IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 22, Issue 2 Ser. 3 (Mar. – Apr. 2025), PP 01-11
www.iosrjournals.org

Formulation Of Anti-Rutting Asphalt Concrete With Recycled Wastes Bottles For Road Pavement

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Abstract
This paper focused on the effect of the addition of polyethylenes on the behaviour of bituminous concretes. A methodology for the formulation and mechanical characterization of asphalt concrete modified by using the addition of recycled wastes plastics (mineral drink preservation bottles) were investigated. Different binder content was performed in order to determine the optimal value with the Marshall test. Afterwards, Thus, for a given granular composition, we have for a given granular composition, varied the binder content in order to determine the content giving the optimal performance in the Marshall test. With this binder content, we varied the polyethylene content and evaluated the characteristics using the Duriez, Marshall. On the basis of the mechanical properties obtained, software simulations were carried out to determine the behaviour of the formulated materials. The obtained results with modified asphalt concrete showed that it has a real advantage over conventional asphalt mixes. At a content of 0.7%, plastics allow a gain in stiffness of around 54%. They improve the water resistance of the asphalt and reduce the vertical stresses in the structural layers responsible for the appearance of ruts. This reduction would thus make it possible to achieve financial savings.
Background*: The presence of plastic waste in nature often has negative socio-economic and environmental effects. As plastic is a petroleum by-product, just like bitumen, which is not produced in sub-Saharan Africa, it would be much wiser to study the feasibility of substituting bitumen with plastic, and to investigate the mechanical behavior of asphalt concrete modified with recycled plastic using the Duriez and Marshall tests. And above all, to see whether this new modified asphalt concrete could be a lasting solution to the rutting phenomena encountered on our pavements.*
Materials and Methods*: The aim of this research was to determine the optimum value for the substitution of bitumen by plastic. Secondly, the optimum value was used for the realization of modified asphalt concrete specimens. Finally, the mechanical behavior of the specimens was studied using MARSHALL tests. A numerical simulation was also carried out using Alize software to compare the vertical stress values on reference asphalt concretes and those modified with recycled plastic.*
Results*: Au regard des resultats obtenus dans cette investigation, on observe que la substitution partielle du bitumen par le plastic fondu a amélioré les propriétes mécaniques des bétons bitumineux modifies en comparaison aux bétons bitumineux de reference. On observe une augmentation de la résistance mono axiale vec ou sans immersion, une augmentation de la compacité et de la tenue à l'eau par rapport aux bétons bitumineaux de reference.*
Conclusion: *This investigation has shown that molten plastic can be a serious alternative for combating rutting phenomena in sub-Saharan African pavements, which are sometimes heavily overloaded.*
Key Word: *Bottles wastes, Marshall tests, modelling, road pavement, vertical stress*

Date of Submission: 01-04-2025 Date of Acceptance: 11-04-2025

I. Introduction

Faced with the increase in road traffic, the change in vehicle silhouette and the increase in overloads, the traditional materials used in road construction are behaving less and less satisfactorily because they are being stressed beyond their limits. It is therefore necessary to improve these materials. In Cameroon, bitumen is an expensive road construction material [1]. Bitumen is not manufactured in Cameroon, so there is a real problem of bitumen availability in Cameroon. Decentralization in Cameroon implies that roads, apart from main roads and highway roads, are managed by the mayors of the different administrative districts. Each town hall will therefore have to supply itself from the means at its disposal, materials including bitumen. All these problems cited led us to reflect on the hypothesis of substitution of bitumen by another material.

Plastics are massively present in our daily lives and are practically used in all branches of industry. They are used as raw materials to produce a variety of products such as plastic cups, bottles, household items, plastic storage containers, pipes, etc. Nevertheless, these products eventually become waste and cause serious environmental problems. In Cameroon, 600,000 tons of plastic waste are produced per year. A quantity so large that plastic waste now affects only the mainland but also the river and maritime environments [2].

Given that plastic and bitumen both derive from oil and that plastic, if considered as a material, is very available and very inexpensive, the question arises as to whether plastic could substitute bitumen as a building material.

As asphalt mixes are the most widely used in road construction, it is therefore important to think about mechanisms to improve their behaviour and to provide pavements with materials capable of coping with the increased stresses. This improvement could be achieved by adding polymer to the bituminous mix. Polyethylene is a constituent polymer of most plastics. The addition of polyethylene to asphalt mixes reduces the thermal susceptibility of these materials to high temperatures by increasing the viscosity and developing the elasticity of the binder [3]. Also, we are witnessing an increase in the rigidity of the intermolecular bonds of the binder increasing the adhesion with the aggregates

Others before us have looked at the issue of partial bitumen substitution. There are Serkan and Al, having worked on the Prediction of the Marshall result for dense bituminous mixtures modified by polypropylene using neural networks, allowed us to realize by their that the hypothesis of dense bituminous mixture modified by polypropylene is possible [4].The challenge for us will be to know if the substitution of bitumen by a bitumen-polyethylene mixture can therefore be a solution to the single use of bitumen. Duarte and Al have been part of this scientific challenge twice. First, because of his research on the high-temperature rheological properties of asphalt binders modified with recycled low-density polyethylene and crumb rubber [5]. Then about bituminous concrete mixtures modified with polymer waste by wet and dry processes [2].

