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Evaluation of the Influence of Plastic Waste in Improving the Mechanical Characteristics of Asphalt Mixes (Senegal, West Africa)

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Abstract

The recovery of plastic waste has a positive impact on two fronts: The environment, through waste reduction, and the economy, through its use in road construction. This work involves recycling plastic variants such as Polypropylene (PP) 50% and LDPE (Low Density Polyethylene) 50% in proportions of 2% to 8%, incorporated into a 0/14 BBSG. The results of the Marshall test gave stability values ranging from 826 to 1523 kg and creep values from 5.5 to 2.45 mm. The Duriez test gave r/R values ranging from 0.769 to 0.786, with water absorption percentages from 2.24% to 0.69%. The PCG test at 80 gyrations gave void percentages ranging from 11.9% to 5.23%. The rutting test gives a rutting depth percentage that drops at 30,000 cycles from 11.5% to 1.3%. This study shows a considerable increase in the mechanical characteristics of asphalt mixes by adding plastic waste.

Keywords

Plastic Waste, Marshall, Environmental Impact, BBSG, Recycling

1. Introduction

The premature deterioration that appears on many road and motorway pavements during their first years of service is a major concern for the authorities concerned with the sustainability of infrastructure and the profitability of road investments.

Bituminous mixes are the materials most commonly used in the construction of road surfaces in Senegal. This wearing course is directly affected by traffic-induced loads, and fatigue failure and rutting are often observed in this layer [1]. Today, with the increasing growth in road traffic and the effects of climate change, asphalt concrete pavements are affected by premature deterioration through cracking and rutting. The work of Diouf *et al.* [2] confirms that all roads in Senegal are subject to pothole-type instability, but rutting is the most common. Traditional asphalt mixes made from a mixture of aggregates and pure bitumen no longer meet the very high mechanical, thermal and thermomechanical demands placed on pavements. Faced with these various stresses, the wearing course must ensure maximum quality and durability at the lowest possible cost. This has led to the use of new materials such as polymer-modified bitumens to improve the mechanical performance of asphalt mixes and increase the service life of road pavements [3].

2. Literature Review

Doping the road bitumen conventionally used with plastic bag waste to form a new binder is suited to the climatic conditions of our road surfaces [4]. Furthermore, the use of additives in bituminous mixtures as well as on the modification of bitumen have shown that the addition of polymers to the binder contributes to increasing the cohesion of the interfacial bond between the aggregate and the binder which can improve the stability and Marshall creep of bituminous concrete pavements [5]. Indeed, the addition of HDPE-type plastic waste at percentages ranging from 2% to 8% has shown that there is an increase in Marshall stability and a decrease in Marshall creep [5].

KOWANOU [6] carried out major studies in Benin on these asphalt mixes based on plastic waste. According to these authors, the incorporation of plastic bag powders at percentages of 2% to 20% in the bitumen increased the properties of the bitumen and the asphalt mix.

The quantities of plastic waste produced in the world's ever-growing populations are a real threat to the environment. In West Africa, estimates of plastic waste in Senegal are among the highest. The average production of solid household waste is 171.82 kg/capita/year [7] in the Dakar region, where the population is expected to reach 3,835,019 in 2020 (ANSD, Projection 2020). Disposing of plastic waste is becoming a real challenge because it is non-biodegradable, which poses a major problem for society in terms of solid waste management. Plastic waste decomposes with difficulty, posing a problem of insalubrity and visual pollution. Assessing the waste market provides information on the most viable and profitable waste sector value chains (domestic and international) [8].

From an environmental point of view, the incineration of this waste releases toxic gases that are harmful to health. To combat plastic waste pollution, we have opted to recycle it in road construction, using it as a polymer to improve the mechanical performance of bituminous mixes. Using this plastic waste is an approach that will help to protect the environment and produce high-performance bituminous mixes at low cost. In Senegal, we haven't found any such studies, although they do exist, but they haven't been published. This is still an innovative approach in Senegal, as it has not yet been exploited.

3. Materials and Methodology

The methodology used consisted firstly of a literature review to establish the current state of knowledge about asphalt mixes based on plastic waste. Sampling was then carried out at the Ngoundiane basalt quarry, and the bitumen was supplied by the ERES plant. The basalt aggregates were subjected to physico-mechanical testing for geotechnical characterization for classes 0/3, 3/8 and 8/14 (**Figure 1**).

