Examination of the Possibility of Using Gilsonite in Hot Mix Asphalt Concrete

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ABSTRACT

In hot mix asphalt concrete, bitumen is used as the adhesive and this material has a significant effect on the performance of mix asphalt. In order to improve the performance of the adhesive (bitumen), modifiers (additives) are used. In this study, gilsonite, as a part of bitumen and modifier, has been studied in order to improve the performance of mix asphalt. In this research, a nominal maximum size of 12.5 mm was chosen for the materials. In the first stage, in order to determine the optimum content for each component, three Marshall samples were produced and underwent Marshall tests. According to the Marshall test results, 5.9% was determined as the optimum bitumen content. In the second stage, samples from the optimum bitumen which were part of the gilsonite bitumen were produced and according to the test results, the sample containing 15% of gilsonite had the best performance. In the third stage, samples containing 0.5% more and 0.5% less amount of bitumen compared to the optimum bitumen content and 0%, 6%, 9%, 12%, 15% and 18% of gilsonite were produced and underwent the traditional Marshall and ultrasonic tests, where it was determined that the best performance belonged to the sample with 6.4% of bitumen and 15% of gilsonite. Also, in order to study the rutting of the mix asphalt containing gilsonite, samples with 0%, 6%, 12% and 18% gilsonite were produced and underwent dynamic creep test. The results showed that samples containing 12% and 18% of gilsonite had the least cumulative permanent strain and the highest stiffness modulus at 37.8°C and 54.4°C, respectively.

KEYWORDS: Hot mix asphalt, Optimum bitumen, Gilsonite, Dynamic creep, Marshall test.

INTRODUCTION

Hot mix asphalt concrete is a mixture of gravel, sand, filler and bitumen. Aggregates, as the asphalt-bitumen mixture's frame structure, act as adhesives. A large part of hot mix asphalt concrete, almost 90%, consists of aggregates. Although there's a low content of bitumen in the mix asphalt, it has a significant effect on the desired performance, durability and resistance as the adhesive in asphalt. Any changes in the amount of bitumen directly affect the performance of asphalt. Asphalt is the most common material used for paving, because it provides convenience, peace and durability and is resistant against water. Roads and highways are structures with high manufacturing cost, so they should be designed so that they won't get destroyed over the course of their service time. In their recent studies, researchers have been using different types of modifiers in order to increase asphalt's durability avoiding its destruction over the course of its service time. In this research, gilsonite is used as part of the adhesive (bitumen).

Gilsonite is a bright black asphalt which could be easily crushed and powdered. It will increase the bitumen's viscosity and reduce its penetration grade.

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Studies on gilsonite show that it would improve the bitumen's performance at higher temperatures while causing cracks on asphalt and its friability at lower temperatures. Rutting is one of the most important factors in asphalt pavements' demolition and destruction. These destructions have major sources, one of which is related to the structure and another to mix asphalt's strength and stability against shear deformation.

Evaluation of resistance against rutting using tests like creep test is performed on asphalt samples. Because superpave's traditional instructions aren't enough to determine the modified bitumen's properties, alternative tests, like static and dynamic creep tests, are performed in order to demonstrate the real performance of bitumen modifier. Researchers have mostly used gilsonite and bitumen mixture to study the rheological properties of asphalt.

Bahia et al. (2001) introduced gilsonite as bitumen's modifier in order to improve mix asphalt's performance. Also, Aflaki et al. (2009) used gilsonite as the modifier in sharp evaluation protocol. Kök et al. (2011) used gilsonite and styrene-butadiene-styrene mixture as additives to study bitumen's properties. The amounts of these two additives are chosen to be 4-14% and 2-5%, respectively, depending on bitumen's quantity. The research results showed that the amount of $\frac{G^*}{\mathrm{Sin}(\delta)}$ increases with increasing the amount of gilsonite and styrene-butadiene-styrene, but the rate of this increase in styrene-butadiene-styrene is more than in gilsonite. Also, at higher temperatures, especially at 58-64°C, improvement and increase of $\frac{G^*}{\mathrm{Sin}(\delta)}$ rate are so high and adding gilsonite to the bitumen will increase the bitumen's viscosity.

Ameri et al. (2011) used gilsonite to study the rheological properties of bitumen. The amount of gilsonite used in this research was determined as 4-14%. Research results showed that as temperature increases, the amount of gilsonite has a direct effect on $\frac{G^*}{\mathrm{Sin}(\delta)}$, so that at high temperatures, especially 76-82 °C, the amount of $\frac{G^*}{\mathrm{Sin}(\delta)}$ available in gilsonite is 12% higher than in other situations. Counterwise, at low temperatures, the opposite happens.

Nihat (2013) used different contents of basalt yarn in bitumen to conduct a feasibility study on the usage of yarn in mix asphalt. Marshall and ultrasonic test results showed that mix asphalt with basalt yarn in bitumen is of good feasibility.

