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Physico-mechanical characterization of bituminous mixes: case of asphalting works on the Boundiali-Madinani road.

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ABSTRACT/RESUME

Abstract: *The goal of this research was to evaluate some physical properties and mechanical performances of the bituminous concrete during the construction of Boundiali-Madinani road and ensure that they meet the standards set forth in the specifications. Results showed that the grain distribution curve fit into a narrower spindle for the coarse and fine aggregates and flared for the intermediate aggregates. Binder extraction indicated that the average percentage of soluble binder content is 6,01%. Examining Marshall samples showed an average Marshall stability of 1376,55 kg and maximum Marshall flow of 3,80 mm. Also examining Marshall samples demonstrated that the voids in mineral aggregate (VMA) values are between 15 % and 17 %, the voids in the mineral aggregate frame work filled with bitumen (VFB) values oscillate between 73,69 % and 84,42 %. Further, it was shown that the air voids of the mixtures are between 6,07 % and l2,45 %. All test values are consistent with the specifications limits.*

I. Introduction

In Côte d'Ivoire, the road is one of the main levers for socio-economic development and also a factor of regional and sub-regional integration. The Ivorian road network, a tool for collecting and removing basic products from production areas to marketing and export centers, is clearly degraded due to lack of maintenance [1]. Indeed, given the demands of heavy goods vehicle overloads on our roads, its behavior is significantly disturbed and we are therefore witnessing premature deterioration of our pavements which until then behaved normally [2].

Considering the impact of the effect of road infrastructure on economic development, it is desirable to obtain sustainable and good quality roads. The quality of a road results from the quality of the materials. Materials are designed to meet specific needs, and for this they must meet a number of requirements. The first of these requirements is the criterion of safety vis-à-vis its short-term use and its durability over time to meet all the tasks assigned to it during its service [3]. One of the road materials that deserves special attention is asphalt. Today these bituminous materials, which are mixtures of aggregates and hydrocarbon binder, are by far the most used to form the coating of road structures. The performance of asphalt mixes is therefore a concern of all, because it affects the economy of the entire population [4]. The authorization to use this type of material is most of the time conditioned by the performance of tests in the laboratory and on site (on site), hot and by compliance with the performance thresholds in accordance with the standards in force [5].

The objective of this study is, through this experiment, to determine the physical and mechanical parameters of bituminous concrete (high quality dense mixes and perfectly controlled) as part of the development and asphalting works of the Boundiali-Madinani road. It is therefore a question of determining the stability and the Marshall creep, the compactness and the voids percentages of the bituminous concretes produced as well as their composition.

II. Study area

The project area straddles two departments located in the North of the Ivory Coast: Boundiali and Madinani, precisely between longitudes 6 ° 56'44.4 "W to 6 ° 29'00.4" W and latitudes 9 ° 31'11.6 "N to 9 ° 36'42.6" N (Figure1). Its relief is monotonous, with altitudes varying between 300 and 400 m. However, the study area is dotted with granite domes and inselbergs that are part of the Guinean mountain range that culminates in Mount Nimba [6]. The study area is a savannah region with tropical to subtropical vegetation and a dry tropical climate. The geological substratum of the study area is mainly composed of granites, granodiorites, zones of undifferentiated schists and serictous shales [6-7]. The soils that develop there are moderately and weakly saturated ferralitic type with attenuated rainfall [8].

