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Characteristics of Asphalt Binder and Mixture Modified With Waste Polypropylene

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HIGHLIGHTS

- This paper investigates the probability of using Waste Polypropylene (WPP) as modifier.
- It is aimed to enhance the properties of asphalt binder and mixture.
- Two types of asphalt binder (40/50) and (60/70) were used.
- Three percentages of WPP (1%, 3%, and 5%) were added to (60/70) asphalt binder/mixture,
- The outcomes indicated that 3% of WPP was optimum percentage that gave best results.

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ABSTRACT

Improving asphalt materials to develop the overall performance of asphalt binders and mixtures has been the focus of several investigations made over the past few decades. The application of discarded waste plastics in asphalt modification was one of the steps taken in this direction. Using waste materials in pavement construction would not only enhances asphalt properties but would also bring out significant saving in road material costs and help towards tackling disposal problems of such waste materials, which tend to be hazardous in as much as they can cause pollution of water, soil, and air. The purpose of this paper is to investigate the probability of using Waste Polypropylene (WPP) as modifier to enhance the properties of asphalt binder and mixture. In this paper, two types of asphalt binder (40/50) and (60/70) were used. Three percentages of WPP (1%, 3%, and 5%) were added to (60/70) asphalt binder/mixture to obtain the modified samples that were tested using several laboratory tests and their results were compared to original (60/70) asphalt binder/mixture and to those of (40/50) asphalt binder/mixture besides comparing with the Iraqi Specifications. The outcomes indicated that 3% of WPP was the optimum percentage that gave best results for asphalt binder and asphalt mixture compared to original and other percentages of asphalt samples and according to the Iraqi Specifications.

1. Introduction

Road pavements under intensive environmental effects cannot always meet the desirable quality requirements. For instance, the impact of temperature differences between summer and winter, the load deformation and so on. This results in the fact that pavement service life is decreased[1]. Road pavements have also thermal susceptibilities and often experience thermal cracking in cold weather and creep and distortion in high temperature regions[2]. Moreover, traffic road volume raises and requires a coinciding increase in load bearing capacities of pavements and their service life span. Such factors illustrate the need for developing bitumen with enhanced characteristics compared to that of conventional asphalt binder[3].

Investigators are constantly induced to investigate the probability of utilizing different kinds of waste materials as bitumen modifiers in hot mix asphalt industry (HMA). The fact that the conventional bitumen is relatively expensive besides the massive regulations of the environmental authorities formed some serious motivations for them[4].

The design of improved asphalt mix is achieved using three major variables; weight of scrap tires replaced by coarse base aggregate, particles size of scrap tires, and finally the weight of binder used (bitumen). The improved asphalt mix (IAM) requires a balance between rut resistance and durability to resist cracking and moisture damage (stripping). Accordingly, several factors that influence rut resistance and durability are considered during the design process [5].

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It has been manifested that the performance of bituminous mixtures implemented in the wearing course of road pavements is possible to be enhanced with the aid of different kinds of additives to bitumen like crumb rubber, polymers, and rubber latex, etc.[6].The most used modifiers or additives in HMA industry are polymers, mostly virgin elastomer, and plasterer, but more recently other polymers from plastic wastes have also been investigated. The plastic wastes can improve the properties of asphalt binder and, consequently, the performance and durability of the asphalt mixtures and they present environmental and economic advantages. On this basis, asphalt can be partially replaced by waste plastics [7].

Every day, several types of materials that are either entirely or partly manufactured of plastics are utilized and lastly end up in garbage. The improper disposal of these plastic wastes has become a serious issue particularly in urban areas in terms of its misuse, clogging of drains, its dumping in the dustbin, and aesthetic issues, etc. Depending on plastics quality, they may take anywhere from days to many years to molder in landfills, however, they never decompose entirely in a way that may be utilized by nature. Therefore, plastics are considered to be from the worst waste materials when it comes to environmental contamination and it is required that these wastes must be recycled and not disposed in landfills[6,8].

The objective of this study is to investigate the possibility of utilizing waste polypropylene as asphalt cement modifier to enhance asphalt properties as well as eliminate these waste materials.

