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Case study

Rejuvenation of aged asphalt binder extracted from reclaimed asphalt pavement using waste vegetable and engine oils

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ABSTRACT

After many years in service, bituminous material in roads becomes aged and starts losing its properties. Aged bitumen becomes more brittle and causes a reduction in pavement strength with a decrease in the service life of pavement. The dumping activity of untreated waste oils into landfills or rivers causes negative effect towards an environmental aspect. The objective of this study is to investigate the possibility of using waste oils; waste vegetable oils (WVO) and waste engine oils (WEO), as rejuvenating agents for aged asphalt binder extracted from reclaimed asphalt pavement (RAP). In this study three percentages (1%, 2% and 3%) of both WVO and WEO were added to 20/30 penetration grade aged asphalt. Physical and chemical properties of aged and rejuvenated asphalt binders were investigated using different laboratory tests and evaluated according to general specifications of roads and bridges in Iraq. The results indicated that both of WVO and WEO could effectively soften and rejuvenate the aged asphalt where 1% of WVO and 3% of WEO could restore the aged (20/30) asphalt to its original (40/50) penetration grade. Furthermore, viscosity, temperature susceptibility and aging resistance of rejuvenated asphalt were improved compared to the original asphalt binder. The asphaltenes content decreased as a result of reducing the intensity of carbonyl and sulfoxide of aged asphalt due to the addition of waste oils. Moreover, it could be noted from the results that more concentration of WEO needed to regenerate the aged asphalt compared to WVO. Finally, it can be concluded that rejuvenation of aged asphalt using WVO and WEO is feasible and can be considered as an effective way to recycle both of RAP and waste oils.

1. Introduction

After many years of exposure to climate change and traffic loads, the road would suffer from aging and diminution in the performance of asphalt binder. Asphalt aging results in an increase in binder stiffness and furthermore affects its physiochemical properties. Therefore, aged binder becomes more brittle and causes a decline in pavement strength with a reduction in pavement service life and in this case the surfaces of pavement can be removed which is called as reclaimed asphalt pavement (RAP) [1,2].

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Many roads' pavements need heavy maintenance before the end of HMA design life. Subsequently, there are large quantities of RAP materials to be recycled every year. Reusing of aged asphalt is the key to recycle reclaimed asphalt pavement [3].

The rate of aging depends on several factors, such as chemical composition of bitumen, climate, in addition to the aggregate in the mix [4]. Oxidation and volatiles loss are the main ageing mechanisms of bitumen. As stated earlier, aged asphalt has higher viscosity and it is stiffer than fresh asphalt with marked changes in its composition. These variations would lead to surface raveling, loss of adhesion in the presence of humidity, cracking, as well as brittleness [5]. Therefore, asphalt aging can directly impact on the service life of flexible pavements [6].

Investigations regarding asphalt chemical composition through aging indicated that asphaltenes content increased, whilst the content of aromatics and resins decreased through aging. The increase in asphaltenes content leads the asphalt to become stiffer (i.e., harder), and this can be easily manifested in the reduction in penetration value and the increase in viscosity and softening point of aged asphalt [7].

Previous studies demonstrated that even though the life cycle of HMA has reached the end, the bitumen from old HMA is still valuable. The major problem that has reduced the use of RAP material, to only 15%, is the ageing of asphalt binder. Asphalt mixtures with high content of RAP can be very stiff; nevertheless, too much RAP can result in a reduction in the mixtures performance. As the content of RAP is raised, the risks of fatigue cracking, humidity damage, and thermal cracking become greater. Increasing the percentage of RAP, till 80%, in HMA mixtures is possible using a rejuvenator [8,9]. Rejuvenators restore the original asphaltenes to maltenes ratio in the aged asphalt cements in order to plasticize the aged asphalt and produce a broad-spectrum renovation that compensates the volatile materials and disperses oils while promoting the adhesion [8].

The illegal dumping activities of waste oils into landfills or rivers cause negative effect to environment particularly when there are large quantities of waste oils to be disposed. The utilization of waste oils is a viable alternative to mitigate the associated ecological and environmental problems [10,11].

