Muthanna Journal of Engineering and Technology, Vol. (9), Issue (2), (2021) 25-33
Muthanna Journal of Engineering and Technology
Website: https://muthjet.mu.edu.iq/
Research paper, Short communication, Review, Technical paper

Investigation of Mechanical Performance of the Asphalt Mixture Modified with Waste Cooking Oil

Atheer Muhammed Ali

Al-Muthanna University, School of Engineering, Department of Civil Engineering, Al-Muthanna, Iraq
**Corresponding author E-mail: atheer.muhammed@mu.edu.iq*

Abstract

Many academics have been looking for alternatives to asphalt binders, such as alternative binders for hot mix asphalt (HMA), as a result of increasing environmental restrictions and the rising expense of asphalt binders. The goal of this study was to investigate if bioasphalt might be used as a binder instead of petroleum-based asphalt. Mechanical tests such as Marshall Stability, resilient modulus, and dynamic creep were used to evaluate if there was any improvement in the performance of an asphalt mixture incorporating waste cooking oil (WCO) at various percentages (0, 1.5, and 3%) by weight of the binder. Marshall Stability, resilience modulus, and dynamic creep performance all improved with the addition of 1.5% WCO to the bituminous mixture. Furthermore, the 1.5% WCO mixture had the maximum creep stiffness, with a 36% improvement in resisting permanent deformation as compared to the conventional mixture. As a result of the benefits of this type of waste material in improving the mechanical performance of asphalt mixtures, recycling this waste material will be a suitable technique in waste materials recycling.
.

Keywords: *Asphalt binder; hot mix asphalt; resilient modulus; Stability; waste cooking oil.*

1. Introduction

This Asphaltic material are used to build 96%of roads in most countries. HMA is composed comprised of coarse and fine aggregate particles that are bonded together at high temperatures by an asphalt binder. The conventional asphalt binder is created as a byproduct of crude oil processing. Due to rising environmental requirements for new drilling, decreasing current resources, and refining process improvements that optimize fuel amount while reducing asphalt residue, the cost of asphalt has risen in recent years. The industries attempted to address these challenges by finding alternative binders. Green technology would be useful in this method of creating a new binder that is also environmentally friendly. The researchers were motivated by the sustainability approach to developing bioasphalt, an environmentally friendly asphalt for the highway industry. Nowadays, the research industries encouraged researchers to develop the bioasphalt produced from biomass or biowaste products [1–5]. The development of bioasphalt from these bioproducts might reduce the demand for landfills while also lowering greenhouse gas emissions [3, 4, 6, 7]. Fini et al. [8] investigated the use and characterization of bioasphalt made from manure in the asphalt industry. After swine dung was thermochemically melted into bioasphalt, the heavy residue was utilized as an asphalt modifier (i.e., bioasphalt). The bioasphalt was mixed with the standard base binder (PG 64-22) at 2, 5, and 10% by mass of binder. They found that adding swine manure-based bioasphalt enhanced low-temperature characteristics but decreased resistance to rutting at high temperatures .

Wen et al. [9] and Maharajet al. [10] examined the performance of WCO as an asphalt binder modification. The scientists discovered comparable rheological results, implying that as the amount of WCO in asphalt binders grows, so does the resistance to thermal cracking at low temperatures. In contrast, as the modified asphalt binder's WCO quantity increases, rutting resistance decreases at high temperatures. Waste cooking oil is classified as either vegetable or animal oil, depending on the contents or source [11]. Corn seed oil, sunflower oil, olive oil, palm oil, soybean oil, and other vegetable oils are examples, whereas animal oils include butter, fish oil, ghee, and others. WCO is made following the frying process with a variety of edible animal and vegetable oils [12]. Depending on the amount of activity of the frying process, WCO degrades at different rates [13]. According to Asli et al. [14], the primary chemical components of WCO are oleic acid (43.67%), palmitic acid (38.35%), and linoleic acid (11.39%), as indicated in Table 1. The other compounds are minor compounds.

