Research Article

Influence of Soybean Oil on Binder and Warm Mixture Asphalt Properties

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1. Introduction

Rutting and fatigue cracking are two primary distresses of asphalt pavements. Recently, numerous pavement researchers have tried to improve the asphalt mixtures’ performance characteristics at high- and low-performance temperatures. Moreover, several investigations have been implemented to suggest an appropriate rheological factor to capture the bitumen’s intermediate- and high-temperature properties precisely. The performance grading system introduces the rutting and fatigue factors to examine the high-temperature and intermediate-temperature characteristics of modified and unmodified mixtures, respectively. Various studies have proved that these factors cannot calculate the bitumen’s performance at rutting and its fatigue properties. These parameters exhibit a weak relation with mixture performance. Pavement researchers introduced advanced tests, such as MSCR and LAS tests, for a more precise evaluation of modified binders’ rutting and fatigue behavior [1, 2]. Several studies [1–10] concluded that it is crucial to improve binders with additives to better the mixtures’ strength against mentioned distresses. A large number of
additives involving crumb rubber (CR) [3, 4], styrene-butadiene rubber (SBR) [3, 5], polypropylene (PP) [7], polyethylene (PE) [9], polyolefin elastomer (POE) [6], and nanomaterials [10] including nanocarbon fiber [11] and nanoclay were employed for enhancing bitumen’s performance. Nevertheless, selecting an appropriate type of additive can differ from one country to another country because of countries’ various geographical situations and existent capacities. When paving, specialists should consider factors beyond binders’ proper performance, such as environmental compatibility, economic issues, and modifier production [12].

To produce a usual hot mix asphalt, a lot of energy is used and consequently air pollution can occur. The procedure to produce hot mix asphalts leads to the emission of several greenhouse gases, which in turn reduces the quality of air [13–18]. Warm mix asphalt (WMA) is introduced to reduce mixing compaction temperature of mixtures, which not only brings about a reduction of greenhouse gases and emissions but also decreases energy consumption by reducing mixing and compaction temperature by 30–50°C. Based on the existing literatures [19–28], different types of technologies (chemical and organic additives) are used to make WMA. Several types of chemical additives were used to produce WMA additives such as emulsification agents, surfactants, antistripping additives, and aggregate coating enhancers. Utilization of oil is a very valuable choice among organic additives. In a study performed by Souza [29], utilization of mamona oil to produce WMA was evaluated. The research used 2–9% oil by weight of binder, which resulted in reduction of the mixing and compaction temperature by about 8°C. In another study, 0–3% of mamona oil by weight of binder was used, and mixing and compaction was decreased by 5°C.

Soybean is a grain type, which contains a lot of protein and is utilized by animals and humans. Soybean consists of 17–21% oil and 46% protein [30, 31]. Accumulation of waste oil in the ground occupies a large space in the Earth. If after the frying process of soybean the by-product is not controlled properly, it leads to the pollution of the environment. Therefore, utilization of this waste oil can be adopted as a sustainable path to dealing with the risk. Several researches have previously been conducted to evaluate the effect of waste kitchen oil in reclaimed asphalt pavement. Additionally, several researches have been implemented where bio binders were used [32–34].

In a study performed by Zhang and Li [35], the effect of three warm mix agents on performance of binder with and without SBS was evaluated. Results revealed the softening point of binders containing SBS and three warm agents were higher than SBS modified binders. Based on results, the warm agent stiffens the SBS modified binder, and, as a result, the high temperature stability of specimens enhanced. Addition of zeolite leads to decrease in the resistance of SBS modified binders against low temperature. Hou et al. [36] evaluated the dynamic properties of warm foam modified mixtures in low-temperature areas. Results revealed that rising temperature and lowering temperature lead to increase in the dynamic modulus of warm foam modified binders. Shi et al. [37] evaluated the feasibility of utilization of warm additives to reduce the viscosity of high viscosity asphalt mixture. Surfactant warm additive was used in the current study. Results revealed that warm additive leads to decrease in the viscosity and softening point of binder while increasing the penetration degree and ductility of binder.

