World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

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Studies on the use of quartzite from Bakel (Senegal) in the manufacture of bituminous concrete for road surfacing

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World Journal of Advanced Research and Reviews, 2022, 16(01), 915–922

Publication history: Received on 13 June 2022; revised on 25 October 2022; accepted on 27 October 2022

Article DOI: https://doi.org/10.30574/wjarr.2022.16.1.1120

Abstract

This paper presents an attempt to use crushed quartzite as a substitute to crushed basalt, which is since more than sixty years the most systematically used aggregate on all the Senegalese territory to formulate the bituminous mixes for pavement. This massive use induced a decrease of basalt reserves and it is urgent to find other substitution materials. This article reports an attempt to valorize crushed massive quartzite from Bakel in the region of Tambacounda in Senegal. The studies carried out on a mixture of quartzite composed of 23% of 8/14, 25% of 3/8 and 52% of 0/4 and bitumen 35/50 showed that this quartzite material complies with the rules and practices currently in force in Senegal.

Keywords: Valorization; Crushed; Quartzite; Pavement.

1. Introduction

In Senegal, most of the paved road structures have their pavements formulated using the crushed basaltic rock of Diack in the Thies region of Senegal. This systematic use makes that this material becomes rare.

The work presented in this article deals with the valorization of other resources, those of the massive quartzite rocks located in Bakel in the region of Tambacounda in the southeast of Senegal (Figure 1).

The results of compliance tests carried out on this crushed quartzite material for use in pavement are presented in the following.

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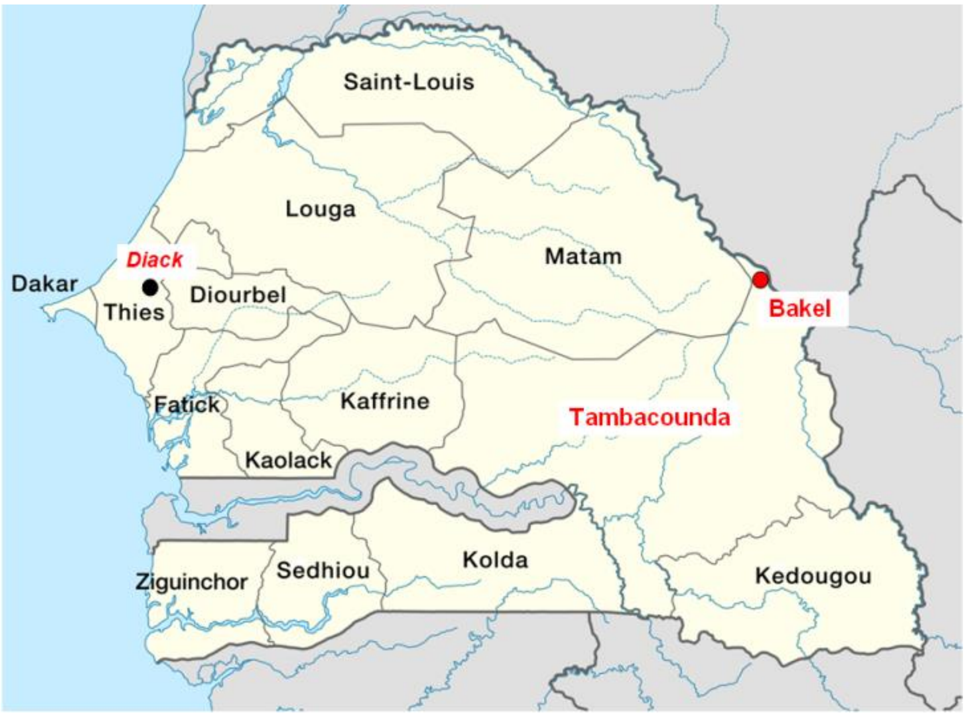

Figure 1 Origin of the studied quartzites (Bakel, Senegal)

2. Materials and Methods

2.1. Formulation of quartzites for their use in bituminous concrete pavement

To determine the tests to be carried out for the formulation studies, we referred to the note 17 of 2008 of the French Committee for Road Techniques (CFTR). This document indicates that the standard NF EN 13108-1 defines 5 levels of formulations tests (noted from 0 to 4) from which the project manager can choose the characteristics to be measured to meet the requirements of the project subject of the contract. These five levels are listed in Table 1.

