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The Effect of Low-Density Polyethylene Addition and Temperature on Creep-recovery Behavior of Hot Mix Asphalt

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Abstract

Industrial and domestic plastic waste is second harmful products to the environment. Considering the technological development and the current way of life, this non-biodegradable waste and its enormous quantities threaten the balance of the ecosystem and human health. The present study was an attempt to investigate the effect of Low-density polyethylene "LDPE" plastic waste, used us asphalt additive, on creep-recovery behavior of Hot Mix Asphalt (HMA). This technique is a contribution to the improvement of the quality and cost of HMA, for alternate materials. In this experimental study, two mixes of asphalts were prepared, basic and modified asphalts, and tested in four points bending test at two different temperatures, medium (20°C) and high temperature (50°C). The use of 5 % of LDPE gave a better thermo-mechanical performance. As well as, a decrease in total deformation by 51 % and 13 % at 20°C and 50°C respectively. A clear improvement of the resistance to the creep permanent deformation, rigidity and lasted in life. This modification serves a powerful, economic and environmental solution for road construction of hot Saharan areas at medium and high temperature of service.

Keywords: Creep-recovery Deformation; Hot Mix Asphalt; Plastic Waste; Modification; Temperature; Performance.

1. Introduction

Hot mix asphalt (HMA), is a type of highway flexible pavement material, formed by mixing of aggregate and bitumen at certain ratios and compacting the resulting mixture at a certain temperature [1]. Researches have cited various factors that affect flexible course performance like the component properties (binder, aggregate, as well as additive) and their proportion in the mix [2]. Asphalt pavement is exposed to a variety of destructive factors, which lead to reduction of their shelf life over time. Considering the high cost of pavement building operations, some necessary measures should be taken to avoid asphalt destruction and mitigate pavement failures [3].

Given the rapid development in various activities, Today plastic is everywhere in our way of life. The use of such non-biodegradable material show that plastic can remain unchanging for 4,500 years in the earth and has generated large volumes of domestic and industrial plastic waste that threaten our environment and the life of humanity, flora and fauna [4]. It is the intention of scientists and researchers, as well as people in authority, to explore waste material recycling for environmental, economical advantages and also the possibility of solid waste reuse in road construction. Reusing waste materials can make a significant contribution to the environment and economy from different aspects, [5, 6].

The first patent registration of asphalt modification processes with both synthetic and natural polymers date back to 1843. Furthermore, experimental projects had already commenced across Europe in the 1930s .The use of modified

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asphalt was actually used first in the late 1970s in Europe. The employed contractors could give warranties and encourage greater motivation and interest in recycling waste material in construction due to their lower costs even if the initial expenses appeared to be higher [7]. In the modern era, however, the first serious utilization of such polymers in fiber reinforcement started in the early 1990s [8].

The polymers utilized to modify asphalt can be classified into three main groups, namely: thermoplastic elastomers, plastomers, and reactive polymers. The use of waste thermoplastics is currently being considered for bitumen modification. Plastics are low-density durable, formable and low-cost materials which, owning to their properties, are widely used in many areas, sectors and industries. There are seven types of plastics: PET (polyethylene terephthalate), HDPE (high-density polyethylene), PVC (polyvinyl chloride), LDPE (low-density polyethylene), PP (polypropylene), PS (polystyrene), and other types of plastics [9]. India, UK, and Ireland are the most experienced countries in looking for new applications for plastic waste including their use in asphalt mixes [10]. The use of plastic wastes in construction of flexible road pavement started in the year 2000. Bitumen plays the role of binding the aggregate together by coating over the aggregate in the construction of flexible pavements. It also improves the strength and life of road pavements. But its resistance towards water is weak. Waste plastics (polythene carry bags, etc.) soften on heating at around 130°C. Thermo gravimetric analysis has shown that there is no gas evolution in the temperature range of 130-180°C. Softened plastics have a binding property. Hence, it can be used as a binder for road construction. Improvement in properties like Marshall Stability, retained stability, indirect tensile strength and rutting was observed in Plastic modified bituminous concrete mixes [11-18]. It was observed that the stiffness increased by 10% for the chemically modified bituminous mixtures. This improvement is attributed to an increase in the bonding forces between the aggregates and the bitumen [19]. The coating of plastic reduces the porosity & absorption of moisture [20].