Table 1: Chemical properties of WCO [14]

Type of acid	WCO (%)
Oleic acid	43.67
Palmitic acid	38.35
Linoleic acid	11.39
Stearic acid	4.33
Myristic acid	1.03
γ-Linolenic acid	0.37
Lauric acid	0.34
Linolenic acid	0.29
cis-11-Eicosenoic acid	0.16
Heneicosanoic acid	0.08
TOTAL	100

Previous studies and their results related to the performance of WCO and its effect on asphalt binder were reviewed, as there were not enough and comprehensive studies on the effect of this type of WCO on asphalt mixtures and their performance at high and low temperatures. The majority of prior research, as a result, concentrated on the performance of asphalt that had been modified using this sort of oil rather than conducting thorough examinations into the performance of modified hot mix asphalt. When it comes to bituminous pavement distress mechanisms, stiffness, rutting resistance, and cracking resistance are the three most important factors to consider when evaluating the performance of asphalt mixes in mechanical tests [15–18]. Waste cooking oil was being added to asphalt to enhance its natural crack healing process under the effect of temperature [19–22]. Researchers from Wen et al. [9] investigated the use of bioasphalt produced by the conversion of WCO in a thermochemical process in a laboratory environment in hot mix asphalt production (HMA). Due to its ability to reduce stiffness in a linear pattern, bioasphalt in the HMA reduced the dynamic modulus . Furthermore, with the addition of bioasphalt, the flow number was reduced, indicating that rutting resistance was decreasing. This meant that as the amount of bioasphalt in the mix increased, the rutting resistance was decreased. Also, it has been observed that the rut depth has increased after addition used vegetable oil, according to a study conducted by Bailey and Zaroob [23]. On the other hand, thermal cracking resistance enhanced by addition of bioasphalt in the HMA at low temperatures. According to Some et al. [24], the addition of oil extracted from sunflower and rapeseed (vegetable oil) to the asphalt binder reduced rutting depth in comparison to the control mixture. According to their findings, the use of waste vegetable oil increased the resistance to irreversible deformation of the material. The performance of the asphalt mixtures containing WCO was tested because there was a lack of previous data about this type of binder modifier with asphalt mixtures.

The two main reasons for using WCO are to conserve natural resources and to find a sustainable pavement alternative. Therefore, the aim of this research was to see if there were any improvements in the performance of HMA mixtures that contain WCO. The mechanical properties of WCO dense graded asphalt mixes were evaluated in the laboratory using tests such as Marshall Stability, ITS, resilient modulus, and dynamic creep.

2. Materials and Preparation

2.1. Waste cooking oil (WCO)

In this study, WCO had been collected from restaurants, which was used several times. It was purified from impurities and food residues during the purification process by using a piece of cotton cloth in the baker. The purification process took an hour as the pure oil at room temperature (31ºC) passing through the cotton cloth was used to modify the asphalt mixtures. Whereas, the impure particles deposited on the surface of the cotton cloth were removed and disposed of. The different properties of WCO were presented in Table 2.

Table 2: Properties of WCO

Property	Value
Flash Point (°C)	281
Viscosity (Pa.s)	0.063
Density (kg/m^3) at 15 °C	911

Table 3 shows the comparison of physical performance between the control and WCO modified binders. Testing the performance of the asphalt mixture, 1.5% and 3% WCO were added to modify the asphalt binder. Due to its polarity, the WCO added to the binder formed a soft modified binder.

Table 3: Trials to determine the optimum WCO content

WCO (%)	Penetration (PEN)	Softening Point (°C)	Ductility (cm)	Viscosity at 135°C and 165°C (cp)
0	65	51	125	410, 200
1.5	70	48	130	400, 225
3	96	45	135	300, 110
4.5	130	34	135	170, 100
6	135	39	135	110, 100

2.2. Asphalt binder

The virgin asphalt binder PEN 60/70 was used in this research. The control binder met the standards as shown in Table 4. The asphalt binder evaluation revealed that between the percentages of 0%, 1.5%, 3%, 4.5%, and 6%, the modified binder containing 1.5% and 3% WCO performed better than those containing the other percentages. This type of normal PEN 60/70 asphalt binder with 51ºC as a softening point was known for making asphalt mixtures.

