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Reclamation and recycling of plastic waste in road construction: Design of a bituminous mix from plastic waste

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Abstract

The purpose of this work is the recovery and recycling of plastic waste as additives in asphalt concrete (AC) in order to make a comparison with the conventional mix. The plastic waste used in this study is recycled plastic bottles made of Polyethylene Terephthalate (PET). The objectives also include the study of the effect of the addition of different percentages of shredded plastic on the properties of the asphalt mix and the comparison with the properties of the conventional mix. The results indicated that recycled plastics can be conveniently used as an additive for bituminous mixes to participate in the sustainable management of plastic waste and the improvement of the performance of the mix. After carrying out a comparative study between the classic mix and the mix modified with recycled plastic, we obtained an optimal bitumen content of 5.33 % to be mixed with an optimal quantity of plastic of 6 % to obtain a mix with better quality. Subsequently, we proposed to carry out a study trying to reduce the quantity of bitumen while maintaining the optimum quantity of plastic (6 %) in order to evaluate the percentage of bitumen that could be substituted with plastic to approach values obtained at the optimum at the level of conventional asphalt concrete. With 6 % of plastic, it is possible to reduce the optimal amount of bitumen from 5.33 % to 5 %, leading to a reduction in the cost per km of road.

Keywords: Asphalt concrete; Recycling; Plastic waste; Polyethylene Terephthalate; Road

1. Introduction

Road construction is an essential step in the economic growth of a country. In other words, the process of economic development anywhere requires the establishment of an adequate road network. As a result, the roadway must have properties allowing the circulation of users under optimal conditions of safety and comfort. The satisfaction of these conditions of use mainly implies certain qualities for the pavement materials. Many countries have in recent years undertaken inventories of regionally available materials and their geotechnical characterization in order to standardize their use in road construction [1, 2, 3].

The dramatic pollution of our planet has been worrying for several decades now. The Earth bears the brunt of the wild dumping of our waste of all kinds. Plastic, long time considered as revolutionary material, is now in the dock. Faced with the urgency of the situation, several initiatives are emerging to minimize the impact of this pollution, in particular the use of plastic in the construction of new types of roads [4, 5, 6, 7]. Faced with the proliferation of plastic waste, this work aims to find a solution to minimize the impact of this pollution, by using plastic waste in bituminous roads [8, 9]. On the other hand, the increase in the traffic load in combination with an insufficient degree of maintenance causes an accelerated deterioration of the road network. These two points have motivated the search for a new type of asphalt with plastic as an additive. As part of this project, we will try to find an adequate formulation to have a mixture of aggregates-bitumen-plastic waste in order to obtain better quality and more economical roads. To develop this

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research, several geotechnical tests were carried out on the plastic waste, the aggregates, the bitumen and the asphalt concrete. The significance of this study is to reduce the amount of waste that the human beings are continuously producing at an alarming rate especially plastic waste by limiting the proliferation of plastic waste through recovering it and using it to create new materials or improve existing ones through innovative ways, thus, promoting long-term recycling in the process and contributing positively to the circular economy and sustainable development goal.

The objectives of this research are to study the effect of addition of different percentages of plastics on the properties of the asphalt mixture, and to carry out a comparative study between conventional asphalt and modified asphalt.

2. Experimental/ Materials & Methods

The materials needed for this study are the classic constituents of hot mix asphalt and plastic waste. The aggregates must be subjected to identification tests such as particle size analysis (EN 933-1), specific density (NF EN 1097 – 3), flakiness index test (EN 933-8), Micro Deval test (EN 1097-1), Los Angeles test (EN 1097-2). A 35/50 penetration grade of bituminous binder was used in this research. A number of laboratory tests were carried on the binder such as penetration test (EN 1426) and ball and ring softening point (EN 1427). Figure 1, Table 1, Table 2 and Table 3 show the physical proprieties of aggregates, plastic waste and bitumen.

