The Impact of Bituminous Asphalt Improvement by Plastic Brushes and Brooms on Pavement and The Environment in Algeria

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Abstract: Among the proposed solutions for the environment protection; the materials recycling, particularly in road sector, the quest for enhancing road surface durability involves the use of various polymers in order to modify the bitumen utilized in the process. The present work aims to experimentally investigate the wet process enhancement of the rheological and mechanical properties of a bituminous concrete of the bearing layer based on class 40/50 bitumen modified by two additives, namely polypropylene PP500P and plastic waste (the fiber scraps of brushes, plastic brushes that are mainly made from this polymer). The main idea was to compare the rheological and mechanical characteristics of bitumen modified by the two additives with the same percentages of addition (2%, 4%, 6%, 8%, 10%) during varying mixing times (1h, 2h, 3h), and therefore analyzing its resistance strength once recycled. The findings demonstrated that the impact of mixing time on rheological and mechanical properties of modified bitumen, as well as the same added percentages of the two additives does not result in the same effects on Marshall Stability, creep, compactness, volume of voids and the water resistance of the bituminous mixtures. In addition, we sought to evaluate the using limit of this type of plastic waste to utilize it as an alternative of polypropylene PP500P, in order to eliminate non-biodegradable plastic from nature.

Keywords: Recycling, Polypropylene, Marshall Test, Improved Bitumen, Plastic Waste, Environment.

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1. Introduction

Recycling materials in all fields has become crucial considering the global issues of environmental protection and sustainable development, especially in the road industry **[1].** The road is considered as a socio-economic development factor of any country **[2]**. As road traffic increases, there arises a necessity to enhance the road's load- bearing capacity to bear heavier loads **[3]**, thus the requirement for developing sustainable road surfaces **[4]**. Although the beneficial effect of the service life of a road surface on economy **[2]**, it has an adverse ecological and environmental effect from the emissions of the asphalt plant. For this reason, the sustainability of pavement materials takes an increasing part in the policy of construction and maintenance of road networks **[1].** From a technical perspective, there is a significant requirement to develop new guidelines for constructing pavements with enhanced rigidity **[5]** that is directly related to the load applied on the pavement **[6].** In this context, several analyses have been carried out on the improvement of the mechanical, rheological and physical performance of bituminous asphalt **[7];** currently, researches focuse on exploring the bituminous asphalt mechanical and rheological performance characteristics **[8].** The good control of these different properties is theoretically applied on the development of a mathematical model of the bituminous mixture **[9]**, practically many additives have been used to improve the properties of the asphalt used in road pavements. **[10]**. Indeed, the addition of different types of additives, such as polymers, can be relied upon to effectively enhance the mechanical and rheological properties **[11],** which are primarily designed for industrial purposes, these materials possess significant characteristics that contribute to the enhancement of bituminous asphalt **[12]**. The bitumen and polymers chemical structure based on their densities facilitate the improvement of certain aspects of bitumen properties by dry or wet methods **[13]**. The dry process enables the creation of formulations in the field **[9]**; also, it is particularly suitable for the use in high-temperature regions. **[14]**. While, the wet process is more advantageous comparing to the dry process in terms of rigidity that is beneficial to rutting, that is considered as a major factor in the service life of road surfaces **[15]**, this process considerably facilitates the compaction of asphalt mixes **[16]**. Furthermore, the choice of modifier for a road project may depend on several factors, including construction capability, availability, cost, and expected performance **[17].** In addition to the environmental factor that is threatened by plastic waste, the latter are non-biodegradable in soils and waters **[14]**, and they have a positive impact on improving the mechanical performance of bituminous concrete, which could be one of the possible solutions to eliminate them scientifically **[18]**. Plastic contributes significantly to the generation of solid waste; every day a large amount of partially or totally plastic items are used and deposited in landfills **[17].** Nowadays, several researches are conducted to find ways for recycling waste in the most sustainable way in different fields **[19]**, in the road field it has been shown that the contribution of improved bitumen is double; the construction and life extension of roads **[20]**. Experimentally, roads are very rigid if the value of Marshall Stability is increased **[21]**. Marshall Stability has been shown to be improved to 5% by adding ethylene powder to a high class binder **[22]**. On the other hand, Ethylene aggregate improves deformation resistance to 3% [23]. For polyethylene; 4% waste of this polymer in granule improves fatigue resistance **[24]**, 5% of this polyethylene incorporated in powder in a medium-class binder; bituminous asphalt is more resistant to deformation **[15]**; yet, when the bitumen class has a high value and the polyethylene form is in powder form, incorporating this polymer into the bituminous coating significantly enhances crack resistance, as indicated by a 6% improvement [14]. In this context, using plastic waste in powder form is more beneficial than in granular form regarding the percentage of plastic waste incorporation. However, it is essential to note that this advantage does not extend to all parameters, such as temperature sensitivity resistance, where a minor improvement is observed with a 2% addition of polyethylene. **[26].** In light of the fact of the low addition percentage of these polymers, the idea of improving bitumen by a mixture of three polymers: ethylene, polyethylene and polypropylene is made at low temperature, with the aim of incorporating more plastic waste, an improvement in the resistance to internal deformation of bituminous concrete is recorded, but this mixture reacts negatively to rutting **[23]**. Thus, despite the proven benefits of bitumen modification by plastomers, the problem of incompatibility with bitumen arises in relation to the non-polar chemical nature of the plastomers **[27]**. A good interaction (plastomer-bitumen) is conditioned by a high class of bitumen and less percentage of addition plastic waste **[28]** which is not beneficial to the environment, or by the incorporation of stabilizing microfibers as a coupling agent with a medium-class bitumen plastomer **[29]**, that could be less economical. Furthermore, when the binder is combined with both the polymer and a coupling agent, it undergoes a physical transformation when exposed to temperature **[30]**, and since temperature influences the bitumen and modified bitumen, it can also react negatively on the rutting depth **[31]**. Thence, the percentage of plastic waste added is directly affected by factors such as temperature, the type of plastomer used, and the class of bitumen employed **[22, 24, 25, 14, 26]**. Additionally, it has been proven that polypropylene incorporated in powder and at low temperature improves the resistance to deformation of asphalt concrete of high class, and that the powder form gives a linear structure **[16]**, the powder form of this polymer reinforced by lignin (coupling agent) gives a linear structure and compatibility with high class bitumen**[32]**, the powder form of the polymer at low temperature directly influences the compatibility (plastomer-bitumen) **[33]**. Also, it has been shown that at 40°C, polyethylene and polypropylene improve the rheological properties of bitumen **[10]**.The desired ideal formulation of an improved asphalt mix is one that supports the potential for bitumen economy after the inclusion of plastic waste, so this formulation must achieve a higher plastic waste utilization rate **[9,28]**. The required resistance is achieved if the pavement is environmentally friendly with a lower material cost **[34]**. Global plastic production in 2017 was estimated at 380tonnes/year **[35]**, two years later annual plastic consumption in Algeria was estimated at 25.8 kg/capita, and polypropylene waste represents 2.04% of the composition of plastic waste **[36]**, the significance of emphasizing plastic recycling in roads cannot be overstated. While developed nations have already embraced this practice, it has now become crucial for underdeveloped countries to actively adopt it.