Through this work, we propose to study the effect of the addition of polyethylene in the form of recycled plastics (bottles for the conservation of mineral drinks) in the formulation of bituminous concretes on their behaviour. It will be a question of formulating a modified bituminous concrete. The results of this formulation will be completed by a numerical simulation of the behaviour of the material thus formulated in order to determine the contribution of this addition in the fight against permanent deformation.

II. Material And Methods

Materials

Bitumen

Regarding the characteristics of bitumen reported in Table 1, the bitumen is used in this investigation is classified as 50/70 grade bitumen. [7, 8, 9]

Table 1: Bitumen identification

Tests	Results	Observations
Penetration at 25°C (1/10 mm)	53	Conform
Relative density at 25°C (t/m^3)	1,02	Conform
Softening point ball ring (°C)	49,6	Conform

Aggregates

Three granular fractions of aggregates were selected for the formulation of asphalt mixes: sand 0/4 mm and two types of gravels (4/6.3 mm and 6.3/10 mm). The physical and mechanical properties are reported in Table 2 [10, 11, 12, 13].

Table 2. Physical and mechanical parameters of aggregates [10, 11, 12, 13].

Tests	0/4	4/6,3	6,3/10
Specific weight (t/m^3)	2.75	2.79	2.79
Surface cleanliness (%)	-	3.0	6.9
Apparent density (T/m^3)	1.68	1.52	1.51
Los Angeles (%)	-	14.1	15.5
Wet Micro Deval (%)	-	11.6	14.2

The grain distribution curves of selected aggregates are reported in Fig.1.

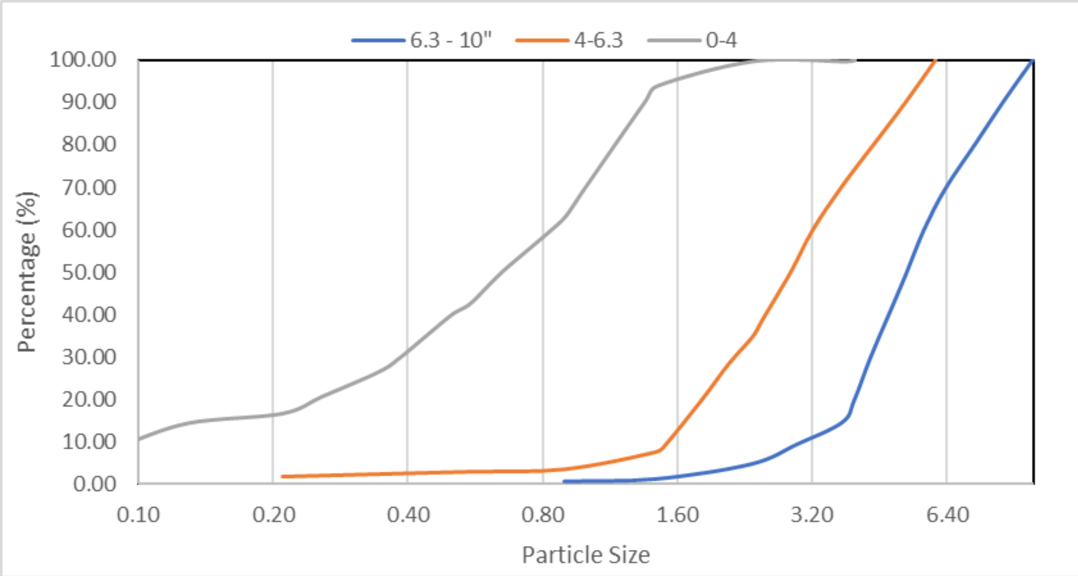

Figure 1: Particle size distribution curves of selected aggregates.

Methods
Asphalt concrete formulation
Granular composition

The aim was to reconstitute an optimal grading curve 0/10 with the three selected grading classes (0/4; 4/6.3 and 6.3/10) which must be included in the specification zone prescribed by the CEBTP's guide to pavement design in tropical countries. Using the algorithm of the French mathematical method for calculating the proportions of the granular fractions shown the following results:

- 53 % of crushed sand 0/4 mm
- 14% of crushed gravel 4/6.3 mm
- 33% of crushed gravel 6.3/10 mm

The different proportions of aggregate produced an optimum granular curve of mixture that is reported in Figure 2. The upper and lower limit are the specification zone that prescribed by CEBTP’s guidance for pavement design in developing countries.