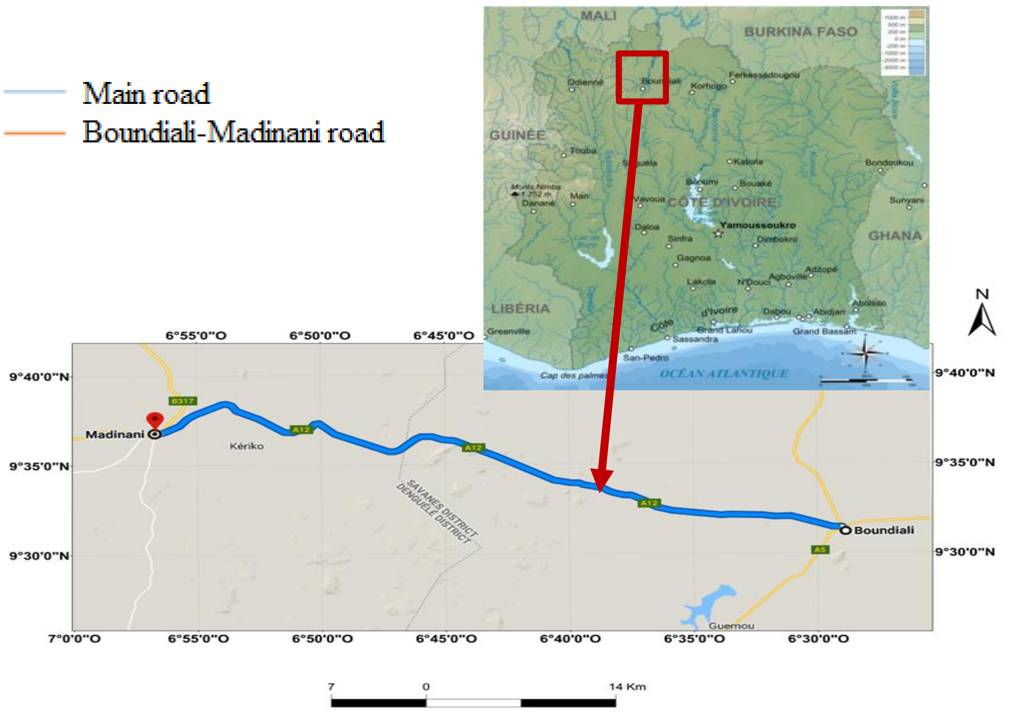


Figure 1. *geographical location of the study area*

III. Methodology

The quality of a material is based on a series of independent tests that will attest to the material's value. Optimizing material properties necessarily requires good characterization. This is how various tests were carried out on the bituminous materials that were used for asphalting the Boundiali-Madinani road per day of manufacture. For each day of implementation, using a sand shovel, at least two elementary catches of material of about 7 kg each were made around the screws of the paver to constitute a sample. Sampling is carried out between the first and the fourth shift of loading a single dump truck. The first compliance test carried out relates to the extraction of the binder from an asphalt mix for its characterization. The purpose of this test is to determine the binder content of an asphalt by extracting them while hot with a solvent (trichlorethylene) which forms an azeotropic mixture with water. This determination is made in accordance with standard NF EN 12 697-1 of August 2012. The aggregates recovered (stripping of aggregates) pass through a series of screens with decreasing openings in accordance with standard NF EN 12697-2 of August 2015. The test determines the distribution of an aggregate uptake expressed as a percentage of the cumulative masses of passers through a specified set of sieves. To determine the performance of the bituminous concretes used for installation and their conformity with the specifications of the specifications, Marshall tests (NF EN 12697-34) were carried out. The Marshall test makes it possible to compact in the laboratory in molds with the aid of a lady in order to make cylindrical specimens. These test pieces (at temperature 60 ° C) are placed between the two semi-cylindrical jaws of a press which approach each other at a constant speed. During the test, the load and the strain are recorded until failure. The compaction temperature corresponds to that required for mixing to ensure a viscosity of 170 mm² / s and allow maximum compactability on site. The test specimens thus prepared are used to first determine the gross density of the asphalt, then its stability, i.e. its resistance to deformation, and finally the deformation undergone by this specimen at the time of its rupture under the application of the maximum load (creep) and their quotient. This test makes it possible to bring out the physical properties such as the percentage of voids, the percentage of voids of the aggregate and the percentage of voids of the aggregate occupied by the binder of asphalt mixtures of dense and hot-compacted asphalt under standardized conditions.

IV. Results and discussion

IV.1 Results

IV.1.1 Composition of asphalt concrete

Table 1 shows the results of the soluble binder content contained in the asphalt concrete 0/14 and the granular distribution of the aggregates of the asphalt concrete after stripping of the mineral material. The values presented were calculated for twenty-two (22) samples taken from the screw of the paver before the application of asphalt concrete. It can be seen in this table that the standard deviations calculated from all the values of the particle size analyzes carried out are relatively low and consequently validate our measurements. The results relating to the granulometry of the granular skeleton contained in the asphalt aggregates, reveal that the proportion of fine or sand aggregates of size between 0 and 4 mm varies from 35.82% to 49.53%. The proportion of intermediate aggregates or small gravel 4/10 is included in the range from 26.65% to 37.20%. Concerning the coarse fraction of aggregates of granular class 10/14, it varies between 9.95% to 28.30%. The granite aggregates used for making bituminous concrete in the section studied are therefore rich in sands and fine gravel.