Table 4: Basic properties of PEN 60/70 control binder

Testing	Result	Standard
Penetration (0.1 mm)	65	ASTM D5/D5 [25]
Softening point (°C)	51	ASTM-D36 [26]
Viscosity (Pa.s)	0.41 (135°C) 0.2 (165°C)	ASTM-D4404 [27]
Ductility (cm)	125	ASTM-D113 [28]
DSR (G*/sinδ)	1.23 Kpa (70°C)	ASTM D7175-15 [29]

2.3. Aggregates

As shown in Table 5, the aggregate sample satisfied the requirements of the Jabatan Kerja Raya (JKR) standard (2008) [30]. Testing was performed on the two primary kinds of aggregates: coarse (14, 10, and 5 mm in size) and fine (3.35, 1.18, 0.425, 0.15, and 0.075 mm in size), which were submitted to SG and WA tests. The water absorption of the coarse and fine aggregates was less than 2%. The coarse aggregate has a lower percentage of water absorption as compared to the fine aggregates. The low percentage of water absorption indicated low bitumen absorption by the aggregates. This showed that fine aggregates will absorb more bitumen than the coarse aggregates due to its high surface area. Nevertheless, the aggregates were acceptable to be used in this study because it passed the requirement.

Subsequently, aggregate impact value (AIV) was less than 30%, which indicated the aggregates can be used in road construction. The lower percentage of AIV implied that higher resistance of the aggregates to impact load. The percentage of aggregate crushing value (ACV) was also less than 30%, which showed high strength of aggregates. Thus, the aggregates were appropriate for use in the performance test of the asphalt mixture, and the results were positive. Also, the results of flaky and elongate aggregates were quite high, about 19 and 23%, respectively. Nevertheless, the values were still acceptable since the results were less than 25% as specified in the requirements. Flaky and elongate aggregates must not be more than 25% or else the probability of the asphalt mixture containing those aggregates will be high.

DOI:10.52113/3/mjet/2021-9-2/25-33

Table 5: Aggregate properties results

Properties	Specification	Value	Requirement
Specific gravity (SG)	ASTM C127	2.695 (Coarse)	-
	ASTM C128	2.633 (Fine)	-
Flakiness (%)	BS EN 933-3	19	<25
Water absorption (WA) (%)	ASTM C127	0.620 (Coarse)	< 2
	ASTM C128	1.051 (Fine)	< 2
Elongation (%)	BS EN 933-4	23	<25
Aggregate crushing value (ACV) (%)	BS EN 1097-2	17	<30
Aggregate impact value (AIV) (%)	BS EN 1097-2	14.4	<30

The gradation size of the aggregate was used to sieve it. Therefore, one of the most important tests for aggregate was sieve analysis. As seen in Figure 1, the selected ACW 14 gradation, which serves as the median in this investigation, fell between the high and bottom bounds of the distribution. The coarse and fine aggregates were combined with a mineral filler to form a cohesive mixture. Hydrated lime was utilized as a filler in this investigation, accounting for about 2% by weight of the aggregates [31].

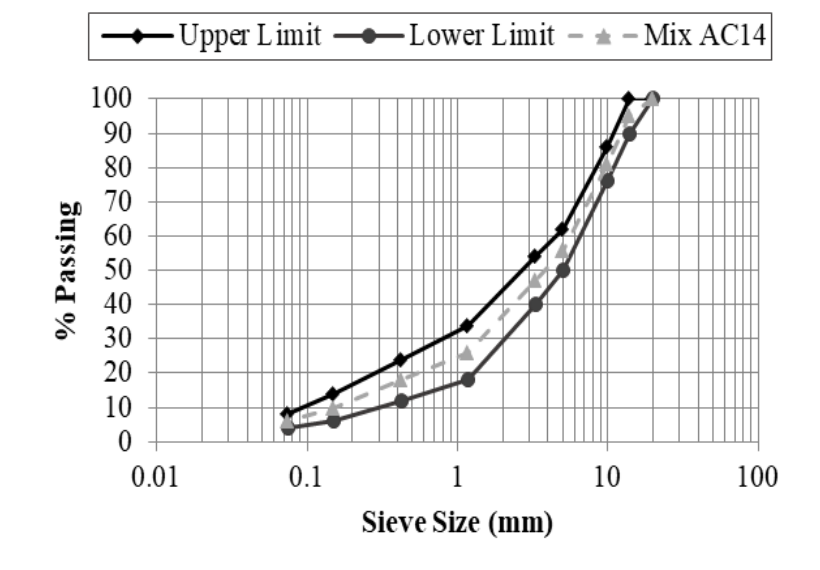

Fig. 1: ACW 14 gradation.