The objective of this research was to determine the limit of polypropylene plastic waste recovery in the fibers form, as well as to compare it with the seed form to lead to a formulation of a very economical asphalt mix: without coupling agent, a bitumen of lower class (40/50), and knead at high temperature in time. This analysis was intended to generate scientific data that could serve as a basis for the disposal and recycling of plastic made by the polypropylene most used daily. Thus, this polymer's recycling efficiency in the building and maintaining of roadways in hot climates. Considering Algeria's reliance on importing polypropylene, this approach proves to be economically viable, environmentally beneficial, and exceedingly profitable, notably in conserving non-renewable natural resources.

2. Methodology

This work is carried out in two steps: first analyzing rheological characteristics of bitumen modified by the two additives: polypropylene PP500P and plastic waste , with the mixing time varied(1h, 2h, 3h) . The second step involves determining the percentage and mixing time that yield the same rheological results and then using to analyze the mechanical characteristics of the asphalt mix.

Aggregate

The experiment of this work is done entirely in the laboratory of technical control of public works of Algiers. The used aggregates are the fractions 0/3, 3/8, 8/15 of the quarry AIN TOUTA d El Hachimia of the wilaya of Bouira. They represent the intrinsic characteristics according to the consecutive standards: NA 458, NA 457 and NA255 (table 1). As well as manufacturing characteristics in accordance with standards: NA256, NF P18-591, and NF EN 933-8. The particle size analysis is according to standard NA 2607, the percentages of the granular fractions obtained (Table 1) fits perfectly in the spindle of the 0/14 semi granular asphalt concrete reference.

Table 1. Aggregate General Characteristics

Test	Results			Specifications
	0/3	3/8	8/15	
intrinsic characteristics				
LOS ANGELES	-	21	22.75	
MICRO-DEVAL Coefficient	-	18	14.80	
Volumic masse (g/cm^3)	2.70	2.69	2.70	
Manufacturing characteristics				
Flattening coefficient		16.17%	20.68%	<25%
Superficial cleanliness		0.6%	1.20%	< 2%
Sand equivalent	47.85%			> 40%
Plasticity index	6,10%			-

The binder

The binder used is the bitumen of class 40/50 are provided by NAFTAL (Algeria), it represents the identification characteristics in accordance with the standards, NA 2617, NA 5192 and NA 5224 successively (table 2).

Table 2. Identification characteristics of the binder used

Essay	Obtained Results	Specifications
Softening point (°)	49	47 à 60

Penetrability at 25°C	46	40 à 50
Relative density at 25°C	1,04	1,01 à 1,04

The Polymer

The type of polymers used is a homopolymer named Polypropylene PP500P with rounded white aggregates of about 3mm, recovered from SABIC deposit in Algiers and imported from Asia. This polypropylene represents the mechanical and thermal properties according to the mentioned norms (table 3).

Table 3. General properties of polypropylene PP500P

Properties	Unit	Value	test method
Fusion flow at 2.16Kg and 230°C	g/10min	3	ASTMD-1238
Tensile strength at performance	MPa	35	ASTMD-638
Elongation to traction to efficiency	%	11.5	ASTMD-638
Bending modulus (1% sequence)	MPa	1480	ASTMD-790A
Impact force cut to 23%	J/m	35	ASTMD-256
Thermal deflection temperature at 455 KPa	°C	100	ASTMD-648
Melting temperature	°C	160	ASTMD-1525B
Hardness	Rockwell	102R	ASTMD-785

Plastic waste

The plastic waste used in this study comes from cleaning brushes and plastic brooms made from polypropylene in Reghaia (ALGERIA), with fibers of identical diameters cut into small pieces of approximately 0.3mm.

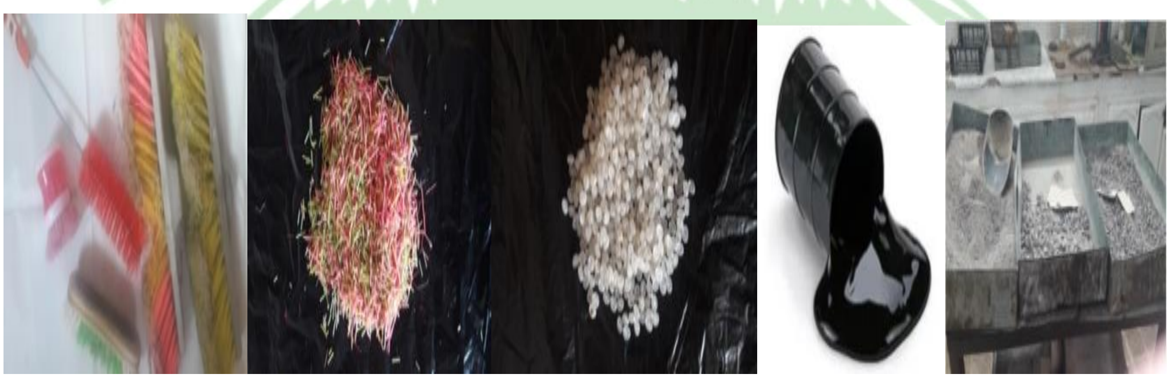

Figure 1 Used Materials

In the first part the mixing speed and temperature are: 700rpm, and 175°C. Then analyze simultaneously the two parameters (penetrability and softening point) of the bitumen.

