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INVESTIGATING THE EFFECT OF OLIVE HUSK ASH ON DYNAMIC CREEP OF ASPHALT CONCRETE MIXTURES

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Abstract

This paper aims at finding out the impact of Olive Husk Ash on the dynamic creep of asphalt concrete. The asphalt concrete mixtures were subjected to a simulation of a creep test using a Universal Testing Machine, and five percentages of Olive Husk Ash by volume of the binder were added. Three loading frequencies (1, 4 and 8 Hz), which simulate vehicle speeds of 20, 40 and 60 miles/hr. respectively and three testing temperatures (5, 25 and 40ºC), which represent cold, moderate, and hot temperatures, were taken into consideration. Olive Husk Ash, sometimes known as olive waste ash, is widely available in Jordan. This study uses olive husk ash as an asphalt additive to recycle it. Additionally, using ash reduces the financial expense of making asphalt mix. The results show that adding ash at the right concentration (10-15%) improves the quality and effectiveness of asphalt concrete mixtures. The addition of OHA to asphalt has a beneficial effect on improving resilient modulus and creep stiffness as well as reducing accumulated strain at various frequencies and temperatures.

Keywords: Asphalt mixtures, Olive husk ash, Creep, Resilient modulus, Stiffness, Strain.

1. Introduction

Every year, Jordan, like other Mediterranean nations, produces enormous amounts of olive oil, which results in enormous amounts of disposal of olives, which can be viewed as an environmental issue because there is no effective and designated way to handle it other than occasionally using it for heating. It is crucial to consider how to use this ash to your advantage when producing asphalt. One facet of new energy awareness is the rise in significant olive husk resources nowadays.

Concrete mixtures made of asphalt and cement are frequently utilized to build flexible pavement. Parking lots, airports, and motorways are examples of applications. For the asphalt-cement concrete mixtures, a satisfactory level of stability, flow, voids in mineral aggregates (VMA), and air voids must be provided. However, it has been noted that those pavements have had noticeable field issues. Permanent deformation, fatigue cracking, bleeding, and ravelling are a few examples of such issues. Therefore, creating new combinations with new qualities by adding various additives to asphalt-cement mixtures is commonly referred to as "modifying bituminous mixtures."

The followings are the objectives of this study:

- Investigating the potential for adding olive husk ash to asphalt mixtures to improve performance.
- Determining the ideal proportion of olive husk ash to produce the best qualities of the asphalt concrete mix.
- Studying the impact of olive husk ash on the dynamic creep of asphalt-concrete mixtures.

Bituminous binders, various-sized aggregates, and air voids are the main ingredients in the asphalt mixture. Crushed stone, cement, and lime are a few examples of common fillers that can be added to the asphalt mixture. Additional research (Carpenter [1], Tons et al. [2], Suheibani [3], Al-sayed et al. [4], Chandra et al. [5], Asi and Assa’ad [6], Do et al. [7], Chen et al. [8], Chen et al. [9], Xiao at al. [10], Modarres and Rahamanzadeh [11], Sobolev et al. [12], Tremblay et al. [13], M. Arabani et al. [14, 15], Mistry et al. [16]) has been done on the use of powder wastes derived from aggregate, stone, brick, marble, lime, sewage sludge-ash, glass, rice, coal, and seashell as an additive or a replacement for the common fillers. The performance of the asphalt mixture has been impacted by the use of the prior fillers in varying degrees. In Jordan, Bani Baker et al. [17] utilized natural bentonite clay as a partial mineral filler replacement in asphalt mixtures. Results indicated that adding natural bentonite clay to asphalt mixtures increases density and stability. The modified mixtures have higher flow and ITS values and lower hydraulic conductivity compared to control specimens. Bani Baker et al. [18] used two methods of high-impact polystyrene (HIPS) polymer addition to asphalt concrete (AC) mixtures to assess the impact of freeze-thaw (FT) cycles on the performance of unmodified AC and AC modified by utilizing supplementary and additional HIPS polymer as asphalt aggregates. The first method's outcomes demonstrated the viability of enhancing AC by employing HIPS polymer to resist efficient FT cycles. However, the second method of adjusting AC did not yield encouraging outcomes.