The objective of this study is to investigate the possibility of using waste oils; waste vegetable oils (WVO) and waste engine oils (WEO), as rejuvenating agents for aged asphalt binder extracted from reclaimed asphalt pavement (RAP). The results of this research would give an indication to the optimum percentages of waste oils needed to be directly added to reclaimed asphalt pavement besides providing a solution to asphalt storage aging.

2. Material used

2.1. Reclaimed asphalt pavement (RAP)

A reclaimed asphalt pavement that was obtained from milling an old pavement was used. The old pavement was constructed in 2012 in KUT city/Iraq which makes the RAP be 6 years old. The original asphalt binder that was used in this pavement was 40/50 asphalt binder and its properties are shown in Table 1.

Table 1
Historical tests result of the original 40/50 asphalt binder.

Property	Iraqi specifications of 40/50 asphalt binder according to SCRB /R9, 2003 [12].	Results
Penetration	40-50	46
Ductility(cm)	>100	>100
Kinematic viscosity (cSt)	Min. 400	441
Softening point (°C)	. . . .	51
Flash point (°C)	Min. 232	292
Residue after TFOT		
% Retained penetration	Min. 55	68
Retained ductility (cm)	Min. 25	90
Specific gravity	1.01 – 1.06	1.04

2.2. Waste oils

The waste vegetable oil (WVO) used in this study was collected from different residential houses and restaurants while the waste engine oil (WEO) was obtained from vehicles workshop. Both WVO and WEO were sieved on #200 sieve in order to dispose any particulate matter and tested in terms of viscosity, specific gravity and water content as shown in Table 2. The tests were conducted in the general company for food products/Baghdad using Brookfield viscometer for viscosity, KERN moisture analyzer for water content and Bingham pycnometer for specific gravity.

Table 2
Tests results of WVO and WEO.

Property	WVO	WEO
Viscosity (cP*)	156	167
Specific Gravity	0.92	0.95
Water content (%)	0.31	0.28

cP = 10^{-3}pa.s

3. Laboratory work

3.1. Extraction and recovery of aged asphalt

The conventional laboratory methods for extraction and recovery of aged bitumen were not appropriate for large quantities of RAP material. Therefore, extraction process was made by soaking the RAP material in a solvent (Benzene in this study) for a day. The asphalt solution was separated from aggregate by decantation. The obtained solution was set undisturbed for another day and decanted, thereby removing the sedimented fines. This method of extraction was used before the approving of AASHO on the centrifugal method [13].

The recovery method implemented in this study consists of heating the asphalt solution obtained from extraction process in a water path for few hours until benzene was completely evaporated, thereby obtaining the aged asphalt binder. The temperature of the water path was kept between (90-95) °C in order to avoid water boiling and ensure the evaporation of benzene as well.

150 kg of RAP was used in the selected extraction and recovery method. 4.8 kg of aged asphalt was extracted which is equal to 3.2% binder content. The properties of the extracted aged asphalt are illustrated in Table 3.

Table 3
Properties of extracted aged asphalt binder.

Property	Iraqi specifications of 40/50 asphalt binder according to SCRB /R9, 2003 [12].	Results
Penetration	40-50	24.4[a]
Ductility(cm)	>100	84[a]
Kinematic viscosity (cst)	Min. 400	663
Softening point (°C)	. . . .	58.5
Flash point (°C)	Min. 232	278
Residue after TFOT		
% Retained penetration	Min. 55	95.5
Retained ductility (cm)	Min. 25	78
Specific gravity	1.01 – 1.06	1.069[a]

[a] Does not meet specification limits.

3.2. Sample preparation

Three percentages (1%, 2% and 3%) of WVO and WEO were added separately into the aged bitumen to prepare the WVO-rejuvenated bitumen and WEO-rejuvenated bitumen. The waste oils and aged asphalt were mixed using a laboratory mixer for (30) min at (1300) rpm to have a homogeneous mix. Waste oils were added while the asphalt was being heated. The mixing temperature was (150 $\pm$ 5) °C. The prepared samples were then set aside to cool down at room temperature in order to be tested later.

3.3. Asphalt binder tests

The following asphalt cement tests were carried out for the aged bitumen and all the rejuvenated 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, D70 and D 1754 respectively. [14,15,16,17,18,19,20]. Besides these tests, Fourier transform infrared spectrometry test (FTIR) was also conducted in order to analyze the chemical composition of the aged and rejuvenated asphalt binders.

