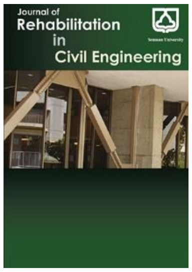
Journal of Rehabilitation in Civil Engineering 8-1 (2020) 133-148

Journal homepage: http://civiljournal.semnan.ac.ir/



Investigating the Effect of AC Overlays Reinforced with Geogrid and Modified by Sasobit on Rehabilitation of Reflective Cracking

Gh. Shafabakhsh[1*]**and S. Asadi**[2]
1. Professor, Faculty of Civil Engineering, Semnan University, Semnan, I. R. Iran
2. Ph.D. Student, Faculty of Civil Engineering, Semnan University, Semnan, I. R. Iran

Corresponding author: *ghshafabakhsh@semnan.ac.ir*

ARTICLE INFO

Article history:
Received: 13 April 2019
Accepted: 26 September 2019

Keywords:
Reflective Cracking,
Asphalt Overlay,
Geogrid,
Sasobit,
Loading Frequency,
Crack Propagation,
Sand Asphalt,
Combination Sample,
Improvement Index.

ABSTRACT

In this paper, the effect of asphalt overlays, which were reinforced with geogrid, modified by sasobit and combination of them on the rehabilitation of reflective cracking, is studied. The laboratory tests were conducted under dynamic loading in bending mode to investigate reflective cracking retardation compared to reference samples. The results illustrated that in a certain range of variables, temperature variations, and sasobit percentages are the most effective parameters on fatigue life and other responses. Another effective variable was the type of interlayer in asphalt slabs. Furthermore, it has been found that the combination of samples (modified by sasobit, reinforced with geogrid and a 3cm sand asphalt layer) (1SP.G.SA & 2SP.G.SA) had a better performance such as improving fatigue life and reducing crack propagation in all loading and temperature conditions compared to the reference samples. Based on the image processing results, the process and shape of crack growth vary greatly at different temperatures. Generally, at low temperatures (20 °C) and frequencies, the cracks grow from bottom to top, and the width of them gets smaller. However, with increasing the temperature and loading frequency, the top-down cracks are also observed, which is due to the reduced resistance of the asphalt resulting from the reduction of adhesion and the fastening between the aggregate and bitumen.

1. Introduction

One of the most important pavement distress is the premature reflective cracking in the asphalt overlays. The movement of the pavement caused by traffic loads, the expansion and contraction of the underlying layers caused by temperature changes, or the

DOI: 10.22075/JRCE.2019.17585.1336

combinations of such phenomena generate tensile, and shear stresses in the new overlay. When these stresses and strains exceed the tensile shear strength of the asphalt pavement, cracking extends in the new overlay. This crack propagation pattern from the underlying and old pavement to the new overlay is called reflective cracking.

Various methods have been applied to control the reflective cracks, but none of them has been successful and just retarded this type of cracks in pavements. One of the newest and the best methods is the use of geosynthetic products or the use of modified overlays with polymer additives and waxes [1].

So far, in many laboratory and field researches, the effect of geogrids has been investigatedon reflective cracking retardation in hot mix asphalt (HMA); however, similar studies have not been carried out on warm mix asphalt (WAM)[2]. In recent years, with the rise in fuel prices and environmental concerns, the tendency of the pavement industry to the use of warm-mix asphalt has increased. Adding some additives such as sasobit, asphaltene A and asphaltene B reduces the mixing temperature by 2 to 30°C with reducing the viscosity. Reducing and compacting asphalt mixtures at lower temperatures, reducing the polluting gas emission, and reducing fuel consumption are some of the important advantages of warm mix asphalt [3,4].

Consequently, the purpose of this study is to evaluate and compare the performance of the hot mix asphalt and warm mix asphalt in expanding reflective cracking. The research is conducted in different conditions such as reinforced or unreinforced with geogrid, modified, or unmodified by synthetic polymer additives.

Although the effect of geogrid and additives on the crack growth retardation in the hot mix asphalt (HMA) has been investigated, the same study on warm mix asphalt has not considered the variations in temperature and loading conditions. This study identifies a propagation trend for reflective cracking by testing asphalt slab samples with different additives and overlays under various dynamic loadings and temperatures in bending mode. Moreover, the index of fatigue growth rate and fatigue life in the asphalt overlay was modeled.

2. Literature Review

Fiping Xiao et al. (2009) evaluated the fatigue behavior of rubberized asphalt mixtures containing warm asphalt additives, including sasobit and asphamin. The fatigue test results showed that the mixtures modified by sasobit had longer fatigue life than the reference samples, but in mixtures containing asphamin, fatigue life was less than them [5,6].

