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Study Of The Mechanical Behaviour Of 60/70 Bitumen And Semi-Gritty Asphalt Concrete Modified With Used Tyre Powder

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Abstract:
Background*: The aim of this work is to evaluate the possibility of improving the mechanical properties of modified bituminous concrete by partially replacing the bitumen with used tyre powder, the main component of which is synthetic rubber. The first step in this investigation was to improve the performance of a conventional class 60/70 bitumen using used tyre powder. Secondly, to formulate a semi coarse bituminous concrete (BBSG 0/10) with our modified binder. The aim was to highlight the mechanical behaviour of class 50/70 bitumen and semi-textured bituminous concrete (BBSG 10) formulated using the modified binder.*
Materials and Methods*: The materials used in this study are those used in the production of bituminous concrete, i.e. aggregates and bitumen. These traditional materials are supplemented by waste tyre powder obtained by crushing the used tyres. The working method consists of partially replacing the bitumen with the scrap tyre powder in a range from 0 to 25%. A semi-textured bituminous concrete was then formulated with each of the previously obtained binders. Finally, mechanical tests were carried out to characterise the new binders and the semi-textured asphalt concrete formulated with the new binders.*
Results*: At the end of the laboratory tests, the various results show that the new Poudrette bitumen binder obtained has a lower class than that of pure bitumen, and the semi-grained bituminous concrete formulated from this new binder has characteristics such as Marshall stability and resistance to water that are superior to that formulated from pure bitumen. Hence the interest in considering the partial replacement of bitumen by used tyre powder in road construction, particularly in areas of high stress such as weigh stations, weighbridges and crossroads.*
Key Word*: bitumen, used tyre powder, asphalt concrete.*

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I. Introduction

The proliferation of used tyre dumps throughout the world can only cause concern, dismay and consternation, not only for international organisations campaigning for the protection of the environment, but also for any citizen who is aware of the health and environmental dangers to which planet earth is exposed. Preserving the environment is a shared responsibility. This type of waste is both bulky and polluting [1]. Protecting the environment is a major concern. It is even a challenge for humanity, given the ever-increasing rate at which it is being destroyed. Governments in all countries, both developed and developing, have realised the seriousness of the danger inherent in the degradation of the ecosystem in general and the environment in particular. At the dawn of the 21st century, we are witnessing an upsurge in all kinds of pollution around cities, endangering the natural environment and creating an alarming situation for the balance of the urban ecosystem. Moreover, the production of waste is part and parcel of human activity, whether domestic, agricultural, industrial or commercial. In Africa, the phenomenon has become more widespread and public with urbanisation [2]. Urbanisation and economic development generally lead to an increase in the production and consumption of waste per inhabitant. Cameroon is therefore experiencing problems with the recycling of used tyres. The practicalities of such an undertaking need to be urgently and thoroughly considered. In this context, the use of used tyres in road construction seems to be an important issue that could systematically contribute to the improvement of sustainable development policies, provided that the products grow at the same rate as the population. Asphalt pavements are currently the most common type of pavement in the world. Uncertainty in the oil markets, ever-increasing costs and environmental issues have never been more topical in our country in particular and in the world in general. The need to adapt to changing oil prices while preserving our limited purchasing power is no longer in question. The aim of this thesis is to formulate, evaluate and understand a new road surfacing material formulated with a binder modified with scrap tyre powder. This study is carried out mainly on wearing courses to improve the performance of the asphalt mix, in particular its rheological, mechanical and acoustic properties. Several articles have been published on this subject by a number of researchers, including FAURE M.1985 [3] , GLAOUI Bachir et al 2014 [4] ; S. Kim et al 2009 [5] ; D. Daryaee et al 2020 [6] ; D. Singh et al 2019 [7] ; Y. Yan et al 2016 [8]; A. Alisov et al 2020 [9]; Z. Zhou et al. 2019 [10]; Alatas T et al. 2013 [11]; Ponniah J et al. 1996 [12]; von Quintus HL 2007 [13]; Brûlé B et al. 1988 [14]; Wang T et al. 2010 [15]; Isacsson U et al. 1995 [16], who have demonstrated in various ways that the addition of polymers to bitumen positively improves the mechanical and rheological behaviour of asphaltic concrete. In this article we will firstly look at the behaviour of a new binder resulting from the replacement of part of the class 60/70 bitumen with scrap tyre powder, and secondly, we will examine the mechanical behaviour of a BBSG10 semi-graded asphalt concrete formulated using the powdered bitumen.

