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# Performance Evaluation of Asphalt Concrete Based on Basalt Aggregates of Diack and Quartzite of Bakel

**Mory Coulibaly[1], Makhaly Ba[2], Macodou Thiam[1], Babacar Diouf[2]**

[1]University Institute of Technology, University Iba Der Thiam of Thiès, Thiès, Senegal
[2]UFR Engineering Sciences, University Iba Der Thiam of Thiès, Thiès, Senegal
Email: mory.coulibaly@univ-thies.sn

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## Abstract

In Senegal, basalt aggregates are the aggregates used for the production of asphalt. They are also in some condition in base layer. However, the only licensed and operated basalt quarry in the west-central part of the country is finished and has reached very important depths thus constituting an environmental threat. This is how quartzite present in the east of the country precisely in the department of Bakel would constitute an alternative to basalt. For this purpose, the performance of two bituminous concretes based on quartzite and basalt was compared. One is made from Diack basalt aggregates, considered as the reference aggregate for asphalt in Senegal and the other is based on Bakel quartzite aggregates, they are both class 0/14. The mechanical performance of two bituminous concretes is evaluated using the Marshall method. The results obtained from the marshall tests give compactness values between 94% and 97% representing the limits laid down in the technical specifications, the creep values for quartzite-based asphalt concrete, while respecting the limit values, are higher than those obtained with basalt aggregates. Thus showing that the former is less resistant to deformation than the former. For both bituminous mixtures, the stability values remain above the minimum value of 1000 kgf set by the specifications. The water resistance test carried out on the two bituminous concretes based on basalt aggregate and quartzite aggregate gives values of immersion/compression ratio (R'c/Rc) equal to 0.72 and 0.82 respectively. These values are above the minimum required value (0.70) in the technical specifications in Senegal.

## Keywords

Quartzite, Basalt, Bituminous Concrete, Marshall, Duriez

# 1. Introduction

Asphalt asphalt is a material composed of aggregates, bitumen as a binder and possibly additives. In the body of the bituminous pavement, the asphalt must have the rigidity required to withstand the traffic-induced stresses; it can also be used as a pavement covering. The aggregates that compose it are aggregates of different dimensions, often represented by a grain size curve. These aggregates form the solid skeleton of the asphalt. They are chosen according to the mechanical and functional characteristics required according to specifications based on current standards or recommendations.

In road construction, the importance of the quantities of aggregates mobilized plays a preponderant role on investments because of the considerable increase in transport costs related to their geographical position, the scarcity of good quality materials and the environment.

In Senegal, basalt is the reference material used for the production of asphalt. It is extracted in quarries located in the administrative region of Thiès. These careers have become, today, overexploited and graduating. Faced with this situation, a diversification of this resource is necessary in order to reduce the transport distances from the quarry to major road construction sites within the country [1].

For example, research has been conducted in recent years on other sources of aggregate supply such as silexite, but with the addition of dope to increase its performance. Further studies on quartzite aggregate cyclic behaviour have led in recent years to lead in recent years to the exploitation of Bakel quartzites in the administrative region of Tambacounda. But its use in road construction remains at the stage of experimental test plates [2] [3].

The objective of this study is to make a comparison between a Bituminous Concrete (BB) based on basalt aggregates and another based on quartzite aggregates.

# 2. Materials

## 2.1. Origin of Materials

The outcrops of Diack in the administrative region of Thiès testify to volcanic manifestations. They are 76 km from Dakar on the same parallel and emerge from the southern slope of the hill of the town of Goundiane [4]. Quarries in this area are the main suppliers of basalt aggregates in the country. They are of volcanic type and are essentially composed of plagioclases and pyroxenes with sometimes other accessory minerals such as olivine [5].

The lithological studies of the Bakel series [6] [7], reveal two domains that overlap towards the East: an external domain and an internal domain. The latter, the subject of this study, is subdivided on the one hand into a series of green shales at the base including ferruginous jasperoids based on ultrabasic formations and original green scistes sedimentary or volcano-sedimentary and on the other hand in a detrital series consisting mainly of quartzites and quartzite sandstones. Quartzite aggregates are currently operated in Bakel, in the administrative region of Tambacounda, 687 km east of Dakar.

