Characteristics of asphalt binder modified with waste vegetable oil and waste plastics

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Abstract. Asphalt binder, which is a by-product of petroleum distillation, is vastly consumed in pavement construction. However, petroleum is highly rare as a nonrenewable source resulting in the short-term supply of petroleum asphalt. The improper elimination of waste oils and plastics presents numerous environmental problems. This paper investigates the possibility of using waste vegetable oil (WVO) in combination with waste plastics; Low density polyethylene (LDPE) and Polyvinyl chloride (PVC), as enhancing additives for (40/50) asphalt cement in order to mitigate the illegal disposal of these wastes and modify asphalt binder properties as well as reduce the consumption of bitumen thereby reducing the cost. Three percentages (1%, 2% and 3%) of waste vegetable oil were firstly added to the control asphalt to prepare WVO-modified bitumen. Three percentages (1%, 3% and 5%) of LDPE and PVC were then added separately to WVO-modified binder. Physical properties of the original and modified asphalts were studied using several laboratory tests. The results indicated that bitumen modified with waste vegetable oil has better thermal cracking resistance and lower rutting resistance and it is more suitable to be used in moderate and cold regions, while the addition of plastic wastes in combination with waste vegetable oil could reverse these effects. As a final result, utilizing suitable amounts of waste vegetable oils and waste plastics as asphalt cement additives can give new binders that are suitable for both hot and cold regions. Finally, it can be concluded that the recycling of waste oils and plastics in hot mix asphalt industry is workable and can be seen as a convenient and valid method for eliminating these wastes.

Keywords
Modified asphalt binder, characteristics of asphalt, waste vegetable oil, waste oil, waste plastics.

1. Introduction
Road pavements under intensive environmental effects cannot always meet the desired 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, increase in traffic road volume requires a corresponding 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].
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. [4].

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 [5].

Every day, several types of materials that are either entirely or partly manufactured of plastics are utilized, which 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, 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 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 [4,6].

Furthermore, the illegal disposal of waste oils formed another challenge to the investigators to consider their recycling in HMA industry. Waste vegetable oils have become a major environmental pollutant as they can be a potential contaminator for rivers and land resources [5].

The objective of this study is to investigate the possibility of utilizing waste vegetable oils and waste plastics as asphalt cement modifiers in order to enhance asphalt properties as well as eliminate these waste materials.

2. Material Used

2.1. Asphalt Binder
Asphalt cement with penetration grade of 40/50 that was obtained from Al-Dora refinery in Baghdad was used. This penetration grade is the most implemented grade in the construction of flexible pavements in Iraq. The properties of this asphalt and its specifications are presented in table 1.

| Property                      | Iraqi specifications of 40/50 asphalt binder | Results |
|-------------------------------|--------------------------------------------|---------|
| Penetration                   | 40-50                                      | 44      |
| Ductility(cm)                 | >100                                       | >150    |
| Kinematic viscosity (cst)     | Min. 400                                   | 393°    |
| Softening point (°C)          | ....                                       | 51      |
| Flash point (°C)              | Min. 232                                   | 220°    |
| Residue after TFOT            |                                            |         |
| % Retained penetration        | Min. 55                                    | 80      |
| Retained ductility (cm)       | Min. 25                                    | >150    |
| Specific gravity              | 1.01 – 1.06                                | 1.054   |

* Does not meet specification limits.

2.2. Waste Vegetable Oil (WVO)
The waste vegetable oil used in this study was a mixed vegetable oil collected from different residential houses and restaurants and sieved on a #200 sieve to ensure there are no particulate matters. The implemented WVO has been tested for its basic properties, shown in table 2, that affect bitumen properties and the tests have been conducted in the general company for food products/Baghdad.
Table 2. Properties of the used waste vegetable oil

| Property          | Results |
|-------------------|---------|
| Viscosity (cst)   | 170     |
| Specific gravity  | 0.92    |

2.3. Waste Plastics

Low density polyethylene (LDPE) from wastewater containers and Polyvinyl chloride (PVC) from waste drainage pipes are the two types of plastic wastes that were used in this study. These plastic wastes were obtained from waste plastic recycling factories. Both of these wastes were grinded into powder and sieved on #100 sieve for LDPE and on #200 sieve for PVC. The properties of the used LDPE and PVC are illustrated in table 3.

Table 3. Properties of the used waste plastics

| Property                                          | LDPE  | PVC  |
|---------------------------------------------------|-------|------|
| Melting temperature (°C) *                         | 115   | 180  |
| Specific gravity *                                 | 0.94  | 1.38 |
| Maximum particle size after grinding and sieving (mm) | 0.15  | 0.075|

* The property was obtained from the plastic factories from which these wastes were taken.