II. Material And Methods

Material:

The materials Used for this Study are as follows:

Aggregates: The aggregates used in this project are natural gneissic materials from the ELOUMDEM quarry located in the town of MBANKOMO division of the MEFOU ET AKONO in the Centre Region Cameroon. The granular classes used are 0/4, 4/6 and 6/10. Typical physical prosperities of aggregates are given below in Table1

Table no 1: Typical physical prosperities of aggregates

Laboratory Test	Standards	Sand 0/4	Gravel 4/6	Gravel 6/10	Specifications
Water Content w (%)	NF P 94-050 [20]	0,35	0,14	0,11	/
Flattening coefficient (%)	NF P 18-561 [21]	/	5,5	3,4	< 20
Apparent density (g/cm^3)	NF P 94-053 [22]	1,54	1,46	1,45	/
Los Angeles (%)	NF P 18-573 [23]	/	28		≤ 35
Micro Deval (%)	NF P 18-572 [24]	/	20		≤ 25
Sand Equivalent (%)	NF P 18-598 [25]	80.20	/	/	≥ 60
Surface Cleanliness (%)	NF P 18-591 [26]	/	0,7	0,6	< 1

Bitumen: According to the recommendations of the practical guide to pavement design for tropical countries (CEBTP), the bitumen recommended for asphalt concrete are 40/50, 60/70 and 80/100. The class of bitumen selected for this investigation is 60/70, in accordance with NF T 65-000 and NF T 65-001 standards, as it is more resistant to rutting in hot climates and is more widely used in the region. Table 2 shows the main characteristics of the bitumen used in this study.

Table no 2: characteristics of the bitumen

Characteristics of bitumen	**Bitumen 60/70**		
	Standards	**Obtain**	**Specifications**
Ball and ring softening point (°C)	NF T 66-008 [27]	50,5	46/54
Penetrability at 25 °C, 100 g, 5s 1/10 mm	NF T 66-004 [28]	65	60/70
Relative density at 25 °C on pycnometer (g/cm^3)	NF T 66-007 [29]	1,02	1,0 - 1,1

Tire Powder: The used tire powder used in this work comes from MICHELIN brand LTX A/T2 used tires. In the absence of suitable industrial equipment, the powder was obtained using the following procedure:

Cleaning used tyres ⇨ Cut the used tyre into 5cm strips ⇨ Grind each cut using a grinder ⇨ Collect the powder that falls off after rubbing and sieve it.

We used two types of used tire powder in this investigation:

- The powder obtained by grinding the whole used tire (P1)
- The powder obtained by grinding only the rubber from the used tire (P2).

The fine powder obtained has a density of 0.82 at room temperature and a melting temperature of between 200 and 220°C, which is compatible with the processing temperatures of asphalt concrete.

Method

Production of the powdered bitumen mixture:

The Production of powdered bitumen is an operation requiring strict control of all the factors influencing the behaviour of the final product [31]. For the purposes of this work, we opted for the following experimental protocol:

- Preparation and preheating of the required mass of tire powder;
- Preheating the bitumen to 175°C in the oven;
- Set the mixer to 1000 rpm;
- Set the heating plate to a constant temperature of 200°C;
- Remove bitumen container and place directly on hot plate;
- Gradually incorporate the powder into the bitumen container and homogenize the mixture;
- Start the mixer and stop it two hours later, the mixture obtained is directly intended for testing.

The powder is added while the mineral skeleton is being mixed with the bitumen. It is added gradually to ensure that the mixture of bitumen and powder is homogeneous at the mixing temperature. The various bitumen and powder contents are shown in Table 3.

Table no 3: Different bitumen and powder contents

Labels	BP1.1 BP2.1	BP1.2 BP2.2	BP1.3 BP2.3	BP1.4 BP2.4	BP1.5 BP2.5	BP1.6 BP2.6
Bitumen dosage (%)	6	5,7	5,4	5,1	4,8	4,5
Powder dosage P1 (%)	0	0,3	0,6	0,9	1,2	1,5
Powder dosage P2 (%)	0	0,3	0,6	0,9	1,2	1,5

Formulation of bituminous concrete

Granular composition

The optimum granular curve for the 0/10 mm asphalt concrete mix design was obtained through the three granular classes retained in this investigation: classes 0/4 mm, 4/6 mm and 6/10 mm. In addition, this optimised curve must fall within the zone recommended by the specifications of the practical guide to pavement design for tropical countries (CEBTP). The following proportions were therefore adopted: 60*% of* 0/4 mm sand, 15% *of* 4/6 mm gravel and 25*% of* 6/10 mm gravel.

Bitumen Dosage

According to the the practical guide to pavement design for tropical countries (CEBTP), bituminous concretes usually contain 5 to 8% bitumen. Previous studies by Touati N. and Tafat A., (2016) [29], Alexandre T. Bachand, (2018) [30], Nango Temgoua U, (2017) [31] and Madjadoumbaye J. and Amine S. (2019) [32], as well as our laboratory work, have enabled us to set the bitumen content in this investigation at 6%.

Formulation

In the course of this investigation, two families of bituminous concretes were formulated: bituminous concretes modified with tyre powder used over the range 0 to 25% with a pitch of 5% (BP1); bituminous concretes modified with rubber powder over the range 0 to 25% with a pitch of 5% (BP2) a total of 12 formulations were carried out the different elements of these formulations are reported in table 4.