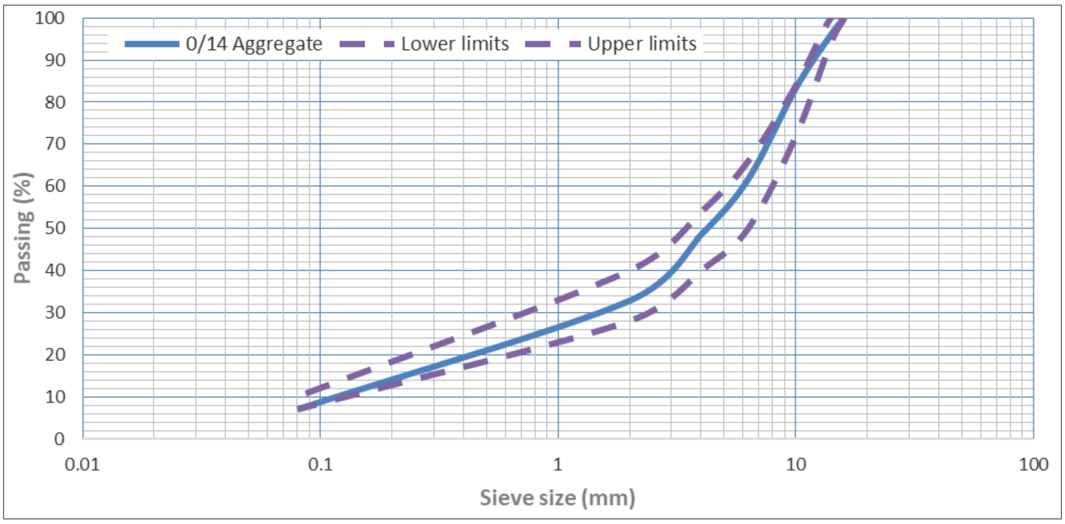

Figure 1 Granulometric curve of the 0/14 aggregate

Table 1 Characteristics of plastic waste

Properties	Characteristics
Plastic Type	Crushed Plastic Water Bottles
Material	Polyethylene terephthalate (PET)
Size (mm)	2mm – 6mm
Density	1.38
Melting temperature (°C)	245

Table 2 Physical and mechanical identifications of basalt aggregates

Parameters	0/3	3/8	8/14	Requirements for AC 0/14
Specific gravity (g/cm^3)	2.88	2.91	2.94	
Flakiness index	-	19.90	8.67	< 25
Los Angeles (%)	-	-	13.4	≤ 25
Micro Deval (%)	-	23.8	22.8	≤ 25
LA + MDE	-	-	36.2	≤ 55

Table 3 Bitumen characteristics

Tests	Results	Technical requirements
Penetration at 25 °C	44.7	30 to 50 (1/10mm)
Ball and ring softening point	54.9	50 to 58 (°C)

Marshall tests are carried out according to NF EN 12697-34 standard. The purpose of this test is to determine the mechanical characteristics (stability and creep) as well as the percentage of voids of bituminous mixtures compacted under standardized conditions. Stability is the maximum force that the sample can withstand and creep (or flow) is the plastic deformation that follows. The purpose of the Duriez test (NF P98-251-4) is to determine, for a given temperature and density, the water resistance of a Hot Mix Asphalt from the compressive strengths with or without immersion of the specimens. It is therefore a simple compression test to characterize the water resistance of bituminous mixes.

The samples are prepared and compacted in standardized molds (Figures 2 and 3). Typically, 5 asphalt mixtures of 1200 g each are prepared with different binder contents, and, for each mixture, 4 samples, one of which is for determining the apparent density; i.e. 20 samples in total. The samples are then compacted using the Marshall hammer.