2. Methodology

The laboratory work of this study consists of modifying the 60/70 asphalt binder with WPP and comparing the results of modified binder/mixture samples with the original 60/70 binder/mixture and the base 40/50 binder/mixture besides evaluating the results with the specifications of State Corporations of Roads and Bridges in Iraq SCRB (SCRB/ R9-2003) [9]. Figure 1 shows the work methodology implemented in this study.

3. Materials Used

3.1 Asphalt Binder

Asphalt cement with penetration grade of 60/70 was used for modification process with WPP, while 40/50 asphalt binder was used for comparison purposes since 40/50 binder is the mostly implemented asphalt in the construction of flexible pavements in Iraq. Both theses binders were obtained from Al-

Dora refinery in Baghdad and their properties are presented in Table 1.

3.2 Aggregate and Filler

The local aggregate implemented in laboratory work is crushed quartz obtained from Al-Nibaie Quarry, which is widely used for bituminous mixtures in Iraq, while the Portland cement, which was used as mineral filler, was obtained from Al-Kufa factory, Iraq. One aggregate gradation was used in this study as shown in Figure 2 for implementation in wearing course which has nominal maximum aggregate size of 1/2”. The gradations are presented in Table 2.

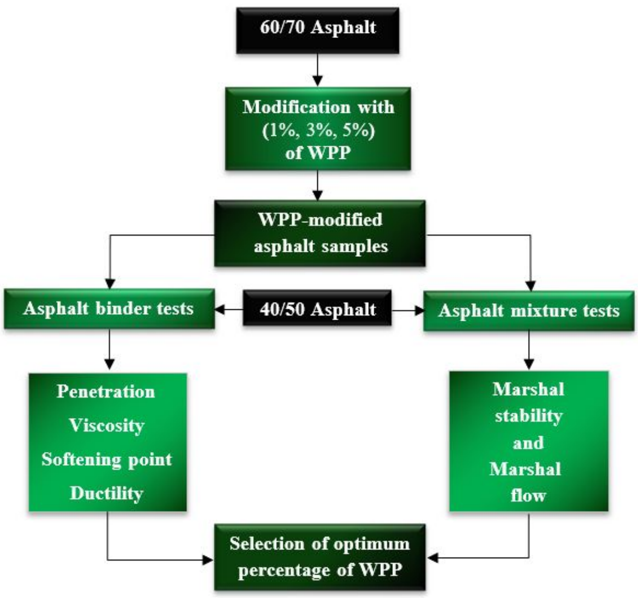

Figure 1: Work methodology of the study

Table 1: Properties of 40/50 and 60/70 asphalt binders

Property	Results of 40/50 Asphalt	SCRB specification of 40/50 asphalt	Results of 60/70 Asphalt	SCRB specification of 60/70 asphalt
Penetration	47	40-50	66	66
Ductility(cm)	146	>100	>150	>100
Kinematic viscosity (cSt)	420	Min. 400	387	Min. 300
Softening point (°C)	51	….	47	…
Flash point (°C)	279	Min. 232	267	Min. 232
Specific gravity	1.051	….	1.46	…

3.3 Waste Polypropylene (WPP)

The waste polypropylene utilized in this study was obtained from a waste plastic recycling factory in Bab Al-Sham, Baghdad in the form of small pieces. This waste plastic was washed and further grinded into powder and sieved on #50 sieve. Figure 3 illustrates the utilized waste Polypropylene and Table 3 presents its properties.

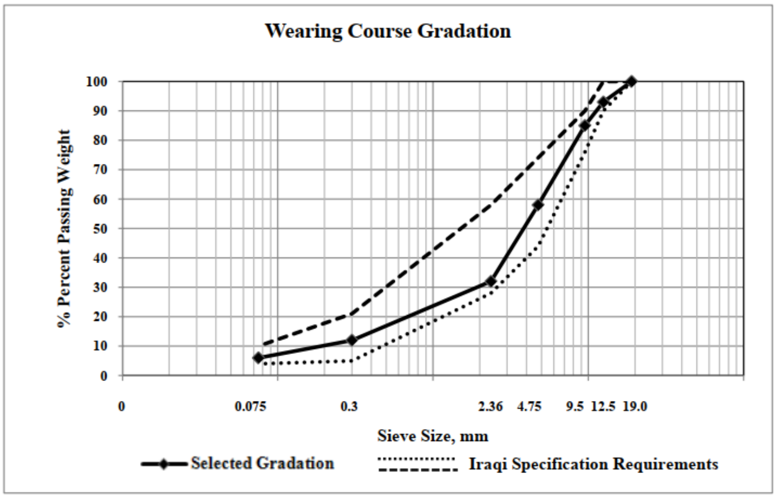

Figure 2: Asphalt mixture gradation with Iraqi specification limits.