Table no 4: Composition of the different formulations

Labels	BBP1.1 BBP2.1	BBP1.2 BBP2.2	BBP1.3 BBP2.3	BBP1.4 BBP2.4	BBP1.5 BBP2.5	BBP1.6 BBP2.6
Bitumen dosage (%)	6	5,7	5,4	5,1	4,8	4,5
Powder dosage P1 (%)	0	0,3	0,6	0,9	1,2	1,5
Powder dosage P2 (%)	0	0,3	0,6	0,9	1,2	1,5
Natural sand 0/4 mm (%)	60	60	60	60	60	60
Natural gravel 4/6 mm (%)	15	15	15	15	15	15
Natural gravel 6/10 mm (%)	25	25	25	25	25	25

Characterisation of the sampled powder bitumen

Penetrability with a needle at 25º (PEN) and ball temperature and TBA ring are the two main tests carried out to characterise the behaviour of bitumen alone and with the addition of used tyre powder. They are carried out in the same way as for ordinary bitumen.

Mechanical characterisation of the sampled bituminous concretes

Mechanical characterisation was carried out on the 12 samples prepared using Duriez tests and Marshall tests. The results obtained were compared with the values recommended by the Practical Guide to Road Design for Tropical Countries and the recommendations specified in the Asphalt Institute. The mix design was carried out progressively according to the different used tyre powder contents. After formulation, two mechanical tests were carried out, namely the Marshall test and the Duriez test.

Marshall test

The Marshall test was carried out in accordance with NF P 98 251-2 [32]. Test specimens were produced by compacting the material and applying shocks generated by a standard weight and height on both sides (50 blows). The specimens are then 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 (Kg) and creep f (mm) are recorded.

Duriez test

The Duriez test was carried out in accordance with NF P 98 250-1 [33]. The purpose of this test is to determine the water resistance of asphalt mixes. The hydrocarbon mix is compressed in a cylindrical mould for 5 minutes by double acting static pressure (Fc = 60kN). One type of specimen is kept without immersion at a controlled temperature (18°C) and constant hygrometry, while the second type is kept immersed for 7 days. The uniaxial compressive strength was measured on each set of samples. The ratio of the strength after immersion to the dry strength (r/R) gives the water resistance of the mix, which must be greater than 0.75 according to the specifications in the Manual for Pavement Design in Developing Countries.

III. Result

Evolution of penetrability

In order to study the effect of tire powder on bitumen is given on table 5

Table no 5: penetrability Test results

		Powder P1		Powder P2	
No	**Test**	**Powder Content %)**	**Results**	**Powder Content %)**	**Results**
1	Penetrability at 25 °C	0	65	0	65
		5	41,1	5	43,2
		10	40,8	10	42,5
		15	38,2	15	39,5
		20	37,1	20	37,9
		25	35,1	25	36,2

In terms of penetrability, Figure 1 give us the evolution from 0 to 25%.

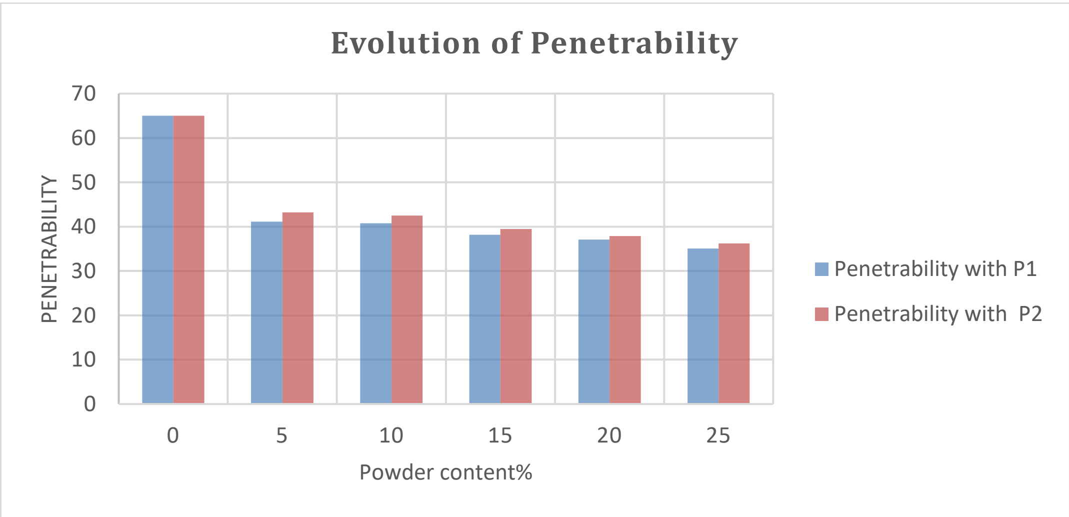

Figure 1 : Evolution of penetrability

The following observations can be made from this figure:
In terms of penetrability, the addition of used tyre powder enables the following observations to be made:

- A notable decrease in penetrability when the powder content increases, which shows that penetrability and powder content are inversely proportional for the two types of powder used.
- The penetrability of bitumen modified with P1 powder is lower than that of bitumen modified with P2 powder. This points to the influence of other tyre components such as metal, textile, zinc oxide, sulphur and other additives in modifying the bitumen.
- Penetrability falls sharply in the 0-5% range. It is around 23 mm for P1 powder and 21 mm for P2 powder.
- Penetrability after substituting 5% bitumen with powders increases by more than 10 mm.
- At 25% powders, the difference in penetrability between P1 and P2 is practically 1mm.
- Overall, the substitution of 25% whole used tyre powder (P1) or rubber powder (P2) has a major influence on penetrability. Penetrability drops by 48% for P1 and 55% for P2.
- From 5% powder content, our new hydrocarbon binder is class 35/50.