The addition of polyethylene leads to a strong increase in the rigidity of material like to a reduction of thermic susceptibility to the high temperatures of service. The applications which are made of these properties are mainly the use out of antiorniérant bituminous mix, and to a lesser extent in layer of reinforcement or to allow the use of materials of weak angularity [14]. The incorporation of different waste materials improves some important properties of the conventional bitumen. Such improvements might indicate a good behaviour at medium/high temperatures and an increase of fatigue and rutting resistance [21]. Recycled polyethylene increases viscosity, cohesive strength and heat resistance of bitumen [22].

The uses of plastic waste help in substantially improving the abrasion and slip resistance of flexible pavement and also allows to obtain values of splitting tensile strength satisfied the specified limits while plastic waste content is beyond 30% by weight of mix [23] .

The waste shredded plastic of size 2 mm to 8 mm of LDPE was used to coat stone aggregates so as to make them as polymer coated aggregate before they were mixed in hot mix plant. The use of 0.76% waste plastic by weight of aggregate and 3% filler significantly improve the volumetric properties of bituminous mixes resulting better performance of BC with plastic waste than control mix [24]. Use of recycled plastics composed predominantly of polypropylene and low density polyethylene in plain bituminous concrete mixtures with increased durability and improved fatigue life. Resistance to the deformation of the asphaltic concrete modified with polythene of low density was improved [25, 26]. When RPE added to bitumen results in a remarkable modification of its rheological response. In the intermediate and high in-service temperature region, RPE modification leads to an increase in the values of the storage and loss moduli, and viscosity, as well as an apparent decrease in thermal susceptibility [27]. By using plastic (LDPE-PP) as a coating over aggregates, the properties of aggregates improved. The plastic coated aggregate samples are more stable than polymer modified bitumen [28]. The asphalt mix with polymer (LDPE plastic waste) presents an increase in stability and a decrease of creep. The best formulation was obtained with adding 5 % of LDPE, which increases the resistance by 16 % relative to witness asphalt [29].

In the present study, attempts are made to use LDPE plastic waste as an additive to improve the asphalt performances. And reduce costs and energy consumption, for an important step towards environmental protection.

2. Materials and Methods

The materials used in this study are: aggregate, bitumen and LDPE plastic waste.

2.1. Aggregate

Three granular fractions (S: 0/3, G1: 3/8 and G2: 8/15) and filler are used in the formulation of Hot Asphalt Mix. In Figure 1, the mix curve has been presented.

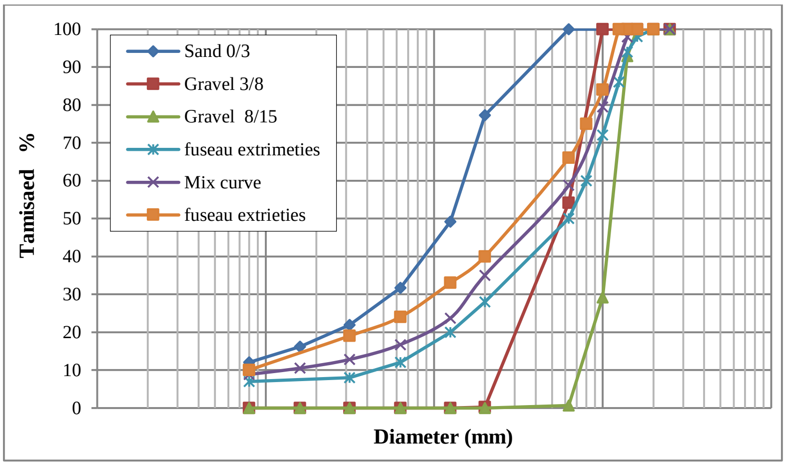

Figure 1. Granulometric curve of the mix curve

In the Table1, the intrinsic characteristics of aggregates has been presented.

