Use of Plastic Waste and Lateritic Gravel in Bitumen Macadam Mix Design

Ibrahima SOW[1], Ibrahima Khalil CISSE[2]

[1]Doctoral School of the University of Thies (ed2ds), Senegal & Comapagnie Sahélienned' Entreprises, Dakar, Senegal

[2]Laboratoire de Matériaux, Mécanique et Hydraulique (LMMH), Ecole Polytechnique de thiès, Thiès, Sénégal

Abstract: ***The performance study of the bitumen macadam mix design with lateritic gravel made it possible to propose their use as a substitute for basalt aggregate in infrastructure projects in the interior of the country. Adding plastic waste to the bitumen made it possible to produce a modified binder of class 20-30 [1]. The Marshall tests, the Duriez test and the diametral compression allowed us to characterize the mechanical performances of three types of formulations F1, F2, and F3. The best performances are obtained with the addition of 15% of plastic waste in the bitumen 50/70 (L3 binder) and at optimal binder contents between 6.0 and 6.5%. The binder L3 used has the following results: the penetration is equal to 27mm (class 20-30), the softening point 50°C (standard value between 46-56°C) and a very good adhesivity rating of Riedel and Weber 5-10[1]. Formula F1 with a granular composition of 0/20 lateritic gravel has good Marshall stability 1320kg at the optimal content of L3 binder of 6.0%, a minimum of 9000MPa for the modulus is obtained at the same content. The percentage of voids equal to 8.5% is well within the 7-9% range. This product meets the specifications of the bitumen macadam BM4. The F2 formula which uses crushed basalt sand and 5/20 lateritic gravel has better performance than F1. The module goes from 9000MPa to 9300MPa, the percentage of voids decreases to the median value of the envelope 7-9 and the stability increases to 1450kg. These characteristics correspond to those of the bitumen macadam BM2. The F3 formula is very similar to the bitumen macadam of class BM3. The r / R ratio is greater than 0.7, the grading is 0/14. It is much denser and has strong resistance to rutting. The minimum thickness becomes thinner and thinner, decreasing from 14cm to 8cm.***

Keywords: Plastic waste, macadam, Marshall, Duriez, Diametric Compression

1. Introduction

For the past twenty years, plastic has represented a significant part of municipal solid waste. Its management is therefore necessary whether from an environmental, economic or social point of view. The first methods put in place to manage plastic waste were landfill and incineration. However, the exponential growth of plastic packaging waste led to the creation of other recycling channels. The global portion of recycled plastic remains very low today: only 20% of the world's plastic waste is recycled, 15% is incinerated, and the rest is amassed in landfills or lost in the environment. Scientists estimate plastic waste to account for 37% of poorly managed waste, and therefore its doomed to pollute the planet, especially the oceans [1].

Previous studies [2-6] have shown that it is possible to use plastic waste in hydraulic concrete and mortars. However, in this research we will focus on their use in macadam mix design: bitumen macadam. Bitumen macadam which is very rarely used in West Africa today provides an effective means to increase the pavement life, reduce the subbase and Road base thicknesses and facilitate the substitution of basalt with new types of material such as lateritic gravel. The use of lateritic gravel and plastic waste in the bitumen macadam mix design is beneficial from both an environmental and economic point of view, especially for projects inside the country, such as the rehabilitation of the Louga-Dara road. It is within this context that lateritic gravel samples were taken from the Ferlo zone in Senegal.

To meet the objectives of the study the following will be carried out:

- A bibliographical synthesis of the laterite from Ferlo and the basalt from Diack
- The preparation of modified bitumen by adding molten plastic waste
- Mix design of bitumen macadam.

2. Materials

2.1 The basalt of Diack

The Senegal-Mauritanian basin, which is the westernmost and most extensive part of the sedimentary basins of the margin of the African Atlantic, includes an area commonly known as the Plateau de Thiès which is the seat of important volcanism towards the end of the Tertiary period. These first volcanic disturbances linked to brittle tectonics due to the Atlantic rifting are manifested by basalt effusions in the Cape Verde peninsula (Cap Manuel, Gorée, Fann) and lava intrusions in the Thiès region corresponding to dykes (Diack, Sène Sérère), or tectonic veins (Keur Mamour, Ravin des voleurs, Thiéo, Bellevue, Sandock, Fouloume)[2]. The Diack zone therefore contains basalt which is a very common effusive magmatic rock. What makes Diack special is that there are three types of facies that cannot be found anywhere else:

- A fine-grained facies, majority, represented mainly by basanites,
- A medium grain facies, less abundant than the preceding facies,
- A coarse-grained facies, represented by a fully crystallized grainy rock

2.2 The lateritic formations of the Ferlo

Laterite samples are taken in Ferlo, specifically in Ndiamane in the department of Dara Djolof.