4. Results and discussion

4.1. Penetration

The effect of waste oils on penetration grade of asphalt binder can be observed clearly in Fig. 1. It is clear from this figure that the extracted aged asphalt binder was 20/30 penetration grade. The value of penetration grade increased progressively by adding both WVO and WEO. Furthermore, it can be noted that the effect of WVO addition on penetration was higher than that of WEO. The increment in the values of penetration is the result of the variation in aged asphalt consistency. Asphalt became softer when waste oils were added. It can also be noted that 3% of WEO has returned the aged asphalt to penetration grade of 40/50 while only 1% of WVO gave approximately the same grade.

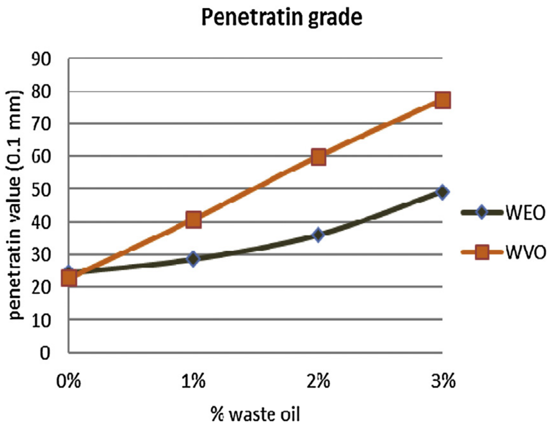

Fig. 1. Penetration test results.

4.2. Softening point

The impact of adding both WVO and WEO on the values of softening point of extracted aged asphalt is illustrated in Fig. 2. This figure states that softening point of aged asphalt decreased with the increment in the proportions of both types of waste oils. However, WEO-rejuvenated asphalts gave higher softening points compared to WVO-rejuvenated asphalts. This decrease in softening point is also the result of the softening effect of waste oils additive which resulted in asphalt binder with higher temperature susceptibility compared to the aged asphalt. Nevertheless, 1% of WVO and 3% of WEO, which returned the aged asphalt to 40/50 penetration grade, have softening points of 57°C and 55°C respectively. These new softening points are higher than that of the original 40/50 asphalt binder (51°C) which resulted in rejuvenated asphalt binder with lower temperature susceptibility.

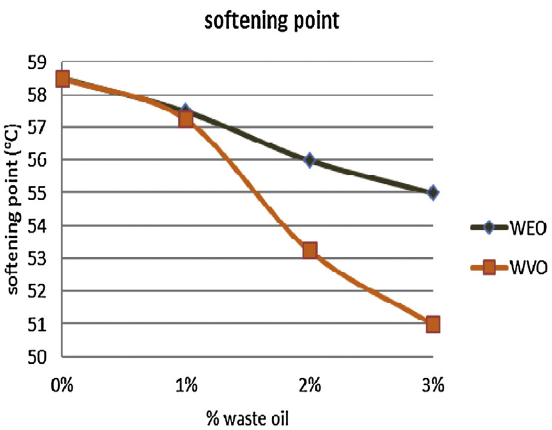

Fig. 2. Softening point test results.

4.3. Ductility

Ductility test results of all aged and waste oils-rejuvenated binders are shown in Fig. 3. It is clear that ductility value of the extracted aged asphalt was (84 cm) which is below the minimum acceptable value (100 cm). The addition of both WVO and WEO has increased the ductility of aged asphalt gradually which supports the increase in penetration value of aged asphalt. It can also be noted that the effect of WVO on increasing ductility values was higher than that of WEO. Nonetheless, WEO-rejuvenated binder of 40/50 penetration grade gave higher ductility value (133 cm) compared to WVO- rejuvenated binder of the same penetration grade which gave ductility value of (108) cm.

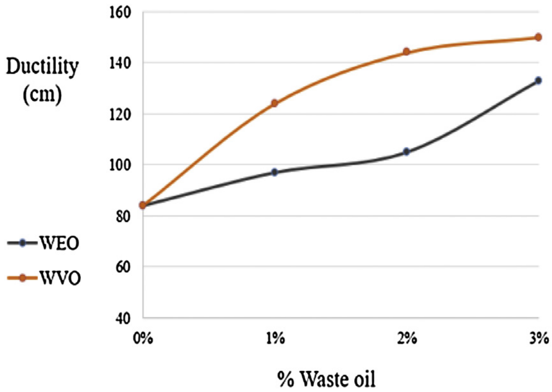

Fig. 3. Ductility test results.