Table 1. Intrinsic characteristics of aggregate

	Granular class		
Test	0/3	3/8	8/15
Cleanliness (%)	-	1.21	0.60
Sand equivalent (%)	68.33	-	-
Sand finesse module	3.03	-	-
Los Angeles (%)	-	-	23
Micro-deval (%)	-	-	17.50
Aapparent volumetric mass kg/l	1.47	1.30	1.30
Absoulte volumetric mass kg/l	2.65	2.66	2.70
Flattening coefficient (%)	-	23.73	15.15
Sand friability Coefficient (%)	48	-	-

2.2. Bitumen

The most commonly bitumen used for road building in our region (south of Algeria) is the bitumen with classification 40/50. It has the following characteristics.

Table 2. Characteristics of pure bitumen

Description	Reference standard	Value
Needle penetration in 1/10 mm at 25 ° C.	NFT66-004	49
Softening point (°C)	NFT66-00	51
Relative density at 25 ° C	NFT66-007	1.03

2.3. Plastic Waste (LDPE)

The plastic waste material used for modified asphalt mix is Low-density polyethylene “LDPE” from plastic bags waste: obtained by shredding using blades of plastic bags (Figure 2). These are shaped casks very thin thickness ranging from 1 to 3 mm^2 (Figure 3), with a melting temperature of 130 -140 °C, and density value equal to 0.950 g/cm^3.

Figure 2. Plastic bag waste (LDPE)

Figure 3. Shredded Plastic bag waste

3. Experiments and Mixing Designs

3.1. Preparation of Specimens

To prepare a modified mix, there are two main processes. In the first process, the polymer can be added directly to the bitumen to obtain a PMB (Polymer Modified Bitumen) [30]. In parallel, some modifiers are rather added in asphalt mixing plant as additives, at the same time as the aggregates. This is the second method. The behavior of the mixtures therefore changes either the granular skeleton or the binder, or both. This process is used in our study. Modification of the asphalt with 5 % plastic waste (LDPE) of bitumen weight gives the most stable optimal formulation [29] that will be retained for the creep-recovery tests.

The preparation of test specimens has gone through several steps:

a) Mixing preparation (kneading at 160 ° C):

In this procedure, the LDPE was added directly to the mixer as an additive at the same time as the aggregates. In this case, bitumen and polymer do not have time to obtain the morphology of a modified binder. The behavior of the mixtures therefore changes either the granular skeleton or the binder, or both.

b) Compaction of the mix (plate compactor size 40 cm x 30 cm):

The compaction was carried out following the European standard (EN 12697-33: 2003) using the compactor (Figure 4) with a mild steel roller (it is a static compactor with a self-propelled mechanical cylinder with forward / reverse). This plate has been sawn into several 20×20×5 cm prismatic specimens (Figure 6) according to the creep-recovery test conditions that will be realized.

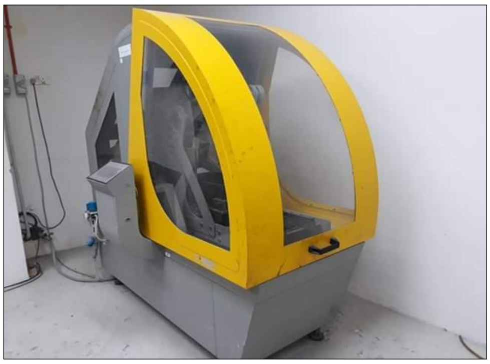

Figure 4. Plate compactor

c) Sawing the plate to prismatic test pieces (dimension 20×5×5 cm).