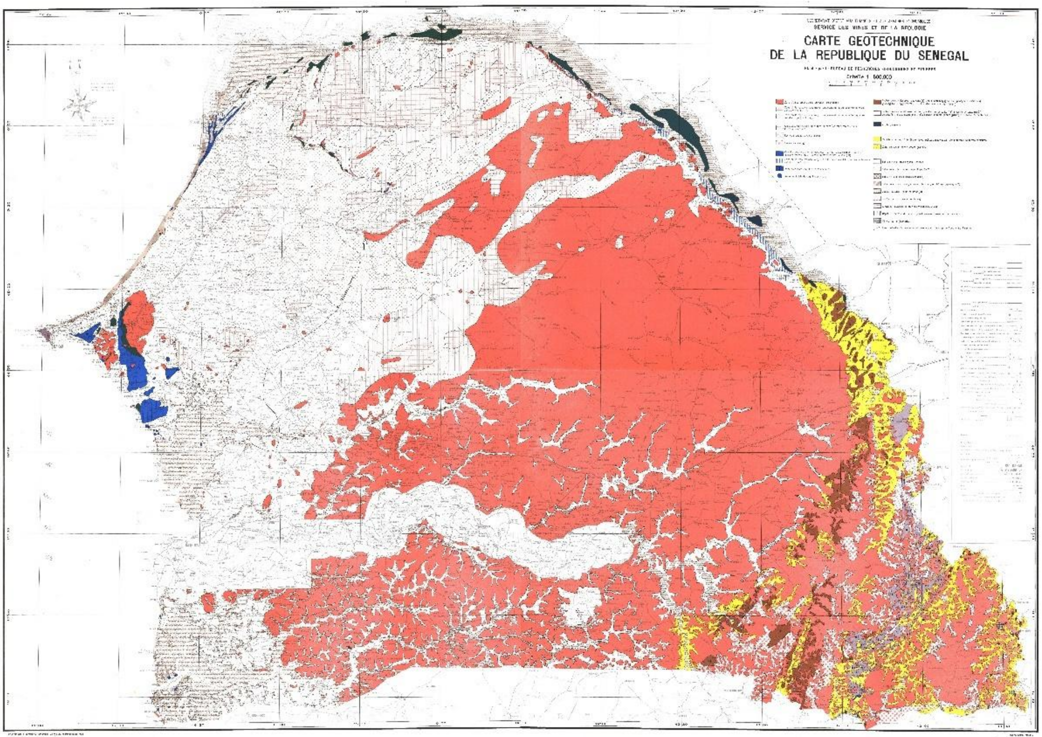

Figure 1: Geotechnical Map of Senegal (Geological and mining research office, 2010)

All the brown colour formations correspond to lateritic facies of variable thicknesses depending on the area. In the Ferlo zone the thicknesses vary from 1 to 2m.The lateritization phenomenon is a process of soil formation, specific to hot and humid tropical regions. It is an alteration of the parent rock, the essential characteristic of which is the dissolution and then the departure of the silica, leaching phenomenon, accompanied by enrichment in iron and alumina in the form of sesquioxides Fe_2O_3 and Al_2O_3. [2].

2.3 Mechanical characteristics of materials

The identification tests carried out are particle size analysis (NF EN 933-1), flakiness coefficient (NF EN 933-3), unit weight (NF P 18-554), bulk density (NF P 98-250-1), Aggregate Crushing value (EN 1097-1), and resistance to fragmentation by impact LA (NF EN 1097-2)[3]. The results are summarized in Table 1.