2.4. Asphalt mixture preparation

The control asphalt binder was mixed with the optimum percentages of the WCO, which were 1.5% and 3% by binder weight. The produced WCO modified asphalt binder was then utilized to create modified asphalt mixes in addition to the control asphalt mixture. The preparation of HMA mixture was performed from the modified binder containing WCO and an aggregate. The ingredients were mixed at 170°C to cover all of the aggregates with asphalt binder. For 75 blow/face compaction criteria, the samples were prepared and compacted using a Marshall compactor. Three replicate samples with 100 mm diameter and an average height of 63.5 mm prepared for both the control and WCO asphalt mixtures. The Marshall technique was used to determine the optimal bitumen content (OBC) in line with AASHTO T 245-15 [32]. Following the calculation of the OBC value for each mixture, the asphalt mixture was made with precise OBC percentages for testing.

3. Experimental sections

3.1. Optimum bitumen content determination

The Marshall technique was used to obtain the OBC value in line with AASHTO T 245-15 [32]. Density, stability, flow, void in the total mix (VTM), and the void filled with bitumen (VFB) were used to determine the OBC value [30]. For ACW14, an OBC value of 4% to 6% is required.

3.2. Asphalt mixture performance tests

3.2.1. Resilient modulus test

The resilient modulus test, which was conducted in accordance with ASTM D7369-11 [33], was used to assess the asphalt mixture's elasticity after repeated impact loading. The asphalt mixture's resistance to permanent deformation as well as its capacity to recover to its previous condition after being loaded with 1000 KN will be evaluated in this test. The test was carried out at 25°C and 40°C. The resilient modulus for the sample was determined using equation 1.

$$M_R = \frac{P}{Ht}(0.27 + \mu) \tag{1}$$

Where the parameters M_R, P, μ, H, and t refer to the resilient modulus (MPa), the applied force (N), the Poisson's ratio, the horizontal displacement (m), and the sample thickness (m), respectively.

3.2.2. Dynamic creep test

The BS EN 12697-25 [34] procedures were followed while conducting the dynamic creep test with a universal testing apparatus. The simplest method for determining rutting resistance during service life is to use this test. The sample mixture was evaluated for 3600 cycles at 40°C for around 30 minutes. The mixture with the highest creep stiffness has a high potential for rutting resistance. Equation 3 was used to calculate the dynamic creep modulus.

$$E = \frac{\sigma}{\varepsilon} \tag{3}$$

Where E stands for the dynamic creep modulus in MPa, σ stands for the applied stress in kPa, and ε stands for the measured vertical strain (mm).

4. Results and discussion

4.1. Volumetric properties, stability and flow result

The OBC of the mixes was determined using the Marshall results shown in Table 6. The control, 1.5%WCO, and 3%WCO were the three forms of mixtures that were prepared. The OBC of the control sample was 5.5% which was the highest value as compared to the other mixtures. While the 1.5% WCO and 3% WCO mixtures had the same OBC value of 5%. The whole OBC values chosen met the JKR 2008 requirements [30].When compared to the other mixtures, the 1.5% WCO had the highest VFB and the lowest VTM. The 1.5% WCO mixture had the best stability, at 10300 N, followed by the control mixture at 9540 N and the 3% WCO mixture at 8900 N. Due to the fluidity properties of the WCO, a 3% WCO mixture had the lowest value of stability. Borhan et al. [35] stability results are in agreement with ours, they discovered that in the presence of the used cylinder oil, the asphalt mixture's stability performance was decreased, and this reduction is the cause of the binder's increasing solvency. The 1.5% WCO mixture had the lowest Marshall flow rate 3.22 mm, while the control and 3% WCO mixtures had flow rates of 3.32 and 3.35 mm, respectively. Due to its stability performance, the stiffness value of 1.5% WCO mixture was reported as the highest value of 3293 N/mm among all mixtures. The 3% WCO mixture, on the other hand, had the lowest stiffness in the Marshall test because it had the lowest stability and the largest flow. Overall, the Marshall test results showed that the 1.5% WCO mixture outperformed the control mixture and the 3% WCO mixture.

