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Plastic Waste Sheets Effects on Reclaimed Asphalt Pavement Performances

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Abstract

This paper aims to examine physical and mechanical performances of a Reclaimed asphalt pavement (RAP) material reinforced with 5 to 15 mm size sheets of plastic waste. The three types of plastic used in the study are: low density polyethylene (LDPE), high density polyethylene (HDPE) and polyethylene terephthalate (PET) with 1%, 1.5%, and 2% dosage by weight of aggregates.
Obtained Duriez test results testify to a 9% to 30% improvement in moisture resistance for all types of plastic compared to virgin mixture while for LDPE waste plastic type workability test attests an acceptable compaction condition for RAP material with less than 1.5% of waste plastic.
Nevertheless, it has been noticed an increase in void index and compaction difficulties starting from 1.5% dosage, resistance to rutting has also improved with the addition of waste plastic, an improvement in fatigue strength was also observed particularly at 2% dosage.

Keywords: pavement, aged bitumen, RAP material, plastic waste, plastic recycling, rutting, fatigue

1 Introduction

Rutting and cracking of roads and highways surface layer built with asphalt concrete could be signs of pavement aging, however they might also be pathologies related to fatigue, manufacturing, or design defects such as poorly adapted mixture design or even inadequate material quality. The increase in road traffic, particularly heavy trucks, accelerates pavements deterioration, mainly the wearing course. Road rehabilitation requires the manufacture of new materials based on increasingly scarce, expensive, and polluting raw materials. Old materials Recycling is an excellent alternative to save energy reduce costs and protect the environment. For the past few decades, the reuse of materials from old pavements milling has become a widely used technique throughout the world, and research is leaning towards both mobilizing the maximum amount of recycled materials and optimizing their performance.
Several studies have evaluated the air pollution by CO_2 gas emission following the production of asphalt mixes, thus a ton of hot mix asphalt emits 48 kg of CO_2 [1], according to national

and European Asphalt Pavement Association [2] in an environmental impact study, this emission can reach 50 kg/t.

As a result, the introduction of recycled asphalt aggregates can dramatically reduce greenhouse gases and reduce the energy required to manufacture and process the raw materials, it is indicated that increasing RAP materials in the mix to just 25% will reduce greenhouse gases by 10% over the overall life cycle by eliminating the fuel consumption required to manufacture and process virgin asphalt raw materials [3]. However, other studies have shown that the use of RAP at 30% and 70% reduces CO_2 emissions by 20% and 35% respectively [4-5].

Technical advantages have also been reported in numerous studies and research, for example, the long-term performance of asphalt concrete (AC) pavements was examined using virgin asphalt mixtures and were compared to those containing only 30% RAP, it was found that the latter performed better than virgin mixtures in terms of rutting and roughness [6], However the addition of aged binders to bituminous mixtures especially at high rates has generally changed the relatively soft binder which is common at both high and low temperatures, by one grade [7].

For this purpose, the introduction of additives of certain types and at certain dosages, could be one of the best remedies to overcome the inadequacies and shortcomings in the use of RAP products at high rates. The quality of binder has a close impact on that of mixes, indeed, to act on the properties of recycled materials, particularly bituminous concretes, in order to rectify certain performances, the understanding of bitumen ageing phenomenon and its new characteristics would be essential.

Multiple searches aimed at improving the quality of aged bitumen by lowering its rigidity and restoring its adhesive capacity. Studies have shown that the incorporation of additives called regenerators or rejuvenators in bitumen matrix, as the example of certain oils, substantially improves the quality of bitumen.
Polymer-based modification of aged bitumen has also shown its effectiveness in correcting mixtures characteristics [8], bitumen modification is mainly done by the so-called wet method where polymer particles are introduced into the binder, on the other hand the so-called dry method consists in incorporating these plastic additives into the mixture during mixing [9-10].
A literature review on the effects of widely used recycled plastics (LDPE, HDPE, PET, PP) on virgin asphalt mixes performances, which may also concern aged bitumen, has been carried out by [11], it was illustrated that polymers and plastics offered a better Marshall stability, thus in general, the addition of plastic waste increases fatigue cracking resistance, nevertheless this resistance occurs essentially from the dosage of 4.5% by weight of bitumen. This improvement is due to the fact that the addition of polymer increases the tensile strength and elastic response in the binder, properties that are strictly related to G^* and δ in the DSR (Dynamic Shear Rheometer) tests [12].