Table 1 Contents of the formulation tests

Formulation test level	Level 0	Level 1	Level 2	Level 3	Level 4
Grain size curve, minimum binder content (T_{lmin}) or K, binder class	x	x	x		
PCG test (NF P 98-252)		x	x	x	x
Water resistance test at 18°C (Duriez test, NF P 98-251-1)		x	x	x	x
Rutting test (NF P 98-253-1)			x	x	x
Modulus of rigidity test (NF P 98-260-2, NF P 98-260-1)				x	x
Fatigue resistance test (NF P 98-261-1)					x

The note also specifies that level 1 or 2 is required for the design of semi-gritty asphalt concrete (BBSG).

For the application to Senegalese practices, the "catalog of new pavement structures and pavement design guide in Senegal" of the Senegalese Agency for Road Works and Management (AGEROUTE-Senegal) of 2015 retains this same principle, i.e. the maximum level of mix design for semi-gritty asphalt concrete (BBSG) is level 2.

For the studies done to formulate the quartzites in the present work, all the tests required by level 4 were carried out namely:

- Gyratory shear press test (PCG) (NF P 98-252) ;
- Duriez test at 18 °C (NF P 98-251-1);
- Rutting test (NF P 98-253-1);
- Characterization test of mechanical performances by complex modulus test (NF P 98-260-2), or by direct tensile test (NF P 98-260-1);
- Fatigue test (NF P 98-261-1).

The results obtained on the different components (bitumen used and quartzite) and the formulated mixture are analyzed in the following.

2.2. Conformity analysis of the results of the formulation of asphalt concrete made with quartzite from Bakel (Senegal) for use in pavement

2.2.1. Conformity of the bitumen used to formulate the studied quartzites

The bitumen used in these design studies is class 35/50. It has a penetrability value of 40 (NF T 66-004) and a ball-ring temperature (NF T 66-008) of 54.8°C. This softening point value (54.8°C) is compatible with the maximum working temperatures of roads in Senegal.

2.2.2. Conformity of quartzite aggregates from Bakel (Senegal)

The aggregates are selected by reference to the French standard XP P 18-540, article 7 (binder course) and article 8 (wearing course). This standard (XP P 18-540) is completed by standards NF EN 13043 and NF P 18-545, to take into account the level required by the current techniques.

The tested mixture is composed as follows:

- 23% quartzite 8/14;
- 25% of 4/8 quartzite and
- 52% of quartzite 0/4.

It results from the application of the above standards combined with the rules set by the AGEROUTE-Senegal guide of 2015 (table 2), that the aggregates usable in pavement must comply with "code B" for a traffic T2 (more than 150 heavy vehicles/day) for the intrinsic characteristics, and with "code III" for the manufacturing characteristics which are not indexed on traffic.

Table 2 Specifications of aggregates for BBSG (AGEROUTE-Senegal, 2015)

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

Table 3 summarizes the requirements set by the NF P 18-545 standard for the intrinsic characteristics corresponding to "code B", and the conformity with the values measured on quartzite samples.

Table 3 Conformity of the Bakel quartzites to the specifications of the intrinsic characteristics of the "code B" of the NF P 18-545 standard

Intrinsic characteristics	Requirements standard NF P 18-545 for « Code B »	Values measured on the quartzite of Bakel	Compliance
Los Angeles Coefficient (CLA)(*)	< 25	between 11.8 and 14.5	compliant
Micro Devalwet Coefficient (CMDE)(*)	< 20	between 4.4 and 7.8	compliant
CLA+CMDE(*)	< 35	between 16.2 and 22.3	compliant
(*): compliance is assured if the 3 conditions (CLA+CMDE, CLA and CMDE) are met simultaneously.			

The analysis of the results shows that the Bakel quartzites comply 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 4.