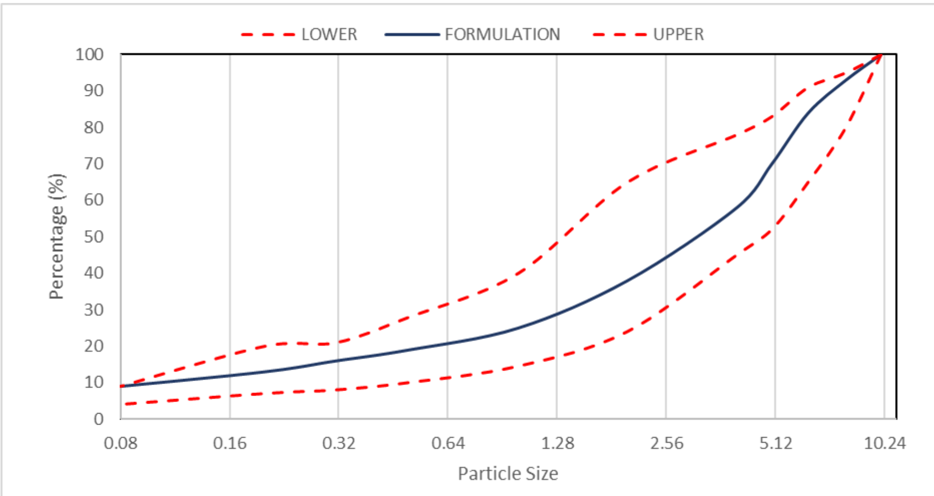

Figure 1: Granular curve of mixes aggregates

Optimum binder content

In order to ensure excellent cohesion between the aggregates, a binder content must be defined and was expressed according to equation 1:

$T_L = \boldsymbol{\alpha}.K^5\Sigma^{1/2}$ (1)

T_L : binder content

- α : factor that take into consideration the specific density of aggregates equal to
- α = 2.65/ specific density of aggregates
- K : Wealth Module equal to 3.3
- Σ : specific surface area of the aggregates assimilated to sphere,
- Σ = 0.25G (> 6.3 mm) + 2.3S (6.3 mm – 0.315 mm) + 12s (0.315 – 0.08 mm) + 135F (<0.08 mm)

After determining the calculated binder content (Eq 1), it was a question of varying this value in order to find the optimal one for this research. Then, three binder contents were selected in this investigation: 5.2%, 5.4% and 5.6%.

Formulation of modified asphalt concrete

The unmodified asphalt concrete specimens were produced with the three selected binder contents. Marshall Tests were performed on unmodified asphalt concrete specimen on each binder content in order to determine the optimum value. Three performance criteria were retained: compactness, stability and creep. The binder content that offers the best performance according to these three criteria will be used for the production of modified asphalt concrete.

The modified asphalt concretes were manufactured as follows. The plastic bottles were collected and heated to a temperature of 245°C (melting temperature). Then, molten plastic materials were introduced into the tank containing binder and aggregates (during mixing).

Three types of formulations were performed: a reference specimen of asphalt concrete (without recycled plastic materials) and two modified specimen asphalt concrete containing respectively 0.5% and 0.7% of molten waste plastic. The ration substitution was investigated by weight proportion of the bitumen.

Mechanical characterization of sampled asphalt concrete

The mechanical characterization of selected specimen concrete was performed through Duriez tests and Marshall tests.

- *Duriez Test*

The Duriez test was carried out in accordance to the French legislation NF P 98-251-4 [14]. This test is aiming to determine the water resistance of asphalt mix. The hydrocarbon mixture is compressed in a cylindrical mould by double acting static pressure (Fc = 60kN) within 5 minutes. A type of the specimens is kept without immersion at controlled temperature (18°C) and constant hygrometry and the second type part is kept immersed for 7 days. Uniaxial compressive strength are performed on each set of specimens. The ratio of the resistance after immersion to the dry resistance (r/R) gives the water resistance of the mixture that must be greater than 0.75 in accordance to the specifications of the manual for pavement design in developing countries. The samples produced are shown in Figure 3

Figure 3: Specimens of Duriez tests

- *Marshall Test*

The Marshall test was performed in accordance to the EN 12697-34 [15]. The specimens are manufactured by compacting the material with applying shocks generated by standard weight and height on both sides (50 shots). Afterwards, specimens are immersed for 30 to 40 minutes in a water bath maintained at a temperature of 60±1°C before the compression test. For each specimen, the tensile strength (stability) P (KN) and creep f (mm) are recorded. The samples tests are shown in Figure 4