Figure 2 Softening point and penetrability tests

The second experimental part consisted in analyzing the effect of each additive on the water resistance, Marshall Stability, creep, compactness and percentage of voids of bituminous mixtures, prepared according to the Algerian standard (NA5227). Mixtures based on bitumen modified by polypropylene PP500P kneaded for 3 hours, while mixtures based on bitumen modified by plastic waste mixed for 2 hours, in different percentages (2%, 4%, 6%, 8%, and 10%).

Figure 3 Preparation and compaction of samples with both additives

Figure 4 Preparation of modified asphalt for crushing

The samples were created using molds with specific measurements: a diameter of 101.6 mm, a weight of the entire mold at 1200g, a height of 63mm, and the process was conducted at a temperature of 160°C (refer to figure 9). The density of bitumen is 1.02 A': The compressive strength in immersion for 7 days at the free area and at a temperature (20-25°C), thereafter the sample was put for 40min in immersion at 60°C, then crushed by jaw crusher. A: Dry compressive strength for 24 hours (20-25°C) after 40min at 60°C, then jaw crushing. The Marshall speed is 5000mm/min

Figure 5 Crushing of the samples

3. Results and discussions: The results of penetrability and softening point after the addition of polypropylene PP500P and plastic waste are given in tables 4 and 5.

Table 3. Penetrability and softening point results with the addition of PP500P

T=1h	Results					
PP500P(%)	0 (control)	2	4	6	8	10
Penetrability at 25C°(1/10mm)	46	44	43	42	41	39
Softening point (°C)	49	51	55	57	57	58
T=2h						
Penetrability at 25C°(1/10mm)	46	43	42	41	39	38
Softening point (°C)	49	52	56	58	60	64
T=3h						
Penetrability at 25C°(1/10mm)	46	42	38	38	36	35
Softening point (°C)	49	54	57	65	67	75

Table 4. Results of penetrability and softening point with the addition of plastic waste

T=1h	Results					
Plastic waste (%)	0(control)	2	4	6	8	10
Penetrability at 25C°(1/10mm)	46	45	45	43	42	42
Softening point (°C)	49	50	52	54	55	55
T=2h						
Penetrability at 25C°(1/10mm)	46	44	42	40	38	37
Softening point (°C)	49	52	53	55	57	60
T=3h						
Penetrability at 25C°(1/10mm)	46	44	42	39	37	37
Point of softening (°C)	49	53	55	59	61	63

Based on the above findings, graphs have been produced that show the evolution of bitumen penetrability (Figures 3 and 4) and softening point (Figures 5 and 6) as additive percentages change (PP500P and plastic waste).