Table 2: Selected gradations for asphalt concrete mixtures (wearing course).

Sieve size		Percent passing (%)
mm	***In***	
37.5	1 ½”	…
25	1”	…
19	3/4”	100
12.5	1/2”	93
9.5	3/8”	85
4.75	No.4	58
2.36	No.8	32
300µm	No.50	12
75µm	No.200	6

Table 3: Properties of the used waste polypropylene

Property	WPP
Melting temperature (°C) *	160
Specific gravity *	0.91
Maximum particle size after grinding and sieving (mm)	0.3

* The property was obtained from the plastic factory from which this WPP was taken.

Figure 3: Waste Polypropylene

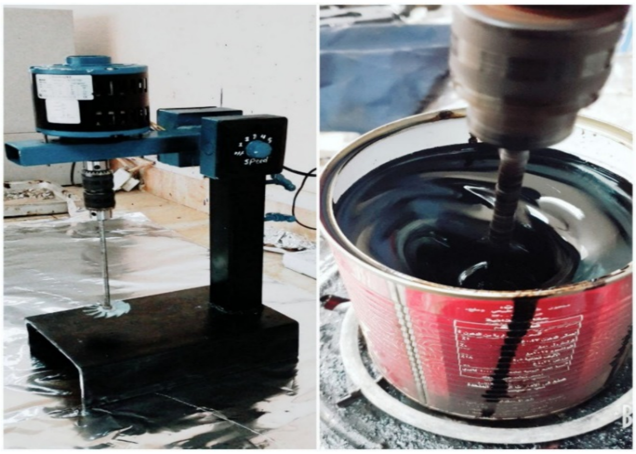

Figure 4: Mixing process of WPP with asphalt binder

3.4 Sample's preparation

The preparation of WPP-modified binders consists of adding three percentages (1%, 3% and 5%) of WPP powder to the 60/70 asphalt binder as suggested by Habib et al.(2011) [10]. WPP and asphalt binder were blended using laboratory mixer for (1) hr. at (1300) rpm to gain a homogeneous mixture as shown in Figure 4. The addition of WPP was during the bitumen being heated at temperature of (165±5) ℃. WPP-modified asphalt mixtures were prepared by mixing the obtained WPP-modified binders along with the aggregate and filler at (150) ℃ (wet process).

3.5 Tests

The following bitumen tests were conducted on the 40/50 and 60/70 asphalt cements and all the modified asphalt specimens: penetration, softening point, ductility, and kinematic viscosity according to ASTM D5, D36, D113, D2170, D 92, D 70 and D 1754 respectively [11-14]to investigate the effects of WPP additive on physical properties of asphalt binder. Furthermore, asphalt mixtures with 40/50 binder, 60/70 binder, and WPP-modified binders were tested in Marshal stability and flow tests according to ASTM D6927 [14].

4. Results and discussion

4.1 Asphalt binder results

The results of the physical tests; penetration, softening point, viscosity, and ductility, performed on base 40/50 asphalt, 60/70 asphalt and WPP-modified asphalt binders are shown in Figure 5.

It is clear from this figure that the penetration grade of 60/70 asphalt binder decreased with the addition of WPP until it reached 30/40 grade with 5% of WPP additive. Compared to base 40/50 asphalt binder, 3% of WPP was the required percentage to gain the same 40/50 penetration grade. The decrease in penetration is because the hardness of bitumen increased with the addition of WPP, where this reduction can be attributed to a change in phase in the binder upon the addition of WPP which resulted in increased internal resistance.

As for softening point, the addition of WPP has increased the softening point of the resulted binders which results in asphalt binders with higher resistance to temperature compared to the original 60/70 binder. It can also be noted that 3% of WPP, which has 40/50 penetration grade, has higher softening point compared with the base 40/50 asphalt binder. The high resistance of WPP to elevated temperatures, compared to bitumen, is the reason behind the increase in softening point of the resulted binders.