Figure 4: Specimens Marshall tests

Numerical modelling

A comparative analysis was carried out on the mechanical behaviour of two pavement layer structures: normal asphalt concrete (0% of recycled waste bottles) and modified asphalt concrete (0.7% of recycled waste bottles). This numerical simulation was carried out using ALIZE 3.0 software. The parameters below were calculated:

- The vertical deformation above the platform that limit value is given by the relationship $\boldsymbol{\varepsilon_{Zadm}} = \boldsymbol{A} \times (\boldsymbol{NE})^{-0,222}$
- The vertical stress at the top of the structural layers that is expressed by the relationship $\boldsymbol{\sigma_{zadm}} = \frac{0,3 \times CBR}{1+0,7 \times \log NE}$
- Vertical deformations above the base layer and the foundation layer respectively $\boldsymbol{\varepsilon_1}$ and $\boldsymbol{\varepsilon_2}$.

The simulation hypothesis is exposed as follows:

A pavement consisting of an asphalt concrete wearing course (6 cm), an untreated crushed gravel base course (20 cm), an untreated lateritic gravel sub-base course (30 cm) and a supporting soil of variable quality (classes S2, S3, S4 and S5) and assumed infinite thickness was chosen. The road pavement is assumed to be loaded a traffic with an equivalent number of axles of 13 T.

III. Results And Discussion

Optimum binder content

The results of the Marshall tests are shown in Figures 5, 6 and 7.