Table 1. *Summary of the results of the particle size analysis and the extraction*

	EXTRACTION 0/14								Binder content
Sieve diameter	14	10	6.3	4	2	0,63	0,315	0,08	
Specifications	94-100	72-84	50-66	40-54	28-40	17-28	13-21	7-10	6
Number of samples	22	22	22	22	22	22	22	22	22
Minimum	90	71	53	42	31,32	17,49	12,01	5,11	5,44
Maximum	99	88	67	54,64	39	27	19	7,30	6,54
Average	94,33	79,48	60,04	47,19	34,56	20,46	1,69	6,20	6,01
Standard deviation	2,54	4,07	3,99	3,71	2,31	1,83	1,61	0,64	0,28
Variance	6,46	16,55	15,97	13,80	5,36	3,36	2,58	0,41	0,08

These aggregates used for the mixes in this work belong to the granular class 0/14 as specified in the CCTP. The average of the passers through the 2 mm sieve is 34.56% which is a high value, which means that the mortar (mixture of 0/2 sand or a 0/4 gravel combined with bitumen) fills almost all of the inter-gravel space of the bituminous mixtures produced. It therefore plays an important role in the characteristics of the mixture and even in the stability of the asphalt concrete produced and placed.

After analysis of Table 1, we also note that the binder content obtained is between a minimum of 5.44% and a maximum of 6.54%. The resulting average amount of bitumen estimated at 6.01% is suitable as it is substantially equal to the maximum value required by the technical specifications 6%. The results of the particle size analysis after stripping of the asphalt concrete 0/14 make it possible to draw the particle size curve (Figure 2) which represents the average of the passers of the aggregates contained in the asphalt concretes supplied.

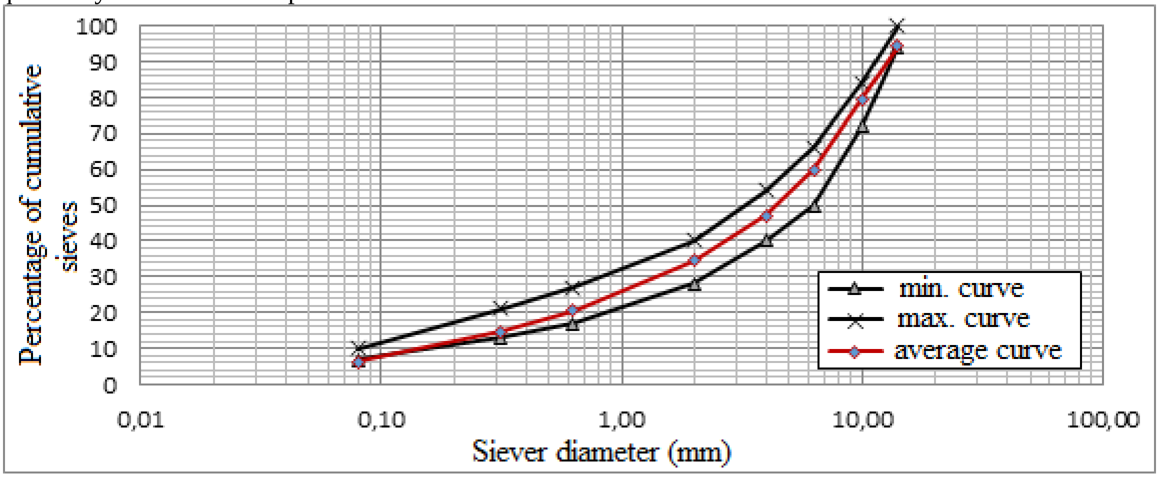


Figure 2. *Average particle size curve of bituminous concrete samples*

On observing this figure, we see that the average value of the percentages of sieve of the aggregates from the mixes is included within the tolerance limits specified in the specifications. In addition, the grain size curve obtained is continuous and looks like a "semi-grainy" curve, an intermediate curve rich in chippings and sand.

Figure 3 below shows the soluble bitumen content obtained after extraction of the binder from the aggregates of the mixes studied by the Kumagawa centrifuge. The amount of bitumen present in the asphalt mix is expressed as the content of the bitumen internal binder in the bituminous mixture. By observing this figure, it appears that the binder content is regular in the first twelve samples and uneven in the last. Such a variation in the binder content shows us that there is bound to be a problem, either in the formulation or with the extraction apparatus. Indeed, it is impossible to have such a difference assuming that the production of asphalt concrete is controlled, that is to say that the quantities of materials defined are actually incorporated into the mixture. As the difference observed is not constant, the most plausible cause seems a priori to be due to a change, in the mineral phase and / or in the binder content of the mixture, in the formulation of asphalt concrete. The average difference from the true or nominal required value is 0.22% and is greater than the minimum value recommended by the specifications 0.03%. In view of the results obtained, based on the binder content we can affirm that the samples studied are not homogeneous.

