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Study of Strengthening of Recycled Asphalt Concrete by Plastic Aggregates

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Abstract: Thermo-recycling is an economical means of using raw materials such as aggregate and bitumen. It contributes indirectly to the protection of the environment. The introduction of plastic PR-PLAST-S (anti ruts) to strengthen new asphalt mix with asphalt millings not only seems a promising solution to recycle the old road materials, but it is also economical and efficient for improving the resistance to permanent deformation that leads to ruts. Such coating formulas can be considered for the maintenance of wearing course of flexible pavements. To simulate the problems of wearing, Marshall Tests and normal Duriez tests have been performed on various formulations of plastic reinforced asphalt concrete. The results show that recycling of pavements can be performed without restrictions up to 30% of milled. With plastic pellets, mixtures behave like new asphalt above 6% addition of PR-PLAST-S.

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Key words*: Asphalt concrete; Milled; Mixing behavior; Plastic granulates.*

Introduction

The wearing layer, long considered as the "noble" layer free from recycled material, typically incorporates 10% of recycled by large companies for majors projects. In the foundation layers, the percentage rises to 30%. Paradoxically, mixes coated with recycled materials may have better mechanical performance than "new" mixes, especially for the foundation layer. According to Olard [1], chemically, the old asphalt "glues" very well to the new bitumen. In addition, all categories of road materials can be recycled. This allows a layer by layer milling, which gives homogeneous aggregates and allows incorporating high levels of recycling in the new road.

In the pavement, the asphalt is subjected to temperatures and time-varying stress. The stress conditions vary depending on the pavement structure and the location. The behavior of an asphalt road is very complex since it depends on temperature (thermoplastic), time (viscous), traffic load, natural oxidative aging, and other parameters [2]. These different behaviors are conferred by the asphalt. It is therefore necessary to describe the behavior of bitumen in physic-chemical, structural, and rheological terms to identify its influence on the behavior of asphalt.

This study aims to integrate and reuse the material milled asphalt pavement in new asphalt concrete by developing a new bitumen with the addition of different percentage of milled asphalt until obtaining a mixture with qualities comparable to a new asphalt by reinforcing with the addition of plastic pellets.

The Materials of the Study

Aggregates

Aggregates used in this study are the fractions commonly used in Algeria for the manufacture of asphalt concrete for wearing. The materials were extracted at the ENG Hachimia quarry (Algeria) and consist of sand 0/3, gravel 3/8, and gravel 8/14.

Identification and Characteristics of Aggregates

To determine the characteristics of three granular classes, the following tests were performed: the actual density (NA 255), the resilience (Test Los Angeles NA 458), the wear resistance in the presence of water (Micro-Deval test NA 457), the flattening test (NA 256), the surface cleanliness (NF P18-591), the equivalent of sand (NF EN 933-8), and the plasticity index. The results are shown in Tables 1 and 2 below.

The results are in accordance with the specifications required according to the shape, the size, and the cleanliness. These production characteristics rank the aggregates on the third (III) category. Manufacturing specifications of the sand tally to the category “a” [3]. Thus, the aggregate analysis can be used in the manufacture of a semi grained asphalt concrete 0/14.

Choosing the Granular Formulation

The objective is to control the arrangement of the skeleton granular mineral and choose a formula that gives a mixture having the best ability to compaction, which could give greater stability to hydrocarbon mixture. The following composition was used (Table 3). The grading curve of the mixture of the three granular classes (Fig. 1) resulting from this composition fits perfectly in the

Table 1. Results of Tests on Aggregate Fractions 8/14 and 3/8.

	Grain Size		Specifications
	3/8	8/14	
True Density [t/m^3]	2.66	2.66	-
Los Angeles [%]	21.02	20.54%	< 25
Wet Micro Deval [%]	19.33	18.85	< 20
Kurtosis [%]	24.17	31.20	< 35
Clean Surface [%]	0.80	1.20	< 2

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Table 2. Tests Results of on Aggregate Fractions 0 / 3.

	0/3	Spécifications
Sand Equivalent 10% Fines [%]	71.88	> 40%
Pasticity Index [%]	6.10	Not Measurable

Table 3. Grain Size Composition of the Mixture.