Table 4 Conformity of Bakel quartzites to the specifications of the manufacturing characteristics of "code III" of the NF P 18-545 standard

Manufacturing characteristics	Requirements standard NF P 18-545 for « Code III »	Values measured on the quartzite of Bakel	Compliance
Granularity Gc	Gc 85/20	Gc 85/20	compliant
Fines content (f)	1	0% passing the sieve 0.063	compliant
Flattening coefficient (Fl)	25	between 13.4 and 17	compliant

The analysis of the results shows that the quartzites of Bakel are in conformity with the characteristics of manufacture of the "code III" of the standard NF P 18-545.

These results show that the intrinsic characteristics as well as the manufacturing characteristics of Bakel quartzite are in conformity with the requirements of the standards in force.

2.2.3. Conformity of the characteristics of the tested mix

For a BBSG 0/14 mix, the gradation requirements set by standard NF EN 13108-1 are defined in table 5.

The analysis of these results shows that the grading curve of the tested mixture presents a slight excess of passing the 0.063 mm sieve.

For the binder content requirements, a significant difference is noted between the old NF P reference documents and the new NF EN 13108-1 standard on asphalt mixes. This difference lies in the expression of the binder content. In the new NF EN 13108 standard, the binder content is expressed in relation to the total mass of asphalt, contrary to the NF P standard which relates the bitumen content to the mass of dry aggregates.

Table 5 Compliance with the NF EN 13108-1 standard for the quartzite mix studied

Passing through the sieves	Standard requirements NF EN 131 08-1	Measured value (in %)
1,4*D	100	100
D	90-100	97
2 mm	10-50	40
0.063 mm	0-12	18

In view of these considerations, the binder content of the tested mix will be:

- 5% according to the NF EN 13108-1 standard and
- 5.26% according to the old NF P standards.

2.2.4. Compliance with the gyratory shear test (PCG)

The gyratory shear press (PCG) test (NF P98-252) performed on the tested mixture gave a percentage of void of 6.6% measured at 80 gyrations. This value is in accordance with the requirements of the NF EN 13108-1 standard which states that the measured value must be between 4% and 9%.

Table 6 Compliance of the tested mixture with the PCG specifications of the NF EN 13108-1 standard

Name	Percentage of voids V_{min}-V_{max} (in %) (gyratory compactor method)	Measured value (in %)	Compliance
BBSG 0/14	V_{min}6 to V_{max}9 (80 gyrations)	6	Compliant

2.2.5. Compliance with the water resistance test

The Duriez simple compression test (water resistance) (NF EN 98-251-1) carried out on the tested mixture gave a value of ITSR or (r/R) of 93.6%. This value is in accordance with the requirements of the standard NF EN 13108-1 which fixes that the measured value must be higher or equal to 70%.

2.2.6. Compliance with the rutting test

Table 7 summarizes the rutting depths measured on the tested mix.

Table 7 Rutting depths measured on the tested mix (NF P 98-253-1 standard)

Number of cycles	Measured rut depths (in %)
1000	3.22
3000	3.77
10 000	4.28
30 000	4.63

The analysis of this table gives a rutting value of 4.63% measured at 30,000 cycles and at 60°C on the tested mixture. This value is in accordance with the requirements of the NF EN 13108-1 standard which requires:

- a P10 category (at 30,000 cycles and 60°C) corresponding to a measured rut depth that must be less than 10% for a class 1 BBSG 0/14 ;

- a P7.5 category (at 30,000 cycles and 60°C) corresponding to a measured rut depth that must be less than 7.5% for a class 2 BBSG 0/14 and
- a P5 category (at 30,000 cycles and 60°C) corresponding to a measured rut depth that must be less than 5% for a class 3 BBSG 0/14.

The analysis also gives a Vi value of 4% and a Vs value of 8%. These results are also in conformity with the thresholds fixed by the NF EN 13108-1 standard which requires for a BBSG 0/14 of class 1, 2 and 3 a value of 5% for Vi and a value of 8% for Vs.