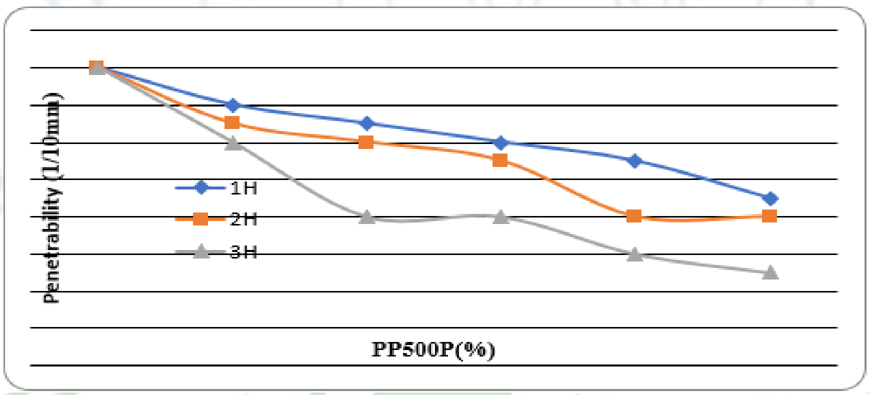

Figure 3 Penetrability by percentage of addition of PP500P

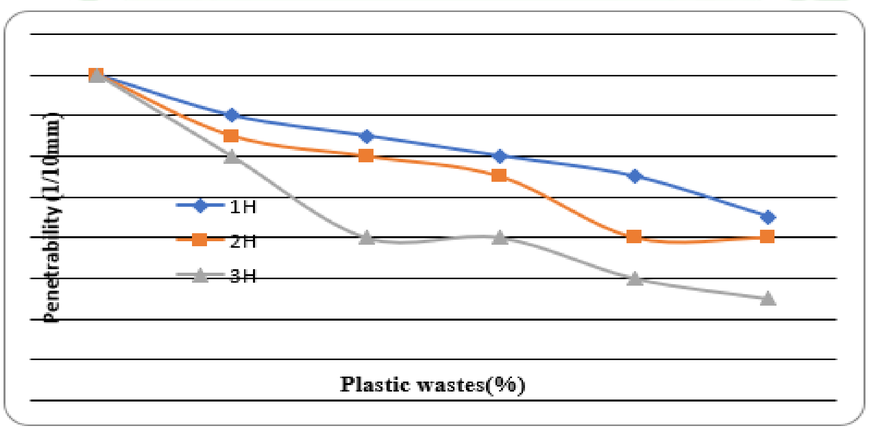

Figure 4 Penetrability as a function of plastic waste

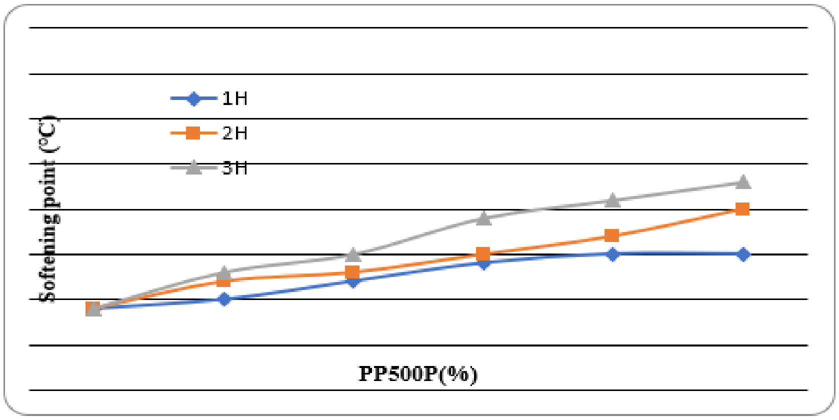

Figure 5 The softening point as a function of PP500P

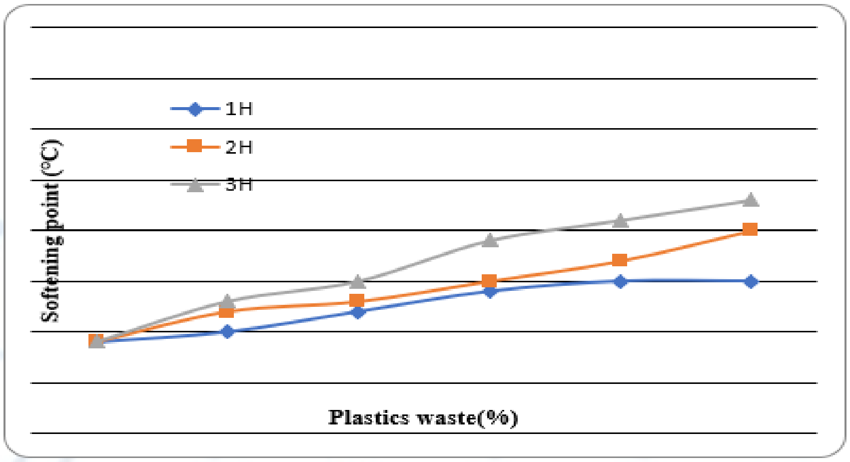

Figure 6 Softening point as a function of plastic waste

The results obtained from the work of the second part are summarized in Tables 5 and 6.

Table 5. Marshall Asphalt Results at PP500P

Addition of PP500P(%)	Marshall Stability (KN)	Creep (mm)	Quotient Marshall (KN/mm)	water resistance	compactness (%)	Void percentage (%)
Additive-free	10.82	3.37	3.21	0.76	95	5
2	13.27	3.20	4.14	0.82	96	4
4	14.02	2.95	4.75	0.81	96	4
6	14.98	2.67	5.61	0.82	97	3
8	15.51	3.18	4.87	0.83	98	2

10	15.52	3.91	3.96	0.85	99	1
specifications	>10.5	<4	-	>0.8	95 - 97	3 - 5

Table 6. Marshall results from asphalt to plastic waste

Addition of plastic waste(%)	Marshall Stability (KN)	Creep (mm)	Quotient Marshall (KN/mm)	water resistance	Compactness (%)	Void percentage (%)
Additive-free	10.82	3.37	3.21	0.76	95	5
2	12.70	3.42	3.71	0.78	96	4
4	12.65	3.71	3.40	0.80	96	4
6	13.16	3.68	3.57	0.81	97	3
8	13.85	3.5	3.95	0.82	97	3
10	14.01	4.13	3.39	0.79	98	2
specifications	>10.5	<4	-	>0.8	95 - 97	3 - 5

Penetrability

The results illustrated in (fig. 3) and (fig. 4), showed a decrement in the penetrability value from 46dmm for base bitumen to 35dmm for PP500P kneaded at 3h, and 37dmm for kneaded plastic waste at 2h, demonstrating that this polymer's rigidity increases in its original form compared to its recycled state by up to 10% of added concentration. The polymer was mixed for 3 hours at a temperature of 175°C, during this process, the polymer turned into a molten state, absorbing some of the oil. Additionally, it released a lower molecular weight fraction into the bitumen. **[37, 38]**, which increases bitumen viscosity and at the end of the process after cooling, the hardened mixture formed with the addition of PP500P more than with the addition of plastic waste. Although bitumen hardening improves the material's rigidity and hence increases its capacity for bearing loads, it can also induce fractures **[16]**. This risk is less in BB modified by plastic waste; they are advantageous in terms of crack resistance comparing to polymers. The decrease in penetrability has a direct relationship with viscosity, and the improvement of resistance to sensibility at temperature **[26]**.

Softening point

The results obtained from (fig. 5) and (fig.6) reported an increase in softening point from 49°C of base bitumen to 75°C for bitumen modified by PP500P and 63°C for plastic waste up to 10% of concentration kneaded for 3 hours of time. The effect of thermoplastic modification does not significantly affect the softening point as penetrability **[37, 38].** This could be explained by the internal structure formed by the polymer, which appears to be thermodynamically stable, and does not significantly affect the softening point **[19]**. Additionally, PP500P has a significant increase than plastic waste. This confirms that polymer modified BB with an increased softening point, improves the performance of the pavement in terms of rutting, fatigue and temperature sensitivity **[16]**.

Further, At 8% addition of plastic waste during 2 hours of kneading, and at 4% addition of polypropylene PP500P during 3 hours of kneading, the bitumen showed the same penetrability value (38°C) and also the same value of the softening point (57°C), i.e. the bitumen needs more mixing time (3 hours) if modified with PP500P, and less mixing time (2 hours) if modified with plastic waste. The latter provides a lower range of softening point variation because of the homogeneity achieved when blending this plastomer with the base bitumen, which is attributed to its low molecular weight **[39]**. In the rest of the experiment the kneading time was set at 3 hours and 2 hours for modified bitumen with PP500P and with plastic waste, respectively.

Effect of PP500P and plastic waste on Marshall stability

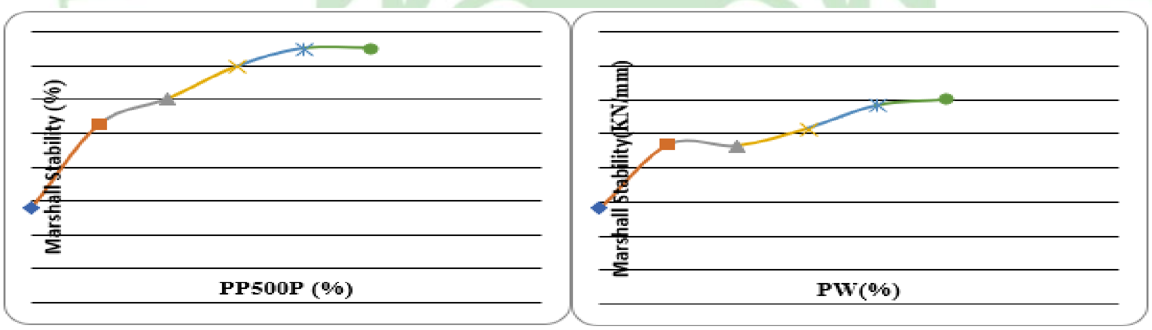

Figure 7 Stability Marshall with Addition of PP500Pet plastic waste

(Figure 7) showed the Marshall Stability variation of the asphalt concret modified by the PP500P and the plastic waste. An increment in the Marshall stability of modified bituminous concrete was noted from the minimum value of 10.82KN obtained for the base AC, to 15.52KN for the PP500P, and to 14.01KN for plastic waste with 10% addition of improvers. Importantly, the PP500P gave a higher stability than plastic waste which also reacts positively on Marshall