Similar to how rubber powder has been used in asphalt mixtures to lessen environmental pollution and paving material costs, see Kallin [19]. To enhance the qualities of the asphalt concrete mix, rubber powder is often added by the wet method as a part of the binder and the dry method as a part of the aggregate (Roberts et. al. [20]). Rubber has been added to asphalt cement or asphalt concrete in several studies to enhance the combinations' characteristics. According to these research (Roberts and Litton [21], Khedaywi and Abu-Orabi [22], Khedaywi et al. [23], Malpass and Khosla [24], the extra rubber could enhance the mix's properties and outcomes, such as fatigue, creep and resilient modulus.

Paving mixtures are evaluated using the Hveem and Marshall tests. However, additional research (Hadipour and Anderson [25] and Van de Loo [26]) showed that traditional mix design experiments are insufficient to produce a critical assessment of paving mixtures. A sophisticated paving mix test must be utilized to assess the critical pavement mix properties. A subsystem inside a larger pavement management system could apply the mixed design process described by Van de Loo [26] based on creep testing. The suggested system enables one to calculate the decline in pavement usage as a function of time. A suitable laboratory technique for examining the long-term permanent deformation and unmodified asphalt mixtures is the dynamic creep test (Kaloush and Witczak [27]). Additionally, the results of the wheel tracking test and the dynamic creep test have strong correlations (Fontes et al. [28]).

Numerous studies using the uniaxial (unconfined) creep test have been carried out as a basis for predicting the behavior of permanent deformation in control and modified asphalt mixtures (Radziszewski [29], Gul [30], Ozen [31], Sengul et al. [32, 33], Ameri et al. [34], Lee et al. [35], Moghaddam et al. [36], Zhang et al. [37], Ziari et al. [38], Imaninasab et al. [39]). Suo and Wong [40] conducted a dynamic cycle compression test to assess how mixture rutting propensity was affected by varying air voids. Using repeated load permanent deformation testing in comparison to dynamic modulus and flow number testing, Zhang et al. [41] determined that permanent deformation testing may be used in place of other laboratory studies to rank the susceptibility of various asphalt mixtures to rutting.

Alsheyab and Khedaywi [42] examined the effects of waste Electric Arc Furnace Dust (EAFD) on the dynamic creep of asphalt concrete mixtures. The authors examined the resilient modulus, creep stiffness, and cumulative strain. Results revealed that the addition of waste EAFD to mixtures had a beneficial effect on improving resilient modulus and creep stiffness as well as reducing accumulated strain at various temperatures and frequencies. The ideal mixture with best performance was at 10% of EAFD. Similarly, Al-Mistarehi et al. [43] examined the effects of recycled materials as fillers on the creep and fatigue behavior of asphalt mixtures. Waste toner, waste medical ash, waste electrical arc furnace dust (EAFD), and waste tire rubber were the four waste materials used in the study. The asphalt concrete mixture's best filler to use was waste toner.

A review of recent literature (Asi and Assa’ad [6], Goh and You [44], Khodaii and Mehrara [45], Mehrara and Khodaii [46], Golalipoura [47], Moghaddam et al. [48], Lavasani et al. [49], Katman et al. [50], Mounes et al. [51], Karami et al. [52], Al-Khateeb et al. [53], Khiavi et al. [54], Behbahani et al. [55], Ziari et al. [56], Khasawneh et al. [57], Jomoor et al. [58]) on the dynamic creep of asphalt cement and asphalt concrete mixtures have revealed that there is no information available on the creep performance of Olive Husk Ash as an additive to the asphalt concrete mixtures.

2. Laboratory Work

2.1. Material used

The materials used in the research are:

2.1.1. Aggregate

One type of limestone aggregate was used in this study. This type of aggregate was obtained from the Northern Jordan. Grading followed the guidelines provided by the specifications of the Jordanian Ministry of Public Works and Housing (MPWH) [59]. Tables 1 and 2 respectively list the aggregate's gradation and properties. The bulk specific gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water, while the apparent specific gravity is the ratio of the weight in air of a unit volume of the impermeable portion of aggregate to the weight in air of an equal volume of water at the stated temperature. Water absorption of aggregates is the percentage of water absorbed by dried aggregate when immersed in water.

Table 1. Gradation of aggregate.

Sieve Size	MPWH specification Limits (%) Passing	% passing (midpoint)
1" (25.00 mm)	100.0	100
1/4 " (19.00 mm)	90-100	95
1/2 " (12.5 mm)	71-90	80.5
1/8 " (9.5 mm)	56-80	68
No. 4 (4.75mm)	35-56	45.5
No. 8 (2.35 mm)	23-38	30.5
No. 20 (850 µm)	13-27	20
No. 50 (300 µm)	5-17	11
No. 80 (180 µm)	4-14	9
No. 200 (75 µm)	2-8	5

Table 2. Properties of aggregate.