Behroozikhah et al. (2017) reviewed the performance of modified asphalt mixtures with fracture mechanisms. The specimens containing sasobit and crumb rubber were tested by resilience modulus test, static creep, and indirect tensile strength test. The results showed that the use of recycled asphalt, sasobit, and crumb rubber simultaneously improves fatigue performance [7].

With regard to the fatigue phenomenon and its direct relation with the fracture mechanics, the expansion of the crack in the overlay can be expressed by three different mechanisms, i.e., tensile mode, shear mode, and torsion mode. In asphalt pavements, tensile and shear patterns are decisive in the failure of asphalt layers. In 1992, De Bondt revealed that placing the wheel near the cracks was effective in their growth. The shear mode, which leads to the distribution of complex shear stresses on the contact between the wheel and the road, was important for surface cracks [8]. However, according to Zahng et al., the predominance of ruptures in the upper layers is due to tensile or opening mode [9].

A lot of research has been carried out to reduce or retard the reflective cracking in the HMA overlays on flexible and rigid pavements. In the first report of pavement distress in early 1921, old cracks were found on the new asphalt overlay, which was major distress in the asphalt pavements. Root (1925) provided the same reports in concrete pavements in the US. In the early twentieth century, Emmons also used bitumen overlay as the first solution to control the cracks and to repair and maintain pavements. Since then, many studies have been proposed to control or retard reflective cracking in asphalt overlays [10].

In the 1970s, the US Air Force launched a National Laboratory Study on reducing asphalt reflective cracks. Based on experiments, in 1977, the organization accepted the use of polypropylene non-woven geosynthetics as an asphalt interlayer. Later on, research into this field was also madeatCaltransUniversity, which highlighted the positive effects of the use of non-woven geotextiles. In the 1970s, despite the reports on the positive impact of non-woven geotextiles in many studies, these materials did not prove to have the power to stop reflective cracks completely. In other words, these materials only retarded the growth of reflective cracking[11].

Based on a study by a group of researchers from the Delft University of technology, using the finite element method and CAPA3D software, the cracks propagation and its paths to the overlay was investigated [8].

Lytton et al. found that the use of geotextiles could reduce stress concentration and prevent the collapse of pavement sealing. Obviously, if the overlay does not reach enough density, the geotextile layer grasps the water in the underside of the layer, and water accumulation will accelerate the process of pavement failure, which will provide conditions for stripping [12].

According to a study conducted at Austin University in 1997, the performance of tensile absorption and sealing improved pavement function. When the thinner overlay was applied with the geotextile layer, it could provide a function similar to the thicker one without any geotextile. According to this report, the use of geotextiles could increase the efficiency of pavement to an equivalent level of use of 1 to 1.8 inches overlay[13].

The results of research in Pozan University by Pozaricki and Grabowski demonstrated the effect of geocomposites and geogrids on the reflective cracks propagation. In this study, the large size samples were removed from pavements and tested at a constant temperature under periodic loading conditions. The cracks growth was measured based on a reinforcement index, which was a function of loading cycles and energy absorption in the sample volume. The larger index meant more fatigue resistance. The results of this study showed that the energy absorption capacity of the reinforced samples by geogrid and geocomposite increased significantly compared to the unreinforced ones. As a result, the overlay reinforcement significantly increased the amount of crack resistances [14,15].

In 2002, Kim and Buttlar, using a three-dimensional numerical analysis, evaluated the numerical strength of the fibers in overlay reinforcement with ABAQUS software. In this study, in addition to the traffic load, the thermal loading effect was considered. Based on this model, firstly, the crack areas were removed, and then new asphaltic materials were deposited on the crack. Next, a geogrid fiberglass layer was placed between the top layer and the old pavement layer [16].

Fallah and Khodaei (2015) addressed the parameters affecting reflective cracking. The aim of this study was to evaluate the effects of stiffness and tensile strength of the geogrid, the type and amount of tack coat, the overlay thickness, the crack width, and the stiffness of the asphalt overlay on the reflective cracking growth. The results of this study showed that the stiffness of the cracked overlay was an important factor for increasing service life. Generally, the performance of the glass geogrids is more effective than the polyester in the asphalt overlay[17].

Fallah and Khodaei (2015) studied the most important parameters affecting on reflective crack retardation in a geogrid-reinforced overlay in the bending mode. The results showed that the modulus of cracked layers and overlays had the greatest effect on reducing the reflective cracking. Also, two models of fatigue life estimation were developed based on fatigue mode I and Paris law modification for fracture mechanics model in mode I. The predicted and measured fatigue coefficient was sufficient for both models [17].