In a recent study, it was confirmed that waste plastics used in bituminous mixes, have no negative impact on the environment (leachability) and / or worker safety (harmful fumes) [13]. several research works found that heating of waste in the range of 109 to 180 C in controlled conditions are not emitting toxic gases, emission will start if we heat beyond 270° C [14].
However, in the literature, only little research has been carried out on the use of polymers derived from recycling (plastic waste) in RAP material, although the majority of the work focused on the use of polymer granules of a few millimeters (1 to 4 mm) to modify bitumen by wet method [15]. In our study we will use instead leaves of about 5 to 15 mm in size from the

shredded plastic waste using dry process; this means we are not looking for modifying bitumen but examining plastic sheets effects on RAP material.
The current research doesn't consist in modifying aged bitumen, nevertheless it consists in exploring physical and mechanical performances of a RAP material reinforced with sheets (in sheet shape) of three types of plastic waste (LDPE, HDPE, PET) with different dosages 0%, 1%, 1.5%, 2% by weight of aggregates, the mixture at 0% is considered each time as a control sample. We have tested moisture resistance for mixtures with all types of plastic and then we chose a RAP material with LDPE to undergo a series of tests to characterize it in relation to specifications of virgin bituminous materials.

The choice of polymer types was made based on their high availability as waste generated from everyday plastic objects [16, 17]. Polymer dosages and their ranges were set taking into consideration dosages used in literature [14-19], however an extension of plastic amount incorporated in the mixtures was adopted after several attempts and experiences to better understand material behavior beyond dosages usually practiced in previous Polymer Modified Bitumen (PMB) researches.

2 Materials and Methods

2.1 Origin of Materials

RAP material used in this research comes from the mechanical milling of asphalt concrete layer during the rehabilitation of National Road N^{o} 27 in the region of Mila (Algeria). The removed wearing course was laid in 2009 and has since undergone local degradation such as rutting and cracking. Archive documents of Roads and Bridges Services permitted the identification of the material mixing design and characteristics of different components as well as the control results related to material implementation.
Plastic waste comes from the industry that recovers various household or industrial objects and articles in the same region. Waste is collected and sorted by type of polymer, then washed with hot water and household detergents, and crushed to different particle sizes. The LDPE products come from soft plastic objects, packaging, bags etc. HDPE products come from rigid piping and packaging, PET plastic comes mainly from soda and mineral water bottles.

2.2 Material Characterization

2.2.1 RAP Material

RAP material was about 10 years old at the time of sampling on site; archive documents reveal a 35/50 grade bitumen with 5.25% binder content, while the aggregates came from a limestone rock. Some characterization tests of the material were carried out, namely:

- Binder content by the distillation column extraction

The results obtained for three samples tested are presented in Table 1.

Table 1: Binder content of RAP material

	Standard	Sample 1	Sample 2	Sample 3	Average
Binder content %	NF EN 12697-4	5.19	5.11	5.16	5.15

- Recovered RAP material aggregate gradation

After extracting bitumen from aggregates, and in accordance with the method of NF EN 12697-2 standard, the recovered material (gravel and sand) will be subjected to a sieve analysis by placing it in relation to a BBSG 0/14 type spindle, as shown in Figure 1, we notice a content of fine elements close to the upper limit due to the milling process that increases their amount by breaking up the aggregates and decreasing their size.

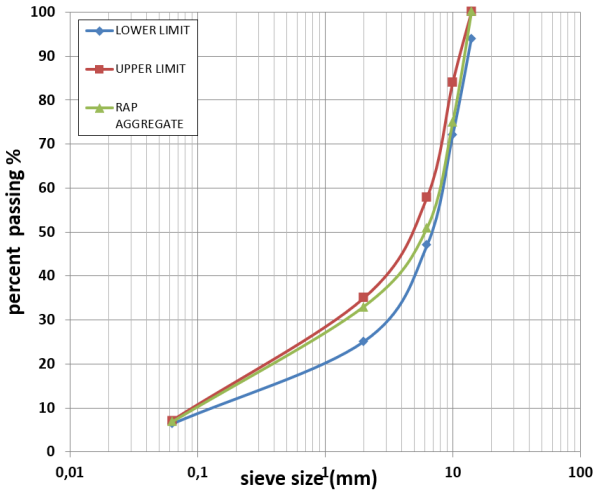


Figure 1: Recovered RAP material aggregate gradation

- Aggregates and sand characterization

Aggregates and sand characterization tests were carried out in accordance with the corresponding standards, density NF EN 1097-6, Los Angeles abrasion test NF EN 1097-2, Micro Deval abrasion test NF EN 1097-1, results obtained are given in Table 2.

