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Research Article

Internet of Things (IoT) and Remote Sensing (RS) Based on Geospatial Information System (GIS) Against Fatigue of Asphalt Bitumen

Shova R Bhattarai [1], Mahdi Feizbahr [2*]

[1] *Department of Civil and Environmental Engineering, Lamar University, Beaumont, TX, 77710, USA*
[2] *School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia*

Keywords

Remote Sensing,
Internet of Things (IoT),
Geospatial Information System,
laboratory equipment,
standard test method.

Abstract

This work investigated the Geospatial Information System (GIS) as a low-cost, high-precision, and rapid method for identifying the (RAP). This work also showed that (GIS) can be linked to new techniques including Remote Sensing (RS) and the Internet of Things (IoT) which can be serious subjects for research in the field of pavement engineering. The results of the present work showed that Remote Sensing (RS) has reduced fatigue and thermal cracks. Moreover, for modified asphalt samples, tests of Marshall stability, flow, resilience modulus, repeated load axial, uniaxial creep and indirect tensile fatigue were carried out.

1. Introduction

The standard test method can be defined based on the internet of things (IoT), Remote Sensing (RS) and Geospatial Information System (GIS) against fatigue of asphalt bitumen. The standard test method allows results of like tests performed by different laboratories to be compared. To ensure the quality of bitumen several tests are performed which are as follows:

- Ductility test.
- Flash and Fire point test.
- Float test.
- Loss on heating test.
- Penetration test.
- Softening point test.
- Specific gravity test.
- Viscosity test.

* **Corresponding Author:** Mahdi Feizbahr
E-mail address: m.feizbahr@gmail.com

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They will provide similar results within the statistical bounds of the method. The standard test method provides the basis for laboratory accreditation programs for Asphalt Tests which are as follows:

- Kinematic Viscosity. The kinematic viscosity of a liquid is the absolute or dynamic viscosity divided by the density of the liquid.
- Superpave Shear Tester.
- Absolute Viscosity.
- HMA Performance Tests.
- Mixture Characterization Tests.
- Flash Point.
- Asphalt Mixture Performance Test.
- Binder Content.

the maintenance of roads is a critical job that can be beneficial to society as a whole. Therefore, the studies about the properties of the material used in road construction can lead to improving the mechanical properties of hot asphalt mixtures. Today, researchers all over the world have conducted extensive tests to distinguish the causes of asphalt failure, which can be used to achieve further knowledge on the pavement which benefits from the roads as a national treasure. Traffic is the most important factor in pavement design. The key factors include contact pressure, wheel load, axle configuration, moving loads, load, and load repetitions [1-7].

In a study by Jay et al., the effect of two natural oils from frying vegetable waste, including corn and soybean oils, and a commercial chemical oil called fuel oil on asphalt bitumen was investigated. The bitumen studied in this study includes PG 64-22 and aged bitumen extracted from recycled asphalt. The main purpose of this study was to calculate the creep hardness of recycled asphalt bitumen to evaluate thermal cracking at low temperatures. Bitumen performance at low temperatures was investigated by bending beam rheometer test, bitumen behavior at high temperatures by obtaining mixing temperature and asphalt density by rotary viscometer test and also grooving mark by dynamic shear rheometer test. In the rotary viscometer experiment, the viscosity of the mixture of bitumen and oils was studied and the results showed that the aged bitumen decreased more than the base bitumen due to the increase in the percentage of oils. Therefore, the mixing temperature and density of the asphalt mixture have been reduced by using the oils studied in this study.

Figure 1 shows the effect of these oils on the grooving index. According to the results of the dynamic cutting rheometer test, the grooving mark has decreased with increasing the percentage of rejuvenating oils, and aged bitumen from recycled asphalt containing corn and soybean oils shows less grooving than they have fuel oil in bitumen. The groove mark of aged bitumen with a higher percentage of frying oils (more than 6%) is less than one kPa in the temperature range of 70-64 ° C, which means a decrease in resistance at high temperatures of bitumen results in an increase of more. The percentage of oil compared to PG bitumen is 64-22. According to the results of the flexural beam rheometer test, the hardness at low temperature of bitumen, according to Figures 2-3 for aged bitumen, decreased significantly with increasing oil percentage. Therefore, the hardness of recycled asphalt has increased and the probability of cracking at low temperatures has decreased.