2.2.1. Conformity of the stiffness modulus measured on the tested mixture

For conformity, the NF EN 13108-1 standard requires, under a temperature of 15° C and a frequency of 10 Hz (or 0.02 seconds), a modulus of rigidity greater than or equal to:

- 5500 MPa for a class 1 BBSG 0/14 and
- 7000 MPa for a BBSG 0/14 of class 2 or 3.

For the purpose of comparison with local conditions, these values must be readjusted in accordance with the average temperatures recorded in Senegal, which are between 30 and 33°C.

A modulus of 1388 MPa was obtained for the mixture tested at 30°C.

This value (1388 MPa) exceeds that of 1300 MPa obtained after adjustment at 30°C and 10 Hz on the LCPC ALIZE program generally used in Senegal for pavement design.

2.2.2. Compliance with the fatigue test

This test is only required if the material is subjected to fatigue, which is not the case for asphalt concrete pavement. This is why BBSG 0/14 level 4 is not included in the standard.

The deformation ε_6 measured on the mix at a temperature of 10° C and 10 Hz, is established at 81.33 10^{-6}. This parameter is purely indicative since the BBSG pavement is not stressed in fatigue.

In addition, the value measured at 10°C is very conservative since the temperature conditions prevailing in Senegal from 30 to 33°C will induce a ε_6 higher than the threshold of 100.10^{-6} required by the NF EN 13108-1 standard.

Moreover, it results from several studies that, for bitumen contents lower than 7%, the fatigue strength increases with the bitumen content. A 1% increase in bitumen content can result in a 25 µdef gain in ε_6.

As already mentioned above, the old and the new asphalt standard differ in the expression of the binder content. In the new standard NF EN 13108, the binder content is expressed in relation to the total mass of asphalt, contrary to the old standard which relates the bitumen content to the mass of dry aggregates.

According to the NF EN 13108-1 standard, the bitumen content of the tested mix is 5% and not 5.26%.

It follows that the binder content must be increased to the minimum prescribed value. This increase will necessarily have an impact on the improvement of fatigue resistance.

2.3. Summary of compliance results for Bakel quartzite

Asphalt mix design requirements are based on a combination of three categories of material characteristics:

- General characteristics: water resistance, gyratory shear resistance and rutting resistance;
- Empirical characteristics: binder percentage and binder class and
- Fundamental characteristics: modulus of rigidity and fatigue resistance.

Table 8 summarizes the requirements established by standard NF EN 13108 for the evaluation of the conformity of an asphalt mix.

From this table it can be seen that the requirements that can be simultaneously set for the conformity of a BBSG can be summarized as performance related to water resistance, gyratory shear strength (PCG), resistance to rutting, and modulus of rigidity.

Finally, it is important to note that this standard excludes the possibility of requiring both empirical and fundamental characteristics. Thus, when the minimum percentage fixed by the standard as well as the class of bitumen are fixed, it is not possible to require performances related to modulus and fatigue resistance.

Table 8 Definition of required tests for general, empirical and fundamental characteristics (CFTR, 2008)

Formulation test level	General characteristics			Empirical characteristics		Basic characteristics	
	Duriez	PCG	Rutting	Minimum binder content (in %)	Binder class	Modulus of rigidity	Fatigue resistance
0				x	x		
1	x	x		x	x		
2	x	x	x	x	x		
3	x	x	x			x	
4	x	x	x			x	x

Thus, with regard to the results obtained within the framework of this work, the bituminous concrete elaborated from the quartzite of Bakel is in conformity for a use in coating.

3. Conclusion

The studies carried out have shown that Bakel quartzite is suitable for use in pavement surfacing in Senegal and that it is therefore possible to use other materials than basalt crushed rock from Diack (Senegal) in this layer. These studies also support the idea of continuing research into the use of local resources in materials that have not been used or have been used very little in road construction in Senegal and thus reduce the costs associated with the transport of materials to projects.

Compliance with ethical standards

Acknowledgements

The authors would like to thank AGEROUTE-Senegal for their considerable contribution to this work.

Disclosure of conflict of interest

No conflict of interest was declared by the authors.

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