Given that gilsonite's performance isn't yet studied while calculating mix asphalt's resistance against rutting and most research studies have been conducted on rheological properties of bitumen, in this research, in order to further study the effect of gilsonite on mix asphalt's performance, in addition to Marshall tests, dynamic creep tests have been used as a criterion to evaluate the rutting of mix asphalt.

MATERIALS

Aggregates

Aggregates used in this research are made of lime. The results of tests conducted on the materials in order to determine the physical and mechanical properties are listed in Table (1). The amounts of coarse aggregate (2.36-19 mm), fine aggregate (0.075-2.36 mm) and fillers (less than 0.075mm) are 63%, 32% and 5%, respectively.

Table 1. Specific gravities of aggregates (gr/cm^3)

Size fraction	Standard	Apparent specific gravity	Bulk specific gravity
Coarse aggregate (12.5-2.36 mm)	ASTM C 127	2713	2562
Fine aggregate (2.36- 0.075 mm)	ASTM C 128	2681	2348
Filler (<0.075 mm)	ASTM C 188	2360	2360
Specific gravity of aggregate blend			2479

The way the aggregates are distributed on the pavement layer is determined according to the ASTM D 3515 standard and the material grading curves are shown in Figure (1).

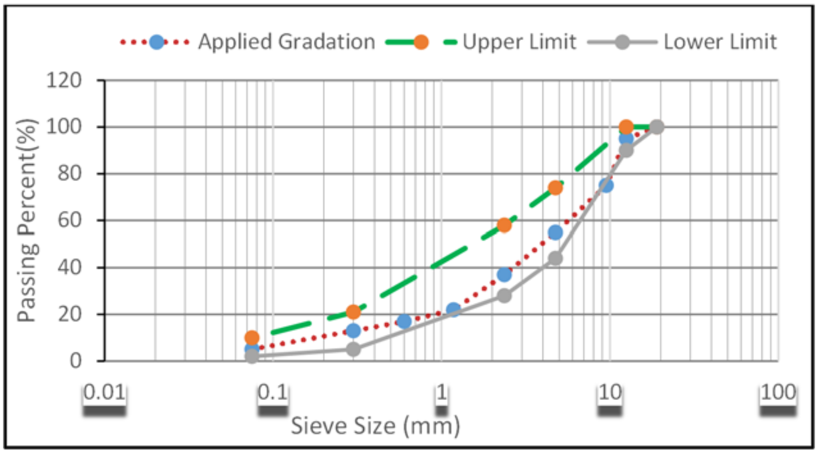


Figure (1): Gradation curves

Bitumen

The bitumen used in this research is of the AC 85/100 type and its properties are listed in Table (2).

Gilsonite

Gilsonite is a natural resinous hydrocarbon which is used in this research. Generally, if bitumen reaches ground surface through cracks and fractures, it will form a natural bitumen lake and if it stays as a closed mass near the surface, it will gradually solidify, oxidize and transform to a hard solid substance called gilsonite. The gilsonite used in this research is provided by Sormak corporation (Iran) and its properties are listed in Table (3). In this research, after considering different gilsonite and bitumen mixing methods by researchers, a four-blade agitator with the rotational speed of 1000 RPM was used at 180°C for 60 minutes to mix gilsonite and bitumen.

Table 2. Results of tests performed on asphalt cement (AC 85/100)

Test name	Average value	Standard
Penetration, 25°C, 100 g, 5 s (1/10mm)	89	ASTM D5
Softening point (°C)	47	ASTM D36
Specific gravity (25°C, kN/m^3)	1030	ASTM D70
Flash point (°C)	232	ASTM D92
Ductility, 25 °C, 5 cm/min	+100	ASTM D113
Loss on heating (wt)%	0.5 max	ASTM D6

Table 3. Physical properties of gilsonite

No.	Test	Result	Test method
1	Ash content wt.%	10 - 15	ASTM-D3174
2	Moisture content wt.%	≤3	ASTM-D3173
3	Volatile matter wt.%	50	ASTM-D3175
4	Fixed carbon wt.%	28	ASTM-D3172
5	Solubility in CS2 wt.%	65 - 75	ASTM-D4
6	Specific gravity @ 25 ºC	1.02	ASTM-D3289
7	Color in mass	Black	--------
8	Color in streak or powder	brown	--------
9	Softening point ºC	175 - 195	ASTM-D36
10	Penetration @ 25 ºC, 10 -1 mm	0	ASTM-D5
11	Solubility in trichloroethylene	62 - 72	ASTM-D2042