Also, corn and soybean oils showed a greater reduction in the amount of creep hardness obtained from the rheometer test of bending beams in bitumen aged with fuel oil. The results showed that adding a large percentage of vegetable frying oil can lower the low-temperature limit of bitumen from minus 22 to minus 28. In general, in these studies, rejuvenating vegetable oil can significantly improve the viscosity and hardness of bitumen by reducing the viscosity and hardness of bitumen, as well as the fatigue of asphalt mixtures [8].

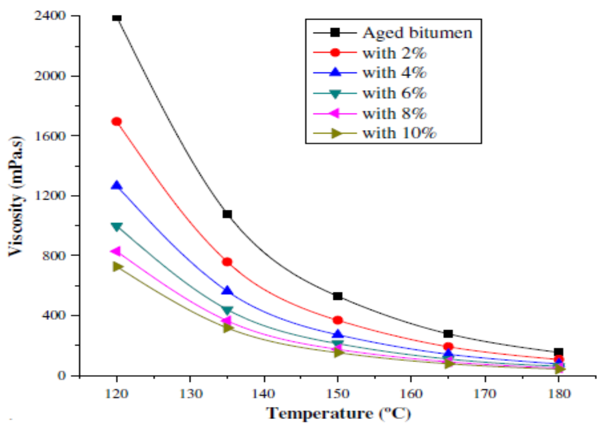

Figure 1. The viscosity of the rejuvenating bitumen the various temperature based on the research of Ji, et al. [8]

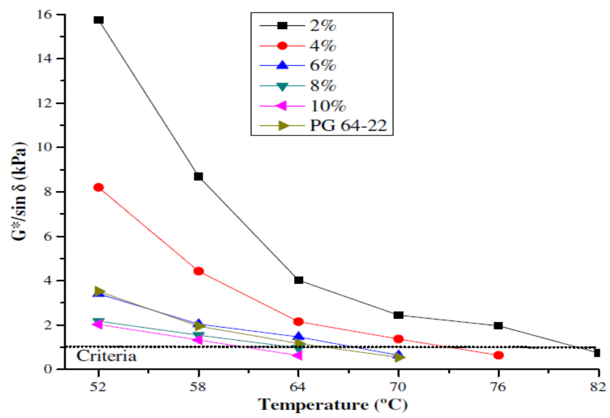

Figure 2. Rutting index of Modified tar based on the research of Ji, et al. [8]

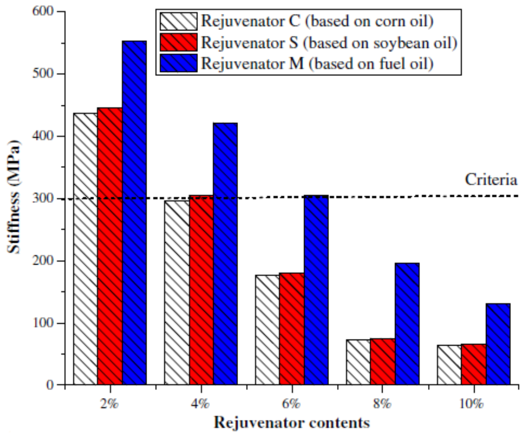

Figure 3. Creep hardness in low temperature of Modified bitumen by rejuvenating based on the research of Ji, et al. [8]