Furthermore, Figure 5 also presents kinematic viscosity test results at 135 ℃. It can be noted that viscosity values of asphalt binder increased with increasing the dosage of WPP. Also, 3% of WPP that resulted in 40/50 penetration grade, has higher viscosity values in comparison with the base 40/50 asphalt. The increase in asphalt viscosity is due to the hardness effect of WPP on asphalt binder which is supported by the decrease in penetration values. The increase in viscosity values would help to improve the resistance to permanent deformations at elevated temperatures thereby increasing the service life of the pavement. Asphalt is a viscoelastic material; temperature has an important effect on its stiffness properties. The fatigue damage or cracking of an asphalt pavement caused by traffic loads is influenced by the stiffness properties of the mix. Fattah et al. (2014) [16] found that the initial stiffness is affected by temperature variation.

Moreover, it is also clear from Figure 5 that asphalt ductility values decrease as WPP was added, where the ductility of near 60/70 asphalt was higher than 150cm and decreased to 96 cm with 5% of WPP addition which is below specification limits. However, 1% and 3% of WPP addition has resulted in ductility values within specification limits (above 100 cm). The decrease in ductility values is the result of the hardness effect of WPP on asphalt binder, which means that the modified binders tend to show more brittle behavior at low temperatures compared to original 60/70 asphalt binder. Nonetheless, 3% of WPP has resulted in ductility value close to that of base 40/50 asphalt binder.

4.2 Asphalt mixture results

The results of Marshall test (stability, flow, and stiffness) on original and modified asphalt mixtures are shown in Figure 6. It can be seen from this figure that the stability values of 60/70 asphalt mixture is (6.5) which is lower than that of 40/50 asphalt mixture and it is also below SCRB specification limits for wearing course. With the addition of WPP, stability values of modified mixtures increased where 3% and 5% of WPP resulted in stability values higher than that of base 40/50 asphalt mixture and exceeded the minimum required value for wearing course according to SCRB specifications that marked in Figure 6. The increase in stability values with the addition of WPP is supported by the increase in viscosity values of WPP-modified binders.

Conversely, the values of asphalt mixtures' flow have decreased with the addition of WPP where the flow value of original 60/70 asphalt mixture was (5) which is higher than specification limits and decreased to (3.5) and (2.5) with 1% and 3% of WPP addition respectively to be within specification limits. The reduction in flow values of WPP-modified mixtures is also supported by the decrease in ductility values of WPP-modified binders. Like the case for stability, stiffness values of modified mixtures, which resulted from dividing stability overflow, were also increased with the addition of WPP.

It can also be seen from Figure 6 that 3% addition of WPP is the optimum percentage for asphalt modification since it gave the best results in comparison with the base 40/50 asphalt mixture and SCRB specifications.

The results of Khalaf et al. (2020) [17] showed that the SBS polymer asphalt mixture gave better moisture sensitivity and better fracture resistance according to the study. It was noted that indirect tensile strength ratio (TSR) increases by 93.1 % and the rut depth decreases by 32.5 % when adding 3% SBS polymer to SMA.

