the Agency of Works and Management of Roads of Senegal (AGEROUTE-Senegal) of 2015. This catalog includes, as shown in Table 1, the same tests defined for each of the 5 levels (noted from 0 to 4) of formulation of standard NF EN 13108-1.

Table 1: Content of formulation tests (AGEROUTE-Senegal, 2015 **[2]**; standard NF EN 13108-1**[5]**)

Formulation test level	**Level 0**	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Grain size curve, minimum binder content (Tlmin) or K, binder class	x	x	x		
Gyratory Shear Press (PCG) test		x	x	x	x
Duriez water resistance test at 18°C		x	x	x	x
Rutting test			x	x	x
Modulus of rigidity test				x	x
Fatigue resistance test					x

By reference to this document and to the French standard NF P 98-150-1 **[6]**, the maximum design level for use in wearing courses of the 0/10 semi-filled asphalt concrete (BBSG 0/10) studied is level 2.

For this level, the performances targeted are those specified in the foreword of the NF EN 13108-1 standard for a 0/10 BBSG. This standard (NF EN 13108-1 [5]) describes both, for this level of mix design, the program of tests to be carried out on each of the constituents and on the compositions (mixtures) formulated from these constituents.

The program of tests carried out on the constituents is given below:

- particle size analysis test (standard NF EN 933-1[7]) and measurement of the flattening coefficient (standard NF EN 933-3 [8]) on the 4/6.3 and 6.3/10 gravel;
- particle size analysis test (standard NF EN 933-1 [7]) and measurement of the flow coefficient (standard NF EN 933-6 [9]) on 0/4 sand;
- methylene blue test on 0/4 sand (standard NF EN 933-9 [10]);
- test to determine the real density and water absorption at 24 hours of sand and gravel (standard NF EN 1097-6 [11]);
- test to determine the real density of cement (standard NF EN 1097-7 [12]);
- Los Angeles fragmentation resistance test (standard NF EN 1097-2 [13]);
- micro-Deval wear resistance test (standard NF EN 1097-1 [14]);
- PSV accelerated polishing resistance test (standard NF EN 1097-8 [15]);
- test to determine the penetrability at 25°C (standard NF EN 1426 [16]) and the ball and ring temperature (standard NF EN 1427 [17]) of 35/50 bitumen and
- RTFOT + PAV test including penetrability (standard NF EN 1426 [16]), TBA (standard NF EN 1427 [17]) and mass variation after RTFOT and PAV (standard NF EN 12607-1 [18]).

For the design studies of the BBSG 0/10, the program of tests to be carried out is as follows:

- test to determine the real density (standard NF EN 12697-5/A with water [19]);
- test of compaction ability with the Gyratory Shear Press (PCG) (standard NF EN 12697-31 [20]);
- Duriez water resistance test (standard NF EN 12697-12 method B [21]) and
- rutting test (standard NF EN 12697-22 large size model at 60°C in air [22]).

3. Presentation of the test results

3.1. Characterization of the different constituents used for the formulation studies

The characterization of the constituents used for the formulation studies is given below.

3.1.1. Test results for Diack basaltic granular constituents

The following figure and table summarize the results of the tests conducted on the Diack crushed materials.