3. Laboratory Work

3.1. Sample Preparation

Three percentages (1%, 2% and 3%) of WVO were added firstly to the neat bitumen to prepare the WVO-modified bitumen. WVO and bitumen were blended using high shear laboratory mixer for (30) min at (1300) rpm in order to gain a homogeneous mixture. The addition of WVO was while the bitumen was being heated at temperature of (150±5) °C.

The preparation of (WVO/LDPE and WVO/PVC) modified binders consists of adding three percentages (1%, 3% and 5%) of LDPE and PVC to a specific WVO-modified bitumen where WVO-modified binder would represent the control asphalt for this part of modification. The same laboratory mixer was used with increasing mixing time to (60) min and mixing temperature to (180±5) °C. Table 4 illustrates the mixing properties (asphalt and additives proportions) for WVO-modified binder and WVO/Waste plastic-modified binder.

Table 4. Mixing properties of modified asphalt binders

| WVO-modified binder | Control asphalt (Neat asphalt) % | WVO % |
|---------------------|----------------------------------|-------|
| 99                  | 1                                |       |
| 98                  | 2                                |       |
| 97                  | 3                                |       |

| WVO/LDPE-modified binder | Control asphalt (WVO-modified binder) % | LDPE % |
|---------------------------|------------------------------------------|--------|
| 99                        | 1                                        |        |
| 97                        | 3                                        |        |
| 95                        | 5                                        |        |

| WVO/PVC-modified binder | Control asphalt (WVO-modified binder) % | PVC % |
|-------------------------|------------------------------------------|------|
| 99                      | 1                                        |      |
| 97                      | 3                                        |      |
| 95                      | 5                                        |      |
3.2. Asphalt Binder Tests
The following bitumen tests were conducted on the original bitumen and all the prepared asphalt specimens: penetration, softening point, ductility, kinematic viscosity, flash point, specific gravity and loss on heating according to ASTM D5, D36, D113, D2170, D 92, D 70 and D 1754, respectively [7, 8, 9, 10, 11, 12, 13].

4. Results and Discussion
Asphalt binder modified with 1% WVO, which gave penetration grade of 60/70 has been selected to be further modified with waste plastics (PVC and LDPE).

4.1. Penetration
The effect of WVO on penetration of asphalt can be noted clearly in figure 1a. This figure illustrates that the value of penetration grade increases gradually as WVO addition is increased. The increment in asphalt penetration values is due to the variation in its consistency where asphalt became softer as WVO is added. Figure 1b shows the effect of plastic wastes additives on asphalt binder modified earlier with 1% of WVO. As it can be seen from the figure, the asphalt binder with 1% WVO and no plastic additives gave penetration value of approximately 63 which falls in 60/70 penetration grade. The addition of both types of waste plastics (PVC and LDPE) reversed the effect of WVO and reduced the penetration grade gradually. The decrease in penetration is due to the fact that the hardness of bitumen increased with the addition of PVC and LDPE.

![Figure 1. Penetration test results (a) WVO-modified binder (b) WVO/waste plastics-modified binder](image)

4.2. Softening Point
The impact of WVO addition on softening point of asphalt is shown in figure 2a. This figure demonstrates that softening point of asphalt decreased with the increase in the percentage of WVO. This effect is also the result of the softening effect of WVO additive. Conversely, adding PVC and LDPE to WVO-modified binder has increased the softening point, as shown in figure 2b, which results in asphalt binder with lower temperature susceptibility. The high resistance of plastics to elevated temperature, compared to bitumen, is the reason behind the increase in softening point of the resulting binder.
4.3. Ductility
Ductility results of unmodified and all WVO-modified binders were higher than (150) cm and could not be recorded since the maximum limit of the used ductility machine was (150) cm.

The addition of 1% of both waste plastics to WVO-modified binder preserved on ductility values higher than (150) cm. Increasing the dosage of waste plastics above 1% reduced the ductility values gradually for PVC additive but dramatically for LDPE additive as illustrated in figure 3. Also, it can be seen from the figure that the addition of LDPE in more than 3% has decreased the ductility value below the minimum allowable limit (100) cm. In case of PVC addition, all proportions of PVC have shown ductility values above (100) cm.

4.4. Kinematic Viscosity
Figure 4 shows kinematic viscosity results (at 135°C) of original and modified asphalt binder. It is clear from the figure 4a that the original 40/50 asphalt binder had a viscosity value below (400) cst, which is the minimum allowable value for 40/50 asphalt according to the Iraqi Specifications of roads and bridges. Adding WVO to the original asphalt reduced the viscosity values gradually, which is the result from the softening effect of oil on asphalt binder.