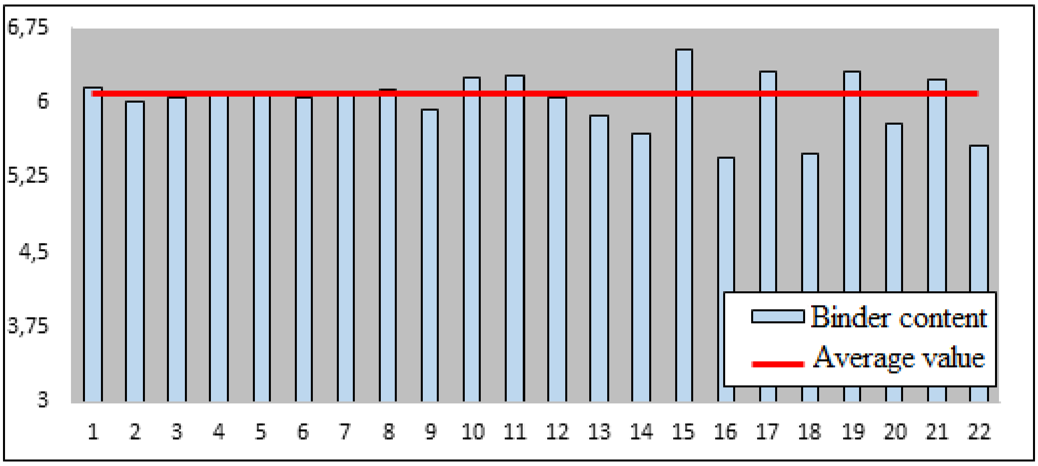


Figure 3. *Evolution of the binder content of bituminous concrete*

IV.1.2. Marshall tests

IV.1.2.1. Mechanical performance

Table 2 groups together the experimental results of the compression tests of the bituminous concrete specimens after preparation, storage at room temperature and in a thermostatic bath set at 60 ° C. Considering the results of the mechanical performance of asphalt concrete, they present satisfactory values and comply with the specifications with regard to creep and Marshall stability at 60 ° C. This indicates that a good application of the mixes could improve their shear strength.

Table 2. *Mechanical characteristics of bituminous concrete.*

Marshall for BB 0/14 mm			
Settings	Creep	Stability	Marshall quotient
Units of measure	mm	Kg	Kg/mm
Specifications	<4	>1000	-
Number of samples	22	22	22
Minimum	2,8	1139	316,39
Maximum	3,8	2173	700,97
Average	3,29	1376,55	421
Standard deviation	0,21	218	80,86
Quality	Compliant	Compliant	

The analysis of the table above shows that the stability values range between 1139 Kg and 2173 Kg and are above the minimum limit required which is 1000 kg. These results provide an empirical measure of the resistance to deformation of the bituminous mixtures produced. The average of the three deformations obtained thus gives an index of the fluidity or flexibility of the asphalt at 60 ° C, the maximum temperature that the coating can reach.

The standard deviation being a measure of the dispersion of the values of a statistical sample, is defined here as the root-mean-square of the deviations from the mean. The standard deviation of creep and Marshall stability are 0.21 mm and 218 kg, respectively. The creep values are less dispersed (low standard deviation) because they are close to the arithmetic mean. On the other hand, the standard deviation calculated from the stability data is large, which results in a large variability of the stability values on either side of the arithmetic mean which is 1377 kg. These values are therefore not grouped around their average.

The variation in the Marshall stability of the different asphalt concrete samples is shown in Figure 4. This graph reveals a great variability in the asphalt concrete manufacturing process in an asphalt mixing plant in the early stages of production. Subsequently, the values obtained follow the same trend (stabilize) and do not call for any particular comment.