The bitumen underwent geotechnical acceptance testing using penetrability tests to confirm its class and TBA (Ring and Ball Temperature) tests to determine its softening temperature. This physical-mechanical characterization, supplemented by bitumen identification tests, was used as the basis for formulating a control 0/14 asphalt concrete. Once the basic formula had been obtained, percentages of plastic waste shredded into small particles with an average size of between 2 and 5 mm were incorporated into the bitumen in order to monitor changes in the mechanical performance of the asphalt mixes. In this article, this polymer-based asphalt concrete will be studied using level 1 formulas (**Figure 2**).

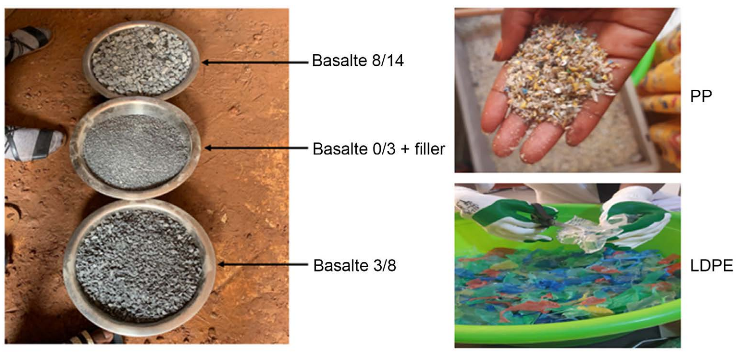

Figure 1. Basalt and plastics used in the study.

Figure 2. Formulation of mixes for the various tests.

So, several tests will be doing such as and Marshall, Duriez, PCG and rutting tests were carried out to monitor the evolution of the mechanical performance of waste plastic-based mixes (**Figure 3**).

4. Results and Discussions

4.1. Characterization of Materials

4.1.1. Characterization of Materials

The aggregates used in this study are the 0/3, 3/8 and 8/14 basaltic fractions commonly used in Senegal to manufacture bituminous concrete for wearing courses. They were sampled at the GECAMINE quarry. The tests carried out on the aggregates relate to their intrinsic characteristics, giving an idea of their physical and mechanical identification. The granulometry allows the distribution of basalt grains according to the mesh and the drawing of curves for each granular class as shown in **Figure 4**.

The aggregate characterization results are compared with the technical specifications of the contract as shown in **Table 1**.

Table 1 shows the characteristics of basaltic aggregates. It shows that the value of the sand equivalent is much higher than that required, which clearly demonstrates the quality of these aggregates. The results also show that the flattening test carried out on basalt indicates a value of 14.9% for class 8/16 and 15% for class 3/8. These values (which meet the project specifications) confirm that the grain shape is adequate. The LA and MDE values confirm the ability of the aggregates to resist impact and wear. The results presented in **Table 2** meet the project specifications and show that the basaltic gravels are well suited to the formulation of 0/14 grade bituminous concrete.

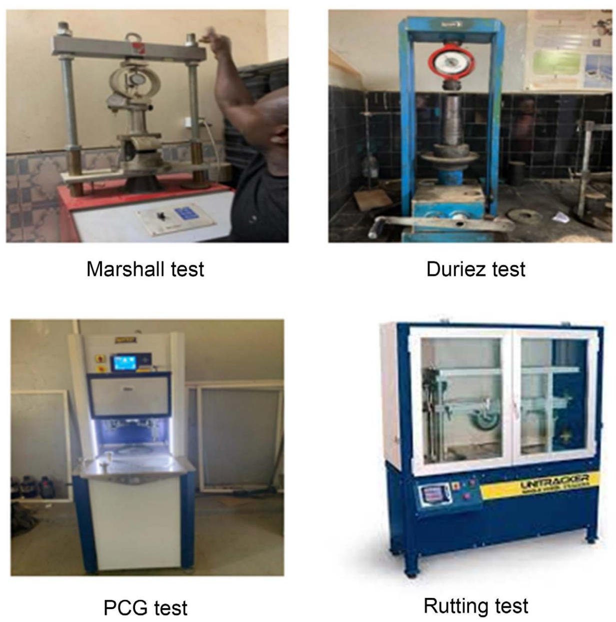

Figure 3. Mechanical tests for the study of the mechanical performance of asphalt mixes.