4.4. Kinematic viscosity

Fig. 4 presents kinematic viscosity test results, at 135°C, of aged and rejuvenated binders. It can be observed from the figure that the extracted aged has a viscosity of approximately (660) cSt. Adding WEO and WVO to the aged asphalt has reduced viscosity values gradually for WEO additive but dramatically for WVO additive. The decline in viscosity values is the result of the softening effect of waste oils on aged asphalt binder. It should be observed, however, that the minimum viscosity values of both types of rejuvenated asphalt binders, among the entire range of percentages, are higher than (450) cSt which is more than that of original 40/50 asphalt binder (presented in Table 1).

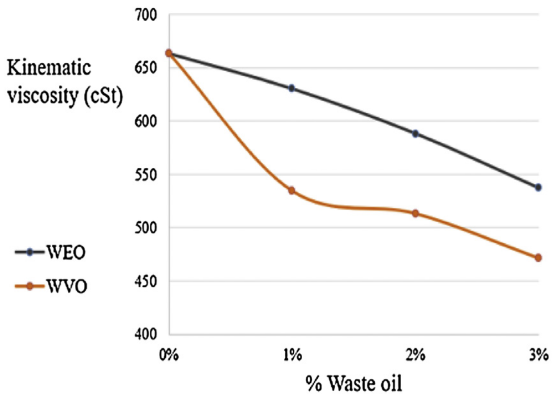

Fig. 4. Viscosity test results.

4.5. Flash point

The results of flash point test for aged and renovated asphalt binders are shown in Fig. 5. It can be clearly seen that both of WVO and WEO have decreased the flash point of the resulted asphalt binders. It can also be noted that the effect of WVO on decreasing the flash point was higher than that of WEO. Nonetheless, all the obtained results were higher than the minimum acceptable value (232 °C) which indicates that all the rejuvenated binders are still safe to handle during construction process.

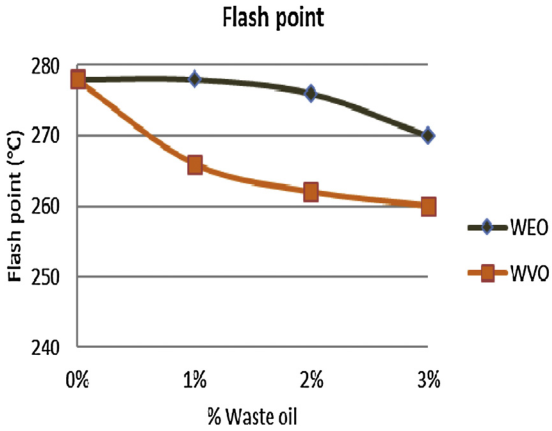

Fig. 5. Flash point test results.

4.6. Specific gravity

The specific gravity of the extracted aged asphalt was 1.069 as shown in Fig. 6. This figure demonstrates that the value of specific gravity has been declined with the addition of both WVO and WEO. Like previous results, the impact of WVO addition was also higher than that of WEO. The decrease in specific gravity value is the result of the lower specific gravity of waste oils compared to that of aged asphalt.

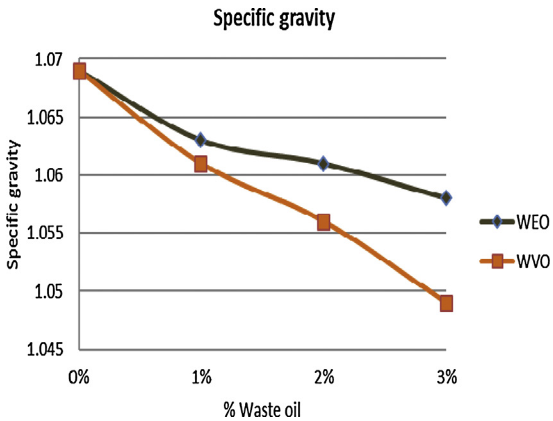

Fig. 6. Specific gravity test results.