Table 6: Marshall results of control and WCO mixtures.

Parameters	JKR Specification [21]	Asphalt mixture at OBC			
		Control 60/70	1.5% WCO	3% WCO	
Stability (N)	>8000	9540	10300	8900	Pass
Stiffness (N/mm)	>2000	2500	3293	2200	Pass
Flow (mm)	2.0–4.0	3.32	3.22	3.35	Pass
VTM (%)	3–5	4.9	3.8	4.2	Pass
VFB (%)	70–80	71.1	75.11	72.3	Pass

DOI:10.52113/3/mjet/2021-9-2/25-33

4.2. Resilient modulus test

The resilient modulus test results at 25°C and 40°C are shown in Figure 2. The resilient modulus performed better at 25°C than it did at 40°C. The 1.5% WCO mixture had the highest resilient modulus at both temperatures, whereas the 3% WCO mixture had the lowest resilient modulus. The 1.5% WCO had a resilient modulus of 5434 MPa at 25°C, whereas the 3% WCO had a resilient modulus of 2735 MPa. The best results were obtained with the 1.5% WCO mixture, which was superior to the control mixture (5100 Mpa).The resilient modulus of the control mixture decreased to 888 MPa at 40 C, 1718 MPa for the 1.5% WCO, and 655 MPa for the 3% WCO. The combination with 1.5% WCO has the greatest robust modulus. The elastic property was increased due of the high stiffness of the 1.5% WCO mixture. Borhan et al. [35] observed that adding used cylinder oil to an asphalt mixture decreases its resilient modulus performance when compared to a control mixture. Physically, the soft asphalt mixture with 3% WCO had less elasticity and hence had viscous properties.

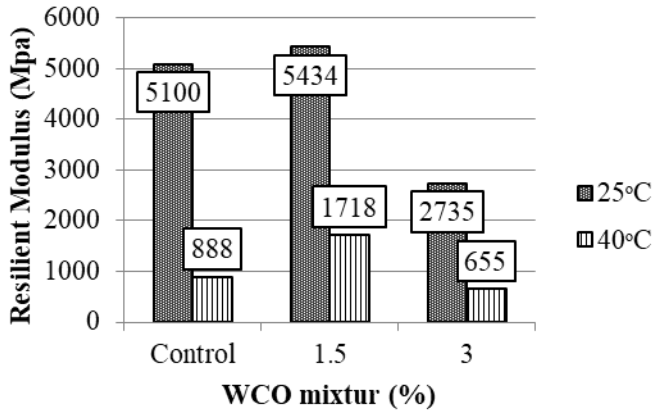

Fig. 2: Resilient modulus results..

The stiffness of asphalt pavements may be used to predict rutting behavior, and mixes with higher stiffness have better rutting resistance [36, 37] . The stiffer mixtures, which have higher stiffness values, are better at distributing the applied load [38]. The stiffness values had a good correlation with resilient modulus for the evaluation of the stiffness of the asphalt mixture, as shown in Figures 2 and 3. The 1.5% WCO mixtures had the maximum stiffness and resilient modulus at both temperatures, followed by 0% and 1.5 % WCO mixtures, respectively.

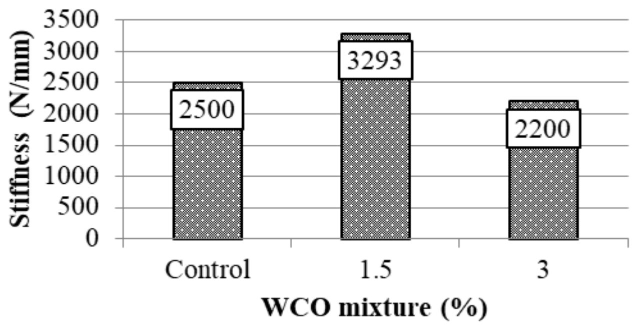

Fig. 3: Stiffness results of mixtures.