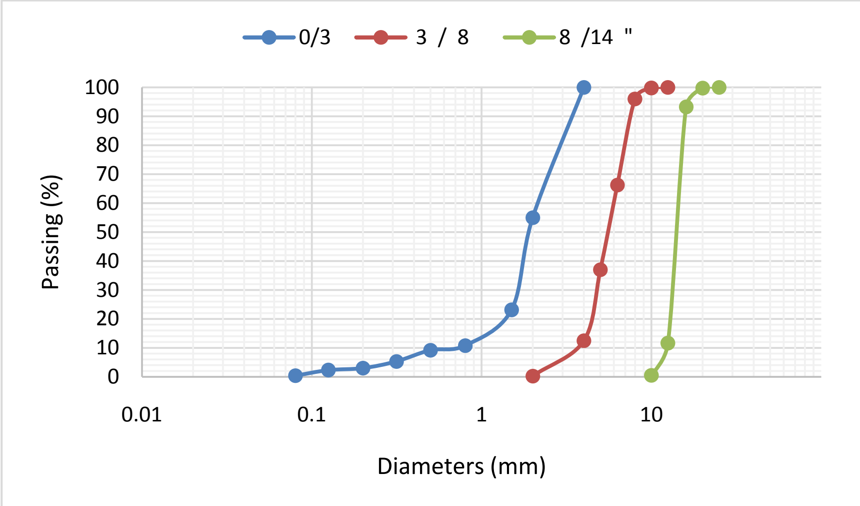

Figure 4. Granulometric curves for granular fractions.

Table 1. Aggregate identification test results.

	Characteristics	Results			Specifications
Physics	Granular Class	0/3	3/8	8/14	
	Specific Gravity	2.96	2.94	2.95	
	Sand equivalent	-	78.6	-	>50
	Bulk density	1.77	1.51	1.70	
Mechanics	LA	-	18.90	10.70	≤25
	MDE	-	17.50	6.10	≤20

Table 2. Penetrability and TBA test results.

Tests	Results	Specifications	Conformity
Penetration Test (1/10)	47	35 - 50	Conform
Temperature of softening (˚C)	53	50 - 50	Conform

4.1.2. The Bitumen

To characterize the bitumen, penetrability and ball and ring temperature tests were carried out in accordance with EN 1426 and EN 142 respectively. The results are given in Table 2.

Table 2 shows the results of the penetrability and TBA tests. These tests show that the bitumen supplied by ERES is class 35 - 35 and that the softening temperature is 53˚C. This means that it can be used in hot regions to minimize bitumen creep.

4.1.3. The Plastic

In this study we used two types of plastic waste.

- LDPE: Low Density Polyethylene

This clear or translucent plastic is flexible, chemically resistant and waterproof. It is more transparent than high-density polyethylene (HDPE). It is used for plastic bags, plastic food wrap, flexible packaging materials, freezer bags, water sachets, etc.

The theoretical melting temperature of LDPE is between 120˚C and 140˚C.

- PP: Polypropylene

Polypropylene (PP) is a thermoplastic and can be identified by the number 5 in the tracking arrow symbol. It has many properties similar to PET, HDPE and LDPE.

Density and melting temperature test results for these plastics are given in Table 3.

These plastics have low densities and very high melting temperatures compared with ambient temperature.

4.2. Formulation of Asphalt Mix

The study of bituminous mix design consists of finding the optimum binder content to ensure a certain threshold of stability, compactness, compactability, resistance to water (uncoating) and creep. To do this, we proceeded to choose a granular mix composed of the three particle size fractions (0/3, 3/8 and the 8/14) fitting perfectly into a reference spindle (Figure 5). In this study we have 34% 0/3, 16% 3/8, 45% 8/14 and 5% filler. The bitumen content found is 4, 9%. However, all level 1 formulation testing will be carried out using this formula.

Table 3. Penetrability and TBA test results.