Figure 2 Preparation and addition of plastic waste in the aggregates before heating

Figure 3 Marshall test molded samples and compression machines

3. Results and Discussion

Figures 4 and 5 show the variation of physical properties of the asphalt concrete (AC) as function of binder (bitumen) content and plastic content, respectively. It is noticed that the stability of the asphalt mixture increases as the bitumen content increases until it reaches the peak at a bitumen content of 5.30%; then it starts to decrease gradually despite the increase in bitumen content. Note that the creep of the asphalt mixture decreases as the bitumen content increases until it reaches the minimum value, which corresponds to a bitumen content of 5.37%. It is observed that the percentage of voids decreases progressively as the bitumen content increases. It is also observed that the compacity increases when the bitumen content increases.

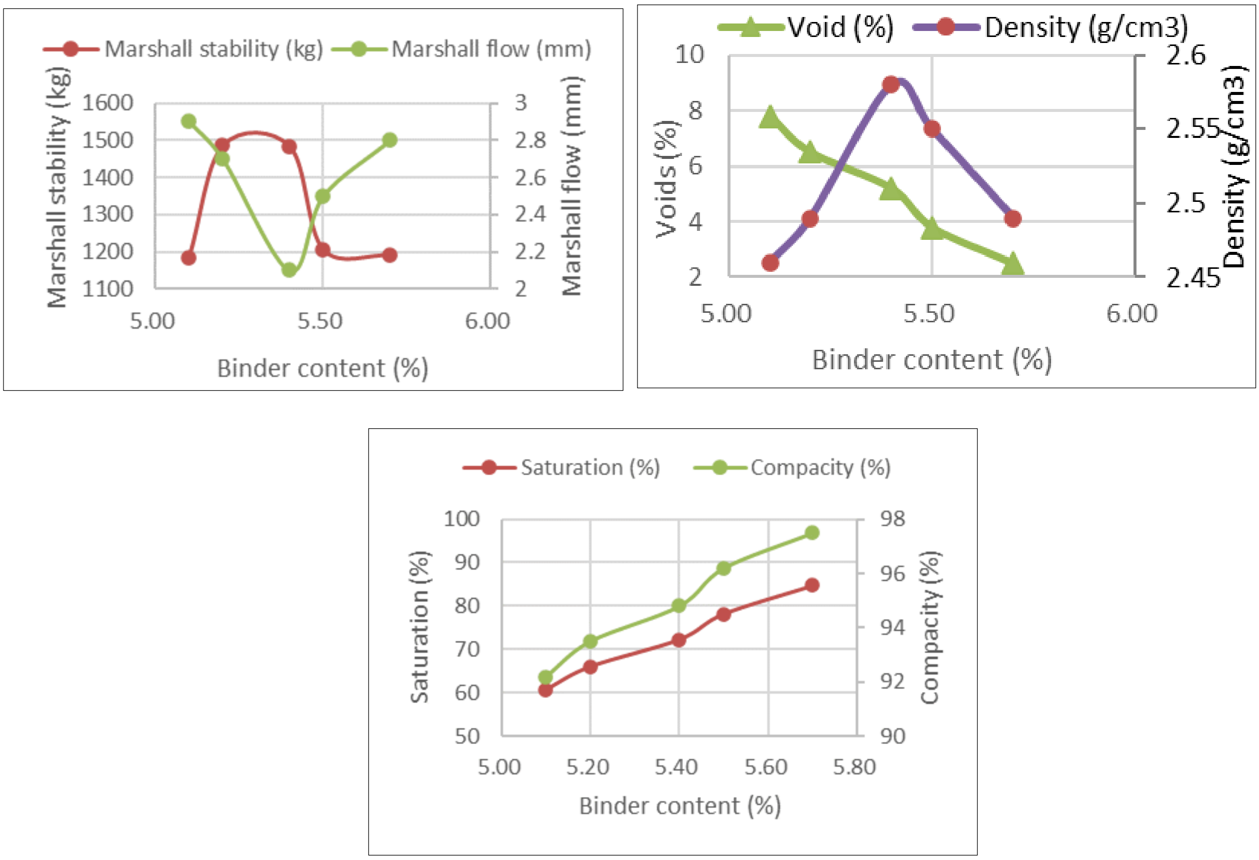

Figure 4 Curves of variation of Marshall test parameters as a function of bitumen content

The optimum bitumen content is the average of three values: the bitumen content at the highest stability (5.30%), the bitumen content at the highest value of the bulk density (5.40 %) and the bitumen content at the median of air voids (5.30 %); i.e. a value of 5.33 %. The results of the Duriez test carried out with the optimum quantity of bitumen (5.33%) comply with the required specifications.