Table 1: Mechanical characteristics of the materials

Materials	classes	Unit weight (g/cm^3)	Maximum Specific gravity (g/cm^3)	ACV	Los Angeles	Flakiness	Absorption
Basalt	0/5	1.77	2.91				0.1
	5/10	1.49	2.98	16		18	0.08
	10/14	1.51	2.98	14	18	8	0.08
Laterite gravel	5/20	1.5	2.30	39	43	22	0.19
	0/20	1.56	2.26	41			0.23

2.4 Theoretical mix of aggregates

Three granular skeletons are used:

- A BM0/14 composed of three basalt classes: 44% of 0/5 crushed basaltic sand, 28% of 5/10 gravel and 28% of 10/14 gravel.
- A BM 0/20 composed exclusively of 0/20 lateritic gravel
- A BM 0/20 composed of a mixture of 40% of 0/5 crushed basaltic sand and 60% of 5/20 lateritic gravel.

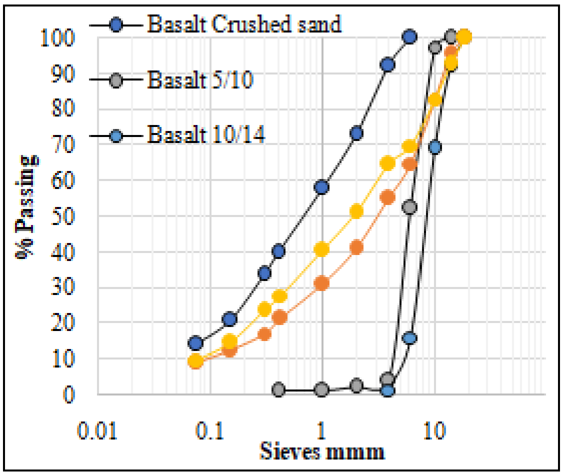

Figure 2: Theoretical mixtures F2 and F3

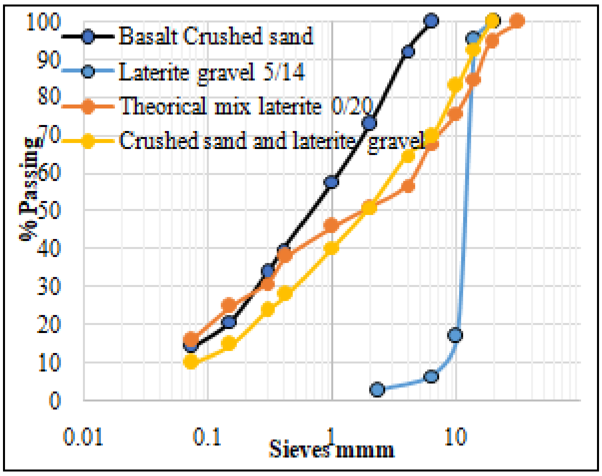

Figure 3: Theoretical mixtures F1 and F2

The particle size analysis shows us well spread compositions. The continuous nature of these granular skeletons gives them good characteristics with regards to their performance with the modified bitumen.

3. Chemical composition of the binder

3.1 Use of recycled plastic waste as an additive to bitumen

3.1.1 General overview of plastic waste

Global plastic production has increased by more than 500% in the past 30 years. In Senegal, the report on the direct import of plastics and plastic products made available by the Senegalese Customs shows that between 2010 and 2013, more than 5 billion CFA francs were spent on the import of plastic products. This represents 5,553 tonnes of plastics. Plastic waste pollutes nature, depletes the soil and prevents plants from growing. Worse, they harm both human and animal health [4].

Negative health impacts

Plastic packaging bags are indeed considered to be very polluting and harmful to health, from use to incineration. The smoke from the incineration of plastic bags contains dioxins that attack the lungs or hormones which can cause cancer and birth defects in new-borns.

Negative environmental impacts

The United Nations Environment Program (UNEP) established in its annual report in 2011 that more than 260 species have been trapped in, or ingested, waste. A recent study of fish that eat plankton from the North Pacific found that each of them had swallowed an average of 2.1 plastic objects. Plastic garbage kills over 1.5 million seabirds, as well as over 100,000 marine mammals each year.

They also have a negative impact on the oceans. According to Greenpeace, of the 100 million tonnes of plastic produced each year, almost 10% ends up in the oceans. And 70% of plastics sink into the sea while the rest sails according to the currents [4].