Khodaei et al. (2009) examined the geosynthetic effects on reducing reflective cracking. Accordingly, 24 specimens were tested with various geogrid positions, pavement types, crack widths, and temperatures, and then crack propagation was measured under cyclic traffic loading. The results showed that the reinforced samples had a significant reduction in terms of cracking expansion. The geogrid placement in the lower one-third of the thickness of the overlay also provided maximum service life [18].

Zamara-Baraza et al. (2011) evaluated the durability of anti-reflective cracking systems containing the geosynthetic layer or geotextile. For this purpose, a dynamic traffic simulation experiment was designed. The stresses were applied to a double-sided sample representing the pavement structure. The results showed that the test process was sensitive to the type of interlayer system and determined the optimal thickness of the tack coat. It was also found that the geogrid has more resistance to the repetitive cyclic loading [19-21].

Gonzalez-Torre et al. (2015) developed a new laboratory method for evaluating the performance of geosynthetics in controlling the reflective cracking in pavements. In this study, a combined cyclic loading was applied in which two types of loading with different frequencies were used. The purpose of this experiment was to investigate the growth of cracks in asphalt mixtures and evaluate the effectiveness of geosynthetics as anti-reflective cracking systems. The results showed that the low-frequency loads caused more damage than high-frequency, and the presence of geosynthetics weakened the development of the crack [22,23].

Noory et al. developed a new method and device for measuring the shear bonding between the asphalt layers. This machine was also capable of measuring tensile strength between the layers. The device was used in evaluating the geocomposite-strengthened specimen. The factors affecting the shear bond were investigated based on a full factorial design. The results showed that temperature, tack coating, and geocomposite mesh size are important factors in the shear bonding between the asphalt layers. To determine the interlayer shear bonding effects on the expanding of reflective cracks, the initiation, and propagation of reflective crack were investigated in shear bonding specimens[24].

In recent years, the four-point bending test is widely used to examine the bending or fatigue behavior of multilayer structures. Volpi et al. (2017) introduced a capacitance-based method for real-time monitoring of crack propagation in sandwich-beam specimens. A simple analytical model has been used to express the relationship between cracks length and measured capacity. This model was compared with the experimental data, and its results showed that the accuracy of this method is sufficient[25].

In 2015, Norambuena and Torre studied the effect of the geosynthetic types on reflective cracking in asphalt pavement. Accordingly, they used eight different geosynthetics. Using a dynamic loading test, the performance of each of the geosynthetics was determined in anti-reflective cracking systems. Moreover, mechanical and thermophysical properties were also studied. The results showed that a geosynthetic with an appropriate tensile behavior did not necessarily have a significant effect on crack propagation in asphalt. Finally, it was determined that resistance to deterioration is an important factor in the behavior of geosynthetics [26].

Moghaddas Nejad et al. (2016) conducted an experiment on geogrid and geotextile reinforced samples with RSM[1] methodology. The results of this study were presented as quadratic regression models for predicting fatigue life and crack growth in the reinforced and unreinforced overlays. The effect of variables such as crack width, temperature, and type of geosynthetic was also considered separately and in conjunction. It should be noted that in this research, traffic loading was modeled dynamically in the shearing mode and based on heavy traffic intensity. Furthermore, a new model was obtained to predict the fatigue life based on the initial strain under the overlay and test temperature. The results showed that the geogrid is the most effective parameter for improving the performance of the overlays against the reflective cracks retardation in the asphalt pavements [27].

One of the experiments on the resistance of overlays with SAMIs[2] under the traffic loading against the growth of reflective cracking to the surface was performed by Ogundipe et al (2012). In this series of experiments, Wheel Track equipment, simulating environmental and field conditions were used to examine the influence of such interlayers in controlling and retarding the cracks. Moreover, the effect of several parameters including temperature, overlay thickness, SAMIs layer thickness and stiffness were analyzed in these systems [28-30].

Zornberg in 2017 conducted a study to investigate the function and application of

---

[1] response surface methodology

[2] stress absorbing membrane interlayer

geosynthetics on roadways. The results showed that using geosynthetics in asphalt overlays lead the pavement to be prevented of reflective cracking. For decreasing lateral displacements, geosynthetics were used as base stabilization [31].

Zofka et al. in 2016 presented an initial part of a study about the merits and demerits of using geogrid in asphalt pavement. According to results, higher fracture energy in the post-peak softening region was demonstrated [32].

Saride and Kumar in 2017 studied the effects of geosynthetic-interlayers on pre-cracked pavements. The results demonstrated a decrease in reflective cracking by the inclusion of interlayers [33].