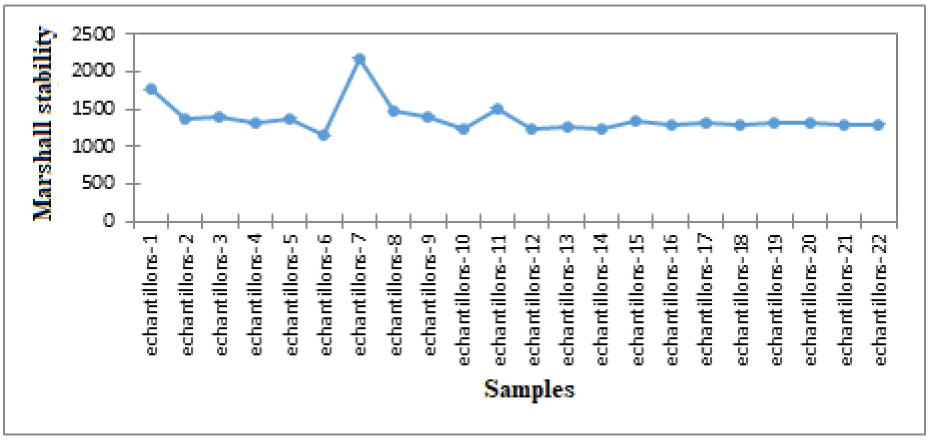
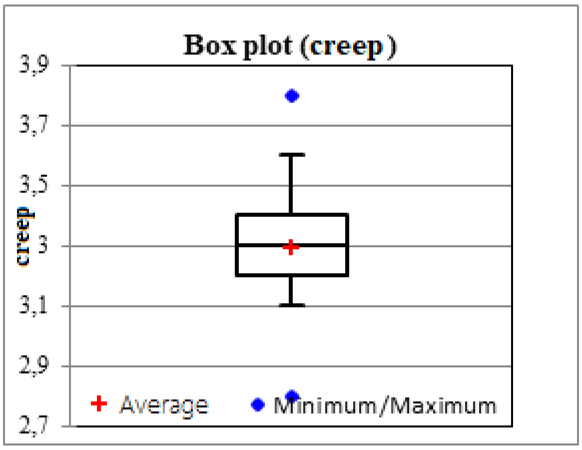


Figure 4. *Evolution of the stability of bituminous concrete.*

Figure 5 shows the distribution of Marshall creep and Marshall quotient data. Creep values vary between 2.80mm and 3.80mm and are greater than the maximum required limit of 4mm for creep. It is also noted that the first quartile and the median of the creep values are respectively 3.2 mm and 3.3 mm. The third quartile is 3.4 mm.

For the yield of bituminous concrete in the different sections studied, the average value of the Marshall quotient is 421 kg / mm (Table 2). This result is an indicator of the good mechanical performance of the asphalt produced. In fact, the higher the Marshall stability, the lower the creep, which therefore induces a high mechanical resistance of the mixes. Otherwise, the mixes will have low mechanical strength. The so-called Marshall stability and creep comply with this condition given the respect of the tolerance thresholds prescribed in the specifications in force.



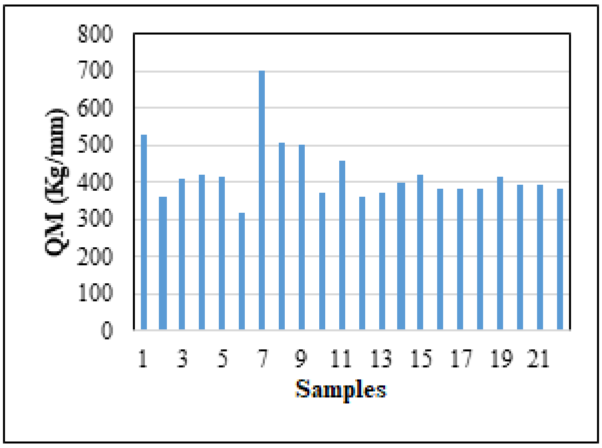


Figure 5. *Box plot of creep and variation of the Marshall quotient*

Values of the Marshall quotient obtained are indicators for the resistance to permanent deformations (creep), shear stresses and also for the rutting of asphalt mixes. The larger values of the Marshall quotient indicate that the hydrocarbon mixtures of these sections are more resistant to permanent deformation (creep).

IV.1.2.2 Physical parameters

The values of the following physical parameters, the Marshall compactness at 50 strokes, the percentage of voids, the percentage of intergranular voids (VMA) and the percentage of voids filled with bitumen (VFB) are presented in Table 3. The results show that the MAV values are between 15% and 17%. These low values make it possible to say that the bituminous concretes used have a semi-grainy texture. For VFB, the values are between 73.69% and 84.42%. These values are essential in the formulation of mixes. They ensure a sufficient volume of the mastic (binder + filler) in the mineral skeleton.