Stability. The increase in Marshall Stability of modified AC could be explained by the good adhesion developed between bitumen and PP500P or plastic coated aggregates due to intermolecular bonding, these intermolecular attractions improved bitumen strength **[40]**. This enhancement was successful by agglomeration, aggregation or flocculation of particles in the multi-phase system **[41, 42]**. The interarticular forces became predominant which contributes to the bitumen improvement and therefore the stability and durability of the AC.

PP500P and plastic wastes on the bitumen creep

Regarding creep (figure. 8) there was a decrease in the value of 3.37mm for the control AC (without additive) to a minimum value of 2.67mm with the addition of 6% of PP500P, and 3.5mm to 8% of plastic waste. Moreover, the addition of PP500P reacts positively on creep, and according to the norm the addition of 2% 4% 6% 8% plastic waste reacts positively on the creep of bituminous concretes. This modified AC behavior returns to the nature of the improver, and also the internal structure of base bitumen plays a key role **[43, 39],** this variation in creep values could be attributed to the increased rigidity of polymer modified bitumen, which improves its resistance to permanent deformation giving a relatively more rigid BB **[44].**

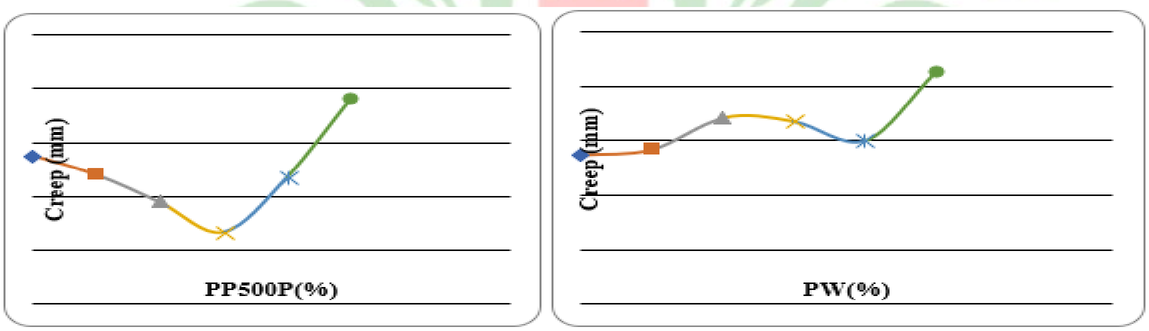

Figure. 8 Creep with addition of PP500P and plastic waste

Effect of PP500P and plastic waste on water resistance

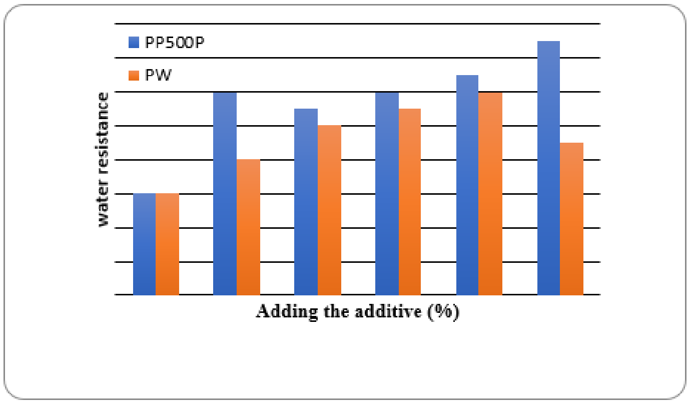

Figure. 9 PP500P Water Resistance and Plastic Waste

According to (figure 9) the mixture without addition does not show a good water resistance (0.76) less than (0.8) (specification). Importantly, the water resistance increased after adding the PP500P and recorded variable values greater than 0.8 to reach 0.85 for 10% PP500P addition, and 0.82 to 8% of plastic waste addition, but it decreased to 0.79 for 10% of plastic waste addition. According to these findings, the adding of plastic waste to bituminous concrete has a positive effect on the water resistance of this asphalt; yet, it is limited to 8%. A good water resistance of a AC means a good moisture resistance, i.e. this mixture is recommended for coatings in wet areas **[29].**

Effect of PP500P and plastic waste on compactness

The change in compactness with each additive is presented in (Figure 10). Interestingly, an improvement of compactness was noted from 95% of the initial mixture to 97% for 6% of PP500P addition of and 8% of plastic waste addition. On the other hand, the compactness was not favorable for both improvers at 10%. This variation in compactness to modified bitumen behaviour may be due to reversible structural degradation commonly found in the multi-phase system of polymer modified bitumen **[41, 42]**. Moreover, the successive concentrations of 6% and 8% of PP500P and plastic waste formed the ideal AC at the time of compaction, less pores between the aggregates and therefore less rutting.