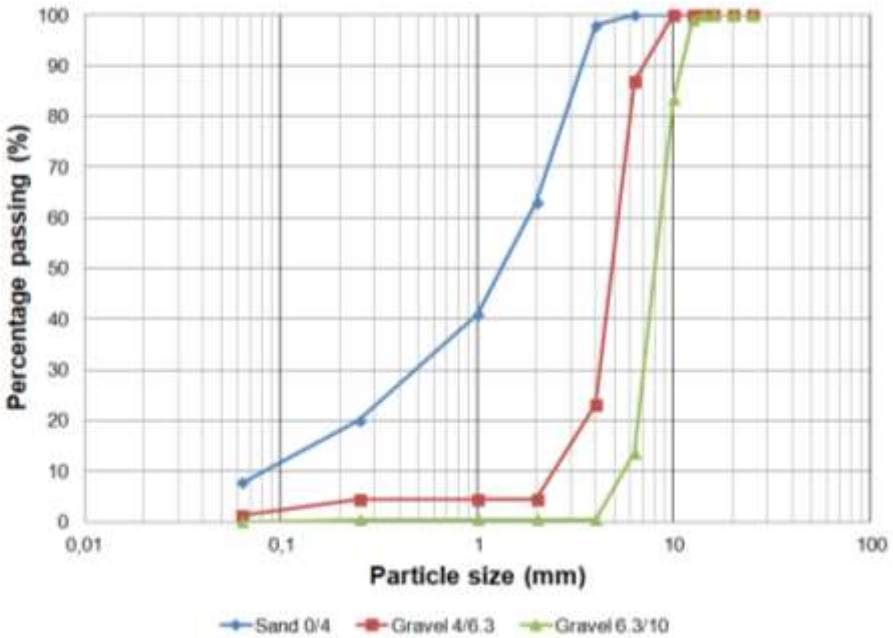

Figure 3: Particle size curves for Diack basalt crushed stone: 0/4 sand, 4/6.3 gravel and 6.3/10 gravel

The analysis of these curves shows a material containing little fines. These findings justify the use of CEM II/B - LL 32.5 R cement as an addition filler.

Table 2: Summary table of the different results of the tests carried out on the basaltic crushed stone of Diack (Thies, Senegal)

Measured characteristics	**Sand 0/4**	**Gravel 4/6.3**	**Gravel 6.3/10**
Fines content f (< 0.063 mm) (%) (NF EN 933-1 [7])	7.7	1.3	0.03
Sand flow Ecs (in seconds) (NF EN 933-6 [9])	40	-	-
Flattening coefficient Fl (%) (NF EN 933-3 [8])	-	21	16
Methylene blue value on the 0/2 mm MB fraction (g/kg) (NF EN 933-9 [10])	0.9	-	-
Real dry density ρ_{rd} (in Mg/m^3) (NF EN 1097-6 [11])	2.91	2.94	2.94
Absolute real density ρ_a (in Mg/m^3) (NF EN 1097-6 [11])	2.94	3.03	3.01
Water absorption coefficient at 24 hours WA24 (%) (NF EN 1097-6 [11])	0.4	1	0.8
Accelerated polishing coefficient (PSV) (NF EN 1097-8 [15])	-	-	51

These results are completed by the Los Angeles test (standard NF EN 1097-2 [13]) and micro-Deval (standard NF EN 1097-1 [14]) which gave respectively the values of 12 (C_{LA} = 12) and 11 (C_{MDE} = 11).
The use of these aggregates, in Senegal, is conditioned by the requirements of the catalog of the AGEROUTE-Senegal of 2015 which fix the rules of their uses in pavement. According to this document, aggregates must comply with « code B » from a traffic T2 (greater than 150 heavy vehicles/day) for intrinsic characteristics, and with « code III » for manufacturing characteristics that are not indexed on traffic (Table 3).

Table 3: Specifications of aggregates for BBSG [2]

Characteristics NF P 18-545 [23]	**Traffic < T2**	**Traffic > T2**
Resistance to gravel fragmentation Wear resistance of gravel Resistance to gravel polishing	C	B
Granularity of the gravel General limits and grain size tolerances for gravel Fine content of gravel Flattening	III	III
Granularity of the sand Tolerance around the typical granularity Sand cleanliness	a	a

The corresponding intrinsic requirements (« code B ») and manufacturing characteristics (« code III ») are dictated by the French standard NF P 18-545.
The table below summarizes the requirements corresponding to the « code B » and the conformity of the values measured on the basalt of Diack compared to these rules.