Parameter	Low-density polyethylene (LDPE)	Polypropylene (PP)
Temperature (˚C)	140.8	155.3
Density	0.93	0.95

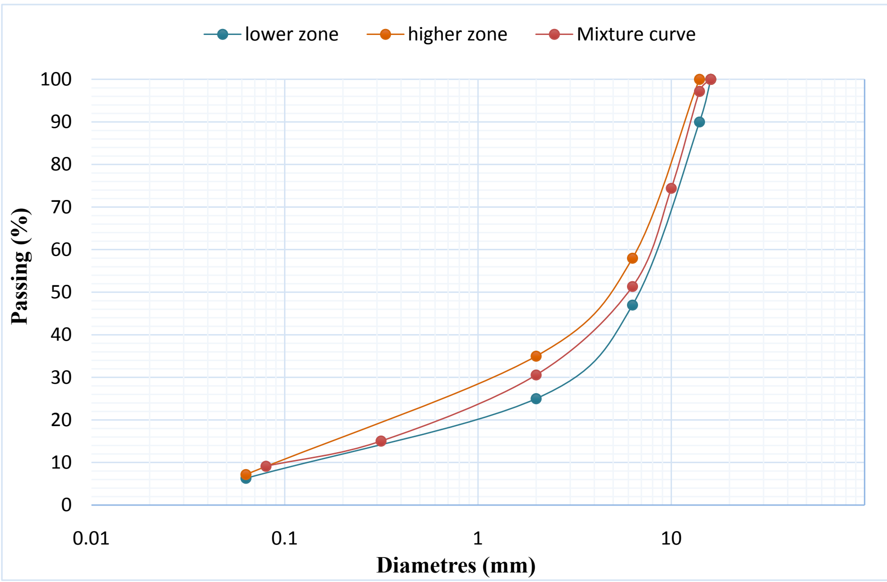

Figure 5. Sieve size curves for the mixture in the reference zone.

Once the basic formula had been worked out, percentages of plastics ranging from 0% to 8% by a 2% interval were added to the initial mix, and Marshall, Duriez and PCG tests were carried out to monitor the evolution of the mechanical performance of waste plastic-based mixes.

4.2.1. Marshall Test

The Marshall test is carried out in accordance with standard NF EN 12697-34 on a sample compacted using a Marshall tamper at a rate of 50 blows per face for a road mix. The cylindrical specimen is then immersed in a hydrostatic bath at 60˚C for 30 minutes before passing through a Marshall press. The results of the Marshall stability and creep tests are shown in Figure 6 and Figure 7.

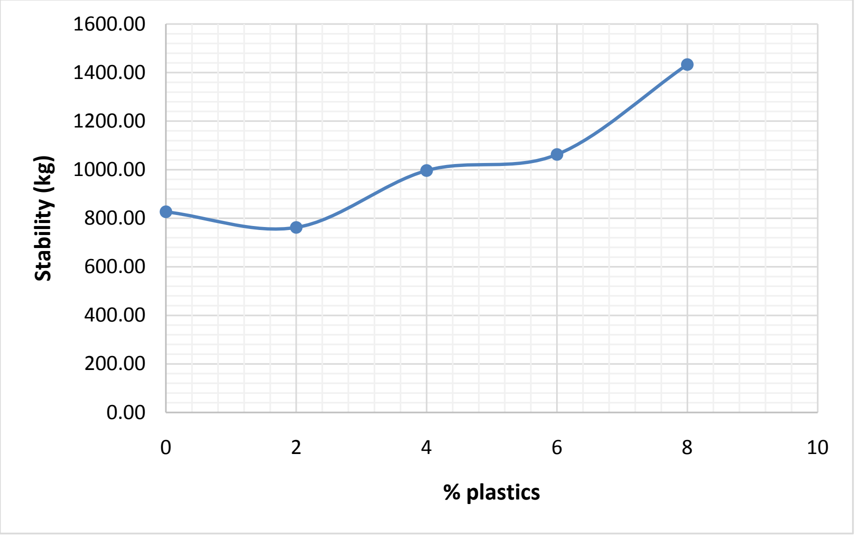

Figure 6. Variation in stability as a function of % of plastics.