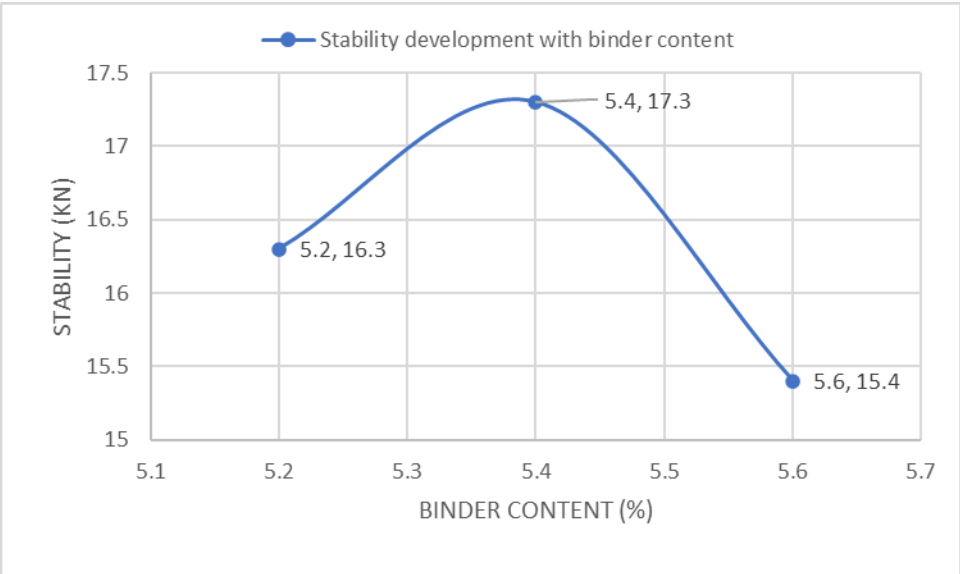

Figure 5: Stability development with binder content

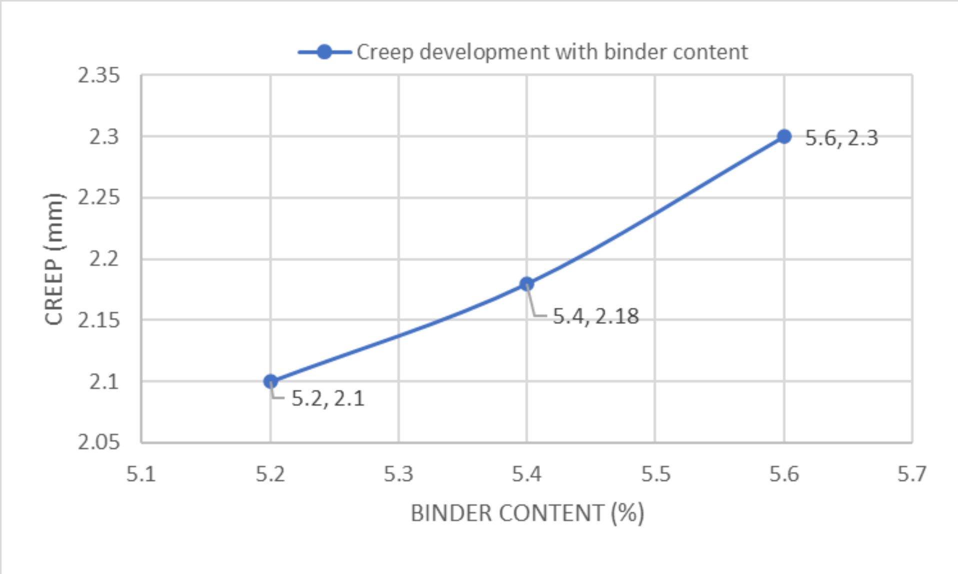

Figure 6: Creep development with binder content

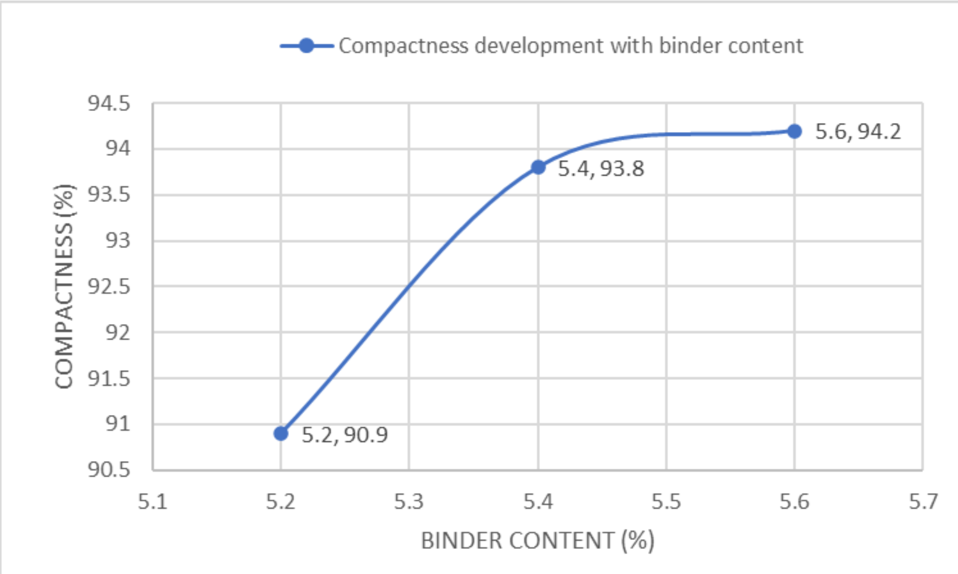

Figure 7: Evolution of compactness with binder content

The grades of binder offering the best performance in relation to the above-mentioned criteria are given in Table 4.

Table 4: Content of best performing binders

Selection criterion	Stability **(KN)**	Creep **(mm)**	Compactness **(%)**
Optimal performance	17,3	2,30	94,2
Corresponding TL	5,4	5,6	5,6

We have therefore retained the value of 5,6 % for the binder content. For this binder content, the performance values for each criterion are: Stability: 15.4 KN, Creep: 2.30 mm and Compactness: 94.18%.

Mechanical Characterization

For the selected binder content, Duriez tests, Marshall tests and single compression tests are carried out on asphalt mixes with different plastic contents. The retained additive contents are: 0%; 0.5% and 0.7%.

Duriez tests

The results of this test allow us to have the evolution of the simple compressive strength with and without immersion, as well as the compactness and water resistance according to the plastic content. These results are shown in figures 8, 9, 10 and11.