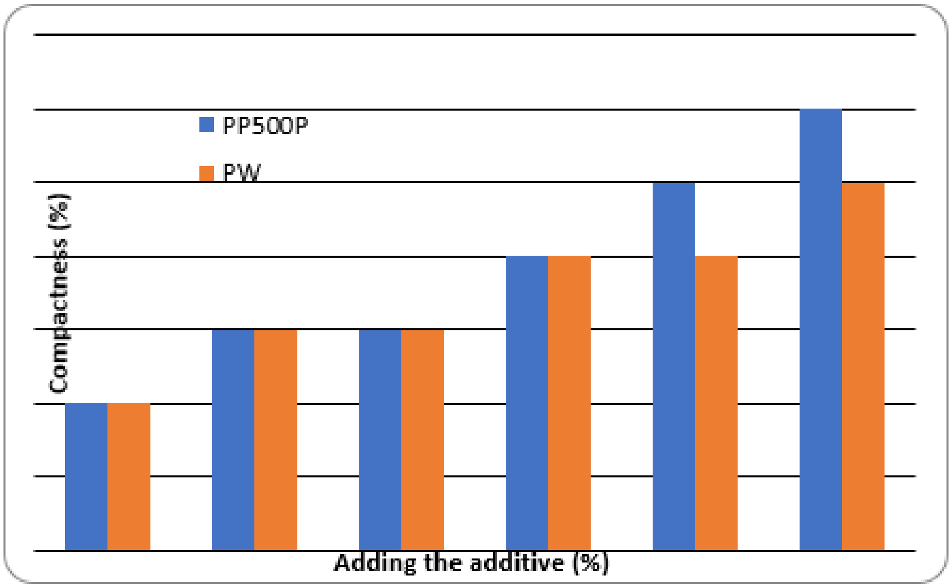

Figure. 10 Evolution of compactness according to PP500P and plastic waste

Effect of PP500P and plastic waste on voids percentage

(Figure.11) demonstrates the variation of the asphalt voids percentage depending on plastic waste and PP500P; this parameter was at 5% for ordinary asphalt, but it decreased to 3% when 6% of additives were included. Favorable values of air voids attribute to the stability of the modified mixture, which can be easily compacted, and therefore, the level of compaction achieved.

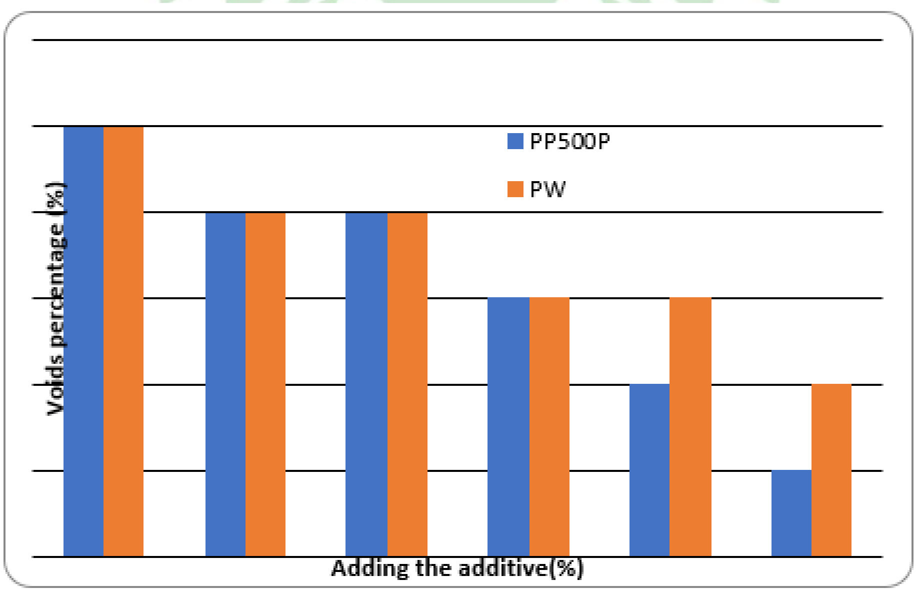

Figure 11 Percentage of voids by PP500P and plastic waste

Effect of PP500P and plastic waste on quotient

The impact of PP500P and plastic waste on the quotient is depicted in Figure 12. The quotient varies from 3.21 KN/mm (without addition) to 3.96 KN/mm (at 10% addition of PP500P), and then 3.95 KN/mm at 8% of plastic waste addition, and finally 3.39 KN/mm. This parameter directly depends on Marshall Stability and creep; thus, the recorded peak is from to the minimum creep value of 2.67mm. Furthermore it could be stated that the addition of PP500P granulate or recycled plastic waste has a positive effect on the quotient of asphalt concrete. The improved values of this AC parameter indicate a greater ability to spread the applied load and resist creep deformation of this AC. According to that, the Marshall Quotient is the measure of permanent deformation in service.

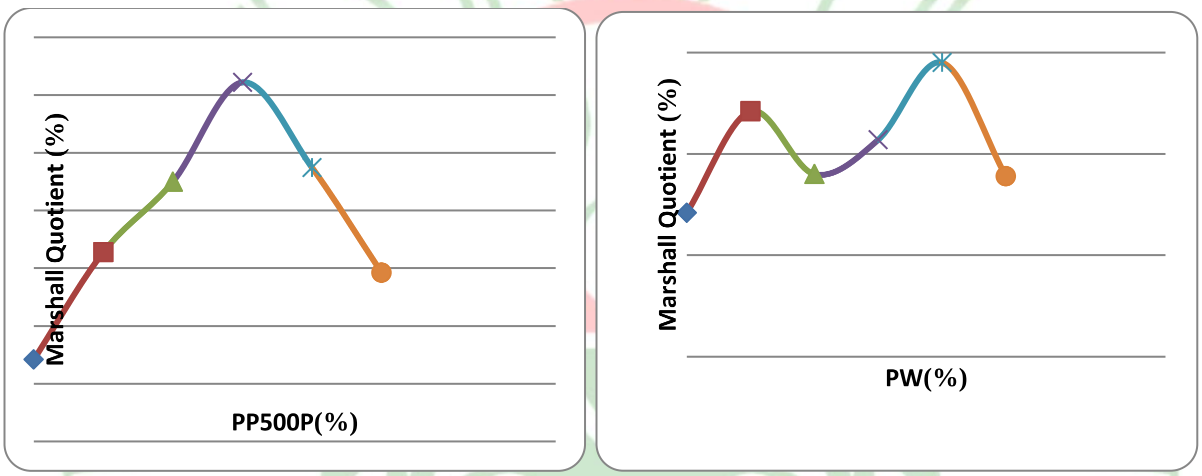

Figure. 12 Marshall quotient according to PP500P and plastic waste

4. Conclusion

The conclusions drawn from this work were as follows:

- The possibility of integrating recycled polypropylene (plastic waste) through the wet process has a significantly positive impact on the rheological and mechanical properties of bitumen.
- Polypropylene is a temperature-resistant plastomer.
- Class 40/50 bitumen showed a good compatibility with PP500P polypropylene waste without coupling agent.
- The rheological properties of bitumen 40/50 were improved in the same way; by 4% of PP500P in grains and by 8% of plastic waste.