## 2.2. Physical and Mechanical Characteristics of Aggregates

The tests for the identification of aggregates make it possible to verify whether the aggregates under study comply with technical standards. To this end, the identification tests carried out on the granular classes (0/3, 3/8 and 8/14) of the two materials under study are: particle size analysis by sieving [8], specific weight for all aggregates [9], density apparent [10], flattening coefficient [11], wear resistance (micro Deval) [12] and fragmentation resistance (Los Angeles) [13]. All results on the physical and mechanical characterization of basalt and quartzite aggregate samples are recorded in **Figure 1** and **Figure 2** and in **Table 1**.

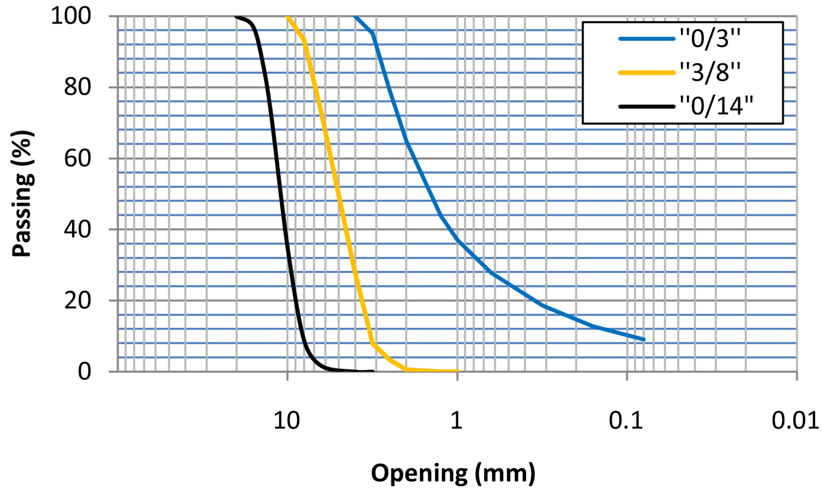


**Figure 1.** Granulometric curve of the basalte.

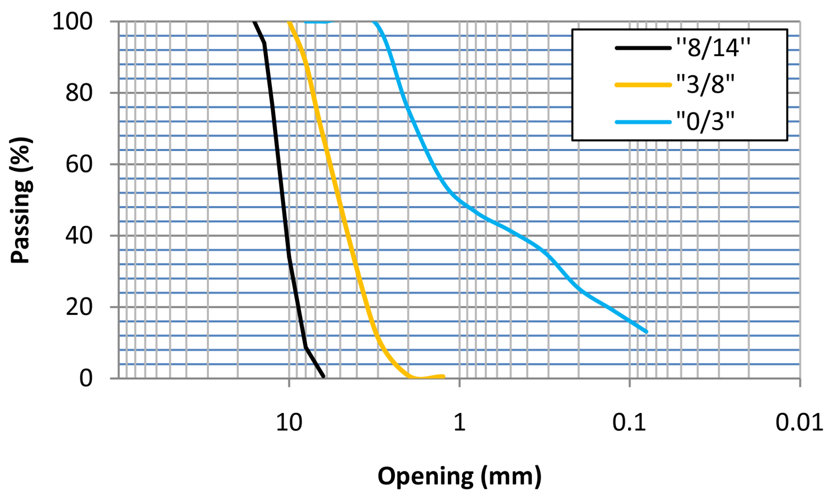


**Figure 2.** Granulometric curve of the quartzite.

**Table 1.** Laboratory tests on basalt aggregates of Diack and quartzite of Bakel.

| Materials | Granular Class | Specific Weight ($t/m^3$) | Apparent Density ($t/m^3$) | Los Angeles (%) | Micro-Deval (%) | Flattening Coefficient (A) (%) |
|---|---|---|---|---|---|---|
| **Basalte** | 0/3 | 2.948 | 1.67 | | | |
| | 3/8 | 2.906 | 1.59 | | 11.4 | 18.92 |
| | 8/14 | 3.01 | 1.66 | 12.14 | 9.5 | 9.7 |
| **Quartzite** | 0/3 | 2.557 | 1.57 | | | |
| | 3/8 | 2.594 | 1.51 | | 11.4 | 21 |
| | 8/14 | 2.615 | 1.4 | 18 | 8 | 8 |

### 2.3. Bitumen Identification

The bitumen identification tests used in this study are: Ball and Ring softening temperature (TBA) [14] and penetration on bitumen [15]. The results in **Table 2** indicate that the bitumen is class 35/50 and that the average softening temperature between 50˚C and 58˚C indicates that the bitumen meets the specifications.