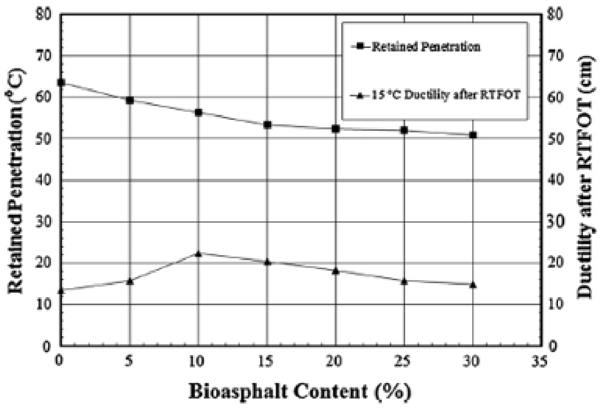

Figure 4. Degree of reversible diffusion and deformation in 15°C temperature after RTFO test based on the research of the Zeng, et al. [9]

Table 1. Results of modified bitumen tests based on the findings of Zeng M et al. [9]

Properties	Bioasphalt contents (%)						
	0	5	10	15	20	25	30
5°C penetration (0.1mm)	5.7	7.3	9.0	11	13	15	18
15°C penetration (0.1mm)	16	20	24	28	33	38	49
25°C penetration (0.1mm)	44	54	64	75	86	97	114
Softening point (°C)	52.8	51.8	50.8	49.7	48.5	47.4	46.1
15oC ductility (cm)	153	134	115	99	74	56	44
Flash point (°C)	270	-	-	262	-	-	256
Solubility (%)	99.6	-	-	65.2	-	-	92.1
Density (g/cm^3)	1.040	-	-	1.031	-	-	1.023
Mass change in RTFOT (%)	0.017	-0.087	-0.187	-0.312	-0.432	-0.523	-0.620
Retained pen. after RTFOT (%)	63.6	59.3	56.3	53.3	52.3	52.1	50.9
15°C Doc. after RTFOT (cm)	13.5	15.8	22.3	20.3	18.2	15.8	14.9

In a study by Zang et al., the effect of castor oil with a weight percentage of 0 to 30% with a growth of 5% on the aging of petroleum bitumen was studied. Mass change, degree of penetration and reversible ductility were compared before and after simulation of short-term bitumen aging during a thin rotating glaze test to evaluate the improvement of bitumen aging resistance. According to Figure 4, which shows the degree of penetration and recurring ductility after RTFO testing for modified bitumen as a function of oil percentage, the degree of penetration decreased moderately with increasing oil percentage. Also, the ductility has changed slightly with increasing oil percentage, which is the culmination of this change in adding 10% oil. According to

Table 1, with increasing oil percentage, the change in bitumen mass after RTFO test has decreased to less than 70%. According to the results, the aging resistance of bitumen has been significantly improved by castor oil [9].

Chen et al. studied two asphalt adhesives under grades A and B with grades 60-80 and 40-60 and bitumen modified by SBS polymer called C, as control samples to investigate the effect of vegetable oil on aging resistance. They paid bitumen. Waste vegetable oil used in this study as a bitumen additive includes frying oil wastes that are separated from the solid particles and water during the filtering process and in weight percentages of 3%, 4%, 5%, 6% and 7% combined with bitumen. Aged bitumen samples were used by rotating thin enamel tests to simulate short-term aging and PAV to simulate long-term aging of bitumen and penetration degree test, before and after aging to determine the strength of bitumen. In this study, the degree of penetration ratio was calculated as a measure of stability against bitumen aging. As shown in Table 2, with the addition of vegetable oil, the penetration ratio has increased compared to the base bitumen, which indicates an improvement in the resistance of bitumen to aging [10].