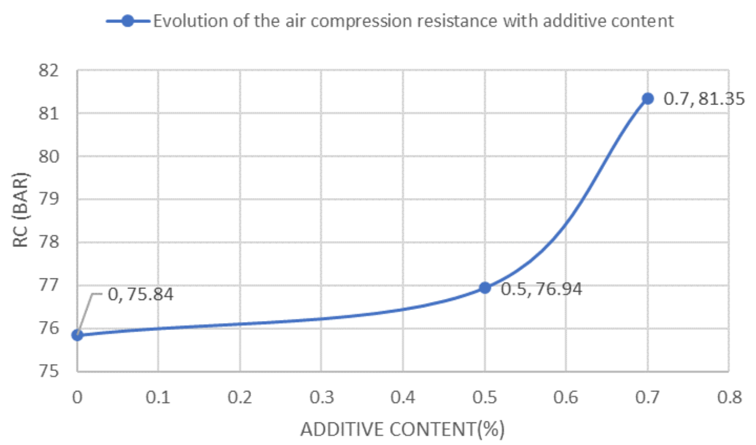

Figure 8: Evolution of the air compression resistance with additive content

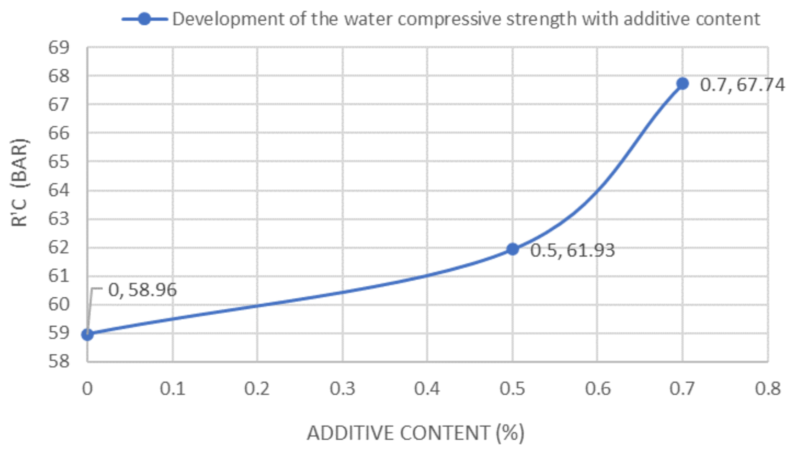

Figure 9: Development of the water compressive strength with additive content

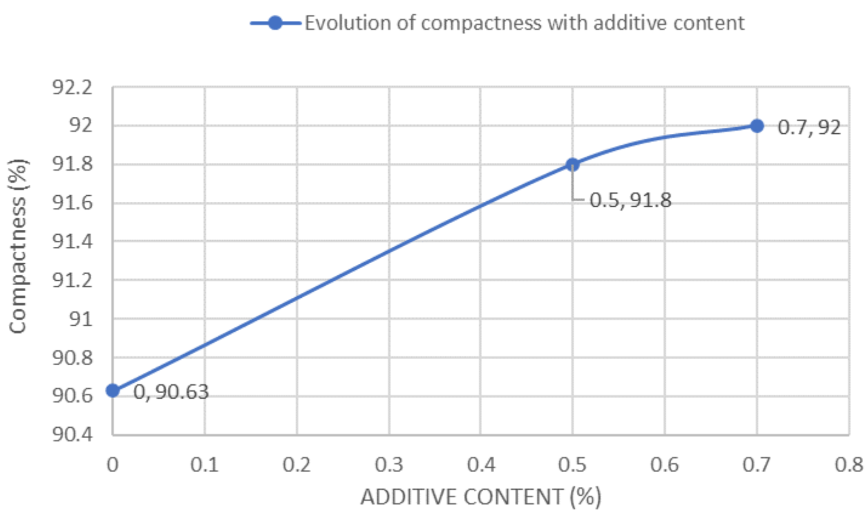

Figure 10: Evolution of compactness with additive content

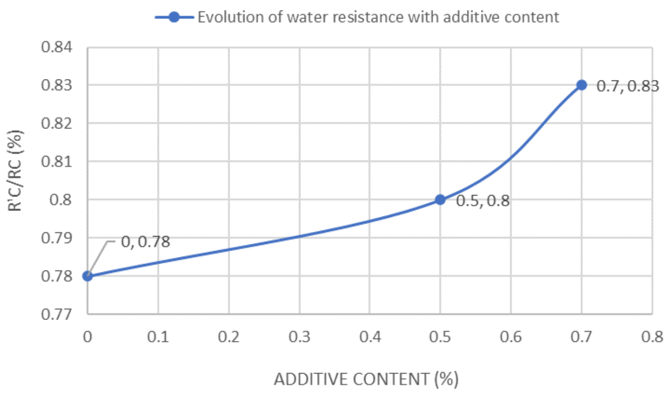

Figure 11: Evolution of water resistance with additive content

Regarding the results, the addition of plastics improves the water compressive strength, the air compression resistance, the compactness and water resistance. It is due to the fact that the polyethylene of the plastics limits the effect of water in the stripping of the aggregates from the mix. So, mechanical properties are increasing with the amount of polyethylene added.

Marshall tests

The Marshall study allows us to evaluate the stability, creep and compactness of asphalt mixes as a function of the plastic content.

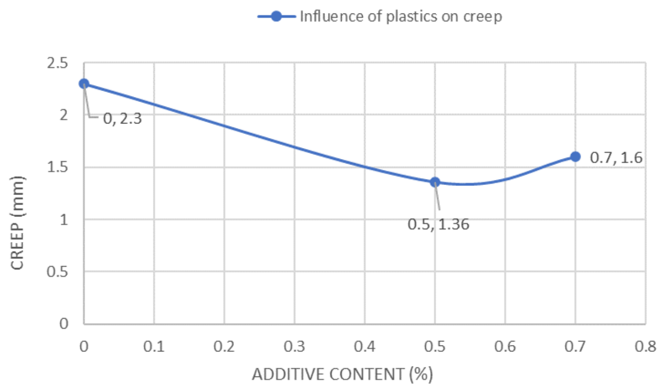

Figure 12: Influence of plastics on creep

Asphalt creep decreases with the addition of plastics to reach the minimum for the 0.5% content before rising again for 0.7% without reaching the creep value of normal asphalt.