## 3. Formulation of Bituminous Mixtures

In this study, the method used is the Marshall method which is an empirical method developed since the 1930s. It is the most used and includes both a formulation test and a part of characterization of the performance of the mixture. Once the particle size of the different granular classes is determined, the mixture curve is determined with the different percentages of each class to be inserted into the spindle defined for the type of asphalt. The spindle used here is the spindle of asphalt concrete 0/14 defined by NF EN 13108-1. The theoretical granular compositions **Table 3** obtained make it possible to draw the granulometric curves of the different mixtures in the chosen reference zone [16] **Figure 3**.

### 3.1. Determination of the Bitumen Content

The minimum quantity of binder is determined according to the size of the mixture obtained. The bitumen content in the granular mixture is related to the richness modulus and the specific surface of the aggregates. For the formulation of bituminous concrete a modulus of minimum richness 3.3 is recommended [17]. For this purpose, modules of richness between 3.3 and 3.8 will be used for the determination of different bitumen contents **Table 4**.

### 3.2. Performance of Bituminous Mixtures with the Marshall Test

From the results of the determination of the theoretical binder content, a Marshall test program is carried out. The test is carried out according to NF EN 12697-34, the purpose of which is to determine the mechanical characteristics,

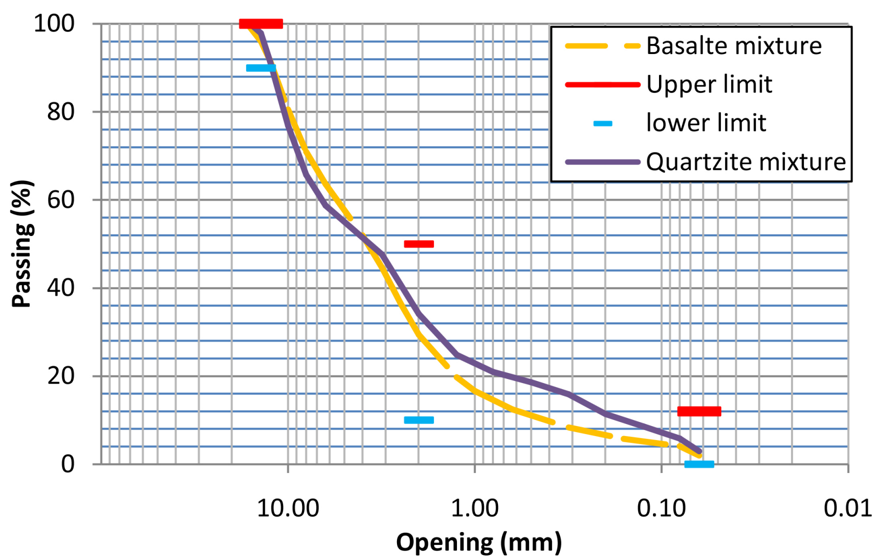


**Figure 3.** Particle size distribution of the various mixtures.

**Table 2.** Penetrability and softening temperature of bitumen.

| Needle penetration | | | | |
|---|---|---|---|---|
| | Measure N˚1 | Measure N˚2 | Measure N˚3 | Average |
| Temperature (˚C) | 25 | 25 | 25 | 43.6 |
| Recess (1/10mm) | 45 | 43 | 42.9 | |
| Softening temperature (Ball ring method) | | | | |
| | Ring N˚1 | Ring N˚2 | Average | |
| TBA (˚C) | 50.3 | 50.45 | 50.45 | |

**Table 3.** Granular composition of the theoretical mixture.

| Materials | Granular class | Proportions (%) |
|---|---|---|
| Basalte | 0/3 | 45 |
| | 3/8 | 25 |
| | 8/14 | 30 |
| Quartzite | 0/3 | 45 |
| | 3/8 | 20 |
| | 8/14 | 35 |

namely creep and stability, then the percentage of voids of the hot asphalt mixture compacted under standardized conditions whose aggregate diameter does not exceed 20 mm. For this purpose, for each bituminous mixture based on basalt and quartzite aggregates, we proceeded as follows.