3.1.2 Method for preparing hard bitumen class 20/30 (modified bitumen)

Method 1: The preparation of the new bituminous binder consistedof first melting, at around 300°C, the plastic bags in a suitable metal container. The liquid obtained was then cooled in ambient air (temperature: 30°C, relative humidity: 75%), then the resulting solid finely ground into powder passing a 0.150mm sieve. The powder will then be added to the bitumen at a minimum temperature of 140°C.

Method 2: it involves heating the bitumen to around 175°C and drowning the plastic waste in the binder.

3.2 Effect of molten plastic on bitumen

Molten plastic has a great affinity for bitumen resins and aromatics; which increases the lifespan of the maltenes. The bitumen aging phase begins with the transformation of the maltenes into asphaltenes which will lead to hardening and embrittlement of the binder. The process ends with the oxidation of the asphaltenes which will cause a loss of flexibility [6]. This new type of binder obtained was analysed to determine the following physical-mechanical properties: the penetrability, the softening point, measurement of the adhesivity of Riedel and Weber [6][9].

3.3 Preparation of modified bitumen

Four formulas were prepared by adding plastic powder to the binder with respective percentages: 5, 10, 15 and 20%. The mass composition of the binder is given in Table 2.

Table 2: Proportions of molten plastic waste in the bitumen 50/70

Weight of binder (g)	100			
Mix	L1	L2	L3	L4
Percentageof molten plastic in the bitumen	5%	10%	15%	20%
Weight of molten plastic in the bitumen (g)	5	10	15	20

The following tests were carried out on these mixes: the penetration, the softening point and the adhesivity of Riedel and Webber.

3.3.1 Penetration test on modified bitumen

The penetration test is carried out in accordance with the procedure outlined in NF EN-1426. It consists of releasing, for 5s, a standard needle with a diameter of 1.0mm, under a load of 100g and then measuring, how many tenths of a millimetre, it sinks into the cooled bitumen being previously immersed in water kept at a temperature of 25°C and taken out just for the test. This parameter is used to define the class of bitumen. The test bitumen, the class of which is determined a priori to be 50/70, was first tested alone in order to serve as a reference. The same tests were then carried out on the four modified bitumen samples L1, L2, L3 and L4; made up of different proportions of plastic powder. The results obtained are listed in Table 3[5].

Table 3: Penetration results of modified bitumen

Binder	Molten Plastic content	Test 1 mm	Test 2 mm	Test 3 mm	Range of values	Average	Classes
L0	0	58	61	61	58-60	60	50-70
L1	5%	48	47	47	48-50	48	40-60
L2	10%	44	45	42	42-50	44	35-50
L3	15%	27	28	26	25-30	27	20-30
L4	20%	20	18	18	18-20	19	NA

The penetration values obtained show that the addition of plastic powder to the bitumen has the effect of decreasing the values, which causes bitumen to harden. Indeed, the expression of the values obtained and translated into ranges of values, average of the values and the classes of membership, the most relevant chosen amongst the nine classes of bitumen defined by EN 1426, made it possible to categorize the different mixtures. The binders L2 and L3 are respectively categorized into class 35-50 and 20-30 and are intended for bitumen macadam and high modulus asphalt [5].

3.3.2 Softening point of modified bitumen

With the softening point of the reference bitumen (class 50/70) being known (standard NF EN 1427), it was sampled, treated and initially tested for reference purposes. Then, the values for the four bituminous binders previously constituted according to the different powder contents mentioned above were determined. The equipment used for this purpose is that prescribed by standard NF EN 1427 [6]. The results obtained are given in table 4.

Table 4: Softening point of modified bitumen

Modified bitumen	Softening point			
Mixes	Test 1	Test 2	Test 3	Average
L0	42	43	42.5	42.5
L1	44	43	43.5	43.5
L2	45	43	44	44
L3	51	50	50.5	50.5
L4	>110	>110	>110	

According to the standard EN1427 the admissible temperature range is 46-56. According to the results, only the binder L3 is in the range of values of modified bitumen 20-30. The binders L0, L1 and L2 have low values for the bitumen macadam mix design. The binder L4 has temperatures close to the light point of glycol, which is why it cannot be considered.