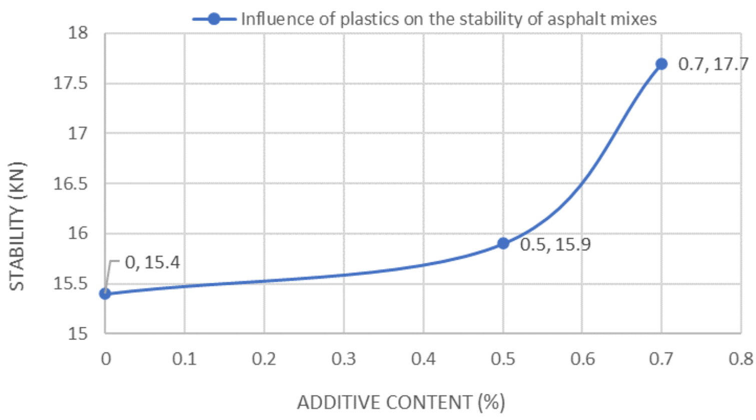

Figure 13: Influence of plastics on the stability of asphalt mixes

Marshall Stability follows a monotonous growth until it reaches the optimum at 0.7% plastic content.

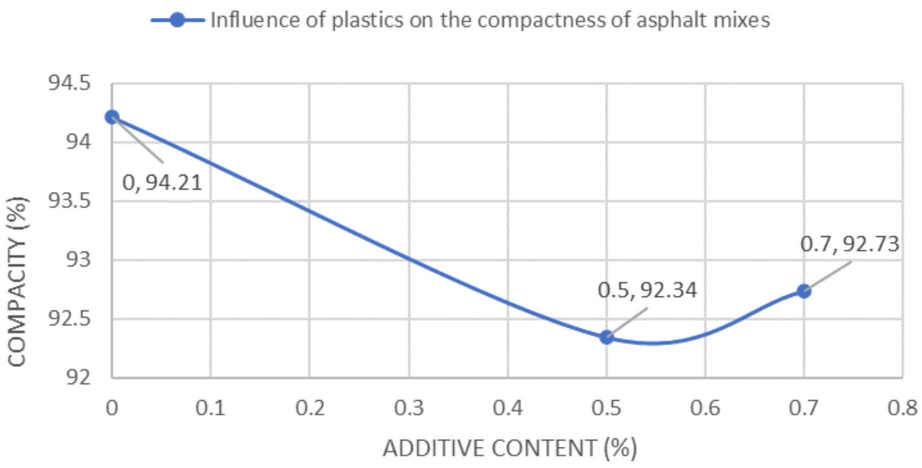

Figure 14: Influence of plastics on the compactness of asphalt mixes

The compactness presents a minimum for the 0.5% grade but rises just afterwards to reach 92.73% for the 0.7% grade.

Regarding fig. 12, 13 14, it can be observed that the addition of melted plastic improved the Marshall stability to the bituminous mixture, but the creep and compactness decreased with the increasing of plastic. Those obtained values remains acceptable and more interesting according to the prescriptions of the CEBTP guidelines.

Numerical modelling

The stresses within the structural layers are shown in figures 15, 16, 17 and 18.