Fractions	Sand 0/3	Fraction 3/8	Fraction 8/14
Percentage [%]	48	12	40

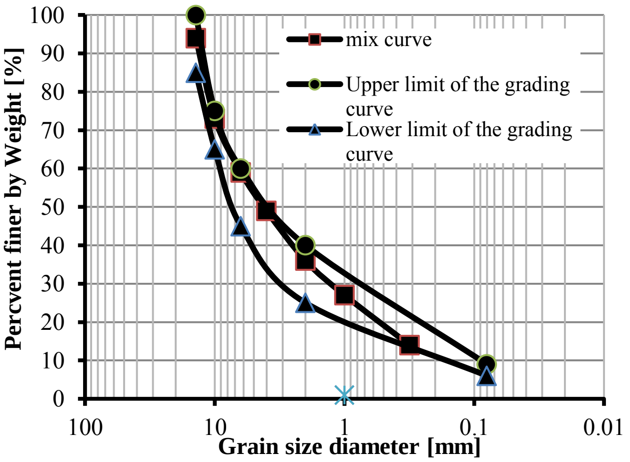

Fig. 1. Grading Curve of the Mixture 0 /14.

Table 4. Tests Results on the Asphalt.

	Results	Specifications
Softening Point (°C)	52	47 - 60
Penetration at 25°C [1/10 mm]	44	40 - 50
Relative Density at 25°C	1.04	1.01 - 1.04

envelope of grading of semi grained asphalt concrete 0/14 according to Algerian standards [3] for the use of bitumen and bituminous mixtures (February 2004).

Bitumen

Bitumen is used in industry for its water resistance and insulation (thermal and acoustic). However, road applications are the most common since, 90% of the bitumen is used as asphalt and surface dressing.

Bitumen is a continuum of various chemical species separated into two families: the insoluble compounds called asphaltene (representing up to 20% by weight for road bitumen) and soluble compounds called maltene. Due to the Algerian bitumen specifications and the Algerian climate, bitumen's manufacturing process, and some pavement performance criteria, the CTTP (Contrôle Technique des Travaux Publics, organization control of public works) recommends new limits specifications bitumen since 2004 in two groups:

- Those made by blowing [$1 \leq IP \leq 3.5$]
- Those made by distillation [$-1 \leq IP \leq 1$]

IP represents the penetration index, which is a fairly important indicator of the thermal susceptibility of bitumen in relation to its chemical composition and is calculated from the penetration at 25°C.

The traditional characterization and classification of bituminous binders based on two empirical standard tests have the advantage of being simple, widely available, reliable and reproducible (the ring and ball softening test temperature [TBA] (NT T 66-008), penetration test and breaking temperature (NF T 66-004). These tests are performed according to the Algerian recommendation on the use of bitumen [4].

The choice of the bitumen class takes into account the following parameters: the stresses applied to the road (traffic, climate and altitude) and the susceptibility of the bitumen temperature which depends on its method of manufacturing. The asphalt must be flexible enough at low operating temperature to prevent cracking and be sufficiently rigid at high operating temperature to prevent rutting [5]. Bitumen used was 35/50 from NAFTAL class.

Characteristics of the Bitumen Used

Analysis of the bitumen used is based on three tests: the relative density at 25°C (standard NA 5224), the needle penetration at 25° C (standard NA 5192), and the ring and ball softening point (standard NA 2617). The results are shown in Table 4.

The analyzed bitumen meets the characteristics of the class according to the standard 35/50 NFT65-001. Mechanical testing of new asphalt was performed, providing the following results. The wealth modulus characterizes the film thickness of bitumen around the aggregates. Marshall Stability is the maximum crushing strength, and the flow is the shortening of the diameter of the specimen at the rupture.

- For Marshall test, the results are summarized in Table 5.
- For normal Duriez test, the results are recorded in Table 6.

The analyzed bitumen meets the characteristics of the class 35/50, according to the standard NFT65-001. The ratio (immersed Resistance / dry Resistance) is the result of the Duriez test, which gives the water resistance of the coating to be compared to the standard.

The Milled

The milled used in this study are cut out from an old semi-rigid road (0/14) of the East West Highway in Bouira (Algeria).

Identification and Characteristics of the Milled

Milling must be performed to obtain items between 7 and 25 mm with a maximum water content of 3%. The test

Table 5. Results of the Marshall Test.