- The low molecular weight of plastic waste at a concentration of 10% provides homogeneity with bitumen and increases the deformation resistance of the improved asphalt mix.
- Marshall Stability was improved by a 4% PP500P grain and 10% plastic waste.
- The fiber form is more advantageous compared to the seed form regarding:
  - ✓ mixing time
  - ✓ resistance to cracking
  - ✓ Reduced asphalt potholes and less rainwater stagnation.
- Utilizing polypropylene plastic to enhance the mechanical characteristics of bitumen affords a reliable method for its safe disposal.
- Recycling polypropylene plastic waste is one of the cost-effective environmental solutions.
- The recycling of polypropylene plastic waste is effective in all high-temperature regions, including Algeria.
- The recycling in road sector could have a positive impact on sustainable development.
- However, forward tests such as indirect tensile stiffness module, indirect tensile fatigue test or four-point bending test, repeated load, axial test, etc., should be necessarily assessed in order to verify the properties of Asphalt Concrete modified to plastic waste polypropylene in the form of shredded fibers without using coupling agents.

References

1. Wei Hu, Xiang shu, Baoshan Huang, Sustainability innovations in transportation infrastructure: An overview of the special volume on sustainable road paving., volume 235/20 octobre2019/ Pp369-377
2. Madeleine Boudoux d'Hautefeuille ***Espaces et sociétés*** 1/ 2014 (n° 156-157), p. 177-195. (la relation entre la route et développement).
3. Sharma, Umesh/ Giri, Harish Kumar/ Khatri, Ankita.Use of Recycled Asphalt Material for Sustainable Road Construction/ Indian Roads Congress /2018-9 / pp 29-36 / Volume 46
4. Durable and Sustainable Road Constructions for Developing Countries, A.A.A. Molenaara, Procedia Engineering 54 (2013) 69 – 81

5. Vatsal Patel, Snehal Popli and Drashti Bhatt, 'Utilization of Plastic Waste in Construction of Roads', International Journal of Scientific Research, Vol. 3, Issue: 4, ISSN No 2277 – 8179, Pg. No. 161-163, April 2014.
6. Al-Haddad, Abdulhaq Hadi Abedali. "Estimated Fatigue Life of Recovery Reclaimed Asphalt Pavement Binder." Key Engineering Materials, vol. 924, Trans Tech Publications, Ltd., 30 June 2022, pp. 243–255. Crossref, doi:10.4028/p-yyxlf0.
7. Md Arifuzzaman a,* , Hisham Jahangir Qureshi a , Abdulrahman Fahad Al Fuhaid a , Fayez Alanazi b , Muhammad Faisal Javed c , Sayed M. Eldin, Novel ensemble modelling for prediction of fundamental properties of bitumen incorporating plastic waste, journal of materials research and technology 2023, volume24, Pages 3334-3351.
8. Gaetano Di Mino. Vineesh Vijayan. Shahin Eskandarsefat. Loretta Venturini and Konstantinos Mantalovas, Inverstigating the Multi-Recyclability of Recycled Plastic-Modified Asphalt Mixtures, ***Infrastructures*** 2023, ***8***(5), 84; https://doi.org/ 10.3390 infrastructures 8050084 April 2023
9. Camilo Vargas et Ali El hanandh, Features Importance and Their Impacts on the Properties of Asphalt Mixture Modified with Plastic Waste: A Machine Learning Modeling Approach, August2022, International Journal of Pavement Research and Technology https://doi.org/10.1007/s42947-022-00213-7
10. Ferdaus, Rashida, et al. "Rheological and Mechanical Properties of Hot Mix Asphalt Incorporating Polypropylene and Polyethylene Fibers." Construction Technologies and Architecture, Trans Tech Publications Ltd, 31 Mar. 2023. Crossref, doi:10.4028/p-sl037b.
11. Raouf Mahmood Raouf, Khalid Mershed Eweed, Nisreen Mizher Rahma**.** Recycled Polypropylene to Improve Asphalt Physical Properties. International Journal of Civil Engineering and Technology (IJCIET). Volume 9, Issue 12, December 2018,pp.1260–1266.
12. Afroz Sultana.SK, K.S.B. Prasad, 'Utilization of Waste Plastic as a Strength Modifier in Surface Course of Flexible and Rigid Pavements' International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 Vol. 2, Issue 4, pg. no. 1185-1191, July-August 2012.

13. Michele Porto, Paolino Caputo, Valeria Loise, Shahin Eskandarsefat , Bagdat Teltayev and Cesare Oliviero Rossi**.** Bitumen and Bitumen Modification: A Review on Latest Advances. Applied Sciences February 2019. DOI: 10.3390/app9040742.
14. Investigating the engineering properties of asphalt binder modified with waste plastic polymer, Ain Shams Engineering Journal 12 num 2(2021) 1569–1574, https://doi.org/10.1016/j.asej.2020.08.035
15. Noor Zainab Habib, Ibrahim Kamaruddin, Madzalan Napiah and Isa Mohd Tan. Rheological Properties of Polyethylene and Polypropylene Modified Bitumen. International Journal of Civil and Environmental Engineering 3 (2) 2011.
16. Johnson Kwabena Appiah, Victor Nana Berko-Boateng, Trinity Ama Tagbor. Use of waste plastic materials for road construction in Ghana. Case Studies in Construction Materials 6 (2017), p 1–7.
17. United Nations Environment Programme (2021). From Pollution to Solution. A global assessment of marine litter and plastic pollution Nairobi, ISBN: 978-92-807-3881-0 Job number: DEP/2379/NA, https://www.unep.org/
18. Luc De Bock, Alexandra Destrée, Stefan Vansteenkiste, Ann Vanelstraete, recyclage des plastiques dans les enrobés-une analyse, centre de recherches routières, bruxel 2020, https://www.crr.be
19. ladi, M., Mashifana, T., & Sithole, N. T. (2023). Utilization of Plastic Waste and Waste Rubber Tyres to Modify Bitumen Binder in Road Construction. In Key Engineering Materials (Vol. 947, pp. 131–138). Trans Tech Publications, Ltd. https://doi.org/10.4028/p-16e0qr
20. Abdul Muqeet Shah, Rida Hameed Lodhi, Muhammad Faisal Javed, Michał Jasiński, Elżbieta Jasińska and Miroslava Gono, Structural Performance of Waste Plastic Bottles Modified Asphalt, Resources 2023, VOL12(1),num10; pp88-117 https://doi.org/10.3390/resources12010010
21. Anurag V. Tiwar and Y R M Rao, Study of Plastic Waste Mixed Bituminous Concrete Using Dry Process for Road Construction . The Asian Review of Civil Engineering ISSN: 2249 - 6203 Vol.. 6 No.2, 2017, pp.1-6 .