Agg. Type	Bulk Sp. Gr	Appar. Sp. Gr	Absorption (%)
Coarse Aggregate	2.581	2.657	3.2
Fine Aggregate	2.703	2.682	4.5
Mineral Filler	2.667	2.492	5.1

2.1.2. Asphalt

Asphalt cement grade 60-70 was obtained from the Petroleum Refinery Company located in Zarqa, Jordan. In Jordan, this asphalt cement is mostly utilized to build flexible pavement. Table 3 provides a list of the asphalt's physical properties. A description of these tests is presented here.

Penetration test: A penetration needle creating a 100 gm equivalent force on the asphalt mixture, at 25°C, for 5 seconds was used. The penetration distance into the asphalt mixture of the needle, in units of 0.1 mm, was reported. The softness of mixtures with greater penetration numbers is called “soft” and is used for cold-climates in addition to asphalt mixtures with low penetration numbers called “hard” are used for warm-climates [60].

Ductility: The ductility of a bituminous material is measured by the distance to which it will elongate before cracking when two ends of a briquette specimen of material are pulled apart at a precise speed and a precise temperature. The test shall be made at a temperature 25±0.5℃ and with a speed of 5cm/min ± 5.0%. The ductility for each mix has been measured and an average value for three specimens' measurements is reported [61].

Softening point (ring and ball): This test covers the determination of the softening point of asphalt in the range from 30℃ to 175℃ using the ring and ball apparatus in an ethylene glycol bath. A steel ball of specified weight is located upon a disk of a sample contained within horizontal equipment. The component is heated in the path. Prescribed rate and the softening point taken as the temperature at which the sample becomes soft enough to allow the ball envelop in the sample material, logged the temperature when the ball attaches the plate [62].

The softening point is described as the temperature at which a bitumen sample is not able to stand the weight of a 3.5-g steel ball. The Ring and ball apparatus was used to obtain the softening point for each mix of the asphalt.

Flash and fire point: This method covers reporting flash and fire points of all petroleum products except fuel oils. The procedure is as follows: First, the test cup is filled to a certain level with the specimen. Then, the temperature of the specimen is increased rapidly at first and then at a low constant rate as the flashpoint is reached. After that, and at specified intervals, a small test flame is passed across the cup. The lowest temperature at which the application of the test flame causes the vapours above the surface of the liquid to ignite is taken as the flashpoint. Also, to report the fire point, the test is continued until the implementation of the test flame causes the oil to ignite and burn for at least 5 seconds [63].

Specific gravity: The specific gravity of asphalt cement (binder) is being used mainly for two reasons [64].

(i) Asphalt enlarges when heated and shrinks when cooled; this means that the volume of a given amount of asphalt cement (binder) will be increased at higher temperatures and decreased at lower ones. Thus, there must be designated measures to modify the temperature-volume.

(ii) It is necessary to determine the percentage of voids in the compacted pavement. The addition of OHA to asphalt cement (binder) was in several percentages.

Table 3. Properties of asphalt.

Properties	ASTM Test Designation	Test Result	MPWH Specific. [59]
Penetration (0.1 mm) at 25ºC, 100 gm, and 5 sec.	D5	64	60-70
Ductility (cm) at 25ºC	D113	114	100+
Softening Point, ºC	D36	50	45-52
Flash Point, ºC	D92	320	300-330
Fire Point, ºC	D92	325	300-330
Specific Gravity	D70	1.017	1.01-1.02

2.1.3. Olive husk ash

Olive husk was burned at 400ºC in an oven until full burning was accomplished to produce olive husk ash. The ash was sieved through the No. 100 sieve. The ash has a specific gravity of 2.23. The chemical composition and gradation of the OHA are listed in Table 4.

Table 4. Olive husk ash chemical composition and gradation [65].