The present study aims to assess the way new and waste soybean oil (0%, 1.5%, 2.5%, and 3.5% by weight of binder) play a role in reducing mixing and compaction temperatures. Moreover, binders rheological characteristics as well as SMA mixture mechanical characteristics were investigated. The modified binders’ performance was assessed through implementing the physical tests (penetration grade, softening point) as well as rheological tests (rotational viscosity, DSR, MSCR, and LAS tests). Two-factor analysis of variance (ANOVA) was applied to analyze the data. Furthermore, asphalt mixtures’ properties were investigated using (ITS), dynamic creep, resilient modulus (Mr), and FPB tests. Figure 1 indicates the research flowchart of the present study.

2. Materials and Methods

2.1. Materials

2.1.1. Aggregates. Telo quarry, in the north of Tehran Province, Iran, was defined as an aggregate source for this research. The aggregates’ properties (physical as well as chemical) are presented in Tables 1 and 2, respectively. Nominal maximum aggregate size was 12.5 mm. Figure 2 represents aggregate gradation used for fabricating different mixtures.

2.1.2. Bitumen. Two kinds of a virgin AC-60/70 and AC-85/100 binder have been applied. Physical properties of modified binders were investigated, and binder test outcomes are presented in Table 3.

2.1.3. Fiber. Usually, fiber is added to diminish binder drain down. The National Cooperative Highway Research Program (NCHRP) Report No. 425 was used to define the optimum content of asphalt binder [40]. The present paper proposes using 0.3% cellulose fiber to diminish the binder drain down as a better way. Table 4 depicts the fiber physical traits.

2.1.4. Soybean Oil. Soybean oil needed for the study was purchased from market. To gain waste oil, the new oil is fried...
and after that, the fried oil is collected. Then, the oil is decanted and filtered using paper filter. Table 5 shows chemical and physical properties of soybean oil. Results indicated that acidic index of waste oil is 193% higher than new oil. The literature suggests that water following through the frying process brings about a hydrolytic reaction, and, as a result, the free fatty acids and diglycerides are produced, and hence the acidic index increases. As such, the stiffness of bitumen increases, and the consistency of asphalt binder improves.

2.2. Sample Preparation. First, 600 gr of the base bitumen was heated to 170°C. In order to prepare modified binders containing new oil, the new oil was obtained from a store in Tehran. Waste oil was produced through a frying process of several times of utilization and after that collected and used for research. To prepare a homogeneous modified binder, soybean oil (1.5%, 2.5%, and 3.5%) was gradually added to the binder and stirred for 20 minutes in a high shear mixer at 500 rpm. The mixing procedure was performed according to the existing literature [41, 42]. Several specimen containing differing amount of soybean oil (1.5%, 2.5%, and 3.5%) were produced. In the current study, the “Nsoy” and “Wsoy” stand for “new soybean” and “waste soybean,” respectively. The NCHRP Report No. 425 was used for the outline of the mixture [43]. According to the

![Flowchart of the research approach.](image)

Table 1: Physical properties of aggregates.

<table>
<thead>
<tr>
<th>Aggregate tests</th>
<th>Test method</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk specific gravity</td>
<td>ASTM C127</td>
<td>2.493</td>
</tr>
<tr>
<td>Absorption coarse aggregate (%)</td>
<td>ASTM C127</td>
<td>2.3</td>
</tr>
<tr>
<td>Absorption fine aggregate (%)</td>
<td>ASTM C128</td>
<td>4.1</td>
</tr>
<tr>
<td>Los Angeles abrasion loss (%)</td>
<td>AASHTO T96</td>
<td>22.3</td>
</tr>
<tr>
<td>Two fractured faces (%)</td>
<td>ASTM D5821</td>
<td>93</td>
</tr>
</tbody>
</table>

Table 2: Chemical properties of aggregates.