Conversely, the addition of waste plastics in both types led to ascending trends in viscosity values, which is shown in figure 4b. The increase in viscosity is due to the hardness effect of plastics, which is supported by the decrease in penetration values. Also, it can be seen from the figure that 1% of both
PVC and LDPE have resulted in almost the same viscosity value, which is above the minimum required for 40/50 asphalt.

**Figure 4.** Viscosity test results (a) WVO-modified binder (b) WVO/waste plastics-modified binder

### 4.5. Flash Point

The results of flash point test for WVO-modified binders and WVO/waste plastics-modified binders are shown in figure 5. It can be distinctly seen that both WVO and waste plastics have the same positive effect on flash point of the resulting asphalt binders, which is noted from the gradual increase in flash point values with an increase in the percentages of waste additives. Furthermore, the flash point of the virgin binder was (220℃), which is below specification limits and thus, the addition of WVO and waste plastics made the bitumen safer to handle during the mixing process.

**Figure 5.** Flash point test results (a) of WVO-modified binder (b) WVO/waste plastics-modified binder

### 4.6. Specific Gravity

The specific gravity of unmodified bitumen was 1.054. The addition of WVO has decreased the specific gravity of the resulting samples as demonstrated in figure 6a. The decrease in specific gravity values is the result of lower specific gravity of WVO compared to that of virgin asphalt. However, all the obtained results were acceptable. In case of waste plastic additives, LDPE showed similar effect compared to WVO since its specific gravity is also less than that of asphalt while PVC presented adverse effect on specific gravity values as shown in figure 6b.
4.7. Loss on Heating (TFOT)
Loss on heating test simulates the short-term aging of asphalt during the mixing process. Figure 7a shows mass loss percentages of asphalt binder before and after being modified with WVO. It can be seen from the bar chart that the percentage of loss in the mass of asphalt has reduced gradually with the addition of WVO. The same trend has been noted in figure 7b where both PVC and LDPE had similar effect on reducing the loss in asphalt mass, however, LDPE showed higher effect in decreasing the percentage of mass loss. These results indicate that all waste materials (WVO, PVC and LDPE) used in this study may act as anti-aging additives.

**Figure 6.** Specific gravity test results (a) WVO-modified binder (b) WVO/waste plastics-modified binder

**Figure 7.** Loss on heating test results (a) WVO-modified binder (b) WVO/waste plastics-modified binder

Penetration test had also conducted on asphalt binders collected after TFOT and the results are shown in figure 8. The results indicate that the percentage of retained penetration increased by adding both WVO and waste plastics, which means that the decline in penetration values after TFOT decreased with the addition of (WVO, PVC and LDPE) and therefore, these results supported those obtained from mass loss.
Figure 8. % Retained penetration after TFOT (a) WVO-modified binder (b) WVO/waste plastics-modified binder

Besides penetration, bitumen samples collected after TFOT had also used in ductility test in order to calculate the retained ductility. Ductility results for the unmodified and all WVO-modified binders before and after TFOT were more than (150) cm, which is the maximum limit in the used ductility machine. According to the outcome results, the high retained ductility values of WVO-modified binders indicate that the resulting binders were almost not affected by high temperatures of TFOT.

As for WVO/waste plastics-modified binders, retained ductility results before and after TFOT are shown in table 5. It is clear from the table that WVO/LDPE-modified binders showed a decrease in retained ductility values. Conversely, all WVO/PVC-modified binders gave higher ductility values after TFOT.

The higher ductility values of WVO/PVC-modified binders after TFOT is the result of the long time exposing to high temperature (5 hrs at 163 °C) in TFOT, which led to a complete melting of PVC particles in asphalt binder resulting in a very homogenous asphalt while during the (1) hr mixing, before TFOT, PVC particles were not completely melted and some PVC particles were still existing in asphalt binder resulting in failing the samples before reaching (150) cm in ductility test. However, (1) hr mixing time is still acceptable since all modified binders passed the minimum requirement of ductility test.

Table 5. Ductility of WVO/waste plastics-modified binder before and after TFOT

| %Plastic with WVO-modified binder | Ductility results of WVO/Waste plastics-modified binder (cm) | | | |
|----------------------------------|----------------------------------------------------------|-----------------|-----------------|
|                                  | PVC | LDPE | PVC | LDPE |
| 0%                               | >150 | >150 | >150 | >150 |
| 1%                               | >150 | >150 | >150 | >150 |
| 2%                               | 134  | >150 | 100  | 56  |
| 3%                               | 126  | >150 | 30.5 | 21  |
The following conclusions are obtained from the conducted study:

1- The addition of WVO has increased the penetration and decreased the viscosity (rutting resistance) of asphalt binder. However, the decrease in viscosity is little compared to the increase in penetration where the obtained 60/70 asphalt binder resulting from the addition of only 1% WVO has a viscosity of (380 cst), which is higher than that required for 50/60 asphalt binder (350 cst), which is favorable to be used in moderate and cold regions.