4.7. Loss on heating (TFOT)

Loss on heating test simulates the short-term aging of asphalt during mixing and placing. Fig. 7 shows mass loss percentages of aged and all renovated asphalt binders. It can be observed from the bar chart that the mass loss percentage of aged asphalt was only 0.01% and has increased slightly with the addition of WVO where the maximum recorded value was 0.05%. A comparable trend has been noted for WEO addition but with less intensity where the maximum observed value was 0.03%. the increase in the percentage of mass loss is due to the presence of more volatiles in waste oils compared with the extracted aged asphalt. However, all the obtained results were far below the maximum allowable mass loss.

The percentages of retained penetration are shown in Fig. 8. It can be seen from the figure that the addition of WVO have decreased the percentage of retained penetration gradually while the figure of WEO showed a very slight decrease in the percentage of retained penetration compared to that of WVO. This means that the decline in penetration value of WVO-rejuvenated binders was higher than that of WEO. However, all the obtained results were above (80%) which is higher than that of the original asphalt binder (68%) presented in Table 1.

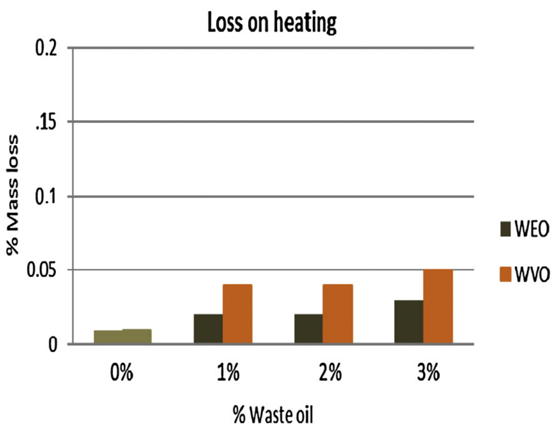

Fig. 7. Loss on heating test results.

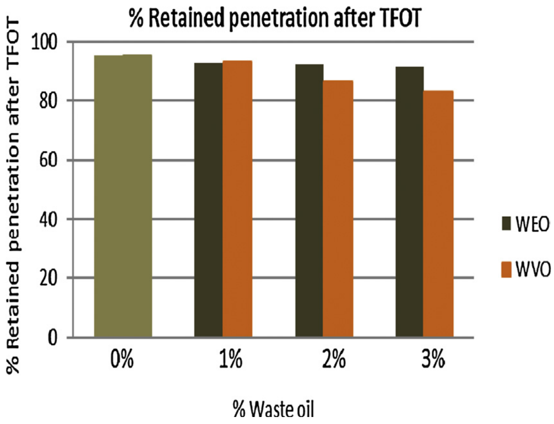

Fig. 8. % Retained penetration test results.

Table 4 illustrates the values of retained ductility compared to that before TFOT for WVO/WEO-rejuvenated binders. It can be observed from the table that all ductility values have decreased after TFOT except for aged asphalt renovated with 3% WVO where the ductility value was higher than 150 cm before and after TFOT. Higher value, above 150 cm, could not be recorded since the maximum limit of ductility machine was 150 cm. It can also be noted that both 40/50 renovated binders, obtained from 1% WVO and 3% WEO, have retained ductility higher than 100 cm which is higher than that of original 40/50 asphalt binder (90 cm) presented in Table 1.

These results indicate that the rejuvenated binders have higher resistance to aging compared to the original binder.

Table 4
Ductility test results before and after TFOT.

% Waste oils	Ductility results of WVO/WEO-rejuvenated binders (cm)			
	WVO		WEO	
	Before TFOT	After TFOT	Before TFOT	After TFOT
0%	84	78	84	78
1%	124	108	97	87
2%	144	125	105	90
3%	Higher than 150	Higher than 150	133	112

4.8. Fourier transform infrared spectrometry (FTIR)

FTIR test was applied in transmission mode in which the wave-lengths that transmit freely across the specimen (not absorbed) can be read with the use of a detector on the other side of the specimen to obtain the percentage of transmittance.

The purpose of this test is to determine the functional characteristics of aged and renovated binders and to identify the interaction (physical or chemical) between waste oils (WVO and WEO) and the extracted aged asphalt.