A-Chemical Analysis of OHA		B-Gradation of OHA			
Element	**Percentage**	**Size (Micron)**	**Percent Finer**	**Size (Micron)**	**Percent Finer**
SiO_2	6.72	150	100.0	4	6.1
Al_2O_3	2.57	75	80.3	3	4.7
Fe_2O_3	0.67	48	69.7	2	3.1
CaO	10.38	32	47.7	1.5	1.7
MgO	2.14	24	35.7	1	1.3
SO_3	0.61	16	23.3		
K_2O	34.01	12	15.1		
Na_2O	2.67	8	11.6		
Loss O I	25.55	6	8.9		

2.2. Preparation of ash-asphalt-cement concrete binders

Both ash and asphalt-cement were separately heated in an oven at a temperature of 145ºC. The stainless steel mixing beaker was cleaned and kept in the oven at about 145°C. To maintain a consistent mixing temperature of 140 to 145ºC, the beaker was set up on a hot plate. The exact quantity of ash (0, 5, 10, 15, and 20% by volume of binder) and asphalt-cement that satisfies the necessary ash to asphalt-cement ratio was mixed in the laboratory mixer for 1 hour at 1,600 RPM. The propeller was about 1.5 cm above the bottom of the beaker. Splashing that may produce air bubbles was avoided while mixing. The aggregate was heated, then added and mixed with the ash-asphalt-cement binder producing the ash-asphalt-cement concrete specimens. Table 5 includes the varying percentages of ash utilized as an addition along with the specific gravity of the ash-asphalt-cement concrete binders. The Marshall Stability and the flow at each percent of ash adding (0, 5, 10, 15, and 20%) are (1545, 1715, 1685, 1750, and 1790kg) and (21.1, 22.2, 17.2, 16.1, and 14.7 (25 mm)), respectively.

Table 5. Specific gravity of binder.

% Ash	Specific Gravity
0	1.017
5	1.085
10	1.162
15	1.245
20	1.288

2.3. Determination of optimum asphalt content

The method outlined in the MS-2 Manual [66] and ASTM D1559 [67] standards was used to establish the ideal asphalt content for the mixture using Marshall mix design of 50 blow procedure, which represents medium traffic. The percentages of the asphalt cement by volume of the asphalt concrete mixtures are equal to (4.5, 5.0, 5.5, and 6.0%). Three specimens from each of the Marshall mix designs were examined for stability, flow, voids in mineral aggregates, air voids, and unit weight. The optimum asphalt cement content is the average number that meets the requirements for maximum unit weight, optimum stability, and 4% air voids. The average value for asphalt cement is 5.25 % of the asphalt concrete mixture. Figure 1 shows the preparation of Marshall specimens and Fig. 2 shows the determination of optimum binder content.

(a) Compact the sample.

(b) Samples for tests.

Fig. 1. Preparation of Marshall specimens.

(a) Test the mixture for bulk specific gravity of specimen (G_{m_b}).

(b) Put the mixtures in water bath at 60˚C.

(c) Tested the mixture for maximum specific gravity of specimen (G_{mm})

(d) Stability and flow tests

Fig. 2. Determination of optimum binder content.

2.4. Dynamic creep test

Using a dynamic creep test, the impact of olive husk ash on pavement design is assessed. The test was carried out using the Universal Testing Machine [68], a well-known equipment depicted in Fig. 3, in accordance with British Standards Institute BS [69]. Specimens for one type of aggregate at optimum asphalt content, ash content of (0, 5, 10, 15, and 20%) were prepared. Specimen's weight and height were measured to determine unit weight for each sample.

Three samples were required for testing for each ash concentration and temperature combination. For each specimen, the width and diameter were measured. Before testing, the samples were kept in a cabinet for twenty-four hours at different conditions (5, 25, and 40ºC). Each specimen under test was set in a jig with its face in contact with two stainless steel loading platens. The upper platen made contact with the loading system via a spherical seating, and the greasy bottom platen was firmly fastened to the load frame. The specimens were subjected to loads by the load cell. To quantify the vertical displacement of the specimen under the applied stresses, Linear Variable Differential Transformers (LVDTs) were attached to the specimen. The stainless steel plates were utilized to evenly disperse the applied pressure across the specimen's surface. Each specimen was subjected to conditional stress at 10 kPa for 120 seconds before being loaded. Without creating any influence, haversine loading was used with loads ranging from (0 and 100 kPa). Tests were run at various temperatures (5, 25, and 40ºC). There were three frequencies used for each level of temperature (1, 4, and 8 Hz). The test's results were computerized, presented, and could be printed.

Fig. 3. Universal testing machine.