Table 4: Conformity of the values measured on the Diack basalt in relation to the requirements of the intrinsic characteristics of the « code B » of the standard NF P 18-545 [23]

Intrinsic characteristics	**Requirements standard NF P 18-545 for « Code B »**	**Values measured on the Diack basalt**	**Compliance**
Los Angeles Coefficient (C_{LA})(*)	< 25	12	compliant
Micro Deval wet Coefficient (C_{MDE})(*)	< 20	11	compliant
C_{LA}+C_{MDE}(*)	< 35	23	compliant

(*): compliance is assured if the 3 conditions (C_{LA}+C_{MDE}, C_{LA} and C_{MDE}) are met simultaneously.

The analysis of the results shows that Diack basalt complies with the intrinsic characteristics of "« code B » of the NF P 18-545 standard.

As for the manufacturing characteristics, the results obtained compared to the normative requirements are summarized in Table 5.

Table 5: Conformity of the values measured on the Diack basalt compared to the requirements of the manufacturing characteristics of the « code III » of the NF P 18-545 standard [23]

Manufacturing characteristics	**Requirements standard NF P 18-545 for « Code III »**	**Values measured on the Diack basalt**	**Compliance**
Granularity Gc	Gc 85/20	Gc 85/20	compliant
Fines content (f)	1	between 0.03 and 7.7	compliant
Flattening coefficient (Fl)	25	16-21	compliant

The analysis of the results shows that Diack basalt complies with the manufacturing characteristics of « code III » of the NF P 18-545 standard.

These observations show that the intrinsic characteristics as well as the manufacturing characteristics of Diack basalt are in conformity with the requirements of the standards in force in Senegal.

3.1.2 Results of tests on Portland cement CEM II/B - LL 32.5 R

The real density of Portland cement CEM II/B - LL 32.5 R was determined in accordance with standard NF EN 1097-7. A value of 3.05 Mg/m^3 (ρ_f = 3.05 Mg/m^3) was measured.

3.1.3. Results of the tests on the 35/50 class of road bitumen

The following table summarizes all the results of the tests carried out on the selected class 35/50 bitumen.

Table 6: Conformity of the values measured on the bitumen in relation to the requirements of standard NF EN 12591 [24]

Measured propreties	**Values measured on 35/50 bitumen**	**Requirements of the standard NF EN 12591 for bitumen class 35/50**	**Compliance**
Penetrability at 25°C (1/10 mm) (NF EN 1426 [16])	40	35-50	compliant
Ball and Ring Temperature (TBA) (°C) (NF EN 1427 [17])	50.8	50-58	compliant
Remaining penetrability after RTFOT (%) (NF EN 12607-1 [18])	63	≥ 53	compliant
Ball and ring temperature (TBA) after RTFOT (°C) (NF EN 1427 [17])	57.4	≥ 52	compliant
Delta TBA after RTFOT (°C)	6.6	-	compliant
Loss of mass (%) (NF EN 12607-1 [18])	- 0.12	≤ 0.5	compliant

The analysis of this table shows that the selected bitumen of class 35/50 is in conformity with the requirements fixed by the standard NF EN 12591 [24].

3.2. Studied compositions and presentation of the results of the formulation tests

3.2.1. Studied compositions

Three mixtures (compositions), noted M1, M2 and M3, were composed with the constituents retained within the framework of this work.

The figure below shows the associated particle size curves.