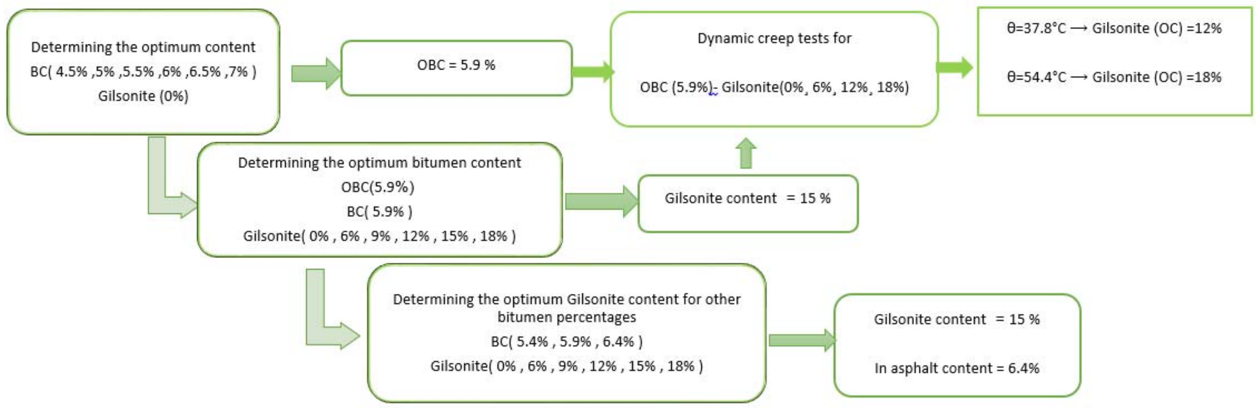
Conducting the Tests

Marshall test in accordance with ASTM D 1559 standard was used to evaluate, compare and determine the optimum contents of bitumen and gilsonite. Also, dynamic creep and ultrasonic tests were conducted to evaluate the rutting of the produced samples and the wave speed, respectively.

Presenting the Mix Design (Marshall Test)

Marshall method is an experimental mix design method. Experimental methods are based on choosing the content of bitumen according to several variables while considering conventional ranges which are based on the experimental setting. The criteria for choosing the optimum bitumen content (OBC) are different among different institutes. Choosing the optimum bitumen content in this research was calculated by averaging the resulting bitumen contents regarding the maximum bulk specific gravity, maximum Marshall stability, bitumen content corresponding to 4% of air voids and voids filled with asphalt content corresponding to 70%. In this research, the Marshall samples were produced according to the ASTM D 1559 standard and for compressing the samples using the Marshall hammer, 75 strokes were applied on each sample side. The granulated materials were kept in 160-170 ˚C oven temperature to dry and the required bitumen for producing the samples is being heated to 145 ˚C before the mixing process.

The test procedure in this research as well as the test results are shown in the following diagram.



Ultrasonic Test

The ultrasonic test, or sonic wave speed determination test, is used to evaluate the quality of mix asphalt. In this test, an acoustic wave *via* an energy probe enters the sample from one side and is received by another probe on the other side. So, the time for the wave to pass through the sample is determined and having the sample's thickness, the wave speed could be calculated by dividing thickness by time (m/s). According to Equation (1), this wave speed is directly proportional to the modulus of elasticity of asphalt.

$$V = \sqrt{\frac{E}{\rho} * \frac{1-\mu}{(1+\mu)(1-2\mu)}} \tag{1}$$

$V\left(\frac{m}{s}\right)$: *wave speed*

$E\left(\frac{N}{m^2}\right)$: modulus of elasticity

$\rho\left(\frac{N}{m^3}\right)$: density

μ: *Poisson's ratio*

After considering 0.35 as Poisson's ratio for asphalt, we'll have:

$$E = 0.623 * \rho * V^2$$

Depending on the asphalt sample's quality, some of the energy will be wasted while passing through the sample and the remaining energy will be received by the receiving probe. Damirboga et al. (2004) conducted this test on concrete and classified the concrete's quality according to wave speed. Speeds of 4500 m/s or more were considered as very great, between 3600 and 4000 m/s as great, between 3000 and 3600 m/s as good, between 2000 and 3000 m/s as medium and speeds less than 2000 m/s were considered as weak. This test was performed based on the ASTM C 597 standard.

Dynamic Creep Test

In this study, the dynamic creep test was conducted by the universal testing machine (UTM), in order to apply repetitive axial stress on the asphalt sample and measure the vertical deformation using a linear variable differential transformer (LVDT). The input data included the sample's dimensions (diameter and height), preload tension, stress frequency and contact stress magnitude which will be controlled by the device's software. In this research, a preload stress of 10kPa, an applied stress of 100kPa, a pulse of applying the stress as 1 second of loading and 1 second of unloading, with a number of loading cycles of 3600 and test temperatures of 37.8 and 54.4 °C were applied and the test was conducted according to the Nottingham asphalt test and EN 2-12697.

One of the most important goals of the dynamic creep test is studying the performance of mix asphalt against rutting and the most important obtained parameter from this test is the cumulative permanent strain, which somehow depends on the rutting resistance of asphalt. So, in this study, this test has been used to compare different types of asphalt samples. The dynamic creep test has several outputs, which can be used for estimating the permanent deformation potential in the mixture. In this research, the cumulative permanent strain's output has been used as one of the important parameters to compare different mixtures. Also, other important parameters, like stiffness modulus, creep rate and modulus of elasticity, have been used in this research.