3.3.3 The adhesivity of Riedel and Weber

Riedel and Weber's test is correspondent to the procedure outlined in standard NFT 66-018. It consists of immersing pellets of 0.50g of binder and crushed sand in solutions of sodium carbonate, of increasing concentrations, and evaluating the degrees of separation of binder-aggregate i.e. the stripping. The aqueous solution of Sodium carbonate (Na_2CO_3) is prepared in five concentrations (S0 …… S4) which are: 0g/l; 0.414g/l; 0.828g/l; 1.656g/l; 3.312g /l. When the stripping begins at a certain concentration, on a given sample and is completed at another concentration with another solution, the score combines the two solutions corresponding to the concentrations of the partial stripping and the complete stripping. Thus, for example, the score 3-5 means that the stripping started with solution S3 (1.656g/L) and was completed with solution S5 (6.625g/L). According to the provisions of the standard, the final scores of 1, 2, 3 and 4 indicate that the binder has sufficient adhesivity, those 5, 6, 7, 8, 9 and 10, good and very good adhesivity. The specifications for each asphalting project clearly specify the required rating. The 50/70 control bitumen was first tested, then the different variants of bituminous binders resulting from the incorporation of the contents of plastic powder mentioned [7]. The measured values are shown in Table 5.

Table 5: Values of the adhesion ratings in relation to the plastic waste content

Modified bitumen	**L0**	**L1**	**L2**	**L3**	**L4**
Coating values	2-6	2-7	5-9	5-10	9-10

The more concentrated the solution, the more aggressive it becomes. The solution S2 has triggered the phenomenon of stripping mixtures with the binders L0 and L1. The mixtures with the binders L2 and L3 show very good resistance to the phenomenon of stripping and coating.

The different types of macadam mix design studied

The three types studied are:

a) F1: composed of 100% lateritic gravel, modified bitumen of class 20/30.
b) F2: composed of 40% basalt sand, 60% lateritic gravel 5/20 and modified bitumen of class 20/30.
c) F3: composed of 100% basalt aggregate

4.1 The Marshall Test

In this method, the resistance to plastic deformation of a compacted cylindrical sample of bituminous mixture is measured when the sample is loaded diametrically at a deformation rate of 50mm per minute. The Marshall method has two main characteristics: density-void analysis, stability and creep tests. The Marshall stability of the mixture is defined as the maximum load supported by the sample at a standard test temperature of 60°C. The flow rate value is the deformation undergone by the test piece during loading up to the maximum load. The flow is measured in 0.25mm units. In this test, an attempt is made to obtain an optimal binder content for the type of aggregate mixture used and the expected traffic intensity [9][10]. The results are summarized in Table 6.

Paper ID: SR20421232155 DOI: 10.21275/SR20421232155

Table 6: Marshall test results

Criteria	Mixes	5	5.5	6	6.5	7	Technical Specifications of Bitumen MACADAM
Stability (kg)	F1	1120	1248	1310	1336	1412	>1000 kg
	F2	1270	1353	1450	1500	1475	
	F3	1800	1904	2135	2274	2301	
Flow (mm)	F1	2.00	2.77	3.00	3.12	3.33	2 - 4
	F2	1.90	2.90	3.15	3.80	4.00	
	F3	1.80	2.20	3.20	3.94	4.15	
Specific gravity (g/cm^3)	F1	2.000	2.017	2.170	2.181	2.130	
	F2	2.360	2.480	2.520	2.600	2.550	
	F3	2.610	2.650	2.720	2.740	2.710	
GMM (g/cm^3)	F1	2.26	2.288	2.281	2.273	2.258	
	F2	2.51	2.63	2.783	2.78	2.72	
	F3	2.81	2.88	2.96	2.965	2.961	
Compaction	F1	88%	88%	95%	96%	94%	88%>C> 93%
	F2	94%	94%	91%	94%	94%	
	F3	93%	92%	92%	92%	92%	
Voids %	F1	12.0%	11.8%	9.0%	7.0%	4.0%	4 - 9
	F2	12.0%	11.5%	8.5%	6.5%	6.0%	
	F3	8.2%	7.4%	7.2%	5.5%	4.2%	
VAM (%)	F1	27	22	20	18	17	>15
	F2	20	22	17	17	16	
	F3	15	17.8	18.1	18.4	18.9	
VFA (%)	F1	62	67	77	79	80	65 - 75
	F2	55	56	65	75	83	
	F3	52	61	76	78	85	

The results obtained compared to the technical specifications show a general trend with regard to the optimal bitumen content.