Evolution of the Ring Ball Temperature
The results of the ball and ring temperature tests are shown in the table 6 below.

Table 6: Ring Ball Temperature Test Result

		Powder P1		Powder P2	
No	**Test**	**Powder Content %)**	**Results**	**Powder Content %)**	**Results**
3	Ring Ball Temperature	0	50,5	0	50,5
		5	47	5	44,5
		10	48,25	10	46,25
		15	48,7	15	48,2
		20	50,5	20	48,8
		25	53,4	25	49,75

Figure 2 shows the evolution of the Ring Ball Temperature as a function of the powder content. The RBT decreases in the 0-5% range in the case of both powders. The softening temperature of the bitumen modified by the P1 powder is higher than that of the bitumen modified by the P2 powder over the whole range of evolution.

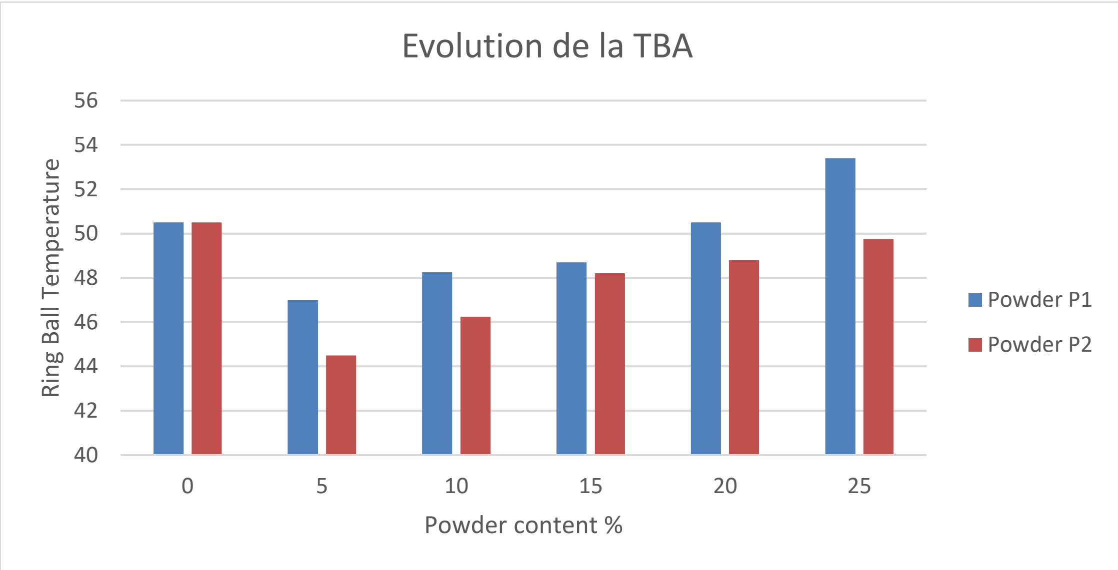

Figure 2 : Evolution of Ring Ball Temperature

In terms of the TBA, this investigation led to the following observations:

- The bead and ring softening temperatures decrease in the 0-5% range for both powders;
- An approximately bell-shaped curve links the temperatures to the powders in the 0-15% interval;
- The softening temperature of the P1 modified bitumen is higher than that of the P2 modified bitumen over the whole range of evolution;

- The minimum softening values for powders P1 and P2 were recorded in the 5-7% range;
- From 22% of P1 powder, the softening temperature becomes higher than that of pure bitumen. At 25% P2, the softening temperature approaches that of pure bitumen;
- Looking at the two curves for the two powders P1 and P2, it can be seen that the two types of powder have the same effect on the softening temperature of the ball and ring, but to different degrees;

Marshall test

The table 7 below shows the results of the Marshall test.

Table 7: Results Of Marshall Test

Test	Powder Content (%)	Results for Powder P 1	Results for Powder P 2
Marshall stability (Kg)	0	1552,5	1552,5
	5	1665	1618,5
	10	1754,5	1702,1
	15	1802,5	1785,5
	20	1845,3	1805,1
	25	1779,5	1737,4
Compacity	0	95,5	95,5
	5	96,19	95,8
	10	96,63	96,15
	15	96,85	96,35
	20	97,45	96,95
	25	94,3	91,75
Creep(1/10mm)	0	3,4	3,4
	5	3,1	3,2
	10	2,9	3
	15	2,8	2,9
	20	2,8	2,8
	25	2,9	3,1
Marshall Quotient	0	4,57	4,57
	5	5,37	5,06
	10	6,05	5,67
	15	6,44	6,16
	20	6,59	6,45
	25	6,14	5,60

Evolution of Marshall Stability

Marshal stability is the first mechanical result obtained. It is clear that powder modified asphalt concrete has better stability than the reference asphalt (0% powder). The maximum stabilities are recorded at a dust content of 20%, after which they decrease but remain higher than that of the reference asphalt mix, as shown in Figure 3.