Presentation and Analysis of Results

Marshall Test Results

In the first stage, asphalt samples were produced with different bitumen contents according to the ASTM D 1559 standard, in order to determine the optimum bitumen content. Asphalt samples' bitumen contents were 4.5, 5, 5.5, 6, 6.5 and 7 % and three Marshall samples were produced from each bitumen content. 18 samples were produced in total and underwent Marshall tests. The results regarding bulk specific gravity (ASTM D 2726) are listed in Figure 2. By investigating the performance of the samples under compressive load, all the samples underwent Marshall stability test as shown in Figure 2 and the results regarding the samples' flow are shown in Figure 3. To obtain the air voids, voids filled with asphalt and voids in mineral aggregate content, theoretical maximum specific gravity determination test was conducted on all samples according to the ASTM D 2041 standard and the obtained results are shown in Figures 2 and 3, respectively.

Using the parameters' results such as bulk specific gravity, Marshall stability, air void and voids filled with asphalt content according to Marshall ASTM D 1559 standard, optimum bitumen content and voids in mineral aggregate (VMA) were controlled according to the standard. The optimum bitumen content was calculated according to the average of the bitumen content regarding the maximum bulk specific gravity, the maximum Marshall stability, the bitumen content corresponding to 4% of air voids and voids filled with asphalt corresponding to 70%:

$$\text{Optimum Bitumen Content} = \frac{6.7 + 5.6 + 5.6 + 5.7}{4} = 5.9\%$$

The amount of flow for the optimum bitumen content will be obtained at 3.39mm (Figure 3), which is within the standard range of 2-3.5mm and is thus acceptable.

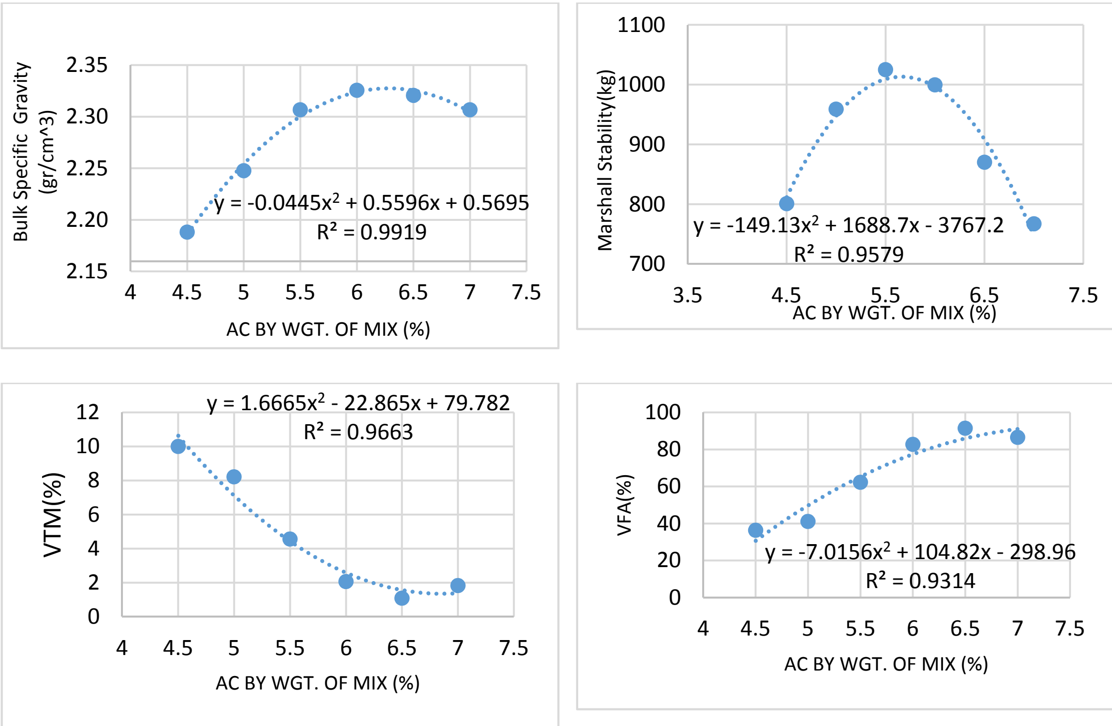


Figure (2): a) Bulk specific gravity (b) Marshall stability (c) Air voids and (d) Voids filled with asphalt

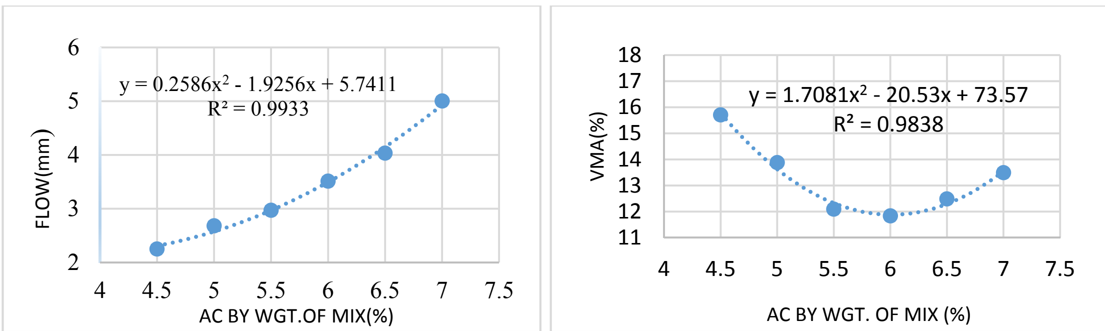


Figure (3): Relationship between flow and voids in mineral aggregate with bitumen content of mixtures