Tests	Laboratory LCTP	Specification
Wealth Modulus	3.62	3.45 - 3.90
Binder Content [%]	6.08	6 -7
True Density	2.38	-
Apparent Density	2.28	-
Degree of Compaction [%]	95.8	≤ 96
Marshall Stability [kg]	875	-
Flow [1/10 mm]	29	-

Table 6. Duriez Test Results.

Tests	Laboratory Results LCTP	Specification
Wealth Modulus	3.62	3.45 - 3.90
Binder Content [%]	6.30	6 -7
True Density	2.38	-
Apparent Density	2.25	-
Degree of Compaction [%]	94.5	91 - 95
Dry Resistance after 07 Days [MPa] (r)	7.6	> 7
Immersion Resistance after 07 Days [MPa] (r')	5.8	≥ 4.6
Ratio (Immersed Resistance/ Dry Resistance) (r'/r)	0.76	> 0.75

Table 7. Intrinsic Characteristic of the Milled.

Tests	Reference	Milled
Los Angeles Coefficient (LA) [%]	NA 458	23
Micro Deval Coefficient (MDE) [%]	NA 457	21

Table 8. Binder Content of Milled.

Tests	Lab. CTTP Results
Wealth Modulus k	2.86
Percentage of Binder % (6/5)	4.85
Specific Surface Aggregates ∑ [m^2/kg]	13.92
Percentage of Fines [%] < 80μm	9

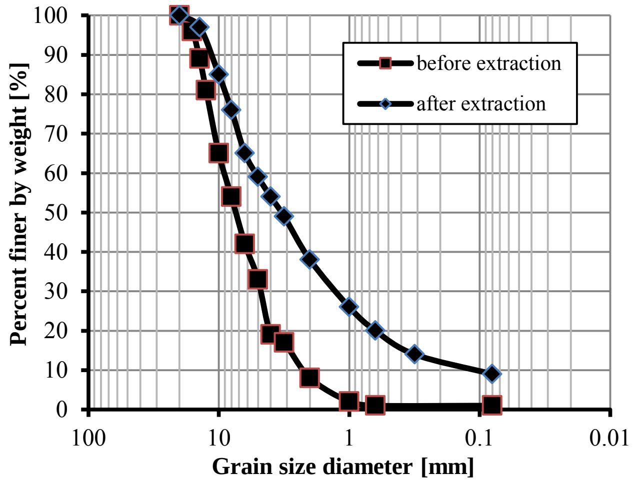

Fig. 2. Grading Curves before and after Extraction of Binder.

Table 9. Characteristics of the Aged Binder.

Tests	Results
Softening Point [°C]	60
Penetration at (25°C) [1/10 mm]	21

resistance to impact and wear gave the following results (Table 7). The Los Angeles coefficient (LA) is lower than the specification, which is 25. This coefficient shows the non-breakability of the milled aggregates. The Micro-Deval coefficient (MDE) is slightly higher than the specification, which is 20, indicating that the aggregates have poor wear resistance in the presence of water.

Table 10. Duriez and Marshall Test Results of Milled Raw.

	Average	Norm
Duriez		
Compactness [%]	84	91-95
Dry Resistance [MPa]	7.1	>7
Immersed Resistance [MPa]	4.8	-
Ratio of (Immersed Resistance/ Dry Resistance)	0.67	> 0.8
Marshall		
Compactness [%]	88	95-97
Stability [kN]	21	> 10.5
Flow [mm]	3.2	< 4
Marshall Quotient	6.56	2.5- 4.5

Size Study Before and After Binder Extraction

After recovery of milled, we move to the quartering and then the milled is sieved; the results are presented in Fig. 2. After extraction of the binder using the Kumagawa method and toluene as solvent, the results of particle size analysis are presented in the same Fig. 2.

Determination of Binder Content

The binder content is determined by weighing the specimen before and after extraction of the binder (Table 8). After recovery of bitumen, characterization tests (penetration and softening point) were conducted. The results obtained on the recovered binder (old) are presented in Table 9.

The old bitumen is relatively hard, which shows that the penetration is low and its degree of softening is slightly high compared to the standard.