<table>
<thead>
<tr>
<th>Type</th>
<th>Oxide content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime aggregate</td>
<td>SiO₂</td>
</tr>
<tr>
<td></td>
<td>17.5</td>
</tr>
</tbody>
</table>

![Aggregate gradation with NMAS of 12.5 mm.](image)
mixture outline, an optimum binder achieved 7.5% binder content. For each of the unmodified and modified mixture types, three replicates were produced.

3. Experimental Program

3.1. Bitumen Tests. Softening point and penetration tests were performed for evaluating unmodified and modified binders’ physical behavior. In addition, RV, BBR, and DSR tests were utilized for assessing various binders’ rheological behavior [43].

3.1.1. MSCR Test. MSCR test was conducted for investigating modified asphalt mixtures rutting behavior according to AASHTO TP 70 “Multiple Stress Creep Recovery (MSCR) Test using a Dynamic Shear Rheometer (DSR)” [44]. Anton Paar DSR with its parallel-plate geometry loading device and a control and data acquisition system were utilized for conducting the MSCR test in the present study. Specimens were tested in replicates using a 25 mm disc and with 1 mm gap setting at temperature of 64°C and at a stress of 100 and 3200 Pa and aged through RTFO process. The tests were performed at the selected temperatures using a constant stress creep of 1-second duration and a relaxation period of 9 seconds, for ten cycles at each stress level.

3.1.2. LAS. LAS test was used for estimating unmodified and modified asphalt mixtures fatigue properties. The LAS test was performed on PAV aged samples. It was conducted in accordance with AASHTO TP 101–14 standards at 25°C [45]. The following equation was used for calculating different binders’ fatigue life:

\[ N_f = A (\gamma_{\text{max}})^B. \]  

Here, the constants \( A \) and \( B \) are determined regarding the viscoelastic continuum damage theory (VECD).

3.2. Asphalt Mixture Tests

3.2.1. ITS Test. ITS test was used to assess the samples’ moisture susceptibility according to the ASTM D6931-12 standard. Samples’ ITS is calculated through the following [46–50]:

\[ \text{ITS} = \frac{2P_{\text{max}}}{D^2t}. \]

Here, ITS stands for mixture’s indirect tensile strength (kPa), \( D \) is the diameter of samples (mm), \( P_{\text{max}} \) represents the maximum load (kN), and \( t \) represents the thickness of specimens (mm).

One of the outcomes of ITS is FE, which can be calculated from the area under the load-deflection curve to failure load through the following [51]:

\[ \text{fracture energy} = \int_0^{\delta_{\text{max}}} P(\delta)d(\delta). \]

Here, fracture energy is the total energy required to failure (J/m²), \( P \) is the applied load (N), \( V \) shows the sample volume, and \( d \) indicates deformation (mm).

3.2.2. Mr Test. ASTM D 4123 standard was conducted to carry out the Mr test. The following equation is used to calculate the samples’ resilient modulus [52]:

\[ M_r = \frac{P (v + 0.2734)}{(\delta t)}. \]

Here, \( M_r \) stands for resilient modulus (MPa), \( t \) stands for specimen thickness (mm), \( P \) indicates load (N), and \( \delta \) indicates the horizontal deformation, which is recovered (mm).

3.2.3. Dynamic Creep Test. In this research, mixture samples’ rutting resistance was examined regarding the US.NCHRP 9–19 at 50°C on specimen that we preconditioned in room temperature. 450 kPa stress level with 0.1 s loading and 0.9 s was applied to unmodified and modified mixtures samples.
3.2.4. Wheel Tracking Test. The mixtures’ resistance against rut depth was examined by the wheel track test at 60°C temperature according to AASHTO standard T-324 [53]. Specimens—which were mixed with the determined asphalt contents from mix design and fabricated by the rolling machine—were of dimensions 300 mm × 300 mm in cross-sectional area and 50 mm in height at an air void ratio of about 7%, according to AASHTO-T324 [53]. The wheel tracking test was performed using 5.5 kg/cm² wheel pressure at 60°C temperature under dry condition. The wheel shall make 22 passes across the specimen per minute. Rut depth of asphalt mixtures was measured for 20,000 passes of 5.5 kg/cm² loaded wheels at 60°C.