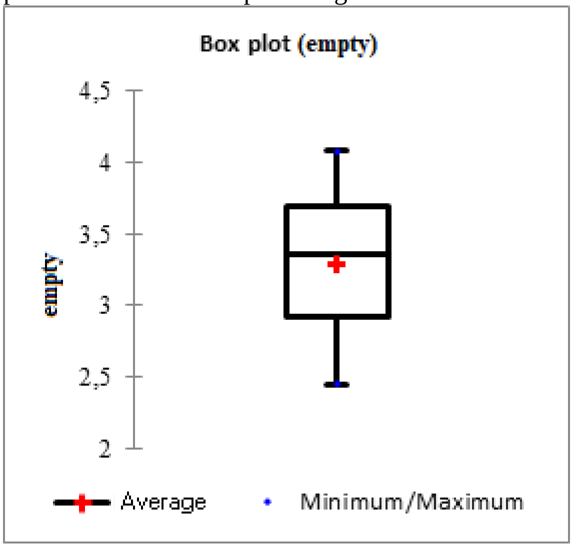
The analysis of this table also shows that the values of the Marshall compactness and the percentage of voids of asphalt concrete all meet the specifications of the specifications. After analyzing the data, we find that the values for the percentage of voids, between 2.45% and 4.07%, fall within the required variation range (3% -6%). Finally, the average value of Marshall compactness is 96.59% and is within the tolerance limits, the minimum and maximum thresholds of which are respectively 94% and 97%. The Marshall compactness values are therefore satisfactory and lie between 96% and 98%.

Table 3. *Physical characteristics determined after the Marshall test*

Samples	VMA (%)	VFB (%)	Compactness (%)	Empty (%)
Specifications	-	-	**94-98**	**3-6**
Samples	22	22	22	**22**
Minimum	**15**	**73,69**	**96**	**2,45**
Maximum	**17**	**84,42**	**98**	**4,07**
Average	**16,05**	**79,32**	96,59	**3,20**
Standard deviation	**0,63**	**2,17**	**0,666**	**0,47**

This good compactness of the asphalt seals the running surface, protects the bituminous mixture against bad weather, excessive oxidation while providing an adequate running surface and increases the density of the asphalt used.

The statistical population of the various VMA, VFB parameters and the percentage of voids is not symmetrical (Figure 6 and Figure 7). The median of the distribution of the above parameters in the boxplots below is not centered. The central part (50% of the numbers) is more spread out compared to the rest of the distribution for the void content and VMA parameters and less concentrated for the VFB parameter.



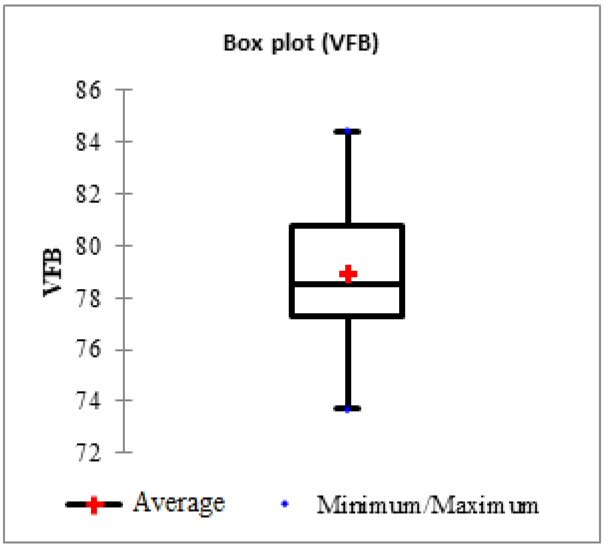
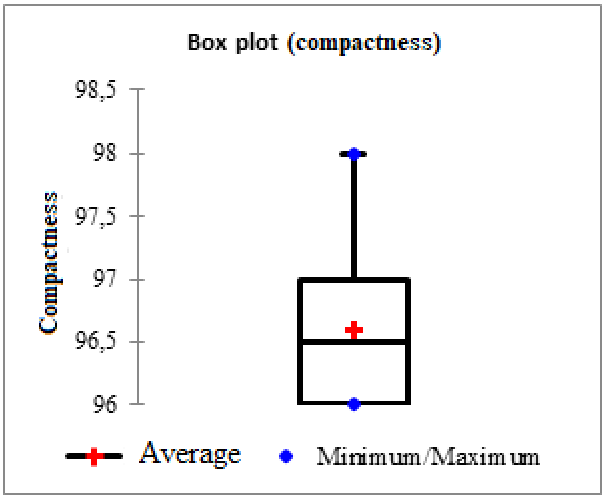