Duriez and Marshall Test Results of Milled Raw

Bituminous concrete samples were made with milled crude to test the mechanical strength of the asphalt by using Duriez and Marshall tests (Table 10).

The compactness obtained with both tests is slightly lower than the norm. In addition, we recorded a low water resistance of a raw milled and a Marshall Quotient, which provides information on the strength of the material to permanent deformation in service [6], indicating that it is higher than the norm. It should therefore be mixed with new asphalt and strengthened by adding plastic.

The Plastic

The plastic is a product of PR Industry, a company that recycles plastic products mainly (plastic films, window profiles, high density polyethylene (packaging of household products)), etc. This polymer (plastomer 95%) size is 4 mm. This additive called PR-PLAST-S in the form of granules (Fig. 3) provides a triple reinforcing effect for the mix:

- A binding effect obtained by dissolving a certain amount of the polymer allowing a particular reduction of the penetration, an increase in temperature ring and ball, and a lowering of the temperature susceptibility.

Fig. 3. Plastic PR-PLAST-S Used.

Table 11. Main Features of the PR-PLAST-S.

Characteristics	Units	Reference Values
Density	g/cm^3	0.910 – 0.965
Melting Point	℃	140 - 150
Granulometry	mm	4
Load	%	Lower than 5
Plastomeres	%	Higher than 95

Table 12. The Four Formulations Tested.

Formulation	Mixtures	Milled Added [%]
A	New asphalt	0
B	New asphalt	10
C	New asphalt	20
D	New asphalt	30

- A reinforcement effect initiated by plastic fibers that build bridges within the skeleton size.
- A blocking effect due to the temporarily softened particles during the implementation. These particles will rearrange during compacting by filling the voids of the skeleton size. These three effects, which reinforce the layer, make a significant improvement in pavement performance and duration of service.

For the traditional road sector, it is used directly in the mixing of asphalt. This product is not yet tested on recycled asphalt concrete. According to Tayfur et al. [7], the polymer modified bitumen is more resistant to permanent deformation, which causes pavement damage by rutting and cracking.

Main Features of the Plastic Used

PR-PLAST-S is a plastic recycled product (cable phone plugs and plastic bottles) which is a highly branched polyethylene; its low density (0.92) confers very good flexibility. Maximum temperature of use is 80°C, and the minimal temperature is -50°C. Translucent with an excellent flexibility, it has good chemical resistance to acids, aliphatic alcohols, esters, hydrocarbons, and ether. The main features are grouped in Table 11.

As the wearing is subject to heavy loads and an aggressive climate that cause rutting, the PR-PLAST-S is an anti-rutting agent. This is why it is chosen from other families of products.

Formulations of Bituminous Mixtures

The bitumen and aggregates that are selected must be coupled to form a mixture. It must have good affinity which is determined by the possibility of wetting of the aggregates with the binder to ensure a certain level of stability, compactness, and resistance to water and creep.

Composition of Mixtures

The manufacture of asphalt in the laboratory was conducted in accordance with standard norm NFP 98-250-1. By varying the percentage of milled in the mixtures, we established four formulations (Table 12).

The formulation A composed of new asphalt is considered as the control sample. For these mixtures, we added the PR-PLAST-S by varying the percentage of addition between 0% and 8%, in 2% increments.

Mechanical Performance Test on Different Mixtures

The following tests are performed to determine the mechanical performance of asphalt concrete:

- MARSHALL test (EN 12697-34): for a given temperature and compaction energy this test determines the percentage of voids, "stability", and "creep" of a high hydrocarbon hot mixture.
- Duriez Test (NA 5226) describes a method designed to determine, for a given temperature and compaction, the water resistance of a hydrocarbon mixture at high temperature from the ratio of compressive strength with and without immersion of the specimens and the percentage of voids.

For better reuse of milled, a new asphalt as a witness was prepared first, and then we operated by varying the percentage of addition of milled while controlling the behavior of mixtures, in other words, Marshall stability, the creep, and the compressive strength at dry and immersed conditions.

In a second step, the asphalt concrete with different percentages of milled have been reinforced by plastic granulates according to the percentages ranging from 2 to 8%. Duriez and Marshall tests were then performed on the reinforced asphalt concrete.