3.2.5. FPB Test. For measuring mixtures’ fatigue life, FPB test was applied regarding AASHTO T321-07 [54]. In the present paper, a constant strain test was applied to examine the samples’ fatigue properties. The compacted slabs were cut to create fabricated beams with a 380×63.5×50 mm dimension according to AASHTO T321-07 standard. Figure 3 indicates the configuration of the test setup. Specimens’ flexural stiffness was calculated utilizing the following [55–57]:

\[ \varepsilon = \frac{12\delta h \times 10^6}{3(G_0 - 4G_1)} \]  \hspace{1cm} (5)

\[ \sigma = \frac{G_b P}{Bh^2} \] \hspace{1cm} (6)

\[ S = \frac{1000\sigma}{\varepsilon} \] \hspace{1cm} (7)

Here, \( \varepsilon \) and \( \delta \) represent maximum microstrain and maximum deformation in the center of the sample (mm), respectively. \( G_0 \) shows the gauge’s inner length (118.5 mm), \( h \) indicates the gauge’s outer length (355.5 mm), \( h \) depicts the length of the sample (mm), \( P \) represents maximum tensile stress (kPa), \( B \) represents beam width (mm), \( F \) stands for the maximum load (kN), and \( S \) is flexural stiffness (MPa).

The following equation is used to obtain the sample’s fatigue life:

\[ N_f = a\varepsilon^{-b} \] \hspace{1cm} (8)

Here, \( N_f \) and \( \varepsilon \) are specimen’s fatigue life and micro-strain level, respectively. \( a \) and \( b \) are constants.

4. Results and Discussion

4.1. Binder Tests’ Results

4.1.1. Physical and Rheological Test Results. Figures 4 and 5 represent the physical bitumen tests’ results for original and soybean modified bitumens. According to the outcomes, adding soybean decreases the softening point and increases the penetration. An increase in soybean percentage leads to an increase in samples’ penetration up to 2.5%, while the softening point of the samples decreases. Several researches, which added vegetable oil to base binder, revealed that by addition of vegetable oil, the ratio of asphaltenes to maltenes decreases, which leads to an increase in the penetration degree of the binder [18]. By increasing the percentage of oil, the softening point of the binder decreases, which results in decreasing the consistency of the binder. It can be concluded that by the addition of oil to the binder, the binder’s sensitivity to temperature increases. Based on the softening point results, among modified binders, binders containing 1.5% waste soybean oil performed the best and hence can be used in the field. This is because it keeps the temperature within the average 50°C, which is higher than the average temperature of Iran. Based on previous research results, the acidic index of waste soybean oil is approximately two times greater than the new soybean oil. By increasing the acid, the hydrolytic reactions improve and lead to the production of free fatty acids and diglycerides based on the presence of water and elevated temperatures while frying [58]. Increment in acid leads to the breaking of the triglyceride’s chains, the chief ingredient of oil is freed, and the oxidation of oil will occur [58]. The mentioned reaction leads to a change in the rheological behavior of bitumen and enhances the stiffness of the binder. Consequently, the rutting performance of bitumen is enhanced. As a result, the penetration results of binder modified by waste oil are lower than new oil.

As Figure 6 shows, adding soybean decreases the original binder’s viscosity. Regarding viscosity test results, it was observed that viscosity decreases by adding soybean percentage. The viscosity results of binders modified by waste oil did not show any significant difference in contrast with binders containing new oil, which indicates that the waste oil can be used instead of new oil in modification. It can be inferred from the results that by increasing the percentage of oil, the mixing and compaction temperatures decrease. Based on the results, an addition of 3.5% oil leads to a decrease of the mixing and compaction temperature down to about 8.1°C for mixtures containing new oil and to 7.2°C for mixtures containing waste oil. Table 6 shows the mixing and compaction temperature of mixtures.