Figure 6. *Boxplot of VFB voids*



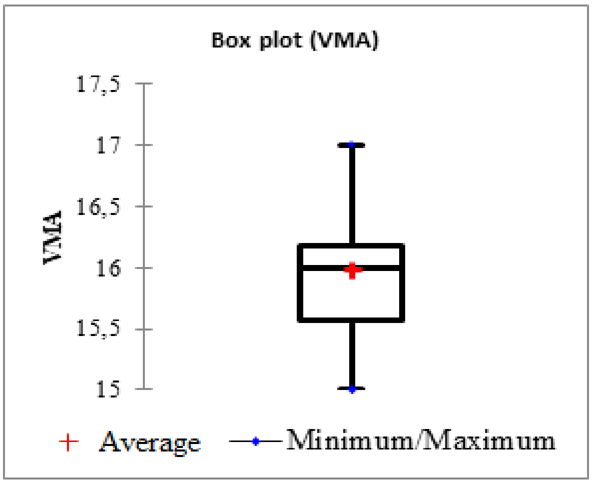


Figure 7. *Boxplots of VMA and compactness*

On the Marshall compactness graph, although the distribution is split into 4 zones (quartiles) of the same size (25%), the ranges of compactness values are not equal. The distribution is more elongated towards the high values of the compactness of the bituminous concrete specimens.

IV.2. Discussion

After analysis of the data, we find that the values of the percentage of voids, between 2.50% and 4%, are in agreement with the literature data which are between 2% and 7% [9]. These (interstitial) voids greatly affect the performance and durability of the asphalt. Thus, a void rate of at least 2% is required, otherwise the asphalt is over-compacted and is susceptible to bitumen bleeding and viscoplastic deformation during the passage of vehicles, or to rutting by creep [10] and [11]. To ensure the durability of the pavements, [12] and [13] suggest that the void content should be limited to a maximum value varying from 6.5 to 8.5% in order to limit air and water infiltration at the top. within asphalt. It has also been reported by [14] and [15] that a hot bituminous mix must be compacted to a void content between 3% and 8%; which corresponds to a compactness rate of 92% to 97%, so that it can perform its service function. This means that hot mix asphalt should not exceed 8%, nor fall below 3% void content during their service life. A high (greater than 8%) or low (below 3%) pore void content can cause pavement deformations such as rutting, displacement and bleeding. In our experience, the values of the binder content vary between a minimum of 5.44% and a maximum of 6.54%. So that bitumen can ensure the durability of hydrocarbon mixtures and guarantee an excellent useful life of the coatings, a study carried out by [16] recommends a binder content of between a minimum of 5% and a maximum of 8% for concrete. "fine" bituminous with 0/8 and 0/10 granularities and "medium" bituminous with 0/12 and 0/14 granularities. In addition, it has been demonstrated that a bituminous binder content in the range 5.50% to 6.50%, allows semi-grained asphalt concrete 0/14 to ensure a certain threshold of stability, compactness, resistance to water (stripping) and creep [5]. The results of the various Marshall tests indicate that the values of the MAS are between a minimum of 15% and a maximum of 17%. For VFB, the values are between 73.69% and 84.42%. A study carried out by [17] on bituminous mixes including aggregates mainly composed of limestone, gave VFB values which are between 72.2% and 74.2%. The values of the MAS meanwhile evolve from 14.8% to 15.8%. For the all-basalt aggregates the VFB values remained unchanged and the VMA values ranged from 13.45% and 14.7%. These results differ from the results of this study. However, it should be remembered that VMAs have the main advantage of having a low effect on the variation of the binder content during production and thus allow the incorporation of a large amount of binder in the bituminous mixture to increase its durability. In addition, the formulation study should be reviewed by choosing asphalt formulation levels suited to the intensity of current traffic. This observation is shared by [2]. According to this author, the indicative values of the Marshall test can in no way predict the evolution over time of the properties of the asphalt mixes used. This same observation is repeated by [18] which shows that certain caveats are made on the method of compaction which is carried out by impacts and of which the compaction load is applied perpendicular to the axis of compaction, which does not make it possible to reproduce efficiently. density during processing. Finally, this formulation method does not take into account the shear strength of the asphalt, associated with rutting, since this is a diametrical crushing.

V. Conclusion

The standardized tests carried out on the asphalt concrete samples during the development project and asphalting of the Boundiali-Madinani road made it possible to appreciate and evaluate the geotechnical parameters that determine the road behavior of the material before implementation. In terms of the composition of the mixes produced, this study shows that the aggregates used are rich in intermediate elements (4/10) and of small size (0/4). The average binder content of this material is close to the threshold value required by the specifications 6%. The results of the Marshall tests confirm that the contractual mechanical and physical performance of the asphalt mixes of 0/14 granularity supplied are achieved. However, the values of the indicators based on the empirical performance of the Marshall test are no longer predictive of the behavior of the bituminous concretes placed. The formulation study should be reviewed by choosing asphalt formulation levels suited to the increased stresses due to the increasing volume of road traffic.