Table 2. The effect of oil on the percent of bitumen penetration based on the research of Chen, et al. [10]

	A0	A4	B0	B3	C0	C2
Before RTFOT Penetration (25ºC, 0.1 mm)	76	80	54	52	59	58
After RTFOT Penetration (25ºC, 0.1 mm)	44	59	36	42	43	45
Mass loss (%)	-0.092	0.036	-0.143	0.030	0.027	0.073
Penetration ratio (%)	57.89	73.75	66.70	80.80	72.90	77.60

Note: A4 refers to aged 60-80 grad containing 6.0%W; B3 refers to aged 40-60 grad containing 5.0%W; C2 refers to aged SBS modified asphalt containing 6.0%W;

In a study by Zargar et al., The effect of waste cooking oil on 50-40 bitumen with 1%, 2%, 3% and 4% by weight and by comparing it with 100-100 bitumen as a control sample to evaluate the strength of bitumen They fought against aging. They used a butterfly mixer as a non-standard method to accelerate bitumen aging in addition to the standard RTFO method to simulate short-term bitumen aging, and the degree of bitumen penetration before and after the RTFO test was calculated as a measure of bitumen stability against aging. The effect of oil on the degree of penetration was showed in Figure 5. The percentage of additive oil increases, the degree of penetration increases almost linearly. This increase in the degree of penetration is due to the decrease in the ratio of asphaltene to malt. According to the results, the penetration degree of control 80-100 bitumen is 85 mm, which is obtained by adding 3% cooking oil to 40-50 aged bitumen, the same degree of penetration is achieved. Based on the results obtained from the degree of penetration, viscosity and G* parameter, the rejuvenated bitumen has a lower tendency to age compared to the base bitumen, which can be explained by the higher percentage of change of asphaltene in the base bitumen compared to the rejuvenated bitumen [11].

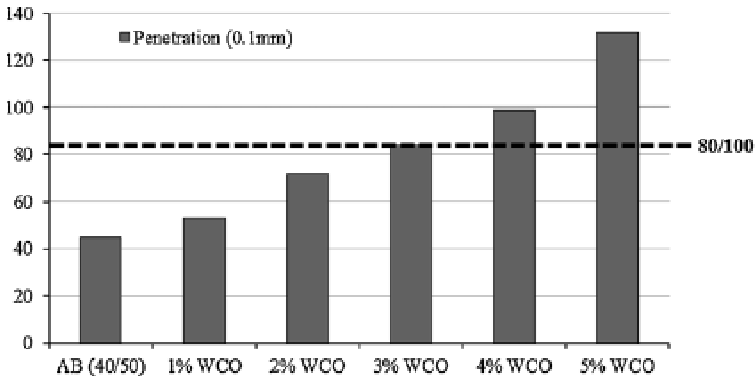

Figure 5. The amount of penetration of bitumen containing rejuvenating based on the research of Zargar, et al. [11]

In a study by Zaumanis et al., The effect of six rejuvenators on coaxial cutting experiment on the fatigue behavior of asphalt mixtures was investigated. Six additives including waste vegetable oil, waste vegetable grease, organic oil, industrial wood oil, aromatic extraction oil and waste engine oil, each with a weight percentage of 12%, were combined with recycled asphalt bitumen. By definition, the number of loading repetitions to achieve a 50% drop in initial hardness is expressed as a valid indicator for evaluating the fatigue behavior of asphalt mixtures. According to the test results in Figure 6, engine oil has the shortest failure cycle compared to other rejuvenating oils and therefore has the highest probability of fatigue failure. However, all samples showed longer fatigue life compared to the base mixture [12].

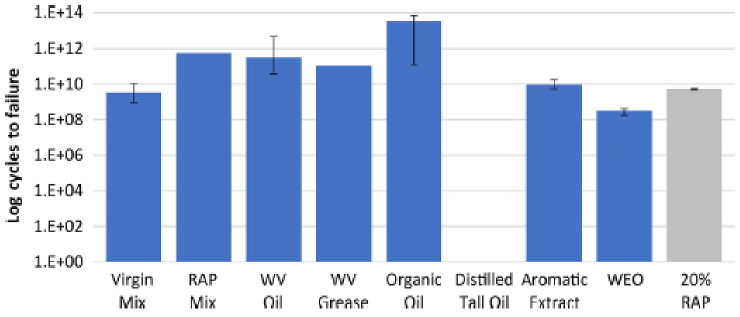

Figure 6. Number of cycles required for failure based on the research of the Zaumanis, et al. [12]