Viscosity-temperature curves are usually obtained for evaluating the susceptibility of temperature as well as measuring the mixtures’ mixing temperature. Figure 7 represents the outcomes of viscosity variations versus temperature for new and waste soybean oil modified bitumens. The test outcomes showed a decrease in binders’ viscosity when utilizing oil, which leads to a decrease in the stiffness of binders. In addition, according to the outcomes, adding waste oil to original binder decreases the viscosity. Moreover, to investigate the susceptibility of binder versus temperature, the Viscosity Temperature Susceptibility (VTS) values were obtained. The findings presented in Table 7 show a reduction in the VTS amount of base bitumen when using soybean oil. Furthermore, the VTS results presented in Table 7 indicate a reduction in the VTS at 90–160°C by soybean oil application.

4.1.2. MSCR Test Results. Rutting behaviors of the binder were evaluated through the MSCR test. Two of the MSCR test results include Jnr factor, and percent recovery (%R) was
Figure 3: Schematic of the FPB fatigue test.

Figure 4: Penetration results of unmodified and modified asphalt mixtures.

Figure 5: Softening point of unmodified and modified asphalt mixtures.
calculated at 100 and 3200 Pa stress levels at 64°C. The binders’ Jnr and %R results at 64°C are demonstrated in Table 8, respectively. In general, the results revealed that—ignoring the levels of stress—using soybean oil increases the value of pure binder Jnr, indicating the production of a binder that enjoys lower rutting resistance with soybean oil modification. When the amount of soybean oil goes higher, the rutting performance worsens. These results suggest that the utilization of soybean decreases the rigidity of binders and, as a result, the elasticity of binders increases. This can help the binder to resist against fatigue cracking. The highest rutting resistance belongs to binders modified with 3.5% oil. Additionally, the 2.5% soybean modified binder has the highest Jnr as compared to other modified binders. In general, the results revealed that regardless of the levels of stress, adding soybean to bitumen increases the value of pure binder Jnr indicating lower rutting resistance of binders modified with additives. The Jnr results of binders containing waste oil do not show any significant difference compared to binders with new oil. These results are in consistency with the penetration, softening, and viscosity of binders. Based on previous research results, the acidic index of waste soybean oil is approximately two times greater than the new soybean oil. By increasing the acid, the hydrolytic reactions improve and lead to producing free fatty acids and diglycerides based on the presence of water and elevated temperatures while frying [48]. Increment in acid leads to the breaking of the triglycerides chains, and the chief ingredient of oil is freed and the oxidation of oil will occur [49]. The mentioned reaction leads to a change in the rheological behavior of bitumen and enhances the stiffness of binders. Consequently, the rutting performance of bitumen is enhanced.

As the results of %R show, the %R of binders containing 1.5% and 2.5% of soybean oil for new and waste types is higher than 3.5% in binders modified by 3.5% new oil, while the results of %R are lower than in the waste oil type. Binders having lower values of %R show lower resistance against fatigue cracking and rutting.

The percentage of difference in nonrecoverable creep compliance (Jnr-diff) was proposed to examine the bitumens’ sensitivity against changes of binders’ stress levels when increasing from 100 Pa to 3200 Pa. The (Jnr-diff) parameter was constrained to 75%. If the (Jnr-diff) goes higher than 75%, it indicates the stress sensitivity of the binder. According to the findings presented in Table 8, the (Jnr-diff) value of modified bitumens is less than 75%.

4.1.3. LAS Results. Tables 9 and 10 present LAS test results. Results indicate that binders’ modification using additives reduces the high-stress levels’ shear stress. Table 9 indicates
the bitumen fatigue life. The bitumen’s fatigue life at one low as well as one high strain levels is presented in Table 9. The results demonstrated that adding soybean oil up to 2.5% enhances the pure binder fatigue life at low strain levels probably because of an enhancement in the flexibility of binder due to the utilization of soybean. Based on the results, fatigue life of binders containing 1.5% and 2.5% new soybean oil has higher values than original binders, and the sample containing 3.5% soybean has lower fatigue life. It can be inferred from the results that samples containing waste oil have lower fatigue life than samples containing new oil except by 3.5% one. By increasing the temperature and percentages of oil, the rigidity of mixtures decreases. The 2.5% oil has the highest decrease. Based on the existing literature, binders with lower stiffens have better fatigue life, which is attributed to the lower thermal stress of the bitumen [59, 60].