Abbreviations list

UFR	: Training and Research Unit
LSTE	:Laboratory of Environmental Sciences and Technologies
VMA	: Voids in Mineral Aggregate
VFB	: Voids in the mineral aggregate frame work filled with bitumen
CCTP	: Technical and Specific Clauses Book
NF EN	: French Standard / European Standard

VI. References

1. BOAD. Etude sur l'entretien routier dans les pays de l'union économique et monétaire ouest africaine (UEMOA) : bilan des 50 dernières années et perspectives (2015) 318.
2. Tapsoba, J. H. Etude de formulation et de mise en œuvre des enrobés : Cas des travaux de renforcement de la route Ouaga-Sakoinsé. *Mémoire Master en ingenierie de l'eau et de l'environnement option Génie-Civil, 2iE, (Ouagadougou, Burkina-Faso)* (2012) 41.
3. Koné, F. K. Planification, suivi et contrôle qualité des terrassements routiers du 3ème pont riviera-Marcory (Abidjan-république de Côte d'ivoire), mémoire pour l'obtention du *master en ingénierie de l'eau et de l'environnement option : génie civil, 2ie, (Ouagadougou, Burkina Faso)* (2013) 76.
4. Barco, C. Influence de la température de compactage des plaques d'enrobés sur la résistance à l'orniérage, Mémoire de Master en génie de la constuction, *École de Technologie Supérieure Université du Québec, (Québec, Canada)* (2007) 193.
5. Bendimerad, K. F. ; Zadjaoui, A. Contrôle des travaux de revêtement en béton bitumineux à module élevé: Cas de l'Ouest Algérien 33 (2015).1-8
6. N'guessan, K..; Diarrassouba, N.; Alui, K..; Nangha, K. Y.; Fofana, I.; Yao-Kouame, A. Indicateurs de dégradation physique des sols dans le Nord de la Côte d'Ivoire :cas de Boundiali et Ferkessédougou (2015) 117.
7. Beaudou, A. G.; Sayol, R. Étude pédologique de la région de Boundiali-Korhogo, Cartographie et typologie sommaire des sols Feuille BOUNDIALI-KORHOGO, (Paris,Fance) (1980) 58.
8. Sosson, C. L. Caractérisation semi détaillée des bassins versants dans la zone agro-climatique de Boundiali. *contraintes socio-économiques a l'adoption des technologies rizicoles* (2004) 70.
9. MTQ, 2012b. Cahier des charges et devis généraux : Construction et réparation : Infrastructures routières, éd. 2012, Québec (QC). *Ministère des Transports duQuébec* (2012) 287.
10. Lamothe, S. Enrobé grenu : Influence du dosage en filler et de l'ajout d'un sable roulé sur le couple ouvrabilité-orniérage. Mémoire de maîtrise en génie de la construction, *Montréal, École de technologie supérieure* (2004) 185.
11. Meunier, M. Élaboration d'un outil de prédiction du comportement de la chaussée à l'orniérage. Thèse de doctorat en génie de la construction, *Montréal, École de technologie supérieure* (2012) 349.
12. Cooley, L. A.; Brown, E. R.; Maghsoodloo, S. Development of critical field premeability and pavement density values for coarse-graded superpave pavements.Coll. « NCAT Report », NCAT Report 01-03. Auburn (AL) : Auburn University, *National Center for Asphalt Technology* (2001) 18 p.
13. Mallick, R. B.; Cooley, L. A.; Teto, M. R.; Bradbury, R. L.; Peabody, D. An evaluation of factors affecting permeability of Superpave designed pavements. In *Transportation Research Board 80th Annual Meeting. (Washington, D.C*., Jan). 25 (2001) 7-11
14. Brown, R. Density of Asphalt Concrete- How Much is Needed. *Transportation Research Board, Washington DC* (1990) 14.
15. Roberts, F.; Kandhal, P.; Brown, E.; Lee, D.; Kennedy, T. Hot Mix Asphalt Materials, Mixture Design, and Construction. *National Asphalt Paving Association Education Foundation. Lanham, MD* (1996) 380.
16. ALBTP; CTGA. Règles techniques pour la construction routière dans les pays africains de la zone intertropicale (Études, conception, construction, entretien), Version incorporant l'ensemble du guide de 1980 complétée par le manuel BCEOM de 1972/1984 (Chap. 6 et 7 du tome 1, tome 2 et tome 3) (2014) 643.
17. Afaf, A. H. M. Effect of aggregate gradation and type on hot asphalt concrete mix properties, civil engineering. *department, faculty of engineering., Minia University*, vol. 42, nº3 (2014) 567–574.
18. Guissi, G. Cours TCH025 : travaux de génie civil, Module 03. *introduction aux enrobés bitumineux* (2016) 35.

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