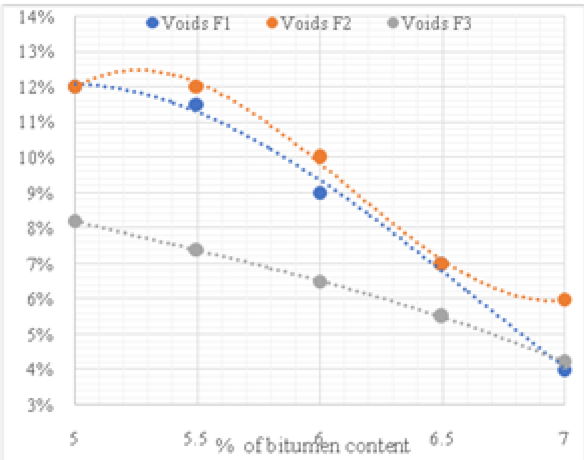

Figure 4: Evolution of voids in the three mixes content of flows in relation to bitumen content

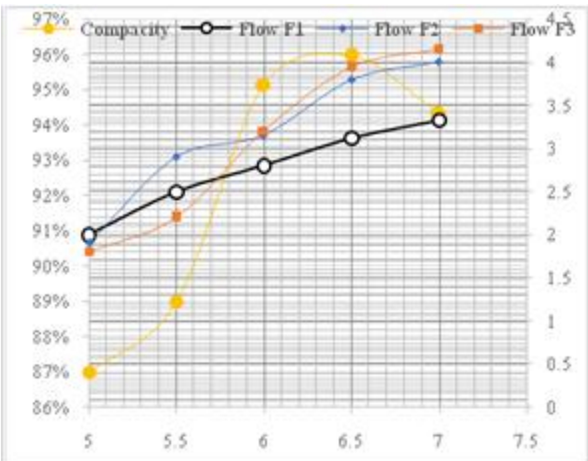

Figure 5: Variation in average compaction of in relation to bitumen

The stability values obtained are greater than the minimum of 1000kg indicated in the technical specifications.

Figure 3 shows that the increase in modified bitumen is inversely proportional to the void percentages. If we reconcile the range of values 4-9 for the percentage of voids in the bitumen macadam, we can define a first interval of modified bitumen percentage, for F1. F2 and F3, which is [6%, 7%].

Figure 4 shows an optimal binder content in the range of values [5.5; 6.5].

4.2 The Duriez test

This consists in determining the stability of a mixture (aggregates and bitumen whose optimum content is defined by the Marshall test) which is subjected to pressure. It is a question of determining, for a given compaction, the compressive strength of a test piece of bituminous concrete of known mass and section. It also makes it possible to define the water resistance of bituminous concrete by the ratio of the compressive strengths with or without immersion of the test piece [11]. The results obtained are listed in Table 6.

Table 6: r/R Ratio of bitumen macadam F1, F2 and F3.

Mixes	Compressive strength after 7 days curing in water at 18 degrees Celsius r(MPa)	Compressive strength after 7 days curing in air at 18 degrees Celsius r(MPa)	r/R
F1	4	5.71	0.67
F2	5.50	8.50	0.65
F3	6.00	7.40	0.81

The values of r/R are more than 0.65 which shows good water resistance for samples F1, F2 and F3.

4.3 Diametric compression

This test is of primary importance in this study because it allows the classification of the formulations according to the different types of bitumen macadam BM1, BM2 and BM3 or the types of asphalt with high modulus EME1, EME2; according to the calculated modules [12]. From the Frocht 1948 approach, it was established Ex = (P (ν + 0.27)) / (ΔH.h). The calculated modules made it possible to draw the graphs below:

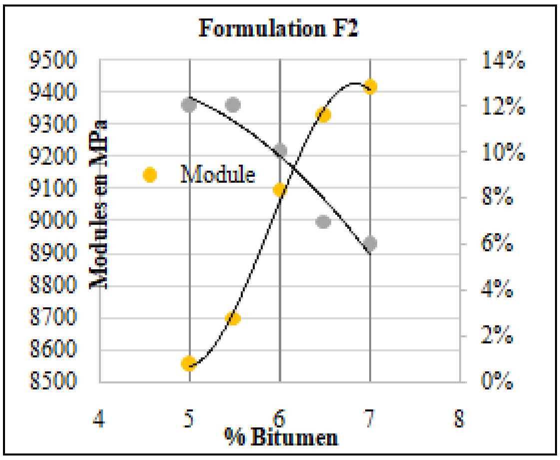

Figure 6 : Intersection of the module and voids in relation to bitumen content in F1

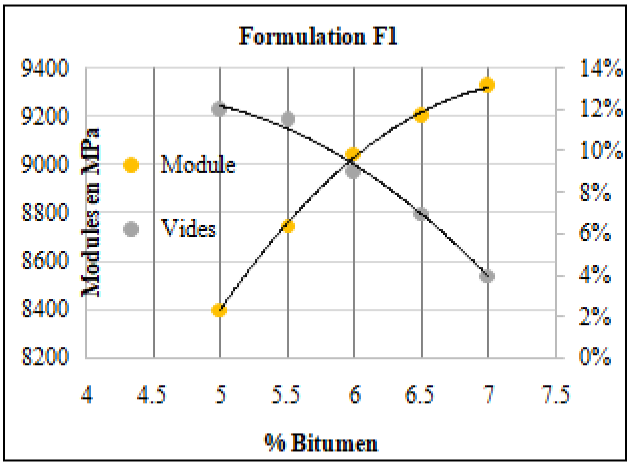

Figure 7 : Intersection of the module and voids in relation to bitumen content in F2

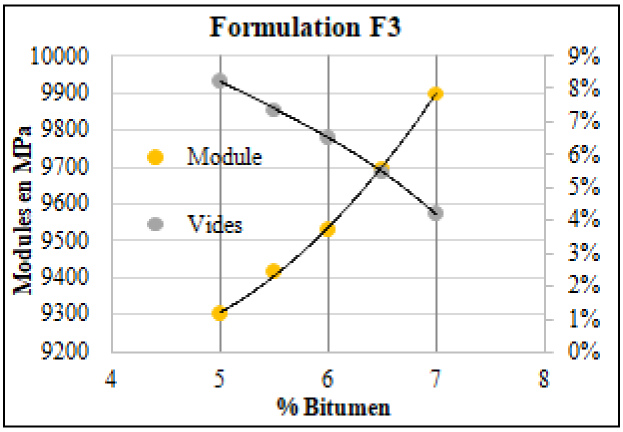

Figure 8 : Intersection of the module and voids in relation to bitumen content in F3

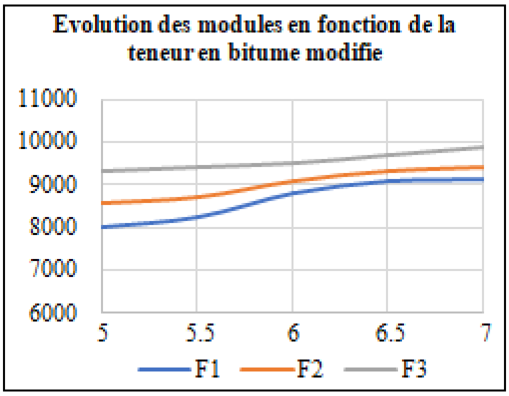

Figure 9 Variation in modules in relation to bitumen content in F1, F2 and F3

Analysis of the data made it possible to locate the formulas F1, F2 and F3 in the typical profiles of the bitumen macadam group.

FIGS. 5, 6 and 7 show the same trend of progression of the modules and regression of the voids of the formulas F1, F2 and F3 in relation to the bitumen content.

Formula F1: the intersection point of the two variables satisfies the conditions for bitumen macadam with the optimal modified bitumen content of 6.0%, which corresponds to a module = 9030MPa, and voids = 9%.

FIG. 6, of formula F2, shows a displacement of the secant point at the optimum binder content of 6.2%.