**Table 4.** Bitumen content by richness modulus.

| Aggregate | Wealth module | Theoretical binder content (%) |
|---|---|---|
| Basalte | 3.3 | 4.57 |
| | 3.4 | 4.72 |
| | 3.5 | 4.85 |
| | 3.6 | 4.99 |
| | 3.7 | 5.13 |
| Quartzite | 3.30 | 5.28 |
| | 3.40 | 5.44 |
| | 3.50 | 5.6 |
| | 3.60 | 5.76 |
| | 3.70 | 5.92 |

The manufacture of five series of test pieces with bitumen content varying from 4.57% to 5.13% for the basalt granulate bituminous mixture and five other series of test pieces for bituminous mixtures based on quartzite aggregates with bitumen content varying from 5.28% to 5.92%. For each bituminous mixture, the evolution of stability and creep is shown.

Selection of the maximum binder content of which the samples meet the conditions of compactness, minimum stability and maximum creep.

- The selection of the optimum binder content using the contents to obtain the optimum values for each parameter. In this case, if the optimum is obtained for the same binder content, it will be retained and if different levels are selected, the arithmetic mean obtained is considered to be the optimum value.
- The selection of the maximum content of which the samples satisfy the conditions of compactness, minimum stability and maximum creep.

### 3.3. Water Resistance Test

The purpose of the Duriez test is to characterize the mechanical strength and water stripping qualities of the asphalt in accordance with NF P 98-251-1. The Harden test is applied mainly to dense or semi-dense materials of bituminous asphalt, whose aggregate diameter is less than 20 mm.

In this part, we will evaluate bituminous mixtures with 4.72% binder content based on basalt aggregates and 5.44% based on quartzite aggregates. For this, it is realized a double-acting static compaction of the specimens, some of which are subjected to the compression test after conservation at 18˚C in air and water under well-defined conditions, while the others are subjected to hydrostatic weighing in order to calculate compactness. For each mixture, a series of seven test tubes is made up and distributed as follows:

- Two single compression tests after 24 hours.

- Two single compression tests after 7 days of air storage at 18˚C.
- Two single compression tests after 7 days in water at 18˚C.
- A reserve to determine the compactness of the mixture.

## 4. Results and Discussions

The geotechnical characterization tests of the two aggregate samples show that basalt is more resistant to fragmentation (LA = 12.14) than quartzite (LA = 18). This difference can be explained from the apparent density and specific weight results which show that basalt is slightly heavier than quartzite with slightly higher values. On the other hand, the micro Deval test shows that quartzite is more wear-resistant than basalt. This can be explained by the mineralogy of the source rock. Quartzite being much richer in silica than basalt has a more wear-resistant ability.

The flattening coefficient of aggregates is a manufacturing property, it then depends on crushing. It represents the percentage of flat elements. The results on the coefficients of class 3/8 on basalt and quartzite show that both aggregates are of category FI10. For class 8/14, the results show that basalt is of category FI20 and quartzite of category FI25. For each bituminous mixture, the parameters determined are: bulk density, Marshall stability, creep, compactness and the percentage of voids filled by the bitumen.

Compactness of bituminous mixtures is a very important factor and is one of the essential characteristics of a formulation. The results for the compactness of the two bituminous concretes (BB 0/14), one made with basalt aggregates and the other with quartzite aggregates are acceptable except the value of 93.44% for basalt which corresponds to a bitumen content of 4.4% Figure 4. Indeed, all other values are between 94% and 97%, which represent the limits set in the technical specifications. This means that any compactness values that meet the specifications can be selected for the Duriez test.