Table 2: Characteristics of aggregates and sand of RAP material

	Standard	Value
Density (g/cm^3)	NF EN 1097-6	2.63
LA %	NF EN 1097-2	26
MDE %	NF EN 1097-1	18

2.2.2 Plastic Waste

Plastic sheets have a maximum dimension of about 15 mm, and a thickness of between 1 and 2 mm. They have been washed with household detergent and dried before being put in separate boxes with marking according to polymer type (Figure 2).

Some characteristics were given by the supplier (particle gradation curve, density), others were determined in our research (softening & melting temperature); Table 3 gives some physical characteristics of waste according to plastic type, while Figure 3 shows particle gradation curve of each polymer.

Table 3: Polymer additives characteristics (plastic sheets)

	Standard	**LDPE**	**HDPE**	**PET**
Density (g/cm^3)	NF EN ISO 3838	0.926	0.979	1.188
Softening temperature ° C	EN ISO 2507	121	134	155
Fusion point ° C	NF EN ISO 3146	185	204	226



Figure 2: Washing and drying of plastic waste

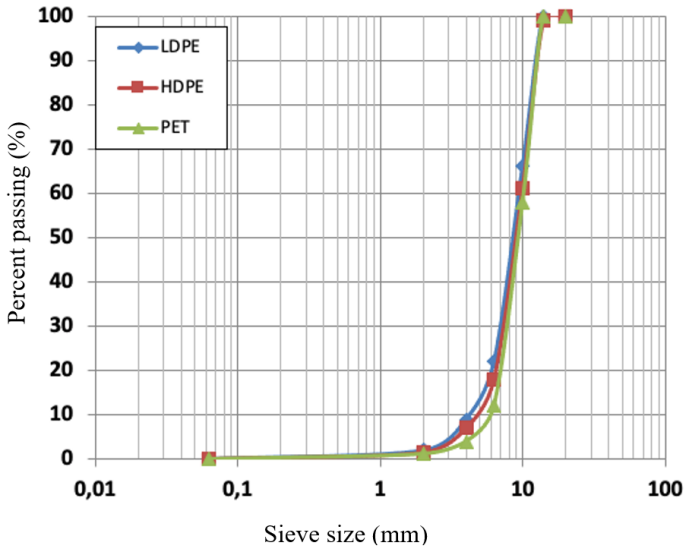


Figure 3: Plastic particle gradation curve of each polymer

2.3 Sample Preparation

RAP material has not undergone any treatment or addition of bitumen; the binder content has been maintained the same. It is heated in a tray at a temperature of 180° C for about 2 hours, while plastic waste is placed in a tray and heated separately in an oven at a temperature of 110° C for 2 hours.

For each type of polymer (LDPE, HDPE, PET), the desired mixture consists of RAP material and plastic waste in different percentages, namely: 0%, 1%, 1.5%, 2% by weight of aggregates.

In a mixer preheated to 180° C, bituminous material is poured into the mixer and rotated at a speed of 200 rpm. Plastic sheets are gradually introduced in order to have a homogeneous mixture; the whole is left to rotate for 2 to 5 minutes depending on mixture quantity.

2.4 Methodology and Test Program

Laboratory tests carried out were conducted in accordance with European standards including sample preparation, procedure, presentation and interpretation of results, standards adopted for each test are given as follows; moisture resistance "Duriez" (NF EN 12697-12 + NF P 98-251-1), SGC test (Superpave Gyratory Compactor) NF EN 12697-31 or PCG in French standards, rutting test NF EN 12697-22 *FWTT* (French Wheel Tracking Test), fatigue resistance NF EN 12697-24. The following tables (Table 4-7) give specifications on the results for each test:

Table 4: Allowable values of Duriez test results

Mixture type (Bitumen grade 35/50)	**Standard**	**r/R**
BBSG*	NF EN 12697-12	0.70
BBME*		0.80

*BBSG (semi-granular bituminous concrete), BBME (high modulus mixes)

Table 5: Specification of void index values in accordance with the recommendations of LCPC (Central Laboratory of Bridges and Roads – Paris - France) [20]