DOI:10.52113/3/mjet/2021-9-2/25-33

4.3. Dynamic creep test

Figure 4 shows the creep stiffness that was computed. It can be seen that the creep stiffness trended in the same direction as the resilient modulus, increasing up to 1.5% mixture and then decreasing for the other 3% mixture. Control, 1.5%, and 3% mixtures had creep stiffness of 210, 285, and 185 MPa, respectively. Based on the results, the highest improvement of creep stiffness, about 36%, was attained by 1.5% mixture. These results were consistent with permanent strain where 1.5% WCO mixture showed the lowest strain owing to its high stiffness.

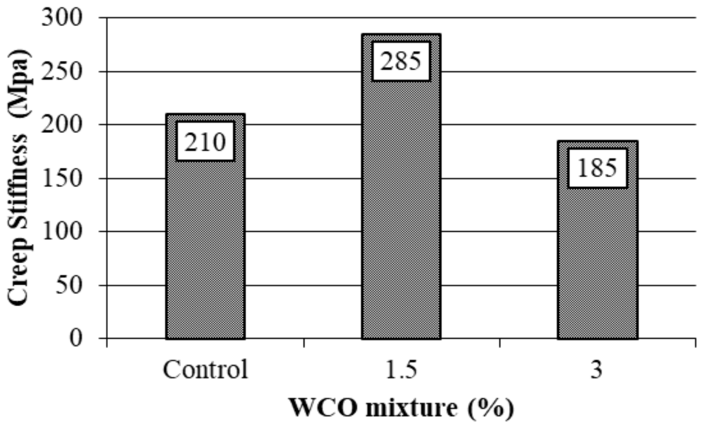

Fig. 4: Dynamic creep stiffness results.

Figure 5 shows the creep stiffness as a consequence of cumulative strain over 3600 cycles, with the 1.5% WCO mixture having the lowest permanent strain relative to the control mixture. According to the findings, the permanent deformation of the 1.5% WCO mixture was 0.52% lower than the control (0.85%) and 3% WCO mixture (0.73%). After modification, the 1.5% WCO decreased the strain rate by around 38.8% compared to the control mixture. The asphalt mixture with 1.5% WCO outperformed the others in terms of rutting resistance. Due to strong interlocking bonding, the rutting resistance of the mixture was enhanced [39].

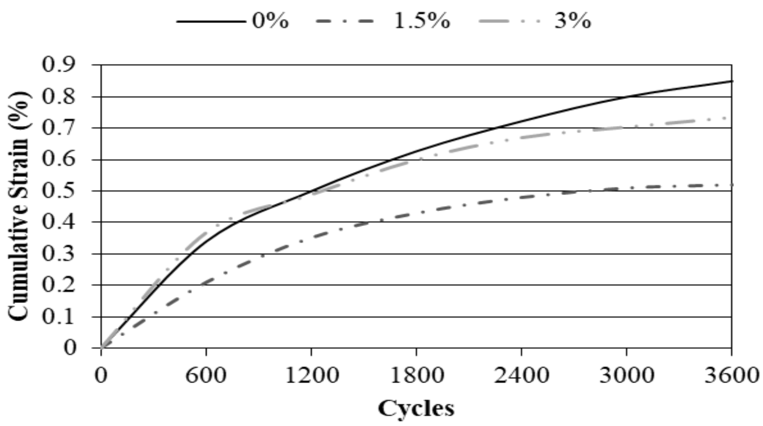

Fig. 5: Cumulative strain of mixtures.

DOI:10.52113/3/mjet/2021-9-2/25-33

5. Conclusion

Three different percentages of WCO (0, 1.5, and 3%) were used to modify the asphalt mixtures in the current investigation. The control mixture was compared to the WCO modified mixtures. The following conclusions were reached based on WCO's evaluation:

1. The volumetric properties, stiffness, and stability of the 1.5% WCO modified mixture are higher than those of the control and 3% WCO, indicating that the mixture properties have improved since WCO addition, with 1.5% WCO being the optimum ratio.
2. The resilient modulus of the 1.5% WCO modified mixture is higher than that of the control and 3% WCO. However, as the percentage of WCO increases, the resilient modulus value decreases.
3. Because the 1.5% WCO mixture had the best creep stiffness and the least cumulative strain of all the mixes, its creep resistance performance was enhanced. In addition, the creep stiffness of the 1.5% WCO mixture rose by about 36% when compared to the control mixture.