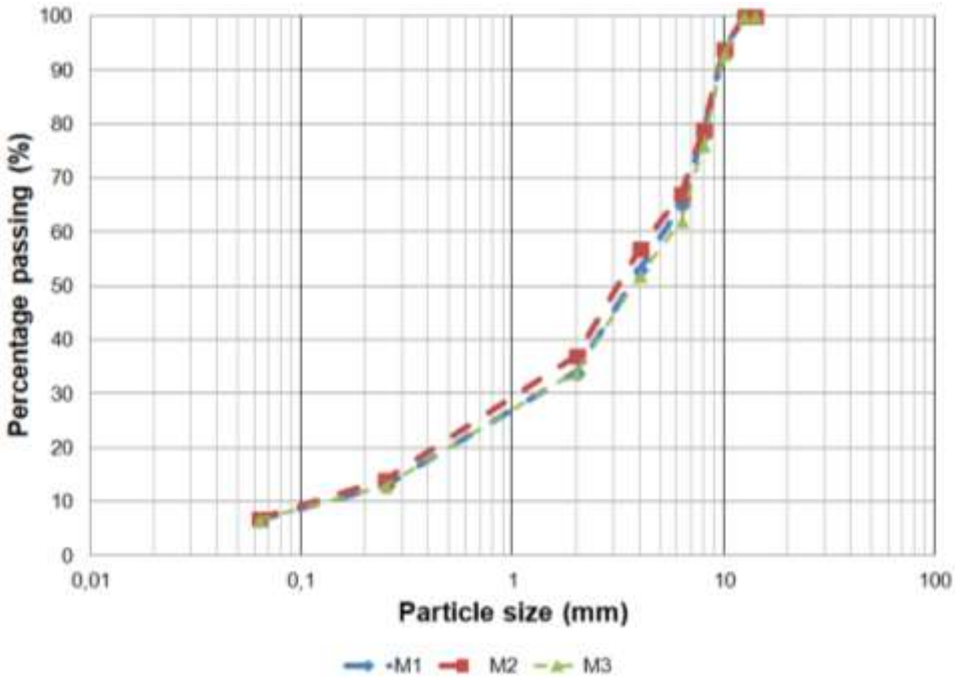

Figure 4: Particle size curves of the M1, M2 and M3 mixtures

The proportions of each of their constituents and their richness modulus are presented in the table and figure below.

Table 7: Constituents of the compositions of mixtures M1, M2 and M3

Compositions of the studied mixtures (%)	Mixture M1	Mixture M2	Mixture M3
Gravel 6.3/10	38.5%	38.0%	43.0%
Gravel 4/6.3	10.0%	5.0%	5.0%
Sand 0/4	49.0%	54.0%	49.0%
Cement	2.5%	3.0%	3.0%
Bitumen 35/50	5.1%	5.3%	5.3%
Wealth modulus (K)	3.5	3.5	3.6

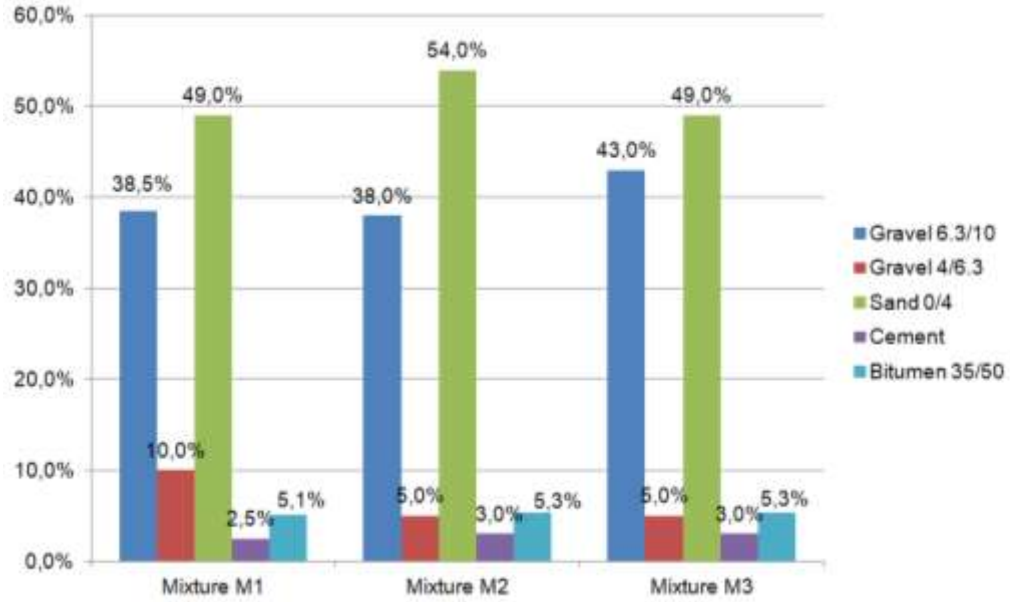

Figure 5: Compositions of M1, M2 and M3 mixtures

The table below presents the results of the conformity of the bitumen content values (TL) to the requirements of the NF EN 13108-1 standard.