Each bituminous mix plate is saws into twelve (12) prismatic specimens:

Figure 5. Plate piece (40×30×5 cm)

Figure 6. Prismatic test piece (20×5×5 cm)

It has been noted: B-HMA: Basic Hot Mix Asphalt (without modification)
M-HMA: Modified Hot Mix Asphalt (with modification by LDPE plastic waste)

3.2. Four Point Bending Deformation

A four-point bending deformation device is used for the creep-recovery measurements. Displacement measurement comparator (sensibility: +/- 0,002 mm) placed in contact under the test specimen in the middle of a prismatic test piece (Figure 7) at 20 ° C, for a loading (01 hours) for a constant load of 4 kg.

Figure 7. A Device of Creep-recovery test

The material is subjected from t = 0 to a constant stress σ_0 for a time t_M, and the evolution of its deformation is followed (Figure 8). If the deformation of the material with constant stress is a function of time, the body is said to be flow or to show a creep phenomenon. The term flow refers more particularly to the case of a deformation which does not resorb when the stress is canceled [31].

Where:

σ_0: the imposed constraint.

t_M: temps of the maximal creep strain.

ε_M: maximum or total strain.

After a time t_M, the stress is abruptly reduced to zero. We continue to follow the variations of the residual deformation as a function of time. The complete curve consists of two parts, the second part being called the recovery curve. Long after the release of the specimen, the deformation tends to a constant value, which can be zero, and it is called permanent deformation.

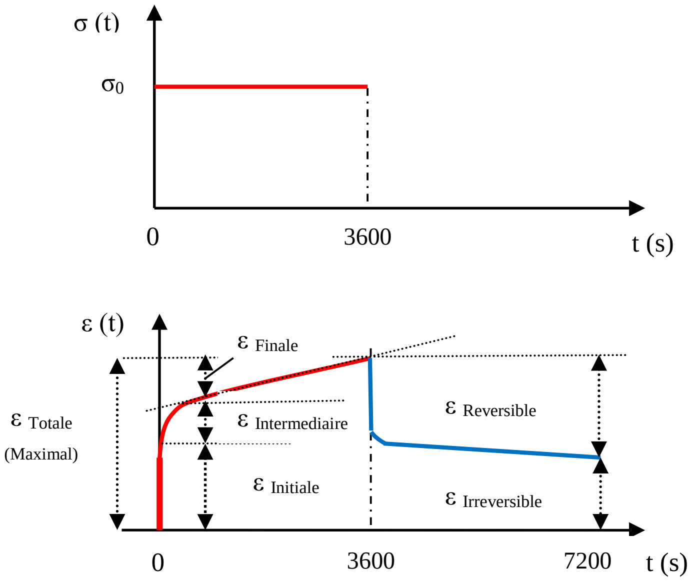

Figure 8. Creep-recovery experience

4. Results and Discussion

4.1. Creep-recovery

In this study, we present the effect of temperature and the use of plastic waste addition on creep-recovery behavior of Hot Mix Asphalt (HMA). In the Figure 8, the curves or creep-recovery of basic and modified mixes asphalts at 20 °C and 50 °C are shown.