Gyrations Nbr	**Standard**	**void index V (Specifications)**
09	NF EN 12697-31	≥ 11 %
80		≤ 08 %
120		≥ 04 %
200		≥ 02 %

Table 6: Permissible rut depth values

Mixture type (Bitumen grade 35/50)	**Standard**	**Mixture class**	**Number of cycles**	**Depth (mm)**
BBSG/BBME	NF EN 12697-22	1	30 000	≤ 10% (P_{10})
		2	30 000	≤ 7.5% ($P_{7,5}$)
		3	30 000	≤ 5% (P_5)

Table 7: Fatigue resistance permissible values [21]

Mixture type	Standard	Class	Specification in fatigue ε_6 10° C 25 Hz in µdef
BBSG	NF EN 12697-24	1 to 3	≥ 100 $(\varepsilon_{6\text{-}100})$
BBME		1	≥ 100 $(\varepsilon_{6\text{-}100})$
BBME		2 and 3	≥ 100 $(\varepsilon_{6\text{-}100})$

3 Results and Discussion

3.1 Moisture Resistance (Sensitivity) Test (Duriez)

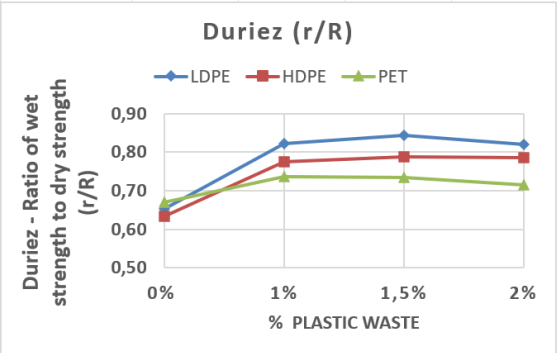


Figure 4: r/R variation as a function of plastic waste type and dosage

Figure 4 illustrates the r/R variation as a function of plastic waste type and dosage, it should be noted that for LDPE & HDPE r/R ratio increases with the dosage of 1% and 1.5% then begins to decrease slightly for LDPE but it stabilizes for the HDPE in the range of 1.5% up to 2% dosage, however r/R ratio increases with 1% of PET and then mixture maintains a plato in the range of 1% up to 1.5% dosage and then starts to decrease, LDPE seems to be less sensitive to moisture with a 30% increase in r/R value at dosage of 1.5% (r/R=0.82), HDPE increased this value by 21% at a dosage of 1.5% and 2% (r/R=0.79) while PET caused only a slight increase of about 9% at a dosage of 1% and 1.5% (r/R =0,72).

A study of Marshall stability in PMB found an improvement in Marshall Quotient with 7.5% PET [14], on the other hand it was indicated a 50% improvement with 4% HDPE all by weight of bitumen [22], these dosage values used to modify bitumen seem to be lower than the dosage we have used (1 to 2% by weight of aggregate equals approx. 20 to 40 % by weight of bitumen). Increase in moisture resistance in RAP material with 1 and 1.5 % dosage is due to the increased adhesiveness in mix that was lost during bitumen aging [23], indeed plastic adheres to aggregates when it softens at the mix preparation temperature (180° C), the closer softening and melting temperatures of plastic are to those of bitumen (Table 3), the greater adhesion increases between mix components, furthermore plastic combines in part with binder [20] which strengthens their bonds. For the PET and due to its high softening temperature relative to LDPE and HDPE, it adheres less strongly to aggregates, nevertheless the decrease in moisture resistance starting from 1.5% of plastic dosage is due to the increase in void index which permits

to water to infiltrate and weaken the material bonds, though compressive resistance doesn't really decrease after 1.5% dosage.

3.2 Compactivity and Workability Test (Superpave Gyratory Compactor)

Six specimens for each type and dosage of plastic (0%, 1%, 1.5%, 2%) were prepared (72 specimens in total), value retained corresponds to the average of the six results found. Figure 5 shows void index regression curves in relation to gyration number for each LDPE plastic waste dosage.