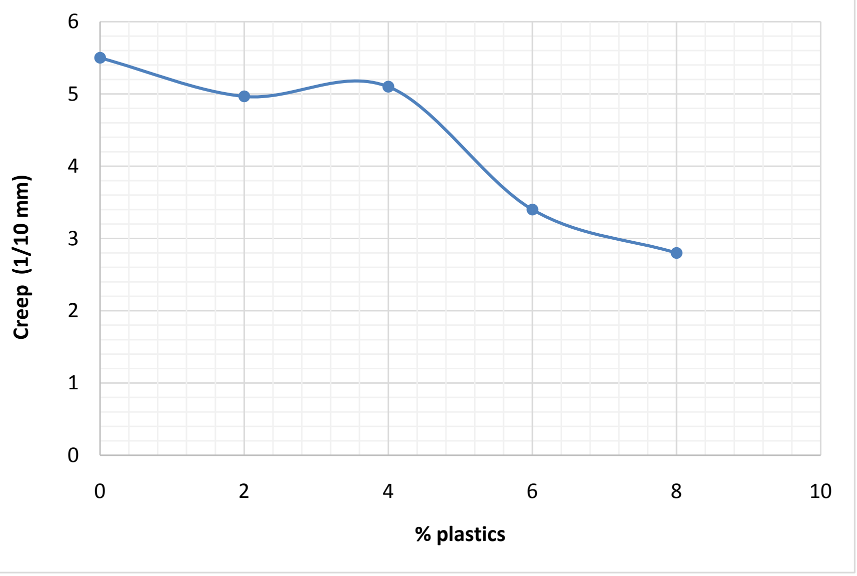

Figure 7. Creep variation as a function of % of plastics.

Figure 6 and **Figure 7** show the evolution of Marshall and Duriez stability as a function of the percentage of plastic. These results show that the Marshall stability increases with the addition of plastic, from 826 kg to 1433 kg. On the other hand, creep decreases as the percentage of plastic increases, from 5.5 mm to 2.80 mm. This shows that the addition of plastic reduces voids and increases asphalt compactness, which in turn reduces creep. However, for the remainder of the tests we adopted a plastic percentage of 7%.

4.2.2. Marshall Test

The Duriez test is used to determine the resistance to stripping under the action of water or the level of resistance to water of asphalt concrete. It is carried out in accordance with standard NF P 98-251-1, 2002. The results are given in **Table 4**.

Table 4 shows that the addition of plastic increases the characteristics of the Duriez test. However, the r/R ratio increases from 0.769 to 0.786. Compactness varies from 89.61% to 97.7% and water absorption decreases from 2.24% to 0.69%. The addition of plastic not only reduces water absorption, but also reduces asphalt stripping. This mix is a good material for use in areas sensitive to variations in water conditions.

4.2.3. PCG Test

The PCG test is carried out in accordance with the standard (NF EN 12697-31, 2019) and is used to characterize the compactibility of bituminous mixes with or without plastic. It is a combination of gyratory shear and a resultant axial force applied by a mechanical head. It is used to calculate the percentage of voids and compactness according to the number of gyrations using the measured height of the specimen. This test was carried out on BBSG 0/14 with percentages of 0% and 7% plastic. The results are shown in **Figure 8**.

The results of the rutting test show that the percentage of voids decreases with the number of gyrations. They also show that the addition of 7% plastic considerably reduces the percentage of voids at 80 gyrations, from 11.9% to 6.23%, and increases compactness, which varies between 88.1% and 93.7%. This shows that the plastic occupies the voids and increases the compactness of the asphalt mix. It also makes it possible to correct the ideal number of voids for an asphalt mix.

4.2.4. Rutting Test %

The rutting test was carried out in accordance with standard NF EN 12697-22, and is used to determine the percentage rutting depth of an asphalt mix. It was carried out on bituminous concrete with two plastic percentages, 0% and 7%. The results are shown in **Figure 9**.

The results show that the incorporation of plastic considerably reduces the percentage of rutting depth, which drops from 11.5% to 1.3% after 30,000 cycles, a reduction of more than 80% in rutting. This can be explained by the fact that the plastic fills the voids, increasing compactness and thus resistance to rutting.

Table 5 summarizes all the results obtained for the study of the mechanical performances of the asphalt based on plastic waste.

The table shows that the 7% mixture gives the best characteristics. It reduces sensitivity to water, increases the rigidity of the asphalt and reduces rutting.