According to the optimum bitumen content obtained from Marshall test (5.9%), bitumen-gilsonite mixtures with 0%, 6%, 12%, 15% and 18% bitumen weight-percents and 3 mix asphalt samples were produced from each of these samples. The sample without gilsonite (0%) was used to control the results. Marshall stability test results are shown in Figure 4. According to the Figure, the samples' Marshall stability increases as the gilsonite content increases. According to the samples not containing gilsonite, it could be concluded that the gilsonite content of 15% has the greatest effect on the samples' Marshall stability.

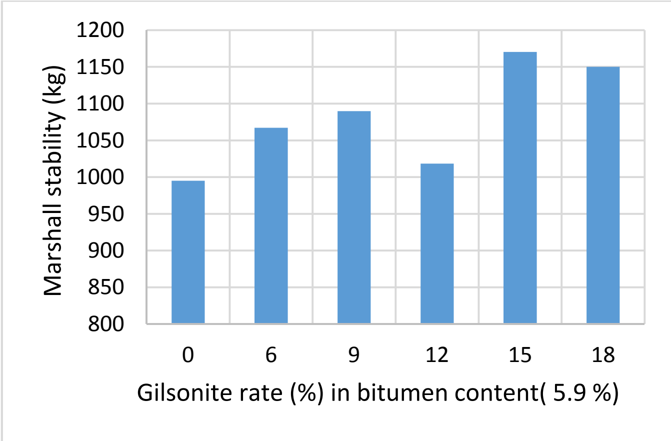


Figure (4): Change in Marshall stability values for optimum bitumen content and different gilsonite rates

To better and more precisely control the optimum gilsonite content, asphalt samples with gilsonite contents of 6%, 9%, 12% and 18% and two more bitumen contents, 0.5% more and 0.5% less than the optimum bitumen content (5.4% and 6.4%), were produced. Marshall test results for these samples are shown in Figures 5-10.

Investigating Figures 5 and 6 shows that the Marshall stability increases by increasing the gilsonite content and the highest Marshall stability has occurred at bitumen and gilsonite contents of 6.4% and 12%, respectively. Generally, increasing the gilsonite content will reduce the asphalt's bulk specific gravity. Also, investigating Figures 7 and 8 shows that for almost all gilsonite contents, except for 9%, increasing gilsonite content will increase air void content as well and this could be one of the reasons for asphalt's bulk specific gravity reduction. Also, increasing gilsonite content results in an approximately downward trend in voids filled with asphalt's content. To suggest the best performance of the gilsonite content in bitumen, according to the Marshall test due to ASTM D 1559 standard, if we consider 4% air content as the controlling criterion for the optimum gilsonite content, the best performance occurs at bitumen and gilsonite contents of 6.4% and 15%, respectively.

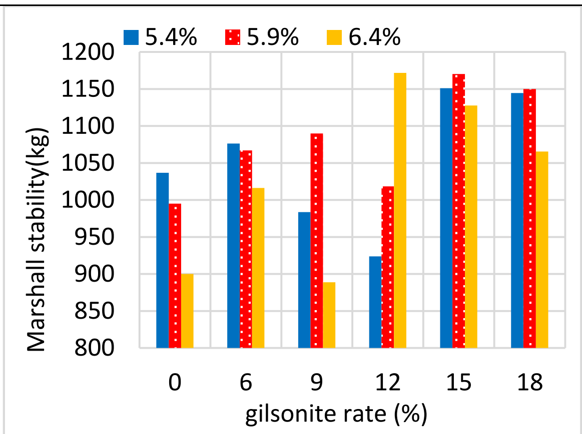


Figure (5): Change in Marshall stability for different bitumen amounts and for certain gilsonite rates

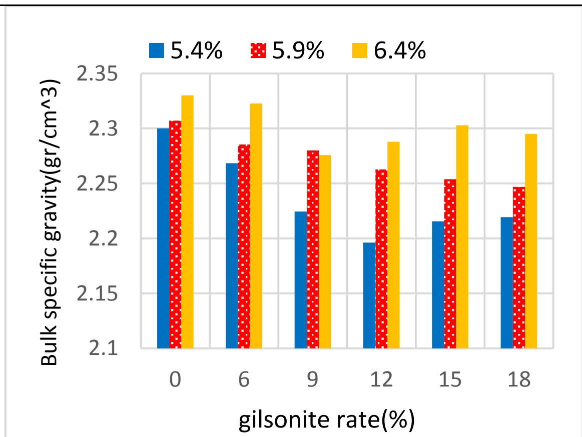


Figure (6): Change in bulk specific gravity for different bitumen amounts and for certain gilsonite rates