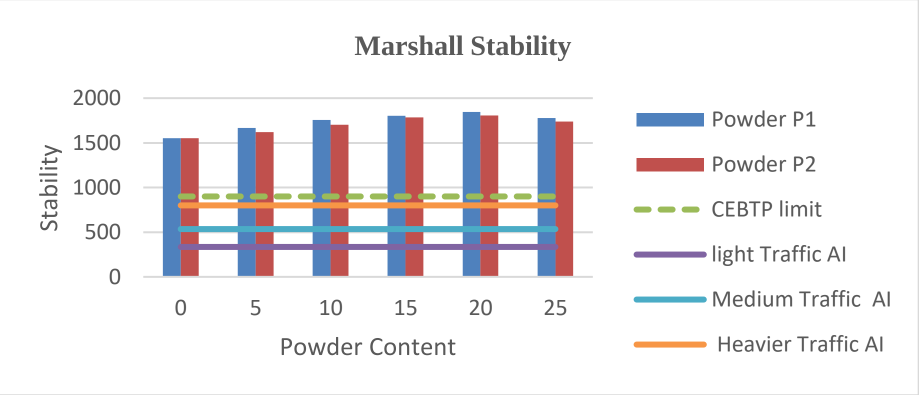

Figure 3: Evolution of Marshall stability

Stability increases almost linearly over the range of 0-20% powders and then decreases after 20%, as shown in figure3. Therefore, for heavy traffic, replacing bitumen with 20% used tyre powder is one of the best solutions in terms of mix design.

Semi-grained bituminous concrete 0/10 (BBSG) formulated on the basis of bitumen-powder has better Marshall stabilities than the reference BBSG, even at 25%, when it decreases. The two types of powder have the same behaviour with regard to Marshall stability, although the bituminous concrete formulated with P1 powder has better characteristics than that formulated with P2 powder.

Over the whole range of substitution of bitumen by used tyre powder, the results are higher than the limits prescribed in the practical guide to pavement design for tropical countries (CEBTP).

Evolution of compactness

Figure 4 shows the evolution of the compactness as a function of the tyre powder content. The compactness increases with the powder content up to 20% where it reaches the value 97.45% and decreases for contents higher than 20% and at 25% it becomes lower than that of pure bitumen.

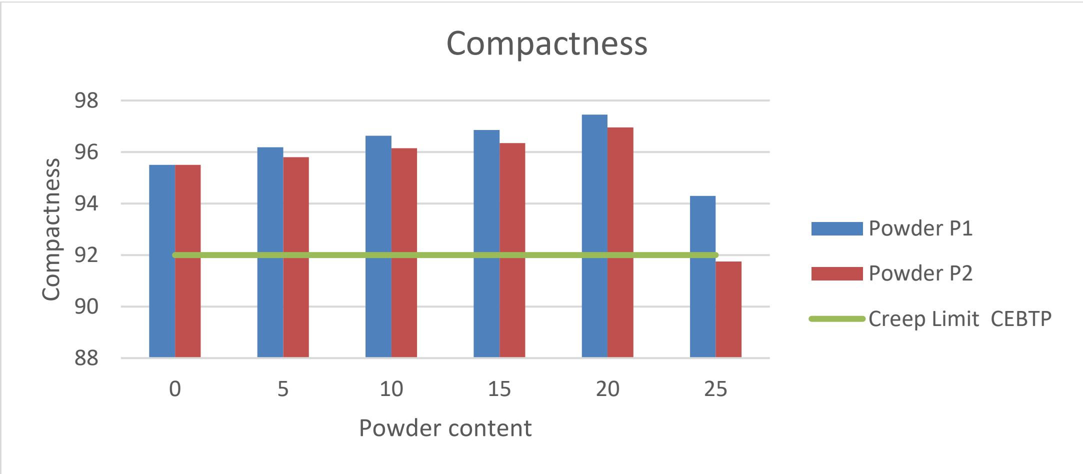

Figure 4: Evolution of compactness

Creep evolution

Creep improves as the powder content increases up to 20% and even at 25% creep remains better than that of pure bitumen.