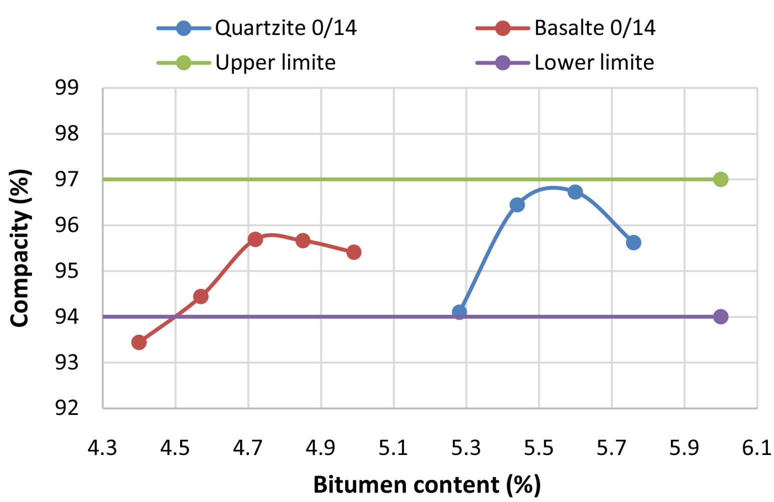


Figure 4. Marshall compacity evolution of basalt and quartzite bituminous concrete as a function of bitumen content.

For the Marshall creep tests, the results obtained for the two bituminous mixtures (BB 0/14) based on basalt and quartzite aggregates are shown in **Figure 5**. The latter represents the evolution of marshall creep with bitumen content for basalt aggregate bituminous concrete and quartzite aggregate bituminous concrete. For both mixtures, we find that creep increases with the bitumen content. For 0/14 bituminous concrete with basalt aggregates, all the bitumen contents comply with the creep limits laid down by the requirements, except for the content of 4.99%, whereas for asphalt concrete based on quartzite aggregates all the bitumen contents are the limits set by the technical specifications except two values 5.6% and 5.76%. With regard to the results on the two bituminous mixtures, we note that the basalt-based BB 0/14 creep remains lower than that of quartzite. This augurs that the latter is less resistant to deformation than the first.

The results obtained on the stability tests on the two bituminous mixtures with different bitumen contents **Figure 6** are satisfactory in relation to the requirements of the requirements. Indeed, the stability values obtained for the two bituminous mixtures remain higher than the minimum value of 1000 kgf.

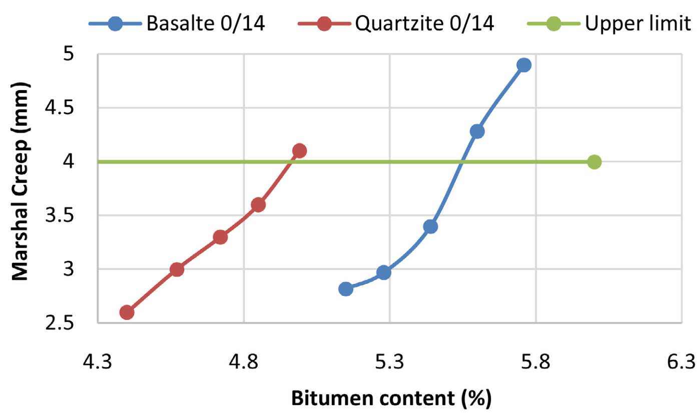


**Figure 5.** Creep evolution of basalt and quartzite bituminous concrete as a function of bitumen content.

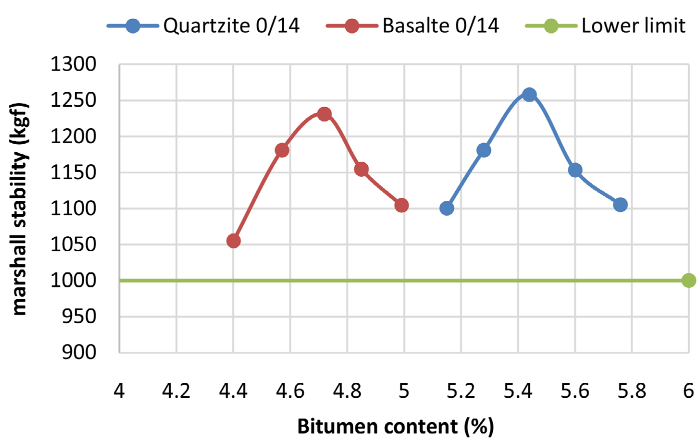


**Figure 6.** Marshall stability versus bitumen content for basalt and quartzite.

In selecting the optimum binder content, there are several methods that can be used:

- The selection of the contents by binding to obtain the optimal values for each parameter studied. If the optimum is obtained for the same content, it is retained. If different grades are used, their arithmetic mean is considered the optimum grade.
- The selection of the maximum content of which the samples meet the conditions of compactness, minimum stability and maximum creep.

In this study, we opted for the first approach because it better optimizes the bitumen content, which is the most expensive component in the asphalt mixture. Thus for BB 0/14 with basalt aggregates, all the bitumen contents meet all the conditions (creep, compactness and stability) except the 4.99% and 4.4% contents. Whereas for BB 0/14 with quartzite aggregates, the contents to be excluded, that is, those that do not meet the criteria are 5.6% and 5.76%.

Following this analysis on the conformity of all the bitumen contents with respect to the studied parameters, it appears that the bitumen content of 4.72% and 5.44% are the values that best meet the criteria for basalt-based BB 0/14 and quartzite-based BB 0/14, respectively. The formulation of BB 0/14 then requires much more bitumen for quartzite aggregates than for basalt aggregates.

The Duriez test results show that for the different bituminous mixtures with the bitumen content selected from the Marshall tests comply with the current specifications. Thus, the specifications set limits for the following parameters:

- The ratio of the compressive strength of the specimens kept for seven days in water at 18˚C to those kept in air at the same temperature shall be at least 0.70. What is checked for all mixtures are in **Table 5** and **Table 6**.
- The required compactness value is between 92% and 96%. Thus, the compactness values obtained for the different mixtures are between these two compactness limit values **Table 5** and **Table 6**.

**Table 5.** Results of tests Harden on BB 0/14 with basalt.

| | | | |
|---|---|---|---|
| Composition (%) | | Basalte 8/14: 30<br>Basalte 3/8 .25<br>Basalte 0/3 45<br>Bitumen 35/50 4.72 | |
| Blend density | | 2723 | |
| TEST DURIEZ | 24 hours at 18˚C | Rc (Mpa) | 5.9 |
| | 7 days air at 18˚C | | 6.2 |
| | 7 days immersion at 18˚C | | 4.5 |
| | Immersion/compression ratio | 0.72 | |
| | Apparent density (t/$m^3$) | 2.432 | |
| | Compacity (%) | 93 | |

**Table 6.** Results of tests Harden on BB 0/14 with quartzite.

| | | | |
|---|---|---|---|
| | Composition (%) | Basalte 8/14: 35<br>Basalte 3/8 .20<br>Basalte 0/3 45<br>Bitumen 35/50 5.44 | |
| TEST DURIEZ | Blend density | 2723 | |
| | 24 hours at 18˚C | Rc (Mpa) | 4.6 |
| | 7 days air at 18˚C | | 6.1 |
| | 7 days immersion at 18˚C | | 5 |
| | Immersion/compression ratio | 0.82 | |
| | Apparent density (t/m$^3$) | 2.173 | |
| | Compacity (%) | 92 | |

With regard to the results obtained for the water resistance test (Duriez test), the bitumen content retained for BB 0/14 based on basalt aggregates and quartzite aggregates is 4.72% and 5.44% respectively.

## 5. Conclusion

This study made it possible to present the geological context and the location of the various quarries that currently exploit the aggregates of quartzite and basalt. It also made it possible to identify and characterize quartzite aggregates in order to compare them with the characteristics of basalt aggregates of Diack. The Marshall Test results for both asphalt mix remain within the standards. However, the creep obtained on quartzite-based mixtures is higher than basalt-based. The two bituminous mixtures give roughly equal compactness values. Hardening tests on quartzite-based concrete and basalt-based bituminous concrete give roughly equal values.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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