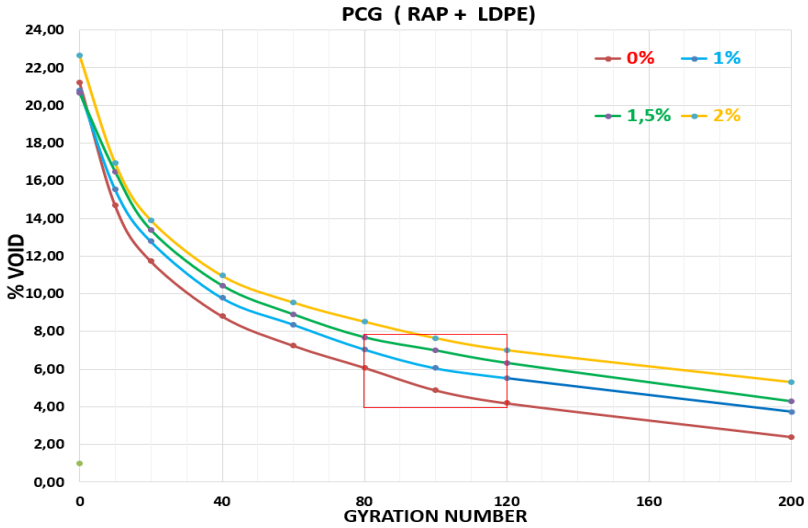


Figure 5: Void index regression curves in relation to gyration number for each LDPE plastic waste dosage

The graph clearly shows that void index increases proportionally with addition of sheets, thus at 80 gyrations and for a dosage varying from 0% (RAP alone) to 2% of plastic, void index increases from 6.1% to 8.8% for LDPE.
At the end of test cycle (200 rotations), for the same variation in dosage (0 to 2%), void index increases from 2.4% to 5.3% for LDPE blend.
In terms of specifications (Table 5), void index values of specimens with 1% and 1.5% of dosage are in conformity, mixture with 2% of LDPE plastic is out of tolerance.
The increase in void index with plastic waste addition is explained by the presence of plastic particles, the plastic sheets were heated to only 110 degrees so as not to stick to each other and then rotate with the bituminous mixture for 2 to 5 minutes which does not allow them to melt sufficiently and fill the voids during compaction especially since these particles were not taken into account during the mixture design [24], this fact is not generally observed in PMB researches according to the literature when void index doesn't increase this way because of fine plastic aggregates used which combine with bitumen and fill void [20].

3.3 Rutting Test (FWTT)

Figure 6 shows the rut depth curves of each mix in relation to cycle number of test wheel.

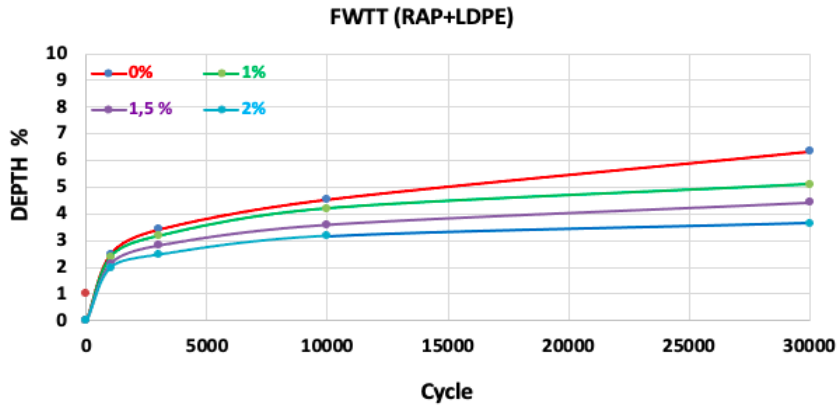


Figure 6: Rut depth curves RAP+LDPE

Curves of rutting test above show that addition of LDPE plastic sheets proportionally increases RAP material resistance to permanent deformation in a substantial way. Indeed, for a plastic dosage varying from 0% (RAP alone) to 2%, rut depth for the RAP with LDPE goes from 6,4 mm to 3.7 mm, these results are in line with those found by [18] with the use of 4% LDPE by weight of bitumen.
Result of plastic waste addition is visible on RAP mixture in this test due to the increase in material stiffness [25-26]. Indeed, this was possible according to compressive strength values in Duriez test (r/R), which gives an indication of material behavior with respect to strain stresses. It is confirmed that values obtained for 30 000 cycles could correspond to 3rd class BBSG /BBME according to Table 6 [20], starting from 1.5% of dosage.

3.4 Fatigue Test

For deformation levels ranging from 87 to µ126 def. Figure 7 shows fatigue curves (Wöhler curves) for LDPE plastic in a semi-logarithmic graph.