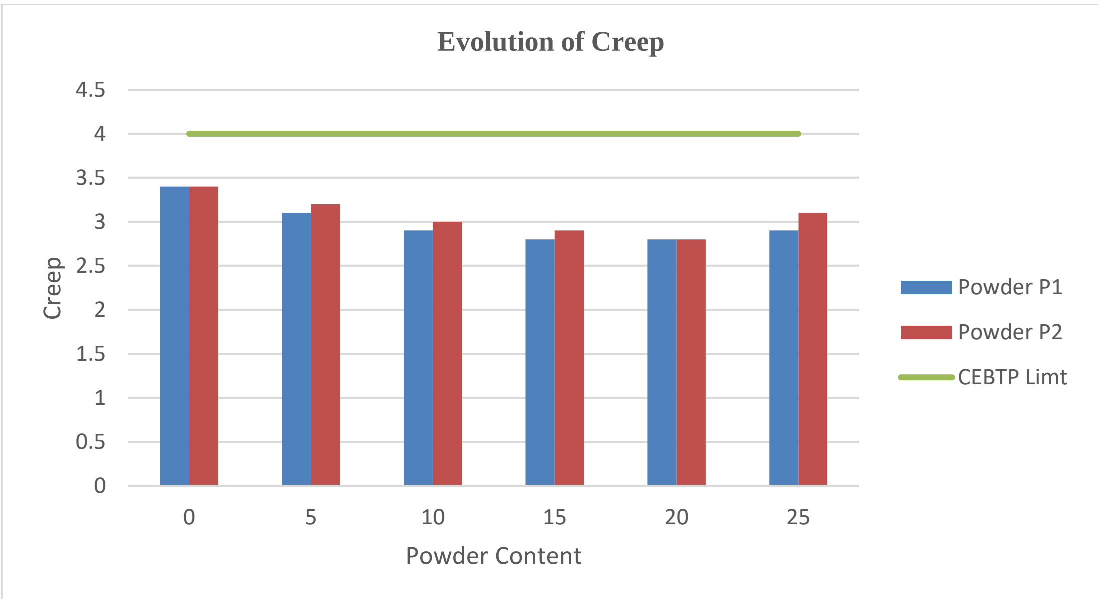

Figure 5: Creep evolution

Evolution of the Marshall Quotient

The evolution of the Marshall quotient (MQ) as a function of the powder content is shown in Figure III.5. The Marshall quotient represents the relationship between stability and creep, and therefore the performance of the specimen. A higher value of QM indicates greater resistance to permanent deformation [34].

The diagram shows that the highest values of the quotient are obtained at 15 and 20%. Therefore, for these contents, formulated asphalt mixes are the most resistant to permanent deformation.

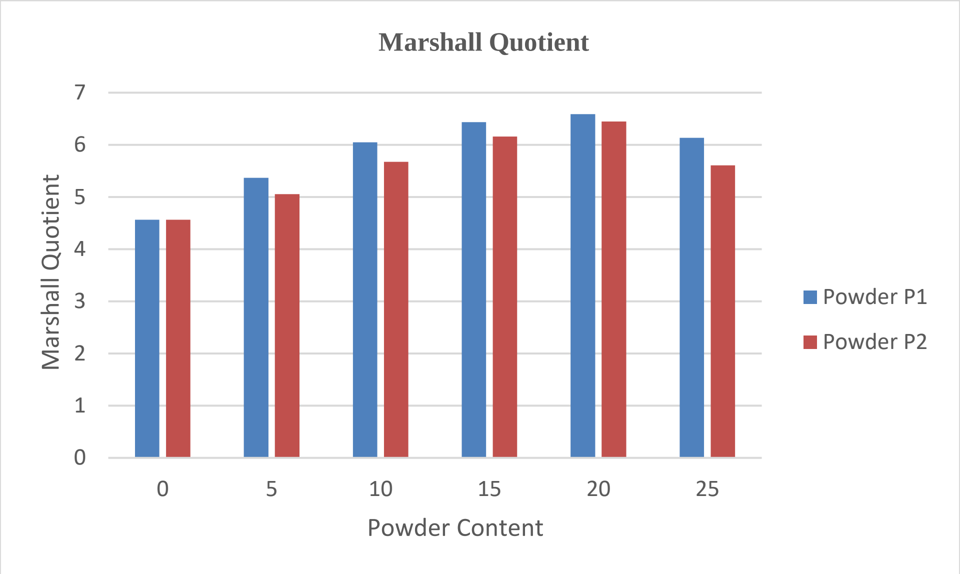

Figure 6: Evolution of the Marshall Quotient

Duriez tests

The table 8 below shows the results of the Duriez test.

Table 8: Duriez Test results

Test	Powder Content (%)	Results for Powder P 1	Results for Powder P 2
RC to air (kg/cm2)	0	75,4	75,4
	5	74	73,9
	10	75,5	74,9
	15	75,7	75,2
	20	75,87	75,5
	25	75,22	75,1
RC after immersion (kg/cm2)	0	66,352	64,85
	5	64,56	64,12
	10	67,77	66,6
	15	67,18	66,1
	20	67,1	65,9
	25	64,46	63,7
Repport immersion/ compression	0	0,880	0,880
	5	0,872	0,868
	10	0,898	0,889
	15	0,887	0,879
	20	0,884	0,873
	25	0,857	0,848
Compacity	0	93,7	93,7
	5	93,4	93,5
	10	93,2	93,4
	15	92,9	93
	20	92,8	92,9
	25	92,6	92,8
Imbibition	0	1,4	1,4
	5	1,3	1,4
	10	1,4	1,3
	15	1,5	1,4
	20	1,6	1,6
	25	1,6	1,5

Changes in air resistance

Figure 7 shows the effect of the types of powder on the air resistance of BBSG 10 semi-grained asphalt concrete obtained from the Duriez test.