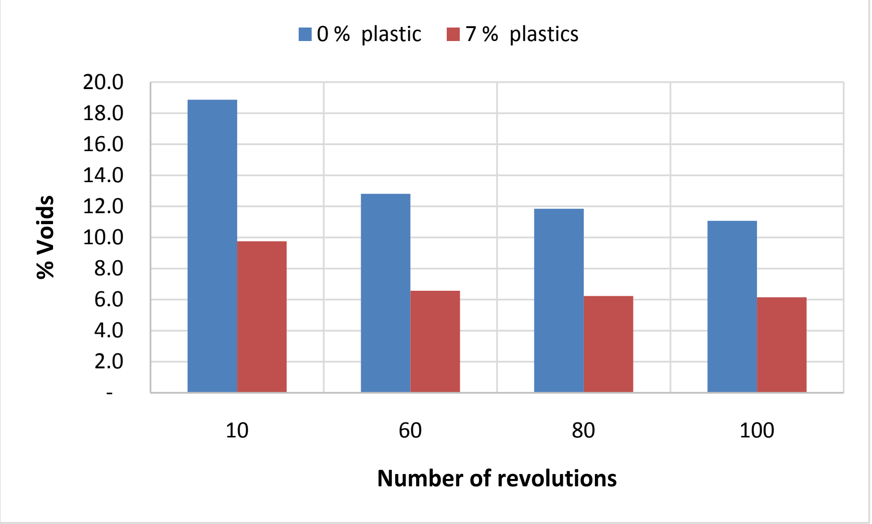

Figure 8. Variation in the percentage of voids according to the number of revolutions and the percentage of plastic.

Table 4. Duriez test results.

Characteristics		Obtained values		Acceptable values
		0% of Plastic	7% of plastic	
DURIEZ NF P98-251-1	Rc'/Rc	0.769	0.786	>0.75
	Compact (%)	89.61	97.7	≤97
	% Water absorption	2.24	0.69	0.93

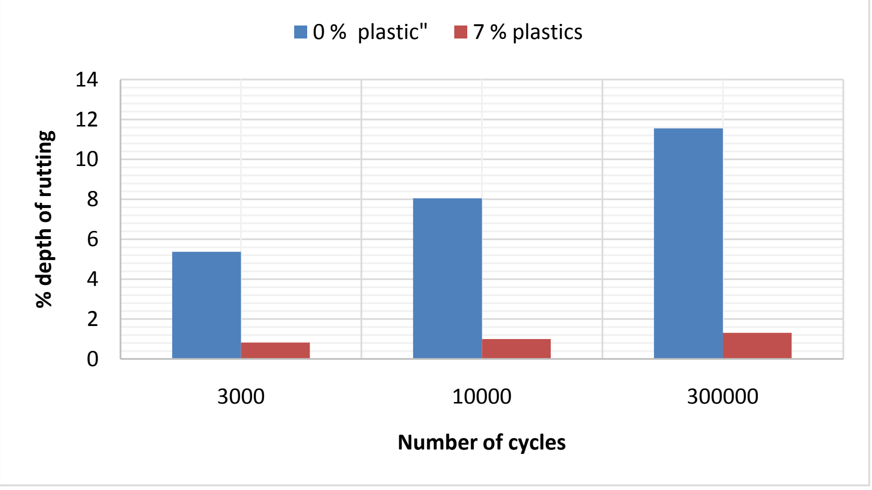

Figure 9. Variation in rutting depth percentages as a function of the number of loading cycles according to the percentage of plastic.

Table 5. Results for mechanical performances.

Characteristics		Obtained values		Acceptable values
		0% of Plastic	7% of plastic	
DURIEZ NF P98-251-1	Rc'/Rc	0.769	0.786	>0.75
	Compact (%)	89.61	97.7	≤97
	% Water absorption	2.24	0.69	0.93
PCG	% voids at 80 girations	11.9	6.23	[4 - 9]
Rutting	Deep of rutting at 30,000 cycles	11.55	1.3	≤5

5. Conclusion

The study showed that large quantities of plastic waste can be recovered and recycled in road construction. In fact, the addition of percentages of plastic ranging from 2% to 7% increases the Marshall stability, reduces creep and increases the compactness of bituminous mixes. It also shows that incorporating plastic increases water resistance and asphalt compactibility, and reduces water absorption and rutting. In the light of these results, this study certifies that the addition of plastic to BBSG is of capital benefit and contributes to a considerable increase in the mechanical characteristics of bituminous mixes. This solves an environmental problem and creates a value chain that will help to improve the quality and durability of our wearing courses.

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Conflicts of Interest

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

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