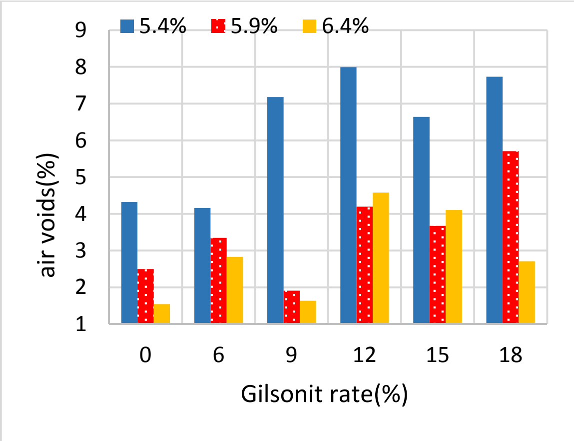


Figure (7): Change in air voids for different bitumen amounts and for certain gilsonite rates

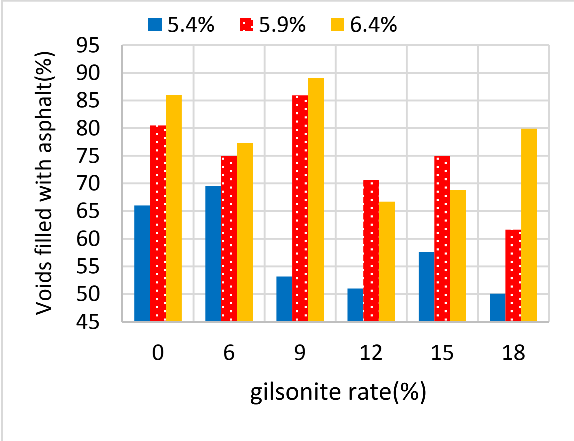


Figure (8): Change in voids filled with asphalt for different bitumen amounts and for certain gilsonite rates

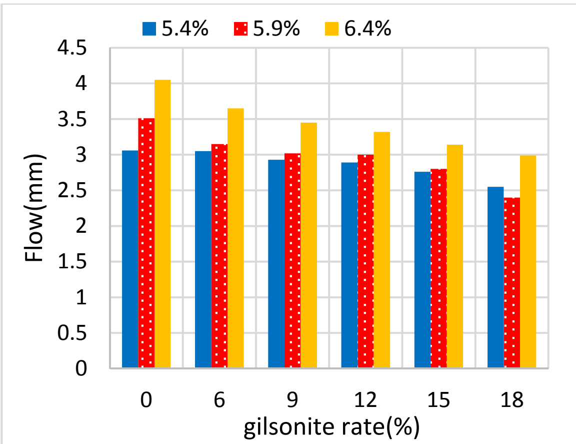


Figure (9): Change in flow for different bitumen amounts and for certain gilsonite rates

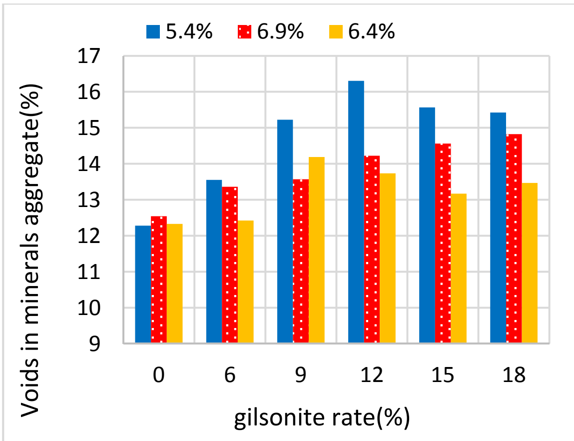


Figure (10): Change in voids in mineral aggregate for different bitumen amounts and for certain gilsonite rates

Ultrasonic Test Results

Wave speed and dynamic modulus of elasticity for each sample are shown in Figures 11 and 12. According to the Figures, the highest wave speed resulted from 6.4% bitumen and 15% gilsonite contents. Given that these contents also had the best performance in the Marshall test, the ultrasonic test also confirms that higher wave speeds result in higher asphalt sample quality. Also, we have a higher modulus of elasticity when the bitumen and gilsonite contents are 6.4% and 15%, respectively. If we consider the results from Toopchi et al. asphalt samples with a bitumen content of 6.4%, a gilsonite content of 15% and a wave speed of 3750 m/s, we will have a great quality.