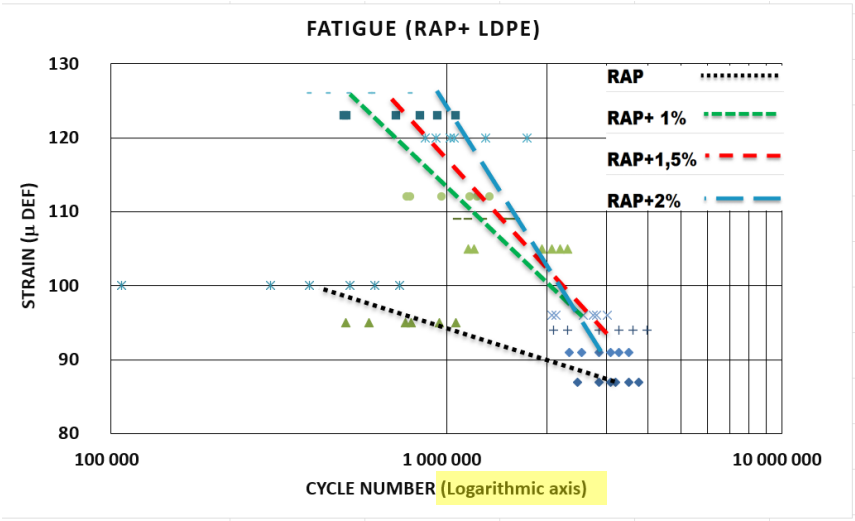


Figure 7: Fatigue curve RAP + LDPE

The general trend of curves shows a clear improvement in fatigue resistance while increasing plastic dosage, however RAP mixture with 2% LDPE plastic sheets added have better fatigue resistance with ε_6 values above 120μdef (specification value ≥ 100 μdef).
Results obtained are due to the increase in tensile strength and enhancement of elastic property in binder due to addition of plastic [12] besides they are due to reinforcement of granular structure of mixture by plastic that adheres to aggregates to form solid bonds and provides a bridging effect in the mixture [27]. Results of the same trend have been found by [28] who showed that addition of more than 10% PET by weight of bitumen, improves fatigue resistance of bituminous mixtures even though they worked on PMB with PET plastic than LDPE and with smaller size particles.

4 Conclusion

According to obtained results from various characterization tests carried out on RAP material reinforced with plastic waste sheets, we note in overall a clear improvement in mechanical performances at precise dosages and for certain types of polymers while the physical characteristics, precisely the void index, will become poor for high plastic dosages, nevertheless very few are similar researches using plastic sheets (5 to 15mm), most of studies are rather directed towards bitumen modification (wet method) with grains of inferior size (1 to 4 mm).
Indeed, addition of LDPE waste to RAP material improved its moisture sensitivity by increasing its compressive strength of 30% at a dosage of 1.5% while HDPE caused a 21% improvement at a dosage of 1.5% and 9% at a dosage of 1% for PET.
The workability test reveals that the addition of plastic waste sheets increases void index values for any type of polymer. It was found that PET comes first followed by HDPE and then LDPE in terms of increasing voids in material. Void index values at 1% dosage for all three types of plastics are within specification, at 1.5% dosage, blend values are acceptable except for material with PET. In addition, mixtures with 2% of all types of plastic are out of tolerance, this means that workability starts to be confused at 1.5% and up of plastic dosage where compaction becomes difficult.
In resistance to permanent deformation test, it is concluded that addition of plastic waste to RAP material leads to results in favor of excellent rutting resistance, mixes submitted for study correspond well to 3rd class BBSG /BBME [20], starting from dosage of 1.5% plastic waste for all types used.
Fatigue resistance of RAP material with different plastic types and dosages was tested, results found express clear improvement in fatigue resistance while increasing plastic dosage particularly with LDPE and HDPE.
Plastic additives used in sheets shape have a key role in creating bonds or bridges between aggregates, thus consolidating the material structure to better withstand different stresses. As a result, the current research was able to highlight physical and mechanical performances of 100% RAP material with recycling plastics in sheets shape, LDPE and HDPE in particular, at a dosage of 1 and 1.5% beyond which workability becomes failing.

It is recommended to study a possible combination of plastic with bitumen addition in order to adjust void index which is considered pivotal in bituminous mixtures quality.

Acknowledgement

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