3. Results and Discussion

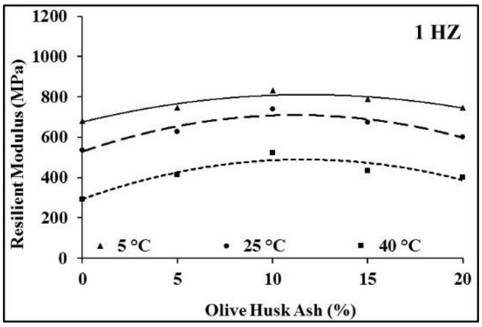
3.1. Effect of ash on resilient modulus

Figure 4 illustrates how ash affects the resilience modulus of an asphalt concrete mix at various temperatures (5, 25, and 40ºC) and loading frequencies (1, 4, and 8 Hz). This figure shows that resilient modulus increases to the optimum value then decreases with the increase of Olive Husk Ash content. Additionally, this figure demonstrates that the optimum ash concentration in the binder is between 10 and 15% by volume.

In Fig. 4, the well-known quadratic regression is used to find the equation of the parabola that best fits the sets of experimental data. The parabolic equations used to predict the resilient modulus and the corresponding relative predictive power of quadratic equations denoted by R^2 are both listed in Table 6 at temperature (5, 25, and

40ºC) levels for different loading frequencies (1, 4, and 8 Hz). The value of R^2 varies between 61.01% and 99.79% with an average value of 79.01% which is relatively close to 1. As known, the closer the value is to 1, the more accurate the model is.

It should be noted that the increase in temperature has resulted in a decrease in resilient modulus. On the other hand, the increase in frequency has resulted in an increase in the resilient modulus for all sets of data presented in Fig. 4. At 8 Hz, the maximum resilient modulus was formed (Figure 4(c), because the numbers of loading and unloading are more than the loading frequencies (1 and 4 Hz) shown in Figs. 4(a) and (b) in one second.



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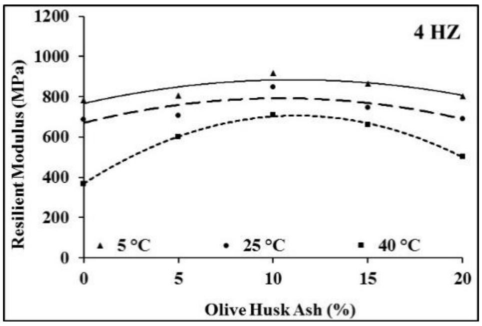

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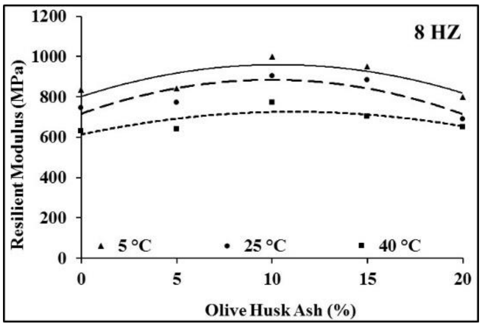


(c)

Fig. 4. Effect of olive husk ash (%) on resilient modulus (MPa) of asphalt concrete mixtures at different temperatures and frequencies using dynamic creep test.

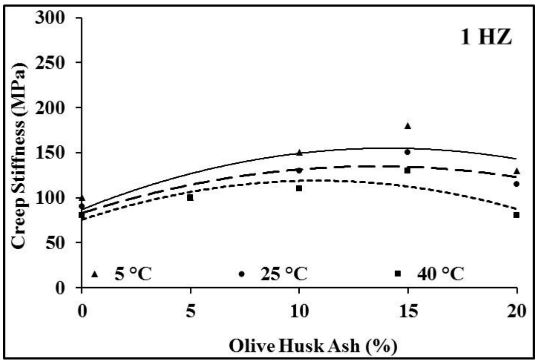
Table 6. Resilient modulus equation and square *R* at different temperatures and frequencies.