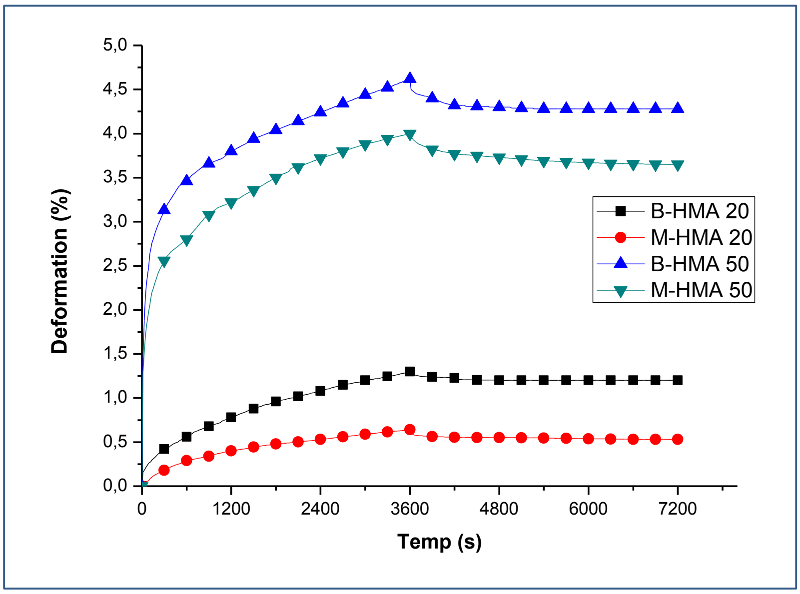

Figure 9. Creep-recovery curves for B-HMA and M-HMA

According to the graphs (Figure 9) we show that measured strains increases with evolution of temperatures.

In the creep part, the deformation consists of three phases, at the beginning of an elastic behavior or one records an instantaneous strain ε_{EC} due to the introduction of the load on the specimen. Then a viscoelastic behavior for the first minutes of loading or asphalt mastic becomes sensitive to medium temperature because of the bitumen viscoelasticity, which gives a parabolic curve and a significant slope. For a longer time (one hour), the mixes asphalts stabilizes and is characterized by a viscous flow behavior (straight line $\varepsilon = a.t + b$), until we arrived at the maximum deformation $\varepsilon_{max.}$

In the second part of recovery, the test piece after the sudden removal of the load tries to recover its original shape. This part also consists of two phases. Immediately after unloading, an instantaneous strain ε_{ER} is recorded. For this the material takes an elastic behavior, then it recovers a part of its deformation known as reversible deformation ε_{rev}. The mix asphalt does not recover all of its deformation, which causes the appearance of permanent residual deformation ε_{res}.

In this case, the M-HMA, which is modified by the LDPE, present a decrease in creep, compared with the B-HMA, from the curves shown in Figure 9, the following parameters can be asan output (Table 3).

Table 3. Parameters of B-HMA and M-HMA at 20 °C and 50 °C

Parameters	B-HMA		M-HMA	
Temperature	20 °C	50 °C	20 °C	50 °C
ε_{EC} (%)	0.2000	2.5000	0.0400	2.0000
ε_{Max} (%)	1.3000	4.6200	0.6400	4.0000
ε_{Res} (%)	1.2020	4.2800	0.1100	3.6500

Where:

ε_{EC}: Elastic deformation in Creep part;

ε_{Max}: Maximal deformation;

ε_{Res}: Residual (or Permanente) deformation.

According to the graphs (Figure 6) we show that measured strains increases with evolution of temperatures.

The creep part consists of three phases at the beginning of an elastic behavior or one records an instantaneous deformation ε_{EC} due to the introduction of the load on the specimen. The latter deformation from 0.2% to 2.5% for 20 and 50 °C respectively. Then a viscoelastic behavior for the first minutes of loading or asphalt mastic becomes sensitive to high temperatures because of the bitumen viscoelasticity, which gives a parabolic curve and a significant slope especially for the temperature 50 °C. For a longer time, the mix asphalt stabilizes and is characterized by a viscous flow behavior (straight line $\varepsilon = a.t + b$), whose deformation speed $\acute{\varepsilon}$ increases with the evolution of the temperature until the arrival reaches maximal deformation ε_{max} where one records a significant maximal deformation of 4.62% for 50 °C.

In this case, the mix asphalt modified by LDPE present a decrease in creep for all the temperatures compared with the unmodified mix, accompanied by a stabilization of the deformation rate of the phase of viscous flow for temperature 50 °C.

4.2. Effect of Temperature

The following graphs (Figures 10 and 11) shows the influence of temperature in the basic and modified HMA.