Results and Interpretation of Marshall Tests

The Marshall method is the recommended method for the analysis and control of asphalt. In the laboratory, it measures the resistance of a specimen to the deformation in the loading phase. Marshall Test results for different prepared mixtures are shown in Fig. 5 for the Marshall stability, Fig. 6 for bulk densities, and Fig. 7 for creep.

Marshall Stability

Marshall Stability is the maximum force that the sample can handle. It assesses the susceptibility of the mix to the deterioration of the

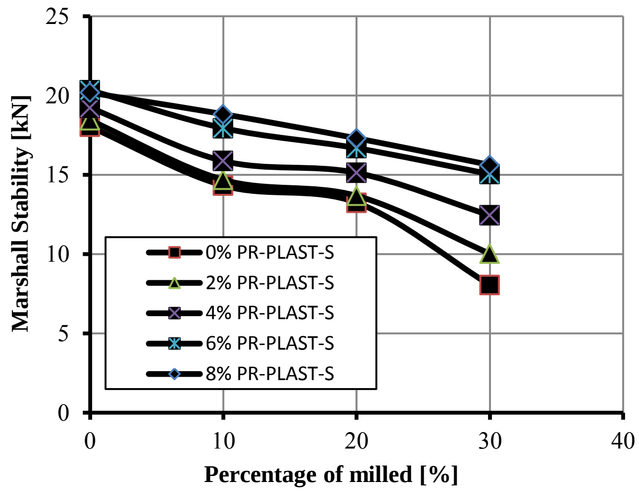

Fig. 4. Marshall Test Results Based on the Percentage of Addition of Milled and Plastic.

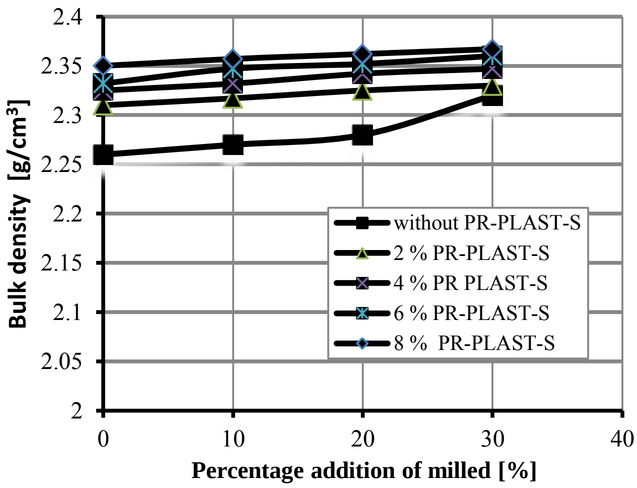

Fig. 5. Variation of Bulk Density Based on the Percentage of Addition of Milled and Plastic PR-PLAST-S.

coating or accelerated aging. The results show the variation of the Marshall Stability based on the percentage of addition of milled and PR-PLAST-S.

According to Fig. 4, the stability achieved with the first formulation without the addition is 18 MPa. This stability decreases more with the addition of milled and reaches a value of 8 MPa at 30% addition of milled. This decrease is due to the addition of milled asphalt, which is old and has lost many of its mechanical and chemical characteristics; aggregates of the different fractions were heavily worn.

Referring to Fig. 4, we see that the Marshall stability improves after addition of PR-PLAST-S. With 2% PR-PLAST-S and without addition of milled, the value of the Marshall stability was 18.44 MPa. It reaches a value of 20.98 MPa with 8%. With the addition of aggregates and milled plastic, a gradual decrease in stability for the four mixtures was recorded. However, as the percentage increases the Marshal stability improves. With 30% added milled the Marshall stability increases from 10.02 MPa with 2% addition of PR-PLAST-S to 12.44 MPa with 4%, to 15.04 MPa with 6%, and to 15.62 MPa with 8%.

The Bulk Density

The bulk density of a body is the mass per unit volume, including the air voids; at a given temperature, density and voids are the elements that characterize the mixture.

The value of bulk density in a natural state (without addition of milled) is 2.27 g/cm^3. After the addition of various percentages of milled, the bulk density gradually increases and reaches a value of 2.32 g/cm^3 at 30% addition of milled. This is due to the presence of milled in asphalt concrete which increases the degree of compaction of the mixture: the bulk densities becoming increasingly important in terms of the addition of PR-PLAST-S (Fig. 5). These values increased from 2.31 g/cm^3 without adding milled to 2.367 g/cm^3 with 30% added milled and 8% plastic. These results show that the addition of milled and plastic gives better compactness; this is explained by the fact that the milled and PR-PLAST-S reduce the voids.