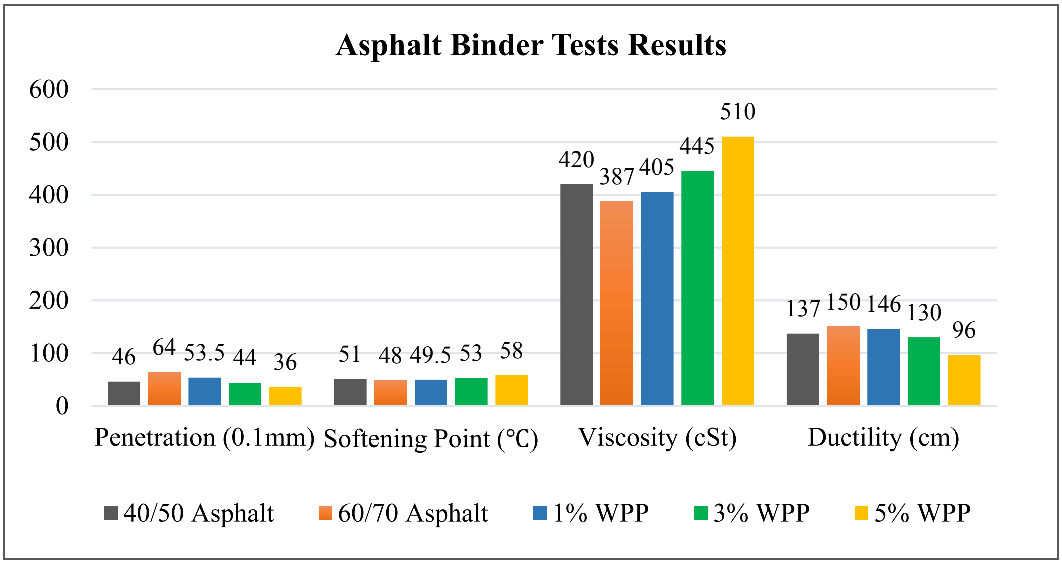

Figure 5: Tests results of original and modified asphalt binders.

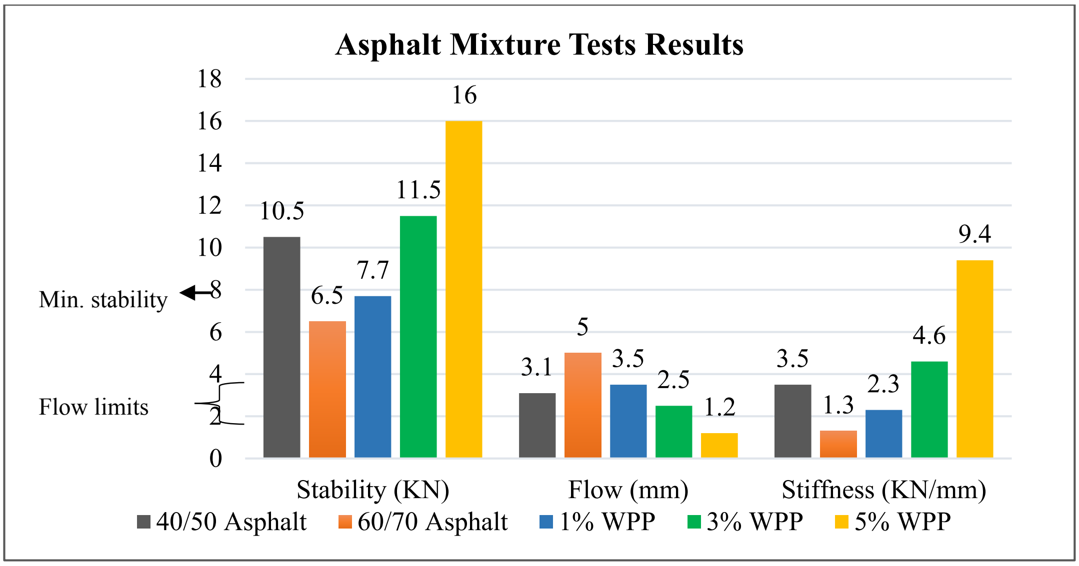

Figure 6: Tests results of original and modified asphalt mixtures.

5. Conclusions

1) WPP has significant effect on modifying the soft (high grades) asphalt binders due to the decrease in penetration values (increase in the consistency) with the addition of WPP.
2) The addition of WPP to the asphalt binder resulted in modified binders with higher viscosity (higher resistance to permanent deformation) but with lower ductility (lower thermal crack resistance).
3) WPP-modified binders have higher resistance to elevated temperature due to the higher softening point values.
4) The stability of asphalt mixture increases with the addition of WPP which indicates higher resistance to permanent deformation.
5) The addition of WPP results in modified asphalt mixtures with better flow values compared to the original mixture.
6) 3% of WPP is the optimum percentage to be added to 60/70 asphalt which resulted in better outcomes for asphalt binder/mixture compared to the original binder/mixture and within specification limits.
7) Finally, it can be concluded that the properties of asphalt binder/mixture can be enhanced with the addition of WPP, especially for high temperature regions. Also, it can be reported that the recycling of WPP in HMA industry is feasible which would also decrease the negative environmental effects.
8) For future works, it is suggested to investigate the influence of other types of waste materials like; waste glass, waste wood ash and other types of plastic wastes on the properties of asphalt binder/mixture besides implementing a combination of two or more waste materials as additives in modification process.

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Author Contribution

All authors contributed equally to this work.

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Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare that there is no conflict of interest.

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