22. Peng Lin, Xueyen Liu, shisong Ren, Jian Xu, Yi Li, Mingliang Li,Effects of Bitumen Thickness on the Aging Behavior of High-Content Polymer-Modified Asphalt Mixture, ***Polymers*** 2023, ***15***(10), 2325; https://doi.org/10.3390/polym15102325
23. Michel Porto, Paolino Caputo, Valeria Loise, Shahin Escandarsefat, Bagdat Teltayv, Cesare Oliviero Rossi, Applied sciences, Bitumen and Bitumen Modification: A Review on Latest Advances, 2019,9(4), 742,pp1-35
24. Abdul-Rahim Ibrahim Al-Hadidy and Yi-qiu Tan. Evaluation of Pyrolisis LDPE Modified Asphalt Paving Materials. JOURNAL OF MATERIALS IN CIVIL ENGINEERING. october 2009. DOI: 10.1061/(ASCE)0899-1561(2009)21:10(618).
25. Silvia Angelone • Marina Cauhape´ Casaux, Manuel Borghi , Fernando O. Martinez. Green pavements: reuse of plastic waste in asphalt mixtures. Materials and Structures. DOI 10.1617/s11527-015-0602-x. March 2015.
26. Estabraq N. Ezzat, Alaa H. Abed, Prediction of modified asphalt concrete rutting depth using statistical model, Materials Today: Proceedings, Volume 42, Part 5, 2021, Pages 1784-179
27. E Yuanita, B E Hendrasetyawan, D F Firdaus, and M Chalid, Improvement of polypropylene (PP)-modified bitumen through lignin addition, Innovation in Polymer Science and Technology 2016 (IPST 2016). IOP Conf. Series: Materials Science and Engineering 223 (2017) 012028.
28. Using Waste Plastics as Asphalt Modifier, Fengchi Xu, Yao Zhao, Kangjian Li , Materials (Basel), 2021, 15(1):110.doi:10.3390/ma15010110 PMID: 35009267PMCID: PMC8745802
29. Zainab Ahmed Alkaissi, Effect of high temperature and traffic loading on rutting performance of flexible pavement, Journal of King Saud University – Engineering Sciences, 32(2018) 1-4, https://doi.org/10.1016/j.jksues.2018.04.005
30. Haibin Li, Lichang Zhou, Jianmei Sun, Sirui Wang, Mingming Zhang, Yihong Hu, andAhmed Abdulakeem Temitope, Analysis of the Influence of Production Method, Plastic Content on the Basic Performance of Waste Plastic Modified Asphalt, polymers 2022, 14(20), 4350, https://doi.org/ 10.3390/polym14204350

31. Mohamed MM. Badry et al 2021 IOP Conf. Ser.: Mater. Sci. Eng. 1090 012032, Effect of Polymer on the Properties of Bitumen and Pavement Layers, Case Study: Expressway No.1, Republic of Iraq.
32. Jaime Preciado , Gilberto Martínez Arguelles , Margareth Dugarte , Alessandra Bonicelli , Julio Cantero , Daniela Vega , Yennis Barros , Improving mechanical properties of hot mix asphalt (HMA) using fibres and polymers in developing countries, materials science and engineering 245, 2017, 022013.
33. Yuetan Ma a , Hongyu Zhou a , Xi Jiang a , Pawel Polaczyk a , Rui Xiao a , Miaomiao Zhang a , Baoshan Huang, The utilization of waste plastics in asphalt pavements, cleaner materials https:doi.org/10.1016/j.clema.2021.100031, vol 2 , issn 2772/3976 November 2021
34. Shubham Bansal, Anil Kumar Misra, Purnima Bajpa, Evaluation of modified boituminous concrete mix developed using rubber and plastic waste materiels, International Journal of sustainable built environment,volume6 , issue2, December2017,pp 442-448
35. Nouali Mohammed**,** Valorisation des déchets de sachets plastique pour des enrobés routiers plus performants, RUGC 2021- Prix René HOUPERT, pp 251-258
36. Centre National de l'informatique et de Statistiques https://www.cnis.fr/
37. A.A. Yousefi, A.A.T. Kadi, composite asphalt binders: effects of modified RPE on asphalt, Journal Mater Civil Engineering, May 2000, PP 113-123.
38. Golestani B, Nejad FM, Galooyak SS, Performance evaluation of linear and nonlinear nanocomposite modified asphalts, Construction and Building Materials 2012; 35: 197-203.
39. Zhu, J., Birgisson, B., Kringos, N. (2014) Polymer modification of bitumen: Advances and challenges. European Polymer Journal, 54: 18-38 http://dx.doi.org/ 10.1016/ j.eurpolymj.2014.02.005
40. Brajesh Mishra, Ravi Shankar Mishra. (A Study on Use of Waste Plastic Materials in Flexible Pavements), International Journal of Innovative Research in Science, Engineering and Technology. , Vol. 4, Issue 8, August 2015, PP 6927-6935
41. N.Z. Habib, I. Kamaruddin, M. Napiah, I.M. Tan, Rheological properties of polyethylene and polypropylene modified bitumen, Int. J. Civ. Environ. Eng. 3(2) (2011).

42. Merusi F, Giuliani F, Filippi S, Polacco G, A model combining structure and properties of a 160/220 bituminous binder modified with polymer/clay nanocomposites. A rheological and morphological study, Materials and Structures 2013 DOI 10.1617/s11527-013-0096-3.
43. D. Sybilsk, New simplified equation for the computation of absolute viscosity of polymer-bitumens, Mater. Struc. 30 (1997) pp. 182187.
44. Olumide Moses Ogundipe The Use Of Polyethylene Terephthalate Waste For Modifying Asphalt Concrete Using The Marshall Test. Slovak Journal of Civil Engineering. Vol. 27, 2019, No. 2, 9 – 15. Polymers 2022, 14(20), 4350; https://doi.org/ 10.3390/polym14204350