The stability of the mixture increases as the plastic content increases until it reaches the peak at 6% of plastic content; then it begins to decline despite the increase in bitumen content. The Marshall flow of the plastic mixture increases continuously as the plastic content increases. It can be seen that when the plastic content increases, the apparent density increases until it reaches a peak which corresponds to an optimal plastic content of 6.20%; then begins to gradually decrease. The percentage of voids gradually decreases as the plastic content increases. The optimum plastic content is the average of the following three values: the plastic content at the highest stability (6.00%), the plastic content at the highest value of the bulk density (6.20%) and the plastic content at the median air voids (5.85%); which gives a value of 6.1% of optimum plastic content. Durez test results comply with required specifications; therefore, the formulation of asphalt concrete with 5.33% bitumen and 6% plastic is appropriate.

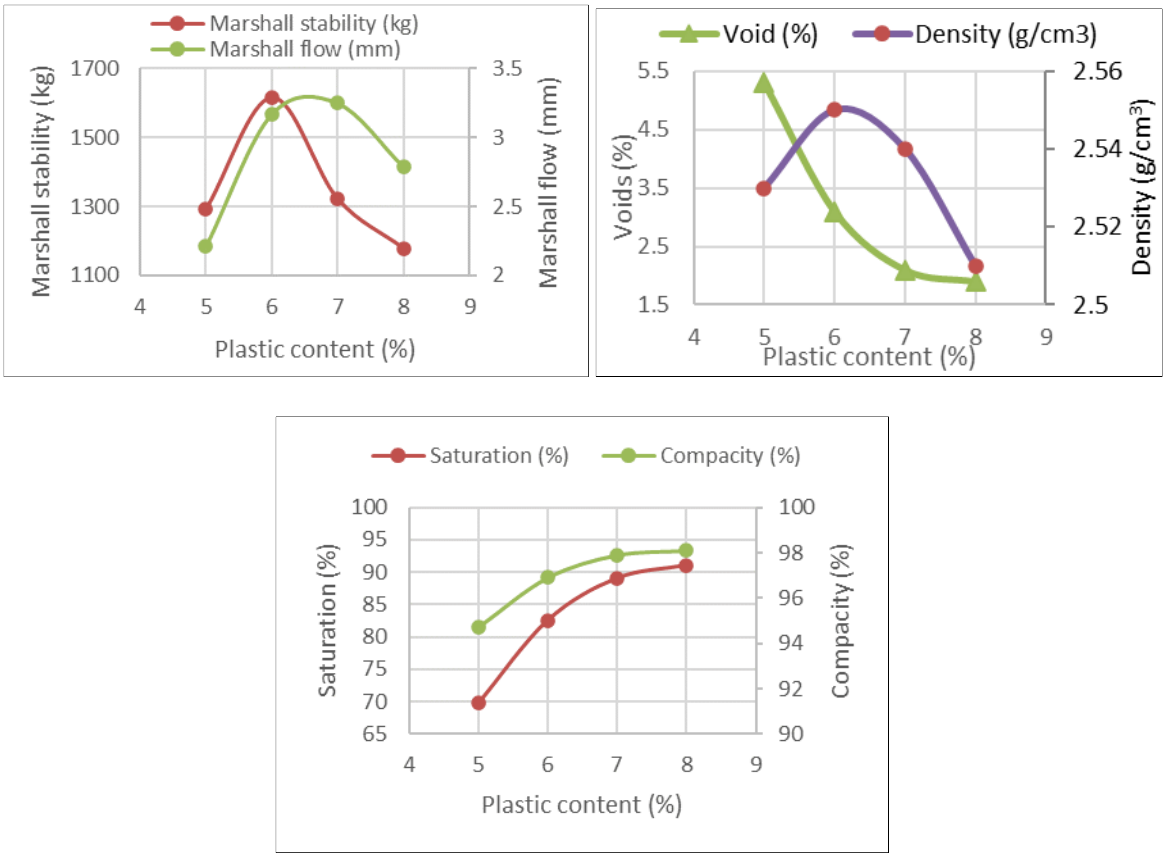

Figure 5 Curves of variation of Marshall test parameters as a function of plastic content