Resilient Modulus Equation and Square R			
Frequency (Hz)	**Temperature**	**Equation**	R^2
1	5ºC	$y = -0.9801x^2 + 23.051x + 675.08$	0.9185
	25ºC	$y = -1.4459x^2 + 32.399x + 528.22$	0.9173
	40ºC	$y = -1.4563x^2 + 33.828x + 292.83$	0.881
4	5ºC	$y = -0.9623x^2 + 21.288x + 766.05$	0.7395
	25ºC	$y = -1.1233x^2 + 23.434x + 669.93$	0.6292
	40ºC	$y = -2.6804x^2 + 60.21x + 367.94$	0.9979
8	5ºC	$y = -1.4934x^2 + 30.721x + 801.53$	0.6714
	25ºC	$y = -1.6921x^2 + 33.736x + 716.33$	0.7458
	40ºC	$y = -0.9142x^2 + 20.319x + 613.02$	0.6101

3.2. Effect of ash on creep stiffness

A time-dependent deformation under constant tension and high temperature is referred to as creep. Figure 5 illustrates how ash affects the creep stiffness of an asphalt concrete mixture at various temperatures (5, 25, and 40ºC) and loading frequencies (1, 4, and 8 Hz). This figure shows that the creep stiffness increases to the optimum value and then decreases with the increase of Olive Husk Ash content. Additionally, this figure demonstrates that the optimum ash content in the binder is between 10 and 15% by volume of binder.

In Fig. 5, parabolic equations are used to predict creep stiffness and the corresponding relative predictive power of quadratic equations denoted by R^2 as listed in Table 7 at temperature (5, 25 and 40ºC) levels for different loading frequencies (1, 4, and 8 Hz). The value of R^2 varies between 63.86% and 86.01% with an average value of 73.65% which is an acceptable value. Creep stiffness has decreased as a result of the temperature increase. This is due to the fast that as the testing temperature increases, the mixture will be softer (flexibility increases with temperature increase) [43]. The creep stiffness has increased as a result of the increase in frequency as shown in Fig. 5, At 8 Hz, the maximum creep stiffness was formed, because the numbers of loading and unloading are more than the loading frequencies (1 and 4 Hz) in one second.



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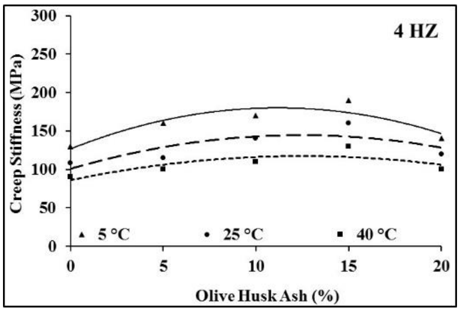

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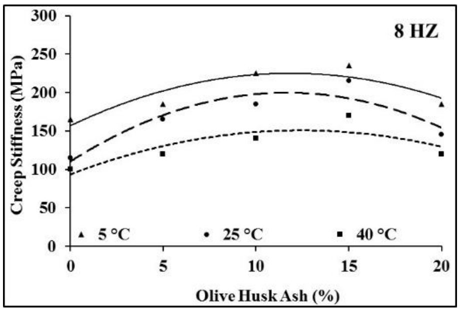


(c)

Fig. 5. Effect of olive Husk (%) ash on creep stiffness (MPa) of asphalt concrete mixtures at different temperatures and frequencies using dynamic creep test.

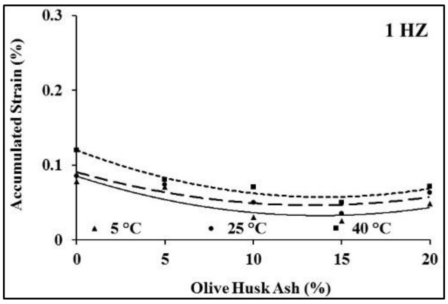
Table 7. Creep stiffness equation and square *R* at different temperatures and frequencies.

Creep stiffness equation and square ***R***			
Frequency (Hz)	**Temperature**	**Equation**	***R*²**
1	5ºC	y = -0.3429x^2 + 9.6571x + 86.857	0.6386
	25ºC	y = -0.2857x^2 + 7.7143x + 82.714	0.7519
	40ºC	y = -0.3714x^2 + 8.0286x + 75.429	0.7206
4	5ºC	y = -0.4286x^2 + 9.5714x + 126.57	0.8145
	25ºC	y = -0.2829x^2 + 7.0371x + 100.66	0.6537
	40ºC	y = -0.2x^2 + 5x + 86	0.6522
8	5ºC	y = -0.4857x^2 + 11.514x + 156.71	0.8166
	25ºC	y = -0.6571x^2 + 15.343x + 110.14	0.8601
	40ºC	y = -0.3714x^2 + 9.2286x + 93.429	0.7204

3.3. Effect of ash on accumulated strain

Figure 6 illustrates how ash affects the cumulative strain of an asphalt concrete mixture at various temperatures (5, 25, and 40ºC) and loading frequencies (1, 4, and 8 Hz). This figure shows that the accumulated strain decreases then increases with the increase of Olive Husk Ash content. The accumulated strain of the modified mixtures is less than those of unmodified mixtures due to the fact that the adhesive forces between particles become relatively weak [70]. Additionally, this figure demonstrates that the ideal ash content for the binder is between 10 and 15% by volume.