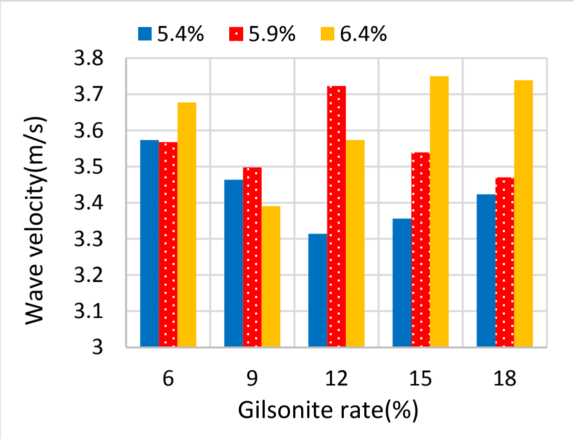


Figure (11): Change in wave velocity for different bitumen amounts and for certain gilsonite rates

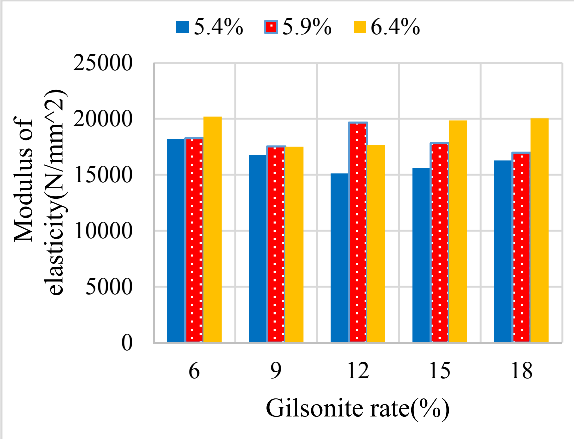


Figure (12): Change in modulus of elasticity for different bitumen amounts and for certain gilsonite rates

Dynamic Creep Tests Results

The dynamic creep test results for the optimum bitumen content and gilsonite contents of 0%, 6%, 12% and 18% at 37.8 °C and 54.4 °C are shown in Figures 13-20. The most important parameters investigated in this test are rutting evaluation, cumulative permanent strain, creep rate, modulus of elasticity and stiffness modulus. Investigating Figures 13-16 shows that at 37.8 °C, increasing gilsonite content will reduce the creep rate and the samples not containing gilsonite have the highest creep rate. Also, gilsonite will reduce the cumulative permanent strain. The lowest cumulative permanent strain occurred at the gilsonite content of 12%. Investigating Figures 13-16 shows that the sample containing 0% gilsonite has the highest modulus of elasticity and the lowest stiffness modulus. The reason is the increase of asphalt's stiffness modulus along with the increase of gilsonite content. Studyig the results shows that at 37.8 °C, the highest stiffness modulus and the lowest cumulative permanent strain belong to the mix asphalt sample containing 12% gilsonite.

In Figures 17-20, regarding the dynamic creep test at 54.4 °C, it can be seen that the highest creep rate, modulus of elasticity and cumulative permanent strain and the lowest stiffness modulus belong to the sample containing 0% gilsonite and the lowest creep rate, modulus of elasticity and cumulative permanent strain and the highest stiffness modulus belong to the mix asphalt sample containing 18% gilsonite. It can also be seen that at higher temperatures, the mix asphalt with more gilsonite content has a better performance and gilsonite will increase the stiffness modulus and therefore reduce the cumulative permanent strain.

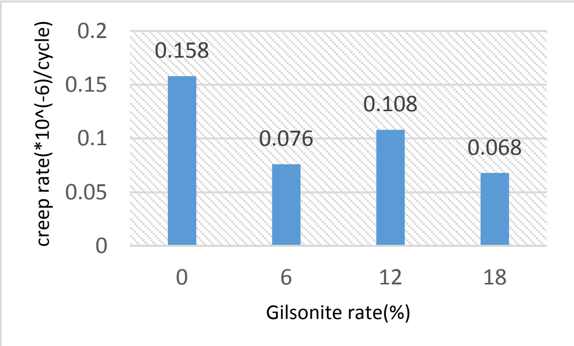


Figure (13): Change in creep rate for optimum bitumen amounts and for certain gilsonite rates at θ= 37.8°C

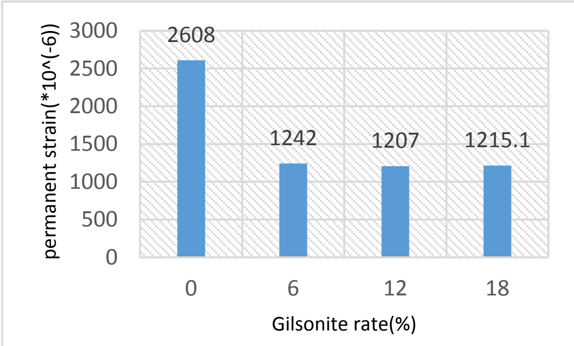


Figure (14): Change in permanent strain for optimum bitumen amounts and for certain gilsonite rates at θ= 37.8°C

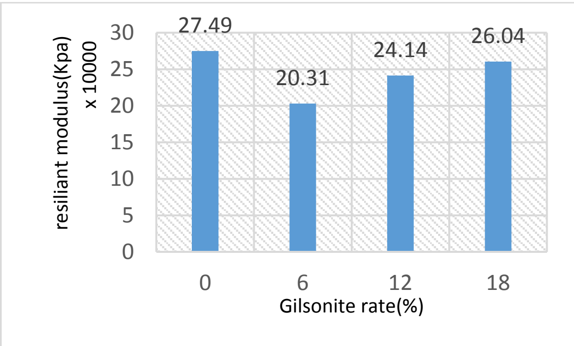


Figure (15): Change in resilient modulus for optimum bitumen amounts and for certain gilsonite rates at θ= 37.8°C