After having made the comparative study between the classic mix and the mix modified with plastic, it is necessary to determine the optimal content of bitumen to be mixed with the optimal quantity of plastic (6%) to obtain a mix of best quality. Subsequently, a study is carried out trying to reduce the amount of bitumen while maintaining the optimum amount of plastic (6%) in order to assess what percentage of bitumen could be substituted with plastic to approach the values obtained at optimum for conventional asphalt concrete (Table 4). The results of the Marshall test show that a bitumen content of 5% with 6% plastic comes closest to the optimal values obtained with the conventional mix at a bitumen content of 5.33%.

Table 4 Comparison between conventional asphalt and asphalt with 5% bitumen and 6% plastic

	Conventional Asphalt Concrete	AC with 5% bitumen and 6% plastic	Variation	Requirements
Bitumen content (%)	5.33	5.00	-0.33	≥ 5.00
Plastic content (%)	-	6.00	-	-
Marshall stability (kg)	1515	1577	+62	≥ 1000
Flow (mm)	2.39	2.71	+0.32	< 4
Density (g/cm^3)	2.557	2.53	-0.027	-
Air voids (%)	5.5	5.3	-0.2	≤ 7.5
Compactness (%)	94.4	94.7	+0.3	94 to 97%

3.1. Comparison between conventional AC and modified AC

The stability values of the two types of mix are all satisfactory, with a slightly higher value for asphalt concrete modified with plastic waste. This improvement in the stability of asphalt mixtures modified with plastic can be explained as a result of the better adhesion developed between the bitumen and the aggregates of the modified asphalt. Due to the intermolecular bonding, attractions between bitumen and plastic are noted, which improves the strength, durability and stability of the mixture. The creep of the two types of mixture meets the requirements. Moreover, the creep of the conventional bituminous mixture is lower than that with plastic. In other words, the bituminous mixture without plastic is more resistant to deformation than that with plastic. The Marshall compactness of the two types of mixtures meets the requirements. Also, asphalt modified with plastic is more compact than conventional asphalt. This justifies a lower percentage of voids for the modified asphalt. The density of the classic mixture is higher than that of the modified mixture. This could be explained by the low density of the added plastic material.

It is noted that the Duriez compactness for the two mixes meets the range of requirements. In addition, that of the mixture with plastic as an additive has a higher Duriez compactness than the other, which leads to greater fatigue resistance. The immersion-compression ratio of the two mixes meets the requirements, but that of the mix with plastic is higher. Consequently, the water resistance of the mixture with the plastic is high. This shows a better impermeability of these roads. The absorption rate is proof of this because it is lower for mixing with plastic.