Table 8: Conformity of the bitumen content values of the M1, M2 and M3 mixtures with the requirements of standard NF EN 13108-1 [5]

Mixtures studied	Standard requirements NF EN 13108-1 for BBSG 0/10 of class 1, class 2 and class 3	Measured values of bitumen content (TL)	Compliance
M1		≥ 5.1 %	non compliant
M2	≥ 5.2 %	≥ 5.3 %	compliant
M3		≥ 5.3 %	compliant

The analysis of the table shows that the bitumen contents of the M2 and M3 mixtures are all in conformity with the requirements of the NF EN 13108-1 standard for a 0/10 BBSG of class 1 or class 2 or class 3 except for the M1 mixture (Table 8).

In spite of these observations, once recomposed and mixed, all these different mixes were submitted to the mix design tests corresponding to mix design level 2, namely:

- the Gyratory Shear Press (PCG) compaction test (standard NF EN 12697-31 [20]);

- Duriez water resistance test (standard NF EN 12697-12 method B [21]) and
- rutting test (standard NF EN 12697-22 large size model at 60°C in air [22]).

3.2.2. Presentation of the results of the formulation tests

3.2.2.1. Presentation and conformity of the results of the compaction tests with the Gyratory Shear Press (PCG) to the requirements of standard NF EN 13108-1

The table below presents the results of the PCG tests and the conformity of these results to the requirements of the standard NF EN 13108-1 for a BBSG 0/10 of class 1 or class 2 or class 3.

Table 9: Compliance of PCG results for M1, M2 and M3 mixtures with the requirements of standard NF EN 13108-1 [5]

Mixtures studied	Requirements standard NF EN 13108-1 for BBSG 0/10 of class 1, class 2 and class 3 - Percentage of voids Vmin-Vmax (in %) (gyratory compactor method)	Percentage of voids measured at 60 gyrations	Compliance
M1		12.9	non compliant
M2	$Vmin_5$ to $Vmax_{10}$ (60 gyrations)	10.0	compliant
M3		15.1	non compliant

The analysis of this table shows that only the M2 mix complies with the requirements of standard NF EN 13108-1 for a class 1 or class 2 or class 3 BBSG 0/10.

In addition to these observations, the performance of this test on the M1, M2 and M3 mixes has highlighted the very rubbing character of the Diack basaltic crushed stone and the need to use compositions (mixes) that are sandier and richer in bitumen.

For this mixture (M2), the values of the real density (MVRe) and the real density of the granular skeleton (MVRg) determined by calculation from the MVRe were then determined. The values obtained are 2.679 Mg/m^3 (MVRe = 2.679 Mg/m^3) and 2.927 Mg/m^3 (MVRg = 2.927 Mg/m^3) respectively.

In what follows, the Duriez and rutting tests will be carried out only on the M2 mixture in accordance with standards NF EN 12697-12 [21] and NF EN 12697-22 [22].

3.2.2.2. Presentation and compliance of the Duriez water resistance results (NF EN 12697-12 Method B) with the requirements of standard NF EN 13108-1

The table below presents the results of the Duriez test (NF EN 12697-12 Method B [21]) obtained on the M2 mixture.