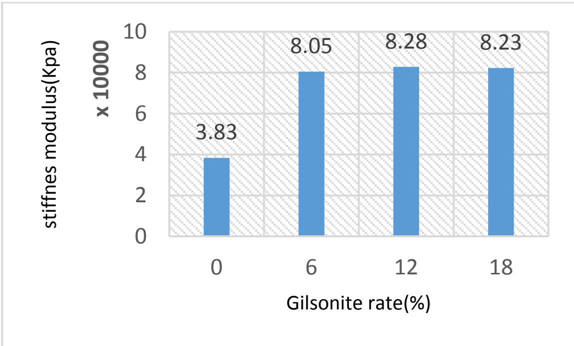


Figure (16): Change in stiffness modulus for optimum bitumen amounts and for certain gilsonite rates at θ= 37.8°C

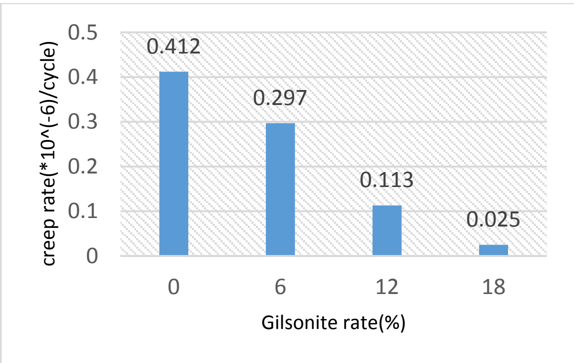


Figure (17): Change in creep rate for optimum bitumen amounts and for certain gilsonite rates at θ = 54.4°C

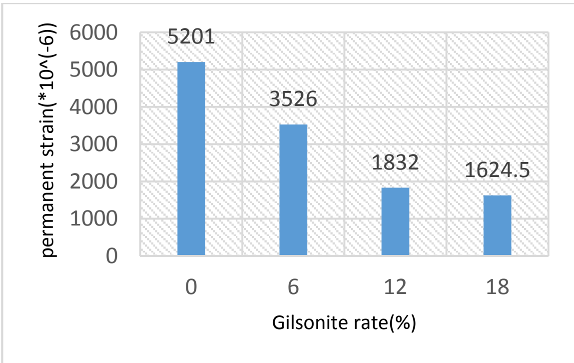


Figure (18): Change in permanent strain for optimum bitumen amounts and for certain gilsonite rates at θ= 54.4°C

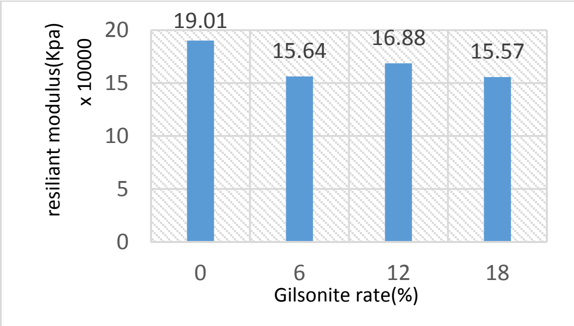


Figure (19): Change in resilient modulus for optimum bitumen amounts and for certain gilsonite rates at θ= 54.4°C

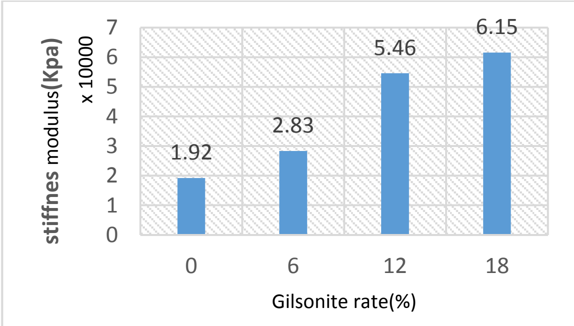


Figure (20): Change in stiffness modulus for optimum bitumen amounts and for certain gilsonite rates at θ= 54.4°C

CONCLUSION

As the research results show, the optimum gilsonite content for materials with nominal maximum size of 12.5mm and optimum bitumen content, is 15 weight percent of bitumen. Also, at 0.5% higher and 0.5% lower than the optimum bitumen content, the optimum gilsonite content remains at 15%.

Increasing the gilsonite content leads to increase the air voids and decrease the bulk specific gravity of asphalt mixes.

Increasing the gilsonite content will increase the speed of the wave passing through the asphalt sample and qualitywise, the sample with 15% gilsonite and 6.4% bitumen has the highest wave speed.

The dynamic creep test results show that at 37.8 °C, the highest stiffness modulus and the lowest cumulative permanent strain belong to the mix asphalt sample with 12% gilsonite and at 54.4 °C they belong to the mix asphalt sample with 18% gilsonite.

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