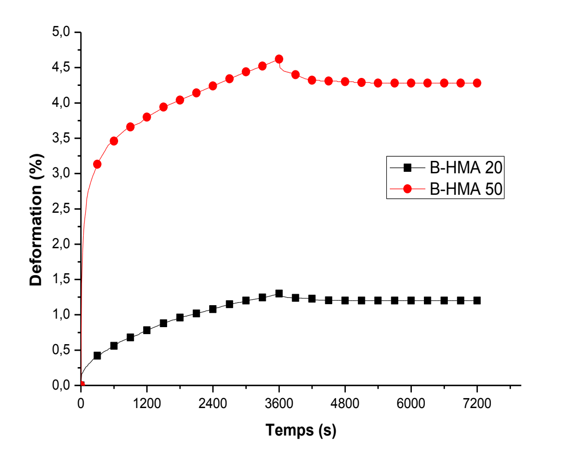

Figure 10. Effect of temperature on B-HMA

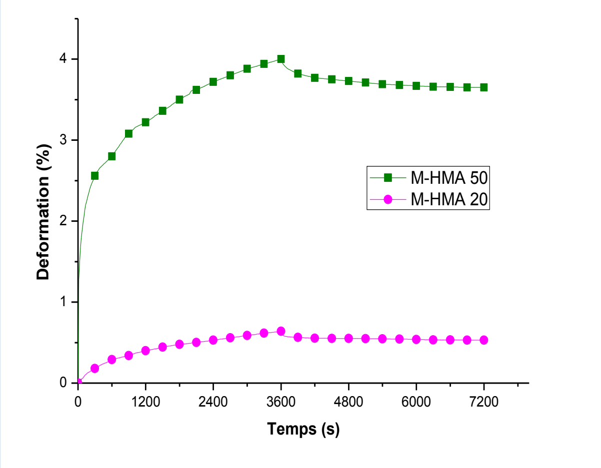

Figure 11. Effect of temperature on M-HMA

For the mixes asphalts (with and without modification) the deformation increased with the evolution of the temperature. Where it is recorded that 50% of deformation are affected by the first minutes (t <5 min).

For the 20 ° C, the parabolic part (due to the viscosity of the bitumen is not significant where a linear and rigidity seam is observed). On the contrary, for the 50 ° C, the parabolic part becomes important and the Bitumen viscosity plays a significant role in the behavior of bituminous mixture, the deformation increased and become more important.

As the temperature increases, the asphalt becomes softer due to the presence of softened bitumen. The binding force between the grains is weakened and under loading consequently, the deformations increase.

4.3. Effect of Plastic Waste (LDPE) Addition

The following graphs (Figures 12 and 13) have shown the influence of plastic waste (LDPE) addition in the basic and modified HMA.