Table 10 depicts the VECD results of the binder. By increasing the percentage of the additives, the $C_1$ and $C_2$ coefficients decrease and increase, respectively. Results revealed that using modified binders at low levels of strain is better.

Binders show better fatigue behavior at lower levels of strain. As in high strain levels, more deformation happens. The binder that was modified does not deform due to its high level of viscosity. Therefore, bitumen having less viscosity shows greater fatigue life compared to modified bitumens having greater viscosity [51, 52].

4.2. Mixture Test Results

4.2.1. Results of Mr Test. Figure 8 exhibits asphalt mixtures specimens’ Mr values. As presented in Figure 8, soybean oil decreases the mixtures’ resilient modulus. Utilizing 3.5% oil modified mixtures decreases Mr value about 15%, probably because of decreasing the specimens’ stiffness by adding soybean oil. This can be due to the decrease in the rigidity of the mixture via increasing the oil. The waste oil modified mixtures have higher rigidity than the new ones, and the Mr of mentioned mixtures are higher. Furthermore, mixtures containing waste soybean oil have lower Mr values than mixtures containing new oil. Mixtures with 2.5% oil have 5% lower MR value than the unmodified sample. Based on the
results, mixtures containing 85/100 bitumen have lower Mr in comparison with mixtures containing 60/70 binder.

4.2.2. ITS Test. Figure 9 presents specimens’ ITS values. The results showed that soybean oil modified mixtures possess lower ITS compared to unmodified samples. Findings show a decrease in the ITS values when increasing the oil content. Moreover, mixtures containing waste oil have lower ITS values than mixtures containing new oil. This can be attributed to the decrease in the rigidity of mixtures due to increasing oil. The waste oil modified mixtures have higher rigidity than new ones; the ITS of mentioned mixtures are higher. Regarding the findings, adding 1.5% oil to unmodified mixture decreases the value of ITS by around 6%, while adding 3.5% oil results in a decrease in the ITS value by around 10%. Based on the results, mixtures containing 85/100 bitumen have lower ITS in comparison with mixtures containing 60/70 binder.

4.2.3. FN Results. The specimens FN are presented in Figure 10. Greater values of FN indicate higher rutting resistance. According to the results presented in Figure 10, applying soybean oil increases the samples’ permanent deformation because the stiffness of the mixture decreases, and this in turn decreases the strength of mixture versus permanent deformation. Moreover, adding oil contents decreases the samples’ FN. The results demonstrate that the permanent deformation resistance improves when rising the percentage of oil. Besides, using soybean oil decreases the specimens’ viscosity and stiffness, and this in turn decreases the rutting resistance. Results revealed that 1.5% oil modified mixtures possess FN 1.7 times lower than the virgin sample, whereas adding 3.5% oil leads to decrease in the mixture modified with FN by 8%. In addition, mixtures containing 60–70 bitumen have higher FN values than mixtures fabricated by 85/100 binder.

4.2.4. Outcomes of the Wheel Tracking Test. Figure 11 represents specimens’ rut depth. Results show that soybean oil increases specimens’ rut depth. Soybean oil decreases the mixtures’ stiffness. Additionally, using soybean oil decreases sample mixtures’ rutting behavior, since as the soybean amount increases, the permanent deformation properties increase. The results also indicated a 2.4% increase in samples’ permanent deformation when adding 1.5% soybean oil, while the use of 3.5% soybean oil leads to a 1.4% improvement in the mixture RD. Also, using soybean oil decreases the mixtures’ stiffness.
oil decreases the specimens’ viscosity and stiffness, and that in turn decreases the rutting resistance. Moreover, mixtures containing waste oil have higher RD than mixtures containing new oil. This is while mixtures fabricated with 85/100 binder have higher RD than mixtures containing 60/70 binder.