In Fig. 6, parabolic equations are used to predict the accumulated strain and the corresponding relative predictive power of quadratic equations denoted by R^2 as listed in Table 8 at various temperature (5, 25 and 40°C) levels and loading frequency (1, 4, and 8 Hz). The value of R^2 varies between 63.89% and 99.91% with an average value of 82.33% which is relatively close to 1. The increase in temperature has increased accumulated strain (flexibility increases with temperature increase) [43]. Also, the increase in frequency has resulted in an increase in the accumulated strain as shown in Fig. 6. At 8 Hz, the maximum accumulated strain was formed, because the numbers of loading and unloading are more than the loading frequencies (1 and 4 Hz) in one second especially for softer or more flexible mixtures (i.e. when temperature increases).



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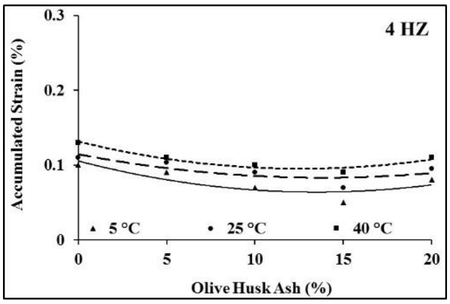

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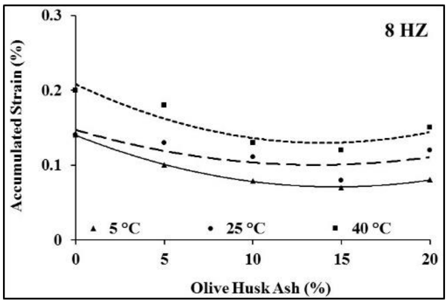

(c)

Fig. 6. Effect of olive husk ash (%) on accumulated strain (%) of asphalt concrete mixtures at different temperatures and frequencies using dynamic creep test.

Table 8. Accumulated strain equation and square *R* at different temperatures and frequencies.

Accumulated Strain Equation and Square R			
Frequency (Hz)	**Temperature**	**Equation**	R^2
1	5ºC	$y = 0.0003x^2 - 0.0076x + 0.0851$	0.802
	25ºC	$y = 0.0002x^2 - 0.0066x + 0.0904$	0.7957
	40ºC	$y = 0.0003x^2 - 0.009x + 0.1198$	0.9511
4	5ºC	$y = 0.0002x^2 - 0.0062x + 0.1054$	0.7413
	25ºC	$y = 0.0002x^2 - 0.0045x + 0.1143$	0.6769
	40ºC	$y = 0.0002x^2 - 0.0058x + 0.1314$	0.9286
8	5ºC	$y = 0.0003x^2 - 0.0094x + 0.1398$	0.9991
	25ºC	$y = 0.0003x^2 - 0.0069x + 0.1469$	0.6389
	40ºC	$y = 0.0004x^2 - 0.0112x + 0.208$	0.8761

4. Conclusions

The following were concluded from this research:

- The 10 to 15% of Olive Husk Ash improves the creep stiffness because it increases the adhesive forces between aggregate and asphalt. Additionally, the same percentage of Olive Husk Ash improves both resilient modulus and accumulated strain by increasing the former and reducing the latter, respectively.
- Temperature had a vital effect on creep stiffness, resilient modulus, and accumulated strain. Creep stiffness and Resilient modulus, therefore, increase with decreasing temperature, but cumulative strain decreases.
- The impact of loading frequency (Hz) on resilient modulus, creep stiffness, and the accumulated strain was significant. Therefore, in addition to accumulated strain, resilient modulus and creep stiffness also increase as loading frequency does. The amount of loading and unloading is greater than the loading frequencies (1 and 4 Hz) in a second, which causes the resilient modulus, creep stiffness, and accumulated strain to reach their maximum at 8 Hz.
- Finally, it has been determined that the findings show promise for resolving an environmental issue and utilizing OHA for flexible pavement.

Conflict of interest

The authors declare no conflict of interest.

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