Since this paper is concerned particularly in analyzing the aging occurring between asphalt samples, only the peak areas around spectral bands at 1700 cm^{-1} and 1030 cm^{-1} will be discussed.

The bands at 1030 cm^{-1} and 1700 cm^{-1} correspond to S=O sulfoxide and C=O carbonyl compounds vibration modes, respectively. The intensities of Sulfoxide and carbonyl peak area can invert the aging and rejuvenating degree of the asphalt. The higher intensity of the bands from the S=O and C=O corresponds to the higher asphaltenes content [7,21].

Fig. 9shows the infrared spectroscopy analysis curves of aged and WVO/WEO-rejuvenated binders at the wavenumber between 500 cm^{-1} and 4000 cm^{-1}. It is clear from the figure that the addition of both WVO and WEO has decreased the

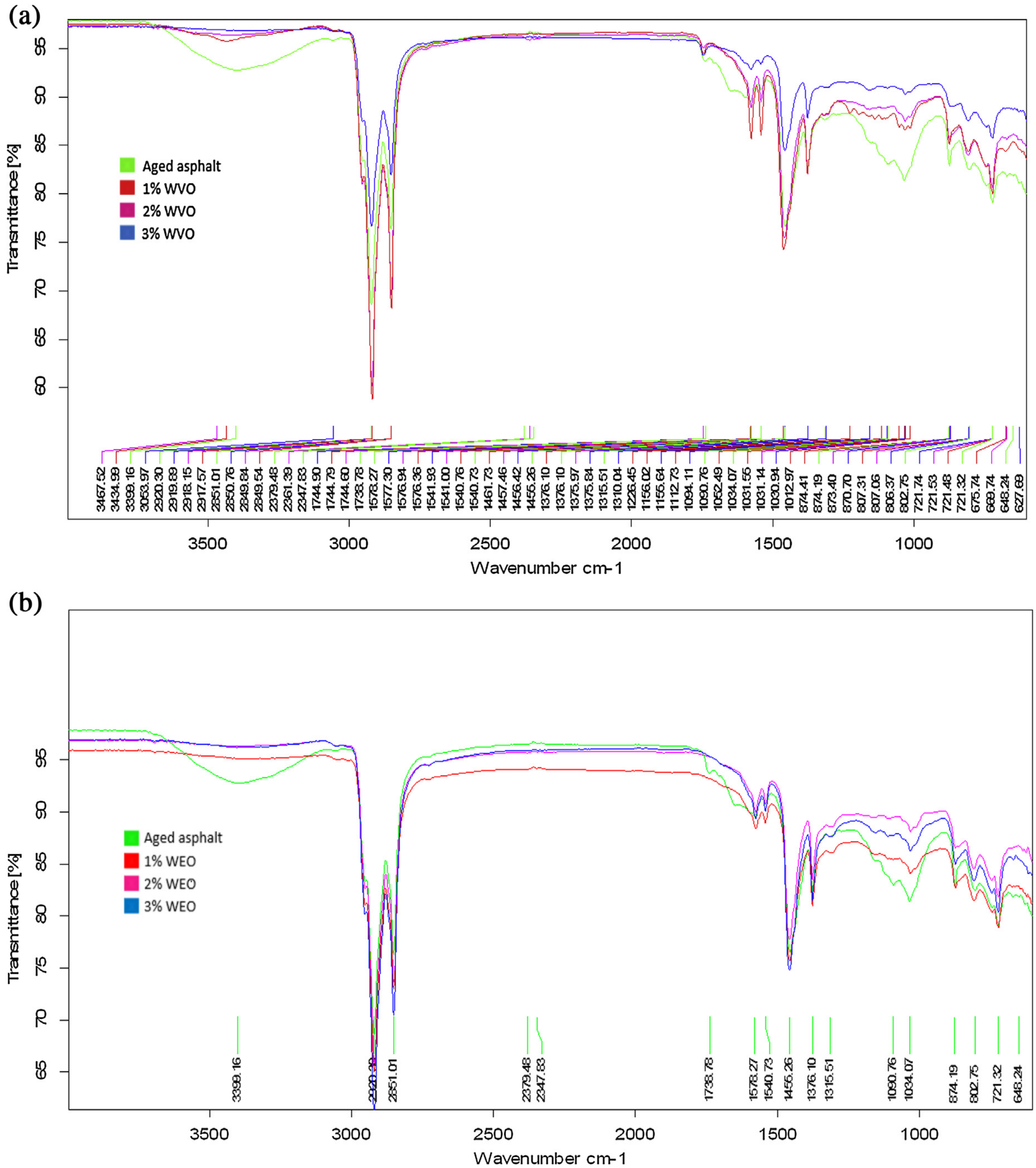

Fig. 9. (a) FTIR results of WVO-rejuvenated binder. (b) FTIR results of WEO-rejuvenated binder.

intensity of (C=O and S=O) peak area compared to that of aged asphalt which means that waste oils can reduce the asphaltene content and offset the aging mechanism thereby rejuvenating the aged asphalt. Furthermore, it can be noted that there was no new peak was observed after adding waste oils. However, physical tests showed variation in the results between the aged and rejuvenated binders which demonstrates that WVO and WEO were physically interacted with the aged asphalt but almost no chemical interaction occurred.

5. Comparison between original and rejuvenated asphalt binders

Information on some of the selected rejuvenated asphalt binders, obtained from this study, and a comparison with the original asphalt binder are shown in Table 5. It can be clearly seen from this table that all the properties of the selected rejuvenated binders are within specification limits of (40/50) asphalt binder although penetration grades were not (40/50) for all of them. These renovated binders have higher viscosity and softening point compared to the original (unaged) binder besides ductility values within specification limits. Furthermore, the aging resistance of rejuvenated binders is higher than that of the original asphalt which can be noted from the higher retained penetration and ductility values after TFOT.

Table 5
Properties of the selected rejuvenated asphalt binders.

Property	Iraqi specifications of 40/50 asphalt binder	Original 40/50 asphalt	Selected rejuvenated binders resulted from the study			