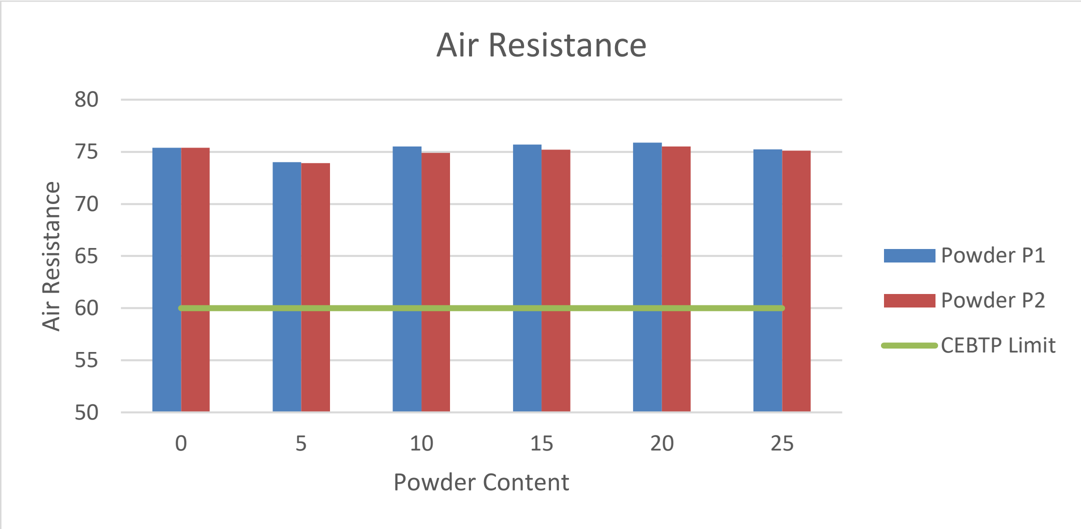

Figure 7: Effect of powder coating on air resistance

- The behaviour of the two types of powder is virtually the same, although the P1 powder shows better results than the P2 powder.
- Air resistance decreases over the 0-5 range and reaches its minimum value at 5% powder content. The difference from the base formulation is 1.4 kg/cm2 for P1 and 1.5 kg/cm2 for P2. Although the air resistance drops in this range, the drop is smaller and therefore not detrimental to our BBSG 10.
- The air resistance increases over the 5-20 range, until it exceeds that of the base mix. The resistance of the base BBSG is exceeded in the 15-20% range for the P1 powder, which remains the range where the best characteristics are observed for our improved BBSG 10. In the case of P2 powder, this is exceeded at 20%.
- The incorporation of powders in the BBSG formulation is beneficial in terms of air resistance.

Influence of powders on water resistance

Resistance to water is a very important factor in the study of bituminous concretes. It is expressed by a ratio of compressive strengths with immersion in water and when dry. Within the framework of this study, figure III 8 shows the behaviour of BBSG 10 formulated with concrete-powder.

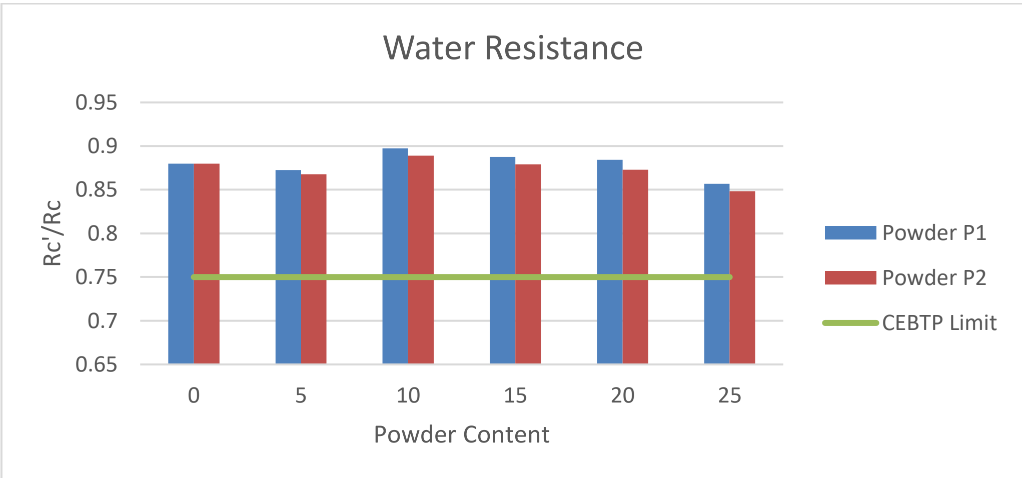

Figure 8: Effect of powder coating on water resistance

- The behaviour of our BBSG10 is the same for the different types of powder, although the P1 powder always has the best P2 characteristics; the water resistance curve of our BBSG is not linear.

- The water resistance drops in the 0-5% powder range by 0.008 for P1 powder and 0.013 for P2 powder.
- Maximum water resistance is observed at 10% powder and is 0.89 for P1 powder and 0.88 for P2 powder.
- In the 10-25 range, water resistance decreases. It should be noted that in the 15-20 range, although water resistance decreases, it remains higher than that of the base formulation for P1 powder and approximately the same for P2 powder.
- The minimum values for water resistance are observed at 25% powder.