Creep

The Marshall flow is the plastic deformation of a sample under a maximum force. NF P 98-251-2 (April 1992) standard specifies a test method aimed to determine, for a temperature and compaction energy given, the stability and the creep called Marshall, a hydrocarbon mixture lime. In this case, the flow is to measure the value of the sag of the specimen by its vertical diameter at the rupture (creep 1/10 mm) using a caliper.

A gradual decrease was observed with the addition of various percentages of milled. The value of creep with no milled added was 3.81 mm. This value decreased to 3.31 mm with 30% addition of milled. This decrease is a sign of increased creep resistance mainly due to the bitumen in the milled; once aged, the asphalt tends to harden.

With the addition of PR-PLAST-S, the values obtained from creep gradually decrease with the percentage of addition of milled. As the percentage of added PR-PLAST-S increases, the creep decreases. Indeed, at 2% addition of plastic creep, values increased from 3.6 mm to 2.75 mm with 30% added milled and 8% of plastic (Fig. 6).

The results of the Marshall tests show Marshall Stability at 30% addition of milled are below the specification required by the norm. After adding PR-PLAST-S, Marshall stability and resistance to creep increases from 4% in addition PR-PLAST-S and asphalt behaves like a new asphalt above 6% in addition PR-PLAST-S.

Marshall Quotient

The Marshall quotient is an indicator of resistance to permanent deformation to the shear strength and for rutting of asphalt. Larger values of the quotient indicates that mixtures are more resistant to permanent deformation knowing that they are considered the leading cause of damage to the hot asphalt [8]. The evolution of the Marshall quotient based on the percentage of added PR-PLAST-S and milled is shown in Fig. 7. The Marshall Quotient clearly shows that the mixtures are resistant to permanent deformation. The addition of plastic pellets has achieved the best resistance to

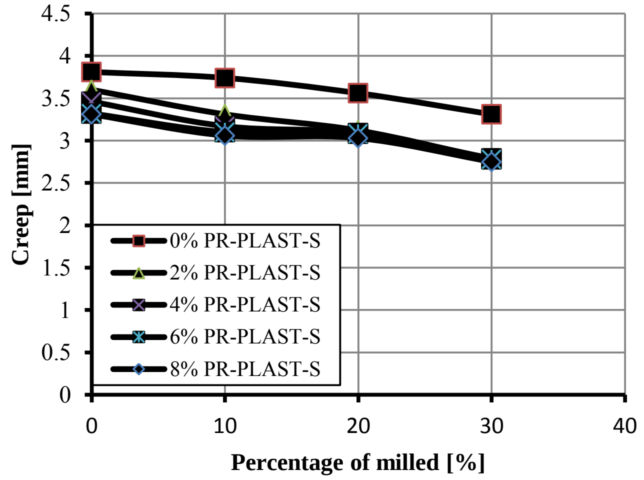

Fig. 6. Variation of Creep Based on the Percentage of Addition of Milled and Plastic PR-PLAST-S.

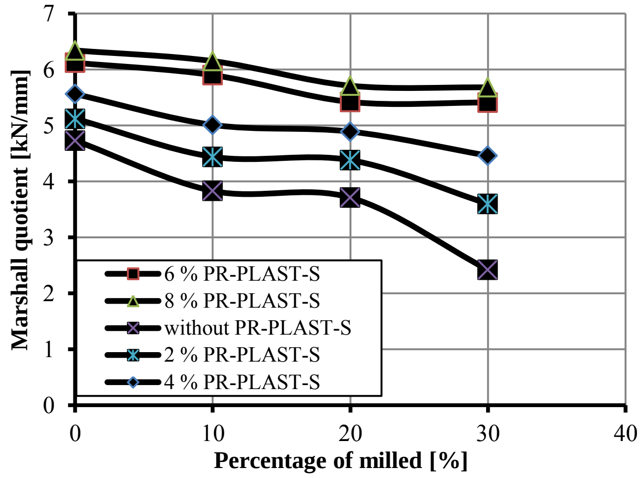

Fig. 7. Evolution of the Marshall Quotient Based on the Percentage of Added PR-PLAST-S and Milled.

permanent deformation.