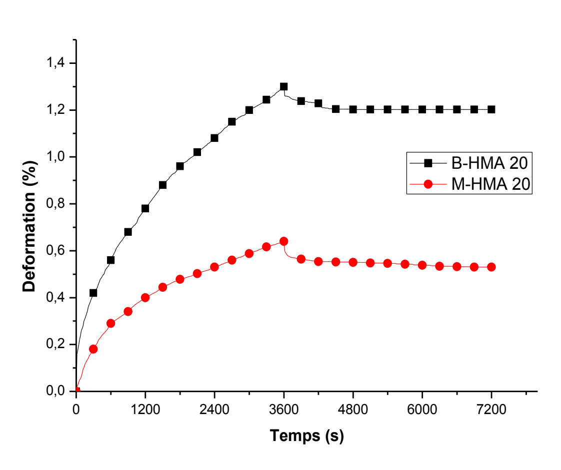

Figure 12. Effect of plastic waste in HMA at 20 °C

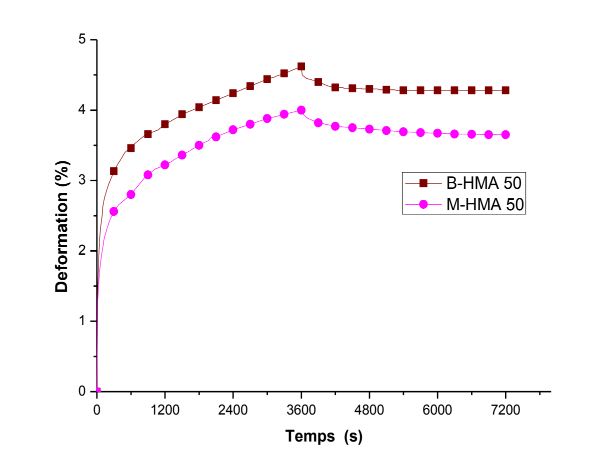

Figure 13. Effect of Plastic waste in HMA at 50 °C

The mix modified by plastic bag waste have a better thermal resistance for both average temperatures of 20°C and high of 50°C, where a decrease of the deformation curves is observed. In this case, the LDPE gives the mixture a good rigidity and stability, which confirms the advantage of using this material to improve the performance of HMA (thermal susceptibility and stability).

When the LDPE melt in the asphalt, it play the role of the binder, it increases the adhesion and the bond between the bitumen and the aggregates. In the molten state, it fills the maximum of the voids of the granular skeleton of the mix. The resistance to permanent deformation has been improved, thus reducing the risk of rutting, which leads to an increase in the life of the road.

4.4. Maximal Creep Deformation ($\mathcal{E}_{MAX}$)

The histogram (Figure 14) shows: An increase in maximal deformation value with increasing in temperature of modified and basic mixture. A decrease in the maximal deformation values of the modified mixes LDPE compared with the base mix for all temperatures which reaches up to 50.76% for T = 20°C.

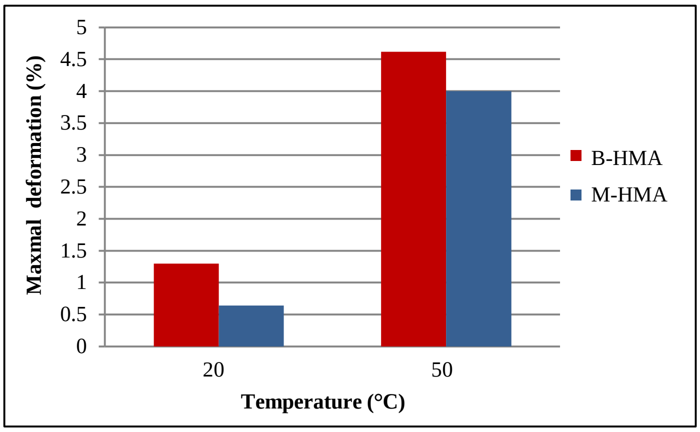

Figure 14. Histogram of Maximal Creep deformation (basic and modified HMA)

The asphalt mix with polymer (LDPE plastic waste) presents an increase in stability and a decrease of creep. The best formulation was obtained with adding 5% of LDPE, which increases the resistance by 16% related to witness asphalt [29].

The use of plastic waste improve the resistance of HMA. This improvement is attributed to an increase in the bonding forces between the aggregates and the bitumen. The coating of plastic reduces the porosity and absorption of moisture.

4.5. Instantaneous Elastic Deformation ($\mathcal{E}_{Ec}$)

According to the histogram (Figure 15), we observe: An Instantaneous Elastic deformation increase with evolution of temperature for basic and modified mixture. A decrease of instantaneous creep value of the modified mix compared with the base mix is noted for all the temperatures, which implies an increase in rigidity which reaches 87%, 11 % for T = 20°C; and T=50°C respectively.

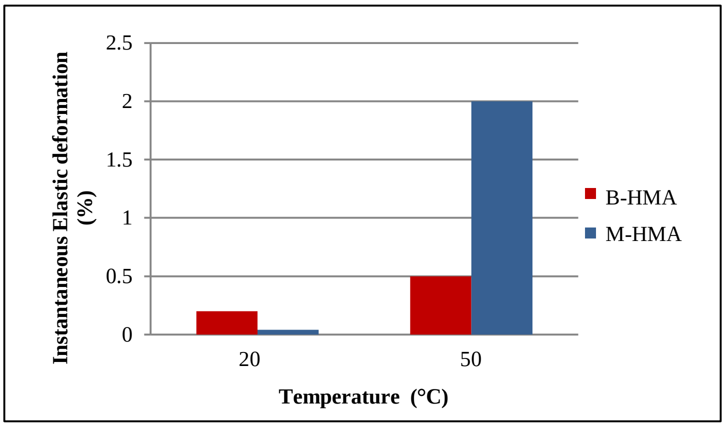

Figure 15. Histogram of Instantaneous Elastic deformation (basic and modified HMA)