			30/40 from 2% WEO	40/50 from 3% WEO	40/50 from 1% WVO	60/70 from 2% WVO
Penetration	40-50	46	36	49	41	60.1
Ductility(cm)	>100	>100	105	133	124	144
Kinematic viscosity (cSt)	Min. 400	441	588	537	534	513
Softening point (°C)	....	51	56	55	57.25	53.25
Flash point (°C)	Min. 232	290	276	270	266	262
% Mass loss		...	0.02	0.03	0.04	0.04
% Retained penetration	55 min	68	91.9	91.2	93.4	86.3
Retained ductility (cm)	25 min	90	90	112	108	125
Specific gravity	1.01 – 1.06	1.04	1.061	1.058	1.061	1.056

6. Conclusions and recommendations

The following conclusions are obtained from the current study:

1 Adding waste oils could increase the low penetration and ductility values of aged asphalt while decreasing the high viscosity (enhance the workability) and softening point.
2 The addition of both types of waste oils, WVO and WEO, could declines the asphaltenese content thereby reducing the hardness of aged asphalt which supports the increase in penetration values and the decrease in viscosity values.
3 The optimum percentages of WVO and WEO that returned the aged asphalt with penetration grade of 20/30 to its virgin penetration grade (40/50) are 1% and 3% respectively.
4 Other rejuvenated asphalt binders (30/40 and 60/70 binders), obtained from adding 2% of WEO and 2% of WVO respectively, are also acceptable to be used in HMA industry since they met all specifications requirements for 40/50 asphalt except for penetration value.
5 All the rejuvenated asphalt binders have higher resistance to aging compared to the original asphalt binder where their percentage of mass loss was very low (did not exceed 0.04%) and their retained penetration and ductility values after TFOT were higher than that of virgin asphalt.
6 The effect of WVO on the properties of asphalt binder was higher than that of WEO which indicates that the higher percentage of WEO may be added to asphalt binder to gain approximately the same effect of adding lower proportion of WVO.
7 Finally, it can be concluded that the addition of waste vegetable and engine oils can effectively regenerate the aged asphalt binder to a condition that is close to its original state thereby enables the recycling of both waste oils and reclaim asphalt pavements.

8 For future work, it is suggested to investigate the rejuvenated asphalt binders in HMA mixes.

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Declaration of Competing Interest

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