1.2. Conclusion and Expression of the Existing Vacuum in Previous Research

So far, much research has been done on the use of additives in the preparation of asphalt mixtures in order to increase their ability against loads. According to these studies, a number of these additives, according to the predictions, have shown good performance against loads, but so far no research has been done on adding natural microorganisms to bitumen and modifying it and evaluating the mechanical properties of the resulting asphalt mixture. And most of the current research in this field has only evaluated the performance of bitumen. Due to the unique characteristics of biosurfactants, it is expected that there will be significant differences in the behavior of the resulting asphalt mixtures with conventional asphalts. For this reason, in the present study, the mechanical behaviors of asphalt mixtures containing rhamnolipid biosurfactant additive with 2% and 4% by weight of bitumen have been evaluated.

2. Methods

In this work to identify of the critical zone with the most needs for the pavement, the GIS Ready maps have been prepared by using ArcGIS-ArcMap software based on the following procedure (Figure 5):

- Exchange of graphic information from CAD space to GIS space.
- Remove errors in CAD space.
- Convert graphic information from DWG format to SHP.
- Complete layers of descriptive and spatial information and fix errors in the GIS space (descriptive and spatial).
- Separated effects are snapped together with appropriate tolerance.
- Eliminate toll errors that are in the wrong place.
- Create primary and external keys for the map toll table.
- Create appropriate tolerance and exchange spaghetti space for topology space.
- Preparation of conceptual model for modeling in GIS space.
- Create a suitable terrestrial database of maps.
- Create the ability to track and perform map analysis.

In this research, after testing and examining the aggregates and bitumen used using the Marshall method, the optimal bitumen percentage of the mixtures was determined. Using this optimal percentage of bitumen, the necessary samples for preparation were prepared and evaluated according to the relevant standards. The following tests are performed on samples of asphalt mixes. The present project, in May 2022, was equipped with Remote Sensing (RS) facilities, sensors and a data logger system. The (RS) in with (IoT) for rapid data intercommunication was used. Then the project points were investigated. Modern technology through advanced sensors and modems was applied for the detection of this asphalt mixtures data.

2.1. Calibration of the Apparatus

Calibration of the apparatus includes the instruments done by (RS) facilities equipped with modems and data loggers. The sensors were employed in the experiments. According to the measurement principle and instructions, the physical quantities detected by the sensors were linearly related to the output and the signals were calibrated in a steady state. The apparatus was calibrated before it leaves the factory; therefore, we needed only to check that the data was consistent with the stored value in laboratory tests to ensure the correctness of transmission. The sensors were calibrated by using a gauge, and a check also needs to be performed to ensure that the sensors are consistent with the stored value in laboratory tests.

2.2. True Specific Gravity of Crushed Asphalt Mixture (1)

The actual specific gravity of Marshall Samples was determined according to ASTM-D2726 standard and used in the mixed design. By definition, the actual specific gravity of asphalt samples is equal to the actual weight of the sample in air. This parameter is determined to calculate the percentage of empty space of the compacted mixture and the percentage of empty space between the aggregates of dense mixtures, which are two important factors in the design of the mixture and the determination of the optimal bitumen [13].

$$G_{mb} = \frac{W_a}{W_a - W_w} \tag{1}$$

where in:

G_{mb}: True specific gravity of asphalt in grams per cubic centimeter,

W_a: sample weight in the air in grams,

W_w: sample weight in water in grams.

2.3. Specific Weight of Maximum Asphalt Mixture

The ASTM D-2041 standard, known as the theoretical maximum specific gravity of the Rice method, was used to calculate the maximum theoretical specific gravity of asphalt mixtures. According to this method, according to the maximum nominal size of stone materials, two kilograms of asphalt mixture is prepared. The mixture is then cooled to ambient temperature and placed in a special glass container under a vacuum pressure of 0.3 / 3.7 kPa for 2 to 15 minutes. This pressure causes air bubbles to escape from the mixture. Specific gravity is calculated by measuring the required values in Eq. (2):

$$G_{mm} = \frac{A}{A + B - E} \tag{2}$$

In this regard:

A: Weight of samples in air in grams,

B: weight of container and lid of glass filled with water 25 ° C in grams,

E: The weight of the container and the lid of the glass and the sample in terms of grams [14-16].