The addition of polyethylene leads to a strong increase in the rigidity of material such as the reduction of thermic susceptibility to the high temperatures of service [15].

4.6. Residual (or Permanente) Deformation

A decrease in permanent deformation for all temperatures, in particular a decrease by 90 % of the M-HMA at 20 °C. This implies a marked improvement in the resistance to rutting and a longer life of the roadway (Figure 16).

Use of recycled plastics composed predominantly of polypropylene and low-density polyethylene in plain bituminous concrete mixtures with increased durability and improved fatigue life. Resist ance to the deformation of the asphaltic concrete modified with polythene of low density was improved [25, 26].

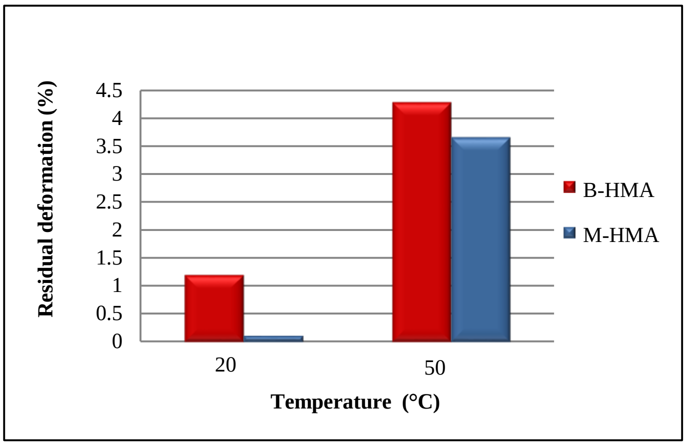

Figure 16. Histogram of Residual deformation (basic and modified HMA)

A comparative study between the modified and unmodified mix was discussed to confirm the advantage of using this modification technique:

- At medium temperature, the total deformations decrease for the M-HMA of the order of 51% compared to the B-HMA. As well as an increase in the rate of reversible deformation is estimated at 56%.
- At high temperatures, the deformation evolve slowly over time for the modified mix. The decrease of the deformations is of the order of 13% at 50°C.

LDPE limits permanent deformations at the end of the test. Increasing the resistance to rutting by the use of LDPE leads to a remarkable decrease in permanent deformation. The use of LDPE plastic helps significantly to improve fatigue resistance, which improves the longevity and performance of the pavement with a marginal economy in the use of bitumen.

5. Conclusion

In general, a better behavior, in the range of medium and high temperatures in creep was observed for the mix modified by LDPE plastic waste. For all the temperatures, more than 50 % of the deformations measured are reached for the first minutes of loading ($t < 5$ min). An increase in the thermal resistance where is noted that from the creep curve, the modified mix is more resistant to temperature compared to the base mix. A decrease in the maximum strain values shown of M-HMA compared with B-HMA for all the temperatures which reaches up to 50.76% for T = 20°C. A decrease of instantaneous creep value of the modified mix compared with the base mix is noted for all the temperatures, which implies an increase in rigidity which reaches 87%, 11 % for T = 20°C; and T=50°C respectively. The introduction of LDPE in mix concrete bituminous increase thermo mechanical performance, as well as an increase in the stiffness of the asphalt mix by stabilization of both viscoelastic and viscous flow phases. The increase in the life of the asphalt by reducing permanent deformation, so the addition of LDPE seems to us a practical, economic and environmental solution.

6. Acknowledgement

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7. Conflicts of Interest

The authors declare no conflict of interest.

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