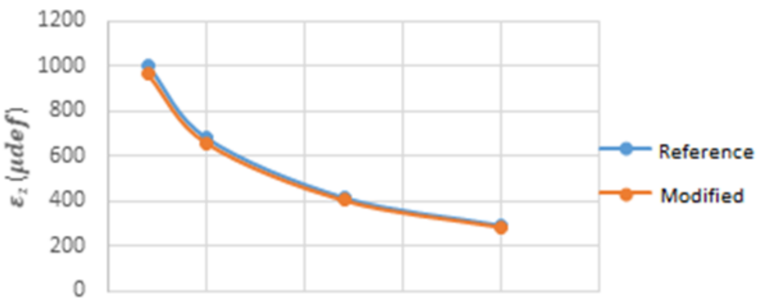

Figure 15: Vertical deformations above the platform

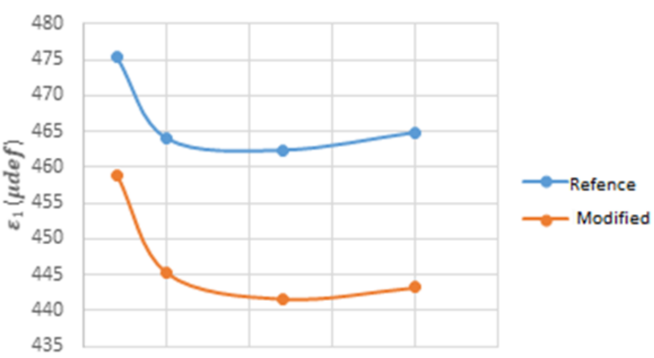

Figure 16: Vertical deformations above the base layer

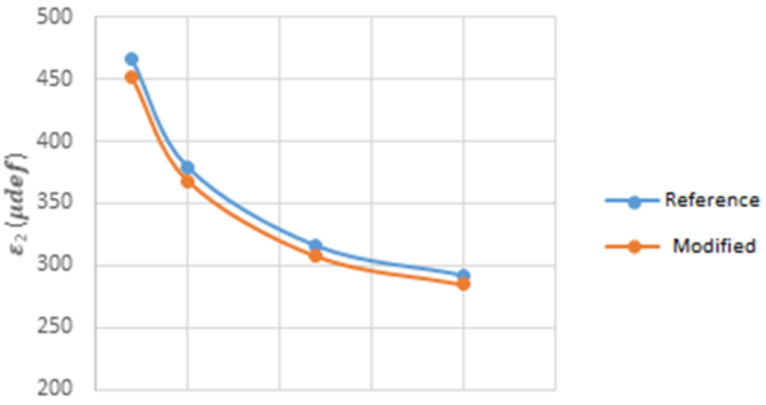

Figure 17: Vertical deformations above the foundation layer

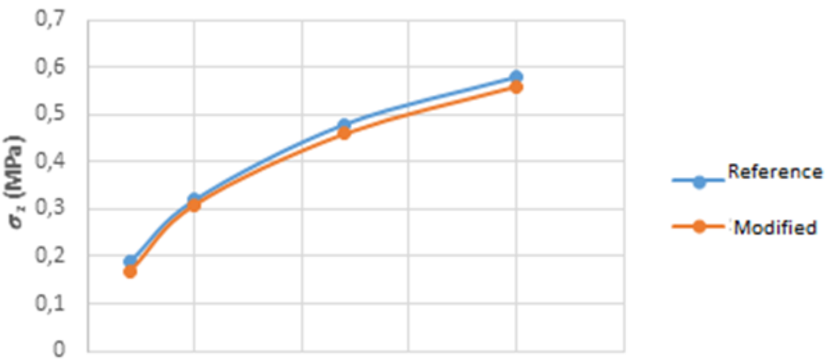

Figure 18: Vertical stresses above the platform

Regarding to the obtained results, the main observations made are as follows:

a) Vertical deformations and stresses within the structural layers and at the top of the platform are reduced with the use of the improved asphalt concrete in the wearing course. Also, we note that these stresses decrease with the increase in the bearing capacity of the platform's constituent material.

b) The stiffer the support platform, the less influence the quality of the wearing course has on the permanent vertical deformations at the base of the structural layers. Nevertheless, this influence is still perceptible.

c) The improved asphalt concrete partially fills the bearing defects of the support platform.

For each type of soil, the use of improved asphalt concrete reduces the vertical deformations in the underlying layers. This highlights the contribution of the plastic materials in terms of resistance to permanent vertical deformations in the structure and therefore rutting. Indeed, the rutting makes the pavement more rigid and therefore the pavement structure less susceptible to vertical deformation. Nevertheless, the higher the quality of the subgrade material, the greater the transverse deformations and the less the influence of the improved pavement layer in combating permanent deformation.

IV. Conclusion

This investigation focused on the effect of addition of polyethylenes on the mechanical behaviour of bituminous concretes. First of all, different binders content were performed through the Marshall test in order to determine the optimal value. Afterwards, three formulations were made: a reference asphalt concrete without additive, two asphalt concrete modified with 0.5 % and 0.7 % of bituminous substitution. Mechanical tests have been performed on samples through Marshall Tests. In addition, a numerical simulation was carried out on a reference pavement structure using Alize 3.0 software. This was followed by the simulation of a bituminous concrete pavement modified with 0.7% recycled plastic waste. Vertical stresses were calculated and compared in the two specimens tested. The main results obtained were as follows:

- - The optimum binder dosage is 5.6% for the production of reference and/or modified asphalt concretes, as it offers the best results in terms of gauge, Marshall stability and compactness;

- the addition of plastics improves the water compressive strength, the air compression resistance, the compactness and water resistance;
- Asphalt creep decreases with the addition of plastics to reach the minimum for the 0.5% content before rising again for 0.7% without reaching the creep value of normal asphalt.
- Marshall stability follows a monotonous growth until it reaches the optimum at 0.7% plastic content;
- The compactness presents a minimum for the 0.5% grade but rises just afterwards to reach 92.73% for the 0.7% grade;
- The improvement of water resistance of the asphalt and the reduction of the vertical stresses in the structural layers responsible for the appearance of ruts.

In conclusion, this investigation has shown that the substitution of bitumen by plastic waste has produced more than satisfactory results, and can therefore be a serious alternative for combating rutting on roads in sub-Saharan Africa.

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