2.4. Percent of Effective Bitumen of Asphalt Mixture

The total amount of asphalt bitumen minus the amount of bitumen absorbed by the aggregate relative to the total mix is called the percentage of ineffective asphalt mixture. In other words, the effective percentage of bitumen in the asphalt mixture is the amount of bitumen that is used only for covering and coating stone materials and is obtained from Eq.3.

$$P_{be} = p_b - \frac{p_{ba}}{100} p_s \tag{3}$$

In this regard:

Ps: Percentage of rock materials to the total weight of asphalt mix,

P_{ba}: Percentage of bitumen adsorption of stone materials in relation to the weight of stone materials [17, 18].

2.5. 3% of Bitumen Absorbed

The amount of bitumen that is absorbed by a part of the porosity of stone materials is called the adsorbed bitumen and is calculated from Eq. (4).

$$p_{ba} = 100 \times \frac{G_{se} - G_{sb}}{G_{se} \times G_{sb}} \times G_b \tag{4}$$

2.6. Determining the Percentage of Empty Space in the Crushed Mixture (5)

To calculate this parameter, which determines the optimal bitumen in asphalt mixtures, the following equation is used:

$$Va = 100 \times \frac{(G_{mm} - G_{mb})}{G_{mm}} \tag{5}$$

In this regard:

Va: Percentage of empty space of condensed mixture,

G_{mm}: Theoretical maximum specific weight in grams per cubic centimeter,

G_{mb}: The actual specific gravity of the condensed mixture in grams per cubic centimeter [19].

2.7. Determining the Percentage of Empty Space of Stone Materials

This parameter is a control parameter of the optimal bitumen percentage for asphalt mixtures, which according to the regulations should not be more than 17% for asphalt mixtures with a maximum size of 12.5 mm. This parameter is calculated from the following q. (6):

$$VMA = 100 - \frac{G_{mb} \times p_s}{G_{sb}} \tag{6}$$

where in:

VMA: Percentage of empty space between rock materials,

Gsb: specific gravity of stone grains in grams per cubic centimeter,

Ps: Percentage of aggregates relative to the total weight of the mixture [20-24].

2.8. Percent of Empty Space of Filled Stone Materials

The percentage of empty space of stone materials filled with bitumen is a part of the empty space between stone materials that is filled with bitumen (this quantity does not include bitumen absorbed by stone materials) and is expressed in terms of volume percentage relative to the empty volume of empty space of stone materials. Eq. (7) was calculated.

$$VFA = \frac{100(VMA - Va)}{VMA} \quad (7)$$

3. Results and Discussion

Roads are the national assets of any country that provide communication possibilities among different points, essentially. Furthermore, the cost of road construction has increased over time, hence, its maintenance or preservation is a critical job that can benefit society as a whole. Thus, researchers have conducted extensive tests to distinguish the causes of failure and maintenance methods, which can be used to achieve further benefits from this national treasure. Considering that most of the main roads in Iran are paved by hot mix asphalt, studies about the properties of asphalt mixtures have significant importance. Previous research showed that the use of different oils in bitumen improves the mechanical function of asphalt, likewise, improving the properties of bitumen binder. Along with previous research, in this study, using different percentages of Rhamnolipid Biosurfactant (0, 2 and 4 ratios to the bitumen weight) as bitumen modifiers, the properties of bitumen as well as hot mix asphalt have been investigated. Flashpoint, dynamic shear rheometer, bending beam rheometer and rotational viscosity tests were carried out on modified bitumen samples (Figure 7).