Table 10: Conformity of the Duriez results (water resistance) of the M2 mixture to the requirements of the NF EN 13108-1 standard

Mixtures studied	Requirements standard NF EN 13108-1 for BBSG 0/10 of class 1, class 2 and class 3 - Water resistance i/C (in %)	Measured value (in %)	Compliance
M2	≥ 70 %	65%	non compliant

The analysis of this table shows that the value of the ratio of the compressive strength after 7 days of immersion in water at 18°C (i) on that of the compressive strength after 7 days of conservation in the air at 18°C (C) obtained of 65 % (i/c = 65 %) is not in conformity with the requirements of the standard NF EN 13108-1 [5] fixed at 70 % for a BBSG 0/10 of class 1 or class 2 or class 3.

These findings confirm the observations already made during the PCG tests on the very frictional character of Diack basaltic crushed stone. This very rubbing character of the aggregates confirms the insufficient water resistance results obtained on the M2 composition.

Similar observations were found by Aidara in 2016 [25] during his work where indirect tensile water resistance tests were performed on basaltic specimens immersed in water at 60°C for 24 hours to produce accelerated aging and on basaltic specimens kept dry at an ambient temperature of 25°C. From this work a value of immersion to compression ratio of 64.54% (ITSR = 64.54%) was obtained. It is concluded from this work that the specification of 70% required by the standards is never met for basalts and that the poor resistance to water noted on these materials is due to the percentage of voids and sensitivity to water at the aggregate-bitumen interfaces. He also concludes that further testing will be required to confirm these findings [25].

3.2.2.3. Presentation and compliance of the rutting test results (NF EN 12697-22) with the requirements of standard NF EN 13108-1

The criterion used is the rut depth measured as a percentage of the thickness of a 50*18*10 cm slab at 30,000 cycles and 60°C (large rut in air).

The table below shows the results of this test obtained on slabs 1 and 2 prepared with the M2 mix.

Table 11: Conformity of the rutting results of the M2 mix to the requirements of the NF EN 13108-1 standard [5]

Mixture M2 studied	**Plate 1**	**Plate 2**	**Average of the values measured on plate 1 and 2**	**Requirements of standard NF EN 13108-1 to rutting for BBSG 0/10 of class 1, class 2 and class 3**	**Compliance**
Percentage of voids (%)	7.8	7.4	7.6	between 5% and 8%	compliant
Rut depth at 30 000 cycles and 60°C (%)	4.2	3.7	3.95	- Class 1 : ≤ 10 % - Class 2 : ≤ 7.5 % - Class 3 : ≤ 5 %	compliant

The table analysis shows that the average values of percentage of voids and rut depth at 30,000 cycles and 60°C are in accordance with the requirements of standard NF EN 13108-1 [5] for a class 1 or class 2 or class 3 BBSG 0/10.

These results confirm the rubbing character already noted during the PCG and Duriez tests of Diack basalts. This character justifies the results of an excellent resistance to rutting obtained and an insufficient resistance to water.

4. Conclusions

The mix design studies carried out in the context of this work have made it possible to determine a mix design that meets the PCG compactibility and rutting resistance requirements of standard NF EN 13108-1 for a class 1, 2 and 3 0/10 BBSG. This determined composition is composed of 49% of 0/4 basaltic sand, 10% of 4/6.3 basaltic gravel, 38.5% of 6.3/10 basaltic gravel, 2.5% of cement CEM II/B - LL 32.5 R and 5.1% of bitumen 35/50.

The results of these studies also made it possible to highlight on this composition the very rubbing character of the basaltic crushed stone of Diack. This observed very rubbing character confirmed the results of an insufficient resistance to water and an excellent resistance to rutting obtained at the end of this work.

These results suggest that the value of the i/c ratio for water resistance of 70% set by the NF EN 13108-1 standard could be reviewed according to local experience and Senegalese climatic constraints in order to make the composition thus obtained compliant.

In order to improve the water resistance, studies on the correction of the grading and the bitumen content could also be envisaged in the extension of this work. Further work on tackiness and the addition of a tackiness dope may also be considered in this regard.

Acknowledgements

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