3.2. Modified asphalt with 6% plastic and lower bitumen content

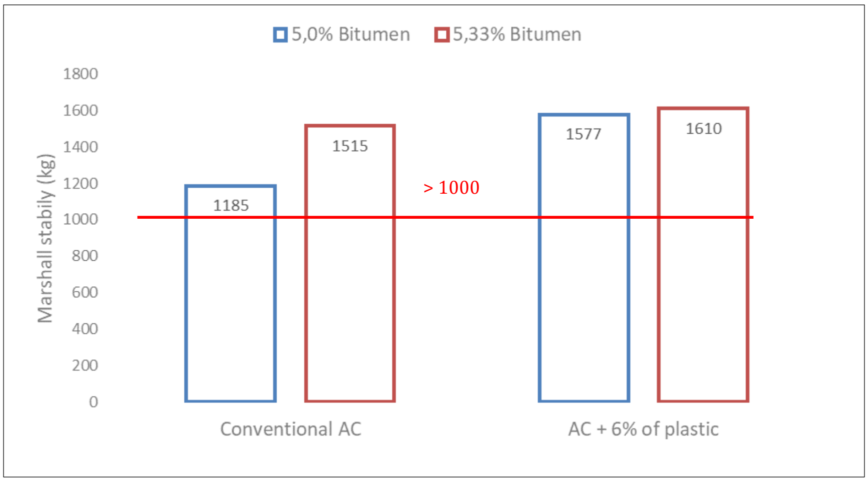

Figure 6 Comparison of Marshall stabilities between conventional AC and AC + 6% plastic

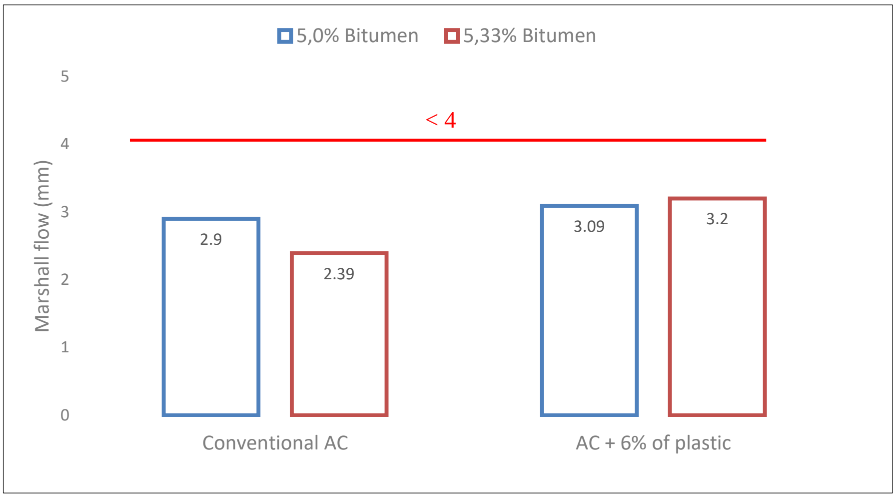

Figure 7 Comparison of Marshall flows between conventional AC and AC + 6% plastic

It is noted that the mix containing 5% bitumen and 6% plastic has a higher Marshall stability compared to conventional mix (figure 6). Conventional asphalt has less deformation than modified asphalt but both values are in accordance with the requirements (figure 7). Classic asphalt also shows a slightly higher density than asphalt containing plastic. Concerning the percentage of voids, it is less important for the modified asphalt. With regard to compactness, it is slightly lower for conventional asphalt compared to modified asphalt; which testifies the rigidity of the asphalt modified with plastic waste. In conclusion, the modified mix with 6% plastic and containing 5% bitumen has similar characteristics to that of the classic mix (without plastic) containing 5.33% bitumen; which reduces the amount of bitumen.

4. Conclusion

The general objective of this research was to study the physical and mechanical characteristics of asphalt concrete mixed with plastic waste and to establish a comparison with conventional asphalt concrete. Plastic can be conveniently used as an additive in asphalt for better management of plastic waste as well as improving its performance. The asphalt modified with plastic has considerable advantages compared to the classic asphalt. The melted plastic on the aggregate provides a rougher surface texture for the aggregate particles in the asphalt mix; which improves the intrinsic properties of the asphalt mixture due to the improved adhesion between the bitumen and the aggregates. This improved stability has a positive influence on fatigue resistance leading to a more durable asphalt concrete pavement. In addition, with 6% plastic, it is possible to reduce the optimal amount of bitumen and the cost per km of road.

Additional studies could be done to try to go further in the recovery and recycling of plastic waste in road construction, in particular by studying other types of plastics. In this perspective, it would be possible to substitute a larger quantity of bitumen with plastic; and perhaps we will even arrive at a complete substitution.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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