Influence of powders on compaction behaviour

With regard to compaction behaviour, the figures below show that the compactness of BBSG 10 formulated with poudrette bitumen decreases as a function of the poudrette content. The variation in compactness over the powder content range is 1.1% for powder P1 and 0.9% for powder P2. The variation in compactness remains low for both types of powder, and is therefore not detrimental to the compaction of our BBSG 10.

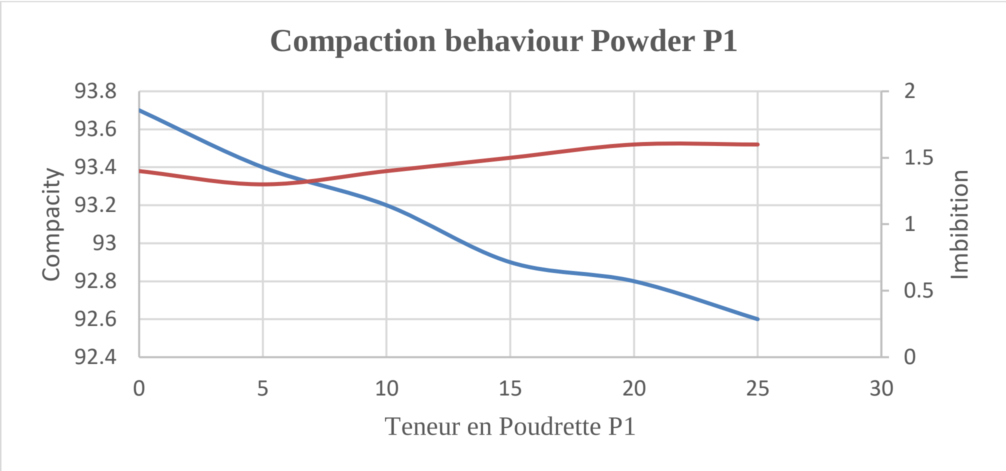

Figure 9: Compaction behaviour Powder P1

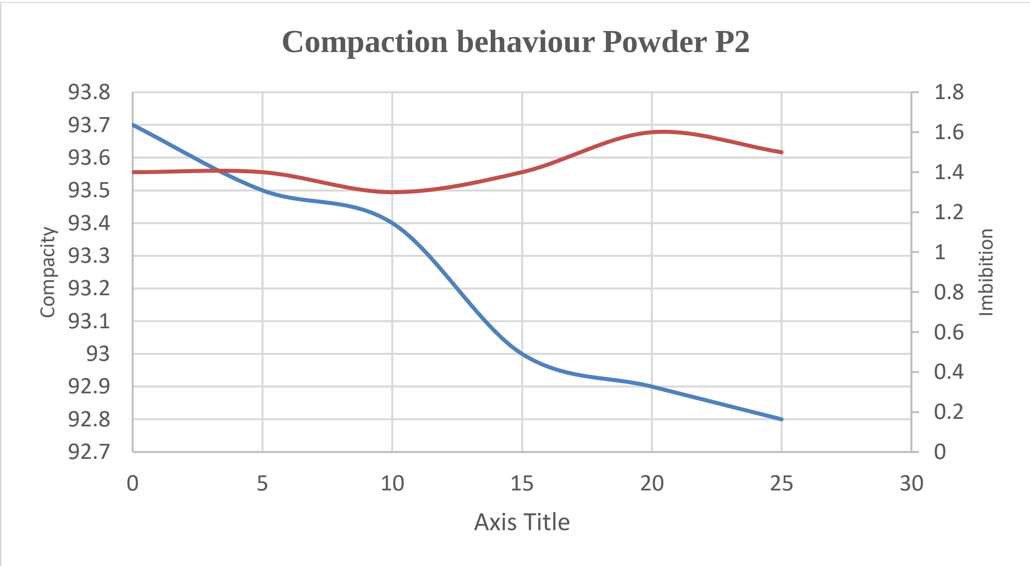

Figure 10: Compaction behaviour Powder P2

IV. Conclusion

In the light of the results obtained on the mechanical characterisation of bituminous mixes modified with used tyre powder P1 on the one hand and with rubber powder P2 on the other. The following conclusions can be drawn:

- The substitution of 60/70 bitumen by used tyre powder reduces penetrability and therefore reduces the binder to a lower class.
- The Ball and Ring Temperature increases, which reflects the increased ductility of the binder.

- Semi-textured asphalt concrete (BBSG 10) has average mechanical properties, which means that its performance, especially its strength, needs to be improved if it is to be used in stressed sections.
- Semi-grained asphalt concrete (BBSG 10) modified by the addition of powders has mechanical performance levels above the limits prescribed by CEBTP.
- The compactness of modified semi-mixed asphalt concrete (BBSG 10) decreases as a function of the powder content but is not detrimental to compaction.
- Modified semi-textured asphalt concrete (BBSG 10) RESISTS water BETTER than ordinary BBSG.
- BBSG 10 modified with P1 powder has the best characteristics than BBSG modified with P2 powder.

As rubber materials only decompose in nature after hundreds of years, the incorporation of these polymeric wastes into roadworks also offers significant environmental benefits.