According to the results, increased awareness of environmental problems and natural resource constraints led to the potential benefit of using the studied WCO in this research in road construction.

References

[1] Al-Mansoori T, Garcia A, Norambuena-Contreras J, Artamendi I. Self-healing properties of asphalt mixtures with embedded capsules. In: Advances in Materials and Pavement Performance Prediction. CRC Press; 2018:551-555.
[2] Al-Mansoori T, Micaelo R, Artamendi I, Norambuena-Contreras J, Garcia A. Microcapsules for self-healing of asphalt mixture without compromising mechanical performance. Constr Build Mater. 2017;155:1091-1100.
[3] Williams RC, Satrio J, Rover M, Brown RC, Teng S. Utilization of fractionated bio oil in asphalt. In: 88th Annual Meeting of the Transportation Research Board, Washington, DC. ; 2009.
[4] Fini EH, Kalberer EW, Shahbazi A, et al. Chemical characterization of biobinder from swine manure: Sustainable modifier for asphalt binder. J Mater Civ Eng. 2011;23(11):1506-1513.
[5] You Z, Mills-Beale J, Fini E, Goh SW, Colbert B. Evaluation of low-temperature binder properties of warm-mix asphalt, extracted and recovered RAP and RAS, and bioasphalt. J Mater Civ Eng. 2011;23(11):1569-1574.
[6] Micaelo R, Al-Mansoori T, Garcia A. Study of the mechanical properties and self-healing ability of asphalt mixture containing calcium-alginate capsules. Constr Build Mater. 2016;123:734-744.
[7] Micaelo R, Al-Mansooria T, Garciab A. Effect of capsules containing sunflower oil on the mechanical behaviour of aged asphalt mixture 2. no Oct. Published online 2016.
[8] Fini EH, Yang S-H, Xiu S. Characterization and Application of Manure-Based Bio-Binder in Asphalt Industry.; 2010.
[9] Wen H, Bhusal S, Wen B. Laboratory evaluation of waste cooking oil-based bioasphalt as an alternative binder for hot mix asphalt. J Mater Civ Eng. 2013;25(10):1432-1437.
[10] Maharaj R, Ramjattan-Harry V, Mohamed N. Rutting and fatigue cracking resistance of waste cooking oil modified trinidad asphaltic materials. Sci World J. 2015;2015.
[11] Yaakob Z, Mohammad M, Alherbawi M, Alam Z, Sopian K. Overview of the production of biodiesel from waste cooking oil. Renew Sustain energy Rev. 2013;18:184-193.
[12] Campanelli P, Banchero M, Manna L. Synthesis of biodiesel from edible, non-edible and waste cooking oils via supercritical methyl acetate transesterification. Fuel. 2010;89(12):3675-3682.
[13] Leong XF, Ng CY, Jaarin K, Mustafa MR. Effects of repeated heating of cooking oils on antioxidant content and endothelial function. Austin J Pharmacol Ther. 2015;3(2):1-7.
[14] Asli H, Ahmadinia E, Zargar M, Karim MR. Investigation on physical properties of waste cooking oil–Rejuvenated bitumen binder. Constr Build Mater. 2012;37:398-405.
[15] Al-Mansoori T, Al-Adhadh A, Hussein J. Influence of Temperature and Rest Period on Damage Repair of Aged Asphalt. In: Key Engineering Materials. Vol 857. Trans Tech Publ; 2020:138-144.
[16] Norambuena-Contreras J, Yalcin E, Garcia A, Al-Mansoori T, Yilmaz M, Hudson-Griffiths R. Effect of mixing and ageing on the mechanical and self-healing properties of asphalt mixtures containing polymeric capsules. Constr Build Mater. 2018;175:254-266.
[17] Al-Mansoori T, Norambuena-Contreras J, Garcia A. Effect of capsule addition and healing temperature on the self-healing potential of asphalt mixtures. Mater Struct. 2018;51(2):1-12.
[18] Widyatmoko I. Mechanistic-empirical mixture design for hot mix asphalt pavement recycling. Constr Build Mater. 2008;22(2):77-87.
[19] Al-Mansoori T, Norambuena-Contreras J, Micaelo R, Garcia A. Self-healing of asphalt mastic by the action of polymeric capsules containing rejuvenators. Constr Build Mater. 2018;161:330-339.
[20] Al-Mansoori T, Norambuena-Contreras J, Garcia A. A Self-Healing Asphalt Mixture by the Action of Microcapsules That Is Ready to Be Used On-Site.; 2018.
[21] Al-Mansoori T, Hussein J, Aziz H. Asphalt damage reservation due to self-repair: A literature review. In: IOP Conference Series: Materials Science and Engineering. Vol 584. IOP Publishing; 2019:12019.
[22] Al-Mansoori T, Micaelo R, Garcia A. Characterization of polymer capsules used for self-healing asphalt pavements. In: Functional Pavement Design. CRC Press; 2016:1167-1174.
[23] Zoorob SE, Mturi GA, Sangiorgi C, Dinis-Almeida M, Habib NZ. Fluxing as a new tool for bitumen rheological characterization and the use of time-concentration shift factor (ac). Constr Build Mater. 2018;158:691-699.