Duriez Test Results and Interpretations

Duriez test results with the addition of milled and plastic PR-PLAST-S are given in Figs. 8, 9, and 10, respectively, for the apparent density, the compression strength at dry conditions, and the wet compressive strength.

Bulk Density

Bulk density is the ratio between the mass of the sample and its apparent volume. The value of bulk density without adding milled and PR-PLAST-S, at its natural state, is 2.24 g/cm^3. This value increases with the various percentages of milled to reach the value of 2.32 g/cm^3 at 30% addition of milled. With the addition of PR-PLAST-S, the bulk densities become more important and reach the value of 2.34 g/cm^3 at 30% addition of milled and 8% of plastic (Fig. 8). The addition of milled and PR-PLAST-S helps occupy the voids leading to an improvement of the bulk density of the mixture.

The Compressive Strength in Air at 18°C

Fig. 9 shows the variation of compressive strength in air at 18°C, depending on the percentage of addition of milled and plastic. The compressive strength in air at 18°C gradually decreases according to the percentage of addition of milled. It goes from a value of 13.02 MPa (without addition of milled) to 12.48 MPa at 30% of milled. This decrease is probably related to the resistance of the milled granules that are less resistant compared to the new aggregates and the aged bitumen contained in the milled.

With the addition of PR-PLAST-S, for a set of plastic content, the compressive strength in air at 18°C, decreases slowly with the percentage of addition of milled. The higher the percentage of plastic, the higher the compressive strength for any percentage of milled considered. Indeed, it increased from 12.65 MPa with 30% addition of milled to 13.21 MPa with 30% and 2% milled plastic; furthermore, it increased to 17.37 MPa with 30% and 8% milled plastic (Fig. 9).

The Compressive Strength of Immersion

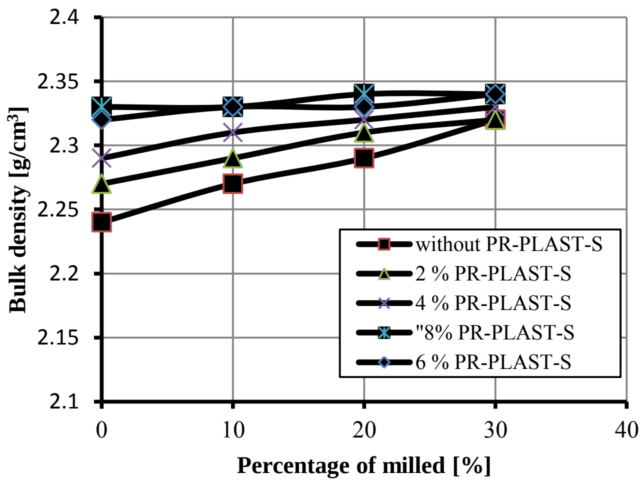

Fig. 8. Variation of Bulk Density Based on the Percentage of Addition of Milled and Plastic PR-PLAST-S.

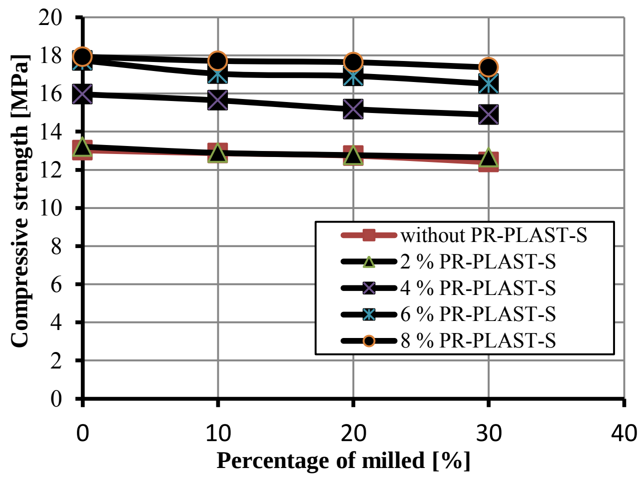

Fig. 9. Variation of Compressive Strength in Air at 18°C According to the Percentage of Addition of Milled and Plastic PR-PLAST-S.