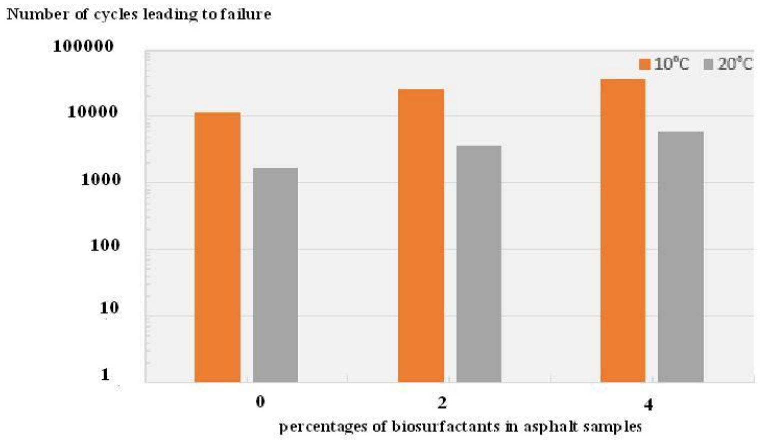

Figure 7. Results related to the number of cycles leading to failure of asphalt samples containing biosurfactants

3.1. Comparison with Other Research.

The effect of six rejuvenators on the fatigue behavior of asphalt mixtures was investigated [25]. Six additives including waste vegetable oil, waste vegetable grease, organic oil, industrial wood oil, aromatic extraction oil and waste engine oil, each with a weight percentage of 12% were combined. Engine oil has the shortest failure cycle and therefore the worst fatigue behavior compared to other rejuvenating oils and therefore has the highest probability of fatigue failure. However, all samples showed longer fatigue life than the base mixture. Fatigue performance improvement for all samples was between 5 and 38%. Organic oil-modified bitumens have the best performance compared to other modified bitumens. Containing 4% rhamnolipid biosurfactant increased by 213%. This indicates the excellent performance of bitumen modified with rhamnolipid biosurfactant against fatigue of asphalt mixtures. However, all samples showed longer fatigue life than the base mixture. Fatigue performance improvement for all samples was between 5 and 38%. Organic oil-modified bitumens have the best performance compared to other modified bitumens. Containing 4% rhamnolipid biosurfactant increased by 213%. This indicates the excellent performance of bitumen modified with rhamnolipid biosurfactant against fatigue of asphalt mixtures. Comparing the results of this study with the results of previous studies, it can be concluded that samples containing rhamnolipid biosurfactant had a better behavior against fatigue compared to samples made with bitumen modified with other oils.

4. Conclusion

The results of this work illustrated that adding more Rhamnolipid Biosurfactants improves the mechanical properties of the asphalt mixture. In the Marshall stability and flow evaluation, the results showed that adding more Rhamnolipid Biosurfactant can bring more stability and less flow value. This fact indicates that the modified samples were more resistant to shear stress. Also, the results of resilience modulus tests, deformation as well fatigue tests showed that Rhamnolipid Biosurfactant was able to improve the properties of asphalt mixtures in all situations.

Suggestions for future research

This work led to raising the following suggestion for improvement of modeling for evaluation of (RAP) containing Rhamnolipid Biosurfactant:

- Make the connection between (GIS), (RS), and (IoT) for rapid data intercommunication to zoning the (RAP) in a little time up to one second.
- Conceptual modeling for prediction of the mechanical behavior due to (RAP).
- Improvement of (RS) facilities equipped with data loggers, (IoT), and GEO-database intercommunication process.
- Evaluate the effect of Biosurfactant on moisture sensitivity of hot asphalt samples.
- Evaluate the use of calcareous stone materials and compare it with siliceous stone materials.
- Performing cost-benefit analysis of using Biosurfactants in asphalt pavements for industrial-scale application.
- For future works, researchers can utilize other methods such as Genetic program (GP) [26], multivariate regression (MVR) [27], and group method of data handling (GMDH) [28] to reduce the fatigue damage and thermal cracks.

Conflict of Interest Statement

The authors declare no conflict of interest.

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