In formula F3 the secant point moves to the optimal binder content of 6.5%

Analysis of the data made it possible to locate the formulas F1, F2 and F3 in the typical profiles of the bitumen macadam group.

a) Formula F1 has the characteristics of BM4 grade bitumen, which are:

- Classic granular skeleton,
- The formula of 0/20 is maintained
- The bitumen is modified using an additive (plastic waste powder)
- The increase in dosage of the binder from 4.5 to 6%.
- The percentage of voids is within the range 7-10
- The r / R ratio ≥ 0.7

For its application a minimum thickness of 11cm is necessary to better respond to the increase in traffic demand.

b) The F2 formula has three differences from F1:

- The r / R ratio ≥ 0.65,
- The percentage of voids is within the range 7-9,
- The increase in dosage of the binder went from 4.5 to 6.2%.

It corresponds to the bitumen macadam of class BM2. The use of F2 requires a minimum thickness of 10cm.

c. The F3 formula is very simulative with the bitumen macadam BM3. The r / R ratio is greater than 0.7, the skeleton is 0/14. It is much denser and has a strong resistance to rutting. The minimum thickness reduces to 7-8cm.

4. Conclusion

The objective of this experimental study is to value plastic waste by using it as an additive for modified bitumen and evaluating the performance of bitumen macadam produced with lateritic gravel. The standardized geotechnical tests were carried out at the laboratories of the Compagnie Sahelienne d'Entreprises and Unixs.

The idea of adding molten plastic powder to the bitumen makes it possible to increase the binding strength of the maltenes, which will delay the aging phase of the binder. Adding 15% of plastic powder melted in the 50/70 bitumen allowed us to manufacture a modified binder which meets the technical criteria of the bitumen class from 20 to 30.

The results highlighted an evolution of the bitumen macadam. Bitumen contents are higher and higher (go from 4.5% to 6% in formula F1, 6.2% in formula F2 and 6.5% in formula F3).

In formulations F1 and F2, where two types of asphalt mixes of BM4 and BM2 were manufactured respectively, it appears clear that the lateritic gravels have alternative performance to Diack basalt.

In the F3 formula we noted an improvement in performance, regularity and a decrease in thickness. These developments give the BM3 more ability to provide better responses to the increase in traffic demands.

With the results obtained, we can conclude that the use of formulas F1 and F2 is of crucial environmental and economic importance in road infrastructure projects in provinces.

References

[1] AFNOR, norme NF EN 12597, Bitumes et liants bitumineux – Terminologie, 2002.
[2] Lemoine (1988) Orogenic Processes in West Africa.
[3] AFNOR, norme NF EN 12591, Bitumes et liants bitumineux – Spécifications des bitumes routiers, 2009.
[4] Boussingault J.B., Mémoire sur la composition des bitumes, Annales de Chimie Physique, 1837, 64, p. 141.
[5] Leroy G., Bitumen analysis by thin layer chromatography (IATROSCAN), Proceedings 4th Eurobitume Congress, 1989, p. 166.
[6] Such C., Francken L., Lesage J., Les matériaux de chaussées traités aux liants hydrocarbonés, Les liants hydrocarbonés, Hermes Science, 2002.
[7] Koot J.A., Speight J.G., Relation of petroleum resins to asphaltenes, Fuel, 1975, 54, p. 179.
[8] Massamba NIDAYE, I K CISSE, 2013 Etude de l'amélioration de la laterite du Sénégal par ajout de sable, BLPC n 280-281, p123 – p137 novembre 20132
[9] Yen T.F., Structural differences between asphaltenes isolated from petroleum and from coal liquid, Adv. Chem., 1982, 195, p. 39.
[10] Pfeiffer J.P., Saal R.N.J., Asphaltic bitumen as colloid systems, J. Phys. Chem., 1939, 43, p. 139.
[11] Traxler C., Rheology and rheological modifiers others than elastomers: structure and time, Bituminous materials: Asphalts, Tar and Pitches, A.J. Hoiberg (ed.), 1964, 1, p. 143-211.
[12] Nellensteyn F.J., The constitution of asphalt, Journal of the Institute of Petroleum Technology, 1924, 10, p. 311. [11] Lesueur D., The colloidal structure of bitumen: Consequences on the rheology and on the mechanisms of bitumen modification, Adv. Colloid Interface Sci., 2009, 145, p. 42.