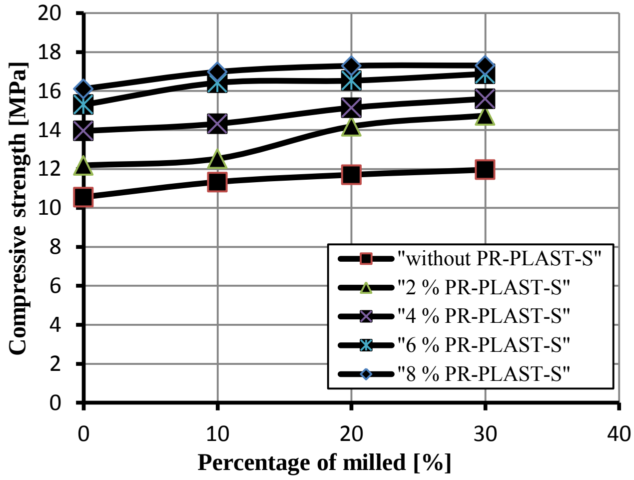

Fig. 10. Variation of Compressive Strength in Immersion, According to the Percentage of Addition of Milled and Plastic PR-PLAST-S.

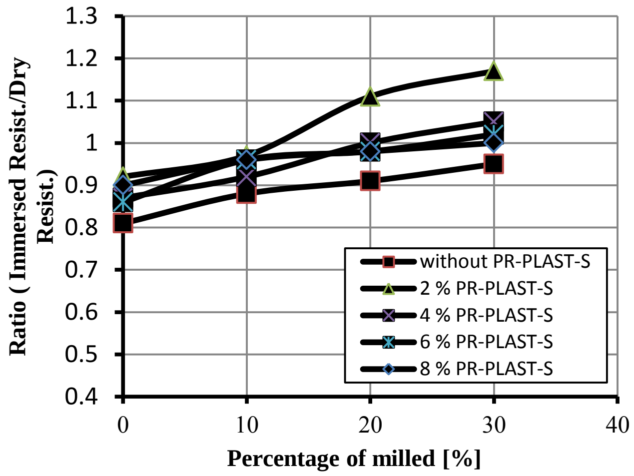

Fig. 11. Evolution of the Ratio of Resistance after Immersion in Dry Strength for the Different Formulas.

Fig. 10 shows the variation of compressive strength in immersion, according to the percentage of addition of milled and plastic.

The compressive strength increases progressively simultaneously with the percentage of adding milled and plastic. Indeed, it rose from 10.56 MPa without milled to 17.29 MPa with 30% added milled and 8% in plastic (Fig. 10). This increase in compressive strength is not only due to the presence of old milled but also to PR-PLAST-S which is very strong and flexible.

According to the results of Duriez tests carried out with addition of milled, the ratio of the immersion resistance to the dry resistance changes with the increase in the percentage of addition of milled. This shows that the milled material resists compression well. This resistance is due to a mixture of old bitumen with new asphalt, which becomes soft once out of the oven; this makes it more resistant to compression.

Ratio of Immersion Resistance to Dry Resistance

This ratio, with or without immersion, is used to characterize the water resistance of asphalt concrete. The ratio of immersion to dry resistance for different formulas with or without reinforcement conforms to the SETRA-LCPC specifications. Indeed, all formulas have better performance in terms of compressive strength especially after the reinforcing with PR-PLAST-S.

Conclusion

This work clearly shows the advantages in the process of building aggregate recycled asphalt concrete with recycled plastics (PR-PLAST-S). On one hand, it allowed industrial waste milled up to 30% to be recycled, and the plastic pellets up to 8%; on the other hand, it allowed asphalt formulas with a low resistance to permanent deformation.

The experimental study is conducted on a series of tests on different mixtures made from recycled asphalt concrete and aggregates plastic for better reuse of the latter in the stress path. The test results with the addition of different percentages of milled show clearly that recycling of pavements can be performed without restrictions up to 30% milled, although the Marshall stability is low at this percentage. However, the creep stability ratio called Marshall Quotient (MQ) clearly shows that the mixtures are resistant to permanent deformation. After strengthening with plastic pellets, mixtures behave like new asphalt above 6% addition of plastic.

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