DOI:10.52113/3/mjet/2021-9-2/25-33

[24] Somé SC, Pavoine A, Chailleux E. Evaluation of the potential use of waste sunflower and rapeseed oils-modified natural bitumen as binders for asphalt pavement design. Int J Pavement Res Technol. 2016;9(5):368.
[25] ASTM D. 5,“ASTM D5/D5M: Standard Test Method for Penetration of Bituminous Materials,.” Annu B Am Soc Test Mater ASTM Stand. 2013;1:5-8.
[26] ASTM. Standard test method for softening point of bitumen (ring-and-ball apparatus). Published online 2014.
[27] D4402/D4402M–12 A. Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer. In: American Society for Testing and Materials West Conshohocken, PA; 2012.
[28] ASTM D. D113. Standard Test Method for Ductility of Bituminous Materials. Annu B Stand. Published online 2007.
[29] ASTM D. 7175 (2015). Stand Test Method Determ Rheol Prop Asph Bind Using a Dyn Shear Rheometer, Annu B ASTM Stand. 4.
[30] JKR M. Standard specification for road works, section 4, flexible pavement. Jabatan Kerja Raya Malaysia, Kuala Lumpur. Published online 2008.
[31] Malaysian Public Works Department. Standard Specification for Road Works- Section 4: Flexible Pavement, JKR/SPJ/2008-S4.; 2008.
[32] Aashto T. Standard method of test for resistance to plastic flow of bituminous mixtures using Marshall apparatus. Am Assoc State Highw Transp Off Washington, DC, USA. Published online 1997.
[33] ASTM D7369. Standard Test Method for Determining the Resilient Modulus of Bituminous Mixtures by Indirect Tension Test. Published online 2011.
[34] BS EN 12697-25. Bituminous mixtures - Test methods for hot mix asphalt-Part 25: Cyclic compression test. Published online 2013.
[35] Borhan MN, Suja F, Ismail A, Rahmat R. The effects of used cylinder oil on asphalt mixes. Eur J Sci Res. 2009;28(3):398-411.
[36] Hınıslıoğlu S, Ağar E. Use of waste high density polyethylene as bitumen modifier in asphalt concrete mix. Mater Lett. 2004;58(3-4):267-271.
[37] Read J, Whiteoak D. The Shell Bitumen Handbook. Thomas Telford; 2003.
[38] Arabani M, Azarhoosh AR. The effect of recycled concrete aggregate and steel slag on the dynamic properties of asphalt mixtures. Constr Build Mater. 2012;35:1-7.
[39] Abdelaziz M, Mohamed Rehan K. Rheological evaluation of bituminous binder modified with waste plastic material. Published online 2010.

DOI:10.52113/3/mjet/2021-9-2/25-33