4.2.5. FPB Test Result. Figure 12 depicts the mixtures’ fatigue life. Regarding the findings, adding soybean oil improves the mixtures’ intermediate temperature performance. As the oil contents increase to up to 1.5%, samples’ fatigue lives increase and then decrease. The density values of mixtures’ fracture energy (FE) are
indicated in Figure 13. As presented in this figure, adding soybean oil enhances the FE probably because using soybean oil enhances the samples’ flexibility. Thus, the specimens’ resistance is improved against cracking. Using soybean oil also enhances the FE of mixtures. The outcomes revealed that the FE results increases up to 1.5% and then decreases by increasing the oil content. Through increasing the temperature and percentages of oil, the rigidity of mixtures decreases. The 2.5% oil has the highest decrease. Based on literature, binders with lower stiffness have better fatigue life, which is due to lower thermal stress of bitumen [59, 60].

4.2.6. Data Analysis Method. To analyze the data, this study made use of the two-factor (additive content and binder type) analysis of variance (ANOVA) (Tables 11 –15), considering MR, ITS, flow number, and rut depth as dependent
Figure 12: Unmodified and modified mixtures’ fatigue lives.

Figure 13: Unmodified and modified mixtures’ fracture energy.
variables that were highly affected by different warm-ad- 
aditive contents and warm additive-binder type interactions. 
Results showed that the warm additive had meaningful 
effects on MR, ITS, and FE; the same was true with the 
effects of the warm additive-binder type interaction.

5. Conclusion

This study aimed to produce WMA by using soybean cooking 
oil, which can be an environmentally and economically 
sustainable alternative. To assess the effect of soybean oil on 
the performance of SMA mixtures, some experiments, such as 
dynamic creep, ITS, Mr, wheel tracking, and FPB tests, were 
conducted. In addition, DSR, MSCR, and LAS tests were 
carried out for assessing the binders' rheological properties.

Based on the findings, we can conclude the following:

(i) Addition of 3.5% oil leads to a decrease in the 
mixing and compaction temperature by about 
8.1°C for mixtures containing new oil and 7.2 °C for 
mixtures containing waste oil.

(ii) MSCR test results demonstrated a decrease in the 
rutting resistance when adding more percentages 
of soybean oil.

(iii) LAS test results showed that applying soybean 
enhances the virgin bitumen intermediate tem-
perature performance. LAS test outcomes showed 
better performance of soybean oil at lower levels of 
strain.

(iv) Based on ITS test outcomes, the tensile strength 
of soybean-modified binders were lower than the 
unmodified sample. This can be attributed to the 
decrease in the rigidity of the mixture through 
increasing oil. The waste oil modified mixtures 
have higher rigidity than the new ones, and the ITS 
of mentioned mixtures are higher.

(v) Mr test results show that using soybean oil causes 
Mr to decrease. It can be due to the decrease in the 
rigidity of the mixture via an increase of oil. The 
material oil modified mixes have higher rigidity 
than the new ones, and the MR of mentioned mixes 
are higher.

(vi) Adding soybean oil decreases the samples’ per-
manent deformation resistance regarding the FN 
values of samples. The findings also indicated a 
decrement of the samples’ stiffness and viscosity in 
the presence of oil, which in turn decreases the 
resistance of the samples against permanent 
deformation.

(vii) The outcomes of the wheel track test demonstrated 
soybean oil increases specimens’ rut depth. This 
can be due to the decrease in the rigidity of the 
mixture by increasing the oil. The waste oil 
modified mixes have higher rigidity than the new ones, and the MR of mentioned mixes are higher.

(viii) The results of fatigue test demonstrated an im-
provement in the samples’ intermediate temper-
ature performance when adding 1.5% soybean oil.

(ix) There is no significant difference between the re-
results of new and waste oil. This phenomenon 
makes it possible to reduce soybean oil production 
and consumption and instead reuse of frying oil.
(waste), which does not have any significant difference as compared to the results of chemical and physical properties.

(x) Based on the results, it can be suggested to use 1.5% soybean oil in asphalt mixtures without compromising the performance of the mixture.

Data Availability

The data can be made available upon request to the corresponding author through email.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References