2- Counter to WVO, the addition of waste plastics (LDPE and PVC) increases the viscosity of asphalt, while decreasing the penetration grade. Nonetheless, the decrease in penetration is little compared to the increase in viscosity, which resulted in binders with higher penetration grades but also with higher viscosity values compared to 40/50 asphalt.

3- The addition of WVO and waste plastics increased the flash point and made the bitumen safer to handle during the mixing process.

4- Both of WVO and waste plastics act as anti-aging additives since they reduced the percentage of mass loss of asphalt after TFOT.

Table 6 concludes some selected modified binders obtained from this study and compares them with the original unmodified asphalt binder.

| Property                  | Iraqi specifications of 40/50 asphalt binder | Original 40/50 asphalt | Selected modified binders resulted from the study |
|---------------------------|---------------------------------------------|------------------------|--------------------------------------------------|
| Penetration (mm)          | 40-50                                       | 44.3                   | 63.8                                              |
| Ductility (cm)            | >100                                        | >150                   | >150 >150                                         |
| Kinematic viscosity (cst) | Min. 400                                    | 393                    | 453 453                                          |
| Softening point (°C)      | ....                                        | 51                     | 49.5 52.5 52.5                                   |
| Flash point (°C)          | Min. 232                                    | 220                    | 245 270 260                                      |
| % Mass loss               | 0.19                                        | 0.13                   | 0.08 0.08                                         |
| % Retained penetration    | Min. 55                                     | 80.5                   | 89 90.4 90.9                                     |
| Retained ductility (cm)   | Min. 25                                     | >150                   | >150 >150                                         |
| Specific gravity          | 1.01 – 1.06                                 | 1.054                  | 1.047 1.054                                       |

It can be noted from the table that the original and WVO-modified binders did not meet all the required properties of 40/50 asphalt binder, especially in terms of viscosity. Conversely, all other WVO/waste plastics-modified binders have met all specification requirements of 40/50 asphalt binder despite the fact that penetration grades were not 40/50 for all of them. For instance, both of 60/70 binder (resulted from adding 1%WVO with 1%PVC) and 50/60 binder (resulted from adding 1%WVO with 1%LDPE) have viscosity values, (459) cst and (453) cst, respectively, more than that required for 40/50 bitumen besides to have high ductility values, more than (150) cm, for both of them. Therefore, they are acceptable to be used in both hot and cold climate since high viscosity value gives indication on good rutting resistance at high temperatures, while high ductility value demonstrates high resistance to low temperature cracking. Furthermore, 50/60 and 40/50 bitumen resulting from 1%WVO with (3%PVC and 5%PVC), respectively have high viscosity values, 501cst and 558cst, respectively and are more appropriate to be used in high temperature regions. Moreover, 40/50 asphalt binder obtained from modifying the virgin bitumen with 1%WVO and 3%LDPE showed very high viscosity value (594 cst), yet, its ductility was just within the minimum acceptable limit (100 cm), which may present thermal cracking at low temperature conditions.

5. Conclusions and Recommendations

The following conclusions are obtained from the conducted study:

1- The addition of WVO has increased the penetration and decreased the viscosity (rutting resistance) of asphalt binder. However, the decrease in viscosity is little compared to the increase in penetration where the obtained 60/70 asphalt binder resulting from the addition of only 1% WVO has a viscosity of (380 cst), which is higher than that required for 50/60 asphalt binder (350 cst), which is favorable to be used in moderate and cold regions.

2- Counter to WVO, the addition of waste plastics (LDPE and PVC) increases the viscosity of asphalt, while decreasing the penetration grade. Nonetheless, the decrease in penetration is little compared to the increase in viscosity, which resulted in binders with higher penetration grades but also with higher viscosity values compared to 40/50 asphalt.

3- The addition of WVO and waste plastics increased the flash point and made the bitumen safer to handle during the mixing process.

4- Both of WVO and waste plastics act as anti-aging additives since they reduced the percentage of mass loss of asphalt after TFOT.
5- WVO has negative effect on temperature susceptibility of asphalt as it decreased the softening point unlike plastic waste additives (LDPE and PVC) as they increased the softening point of asphalt binder.

6- Finally, the current study resulted in that all used percentages of PVC additive (1%, 3% and 5%) in combination with 1% WVO may be considered as optimum percentages depending on the desired properties and climate conditions and is highly recommended to modify the asphalt binder. As for LDPE additive, the optimum percentage in combination with 1% WVO must not exceed 3%.

7- For future work, it is suggested to study the used waste materials as modifiers to HMA mixtures in addition to using WVO as a rejuvenator for aged bitumen in reclaimed asphalt pavements.

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