Sachs et al. in 2016 conducted an experimental study using stacked beam samples separated by geotextile interlayer for potential crack investigation. The results showed such improvement in crack occurring in geotextile-reinforced samples [34].

Habbouche et al. in 2017 reviewed papers that were conducted in Nevada to find best method to decrease reflective cracking in Nevada climate. The results illustrated that the experimental stress relief course (ESRC) mixture had a good performance for mitigating reflective cracking [35].

3. Methodology

As mentioned before, this paper evaluates the performance of asphalt overlays reinforced with geogrid, modified by sasobit, or a combination of them on reflective cracking propagation retardation based on experimental laboratory works and statistical analysis. For this purpose, first, the effect of geogrid, sasobit, and the combination of them was identified on reflective crack retardation in asphalt overlay under different loading frequencies (on mode I) and temperature conditions. Second, the crack propagation point and direction on geogrid reinforced and sasobit modified asphalt overlay, which was affected by various temperatures, were studied in this research.

In this section, the laboratory activities, such as the material preparation (aggregate-bitumen-geogrid and sasobit wax), HMA and WMA mixture design, statistical analysis, sample construction, and the fatigue life test were explained.

3.1. Sample Preparation

The test samples were constructed according to several researchers, such as Sobhan et al.[36], Zamora et al.[19], Moghaddas Nejad et al.[1], Khodaei et al. [37]. Figure 1 illustrates a schematic view of the test.

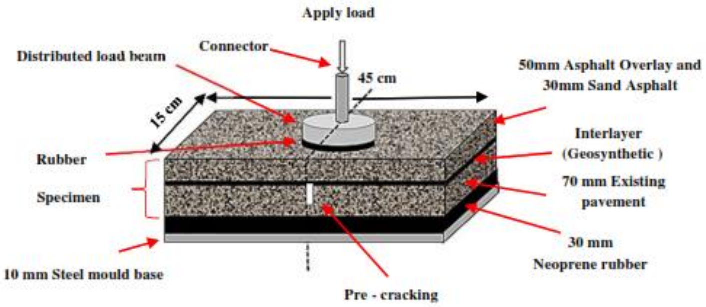


Fig. 1. Schematic of the sample preparation.

Double layer samples were constructed with the 450 mm length, 150 mm width, and 120 to 150 mm height. They were modified by sasobit, reinforced with geogrid, none or both of them. Using PReSBox compactor, the layers were compacted. The air void content averaging was about 4%±0.5

Fig. 2. The sample beam constructed by PReSBox Compactor.

The sasobit, bitumen and aggregates were added to the mixture. A 70 mm-thick layer as bottom layer, A 50 mm thick layer as the new overlay and a 30 mm thick sand asphalt layer as a regular layer composed the asphalt slabs, which is shown in figure 2. A bitumen penetration grade AC 85-100 (PG[3] 58-22) was used as a tack coat for bonding the top layer to the old AC slabs. The old slabs contained a 12.5 mm crack, which was made at the centerline of the layer via a water circular saw. The size of the cracks was chosen according to several researchers, such as Sobhan et al.[36], Zamora et al.[19], Moghaddas Nejad et al.[1] and Khodaei et al. [37]. In this research, the modified and reference samples were placed on the old slabs after using a tack coat and geogrid according to the type of samples. It should be noted that in order to construct WMA, 1 and 2% of the bitumen weigh of sasobit was added to the mixture before the process of adding aggregate.

In this test, for simulating the resilient subgrade, a 50 mm thick neoprene rubber mat with an elastic modulus of 11000 KN/m^2 and stiffness of Shore A= 60 were placed on the base of a steel mold at 10 mm thickness.

3.2. Test Procedure

A UTM-25 servo hydraulic dynamic testing machine was used in this study to apply simulated-cyclic loading to the top center of the samples, which is illustrated in figure3. The loads were cyclic haversine wave, and the loading plate was a 100mm diameter circle. The test frequencies were about 5 HZ for simulating medium and 10 Hz for simulating high-speed traffic loading. During the test, a 9.6 kN maximum load equivalent to 100 psi was applied vertically on the top of the specimen, while the amount of 0.96 KN was applied as the minimum load. The stop point of this test was the time that the vertical crack length reached the full specimen overlay depth.

Fig. 3. Test specimen under loading in UTM-25 dynamic testing machine.

---

[3] performance grade

For each test, two 8-mega pixel digital cameras were set up on both sides of the sample. By launching the experiment, these cameras started capturing every 30 seconds while recording video.

Before launching the test, each specimen was placed at 20 and 40 °C for 2 hours. The crack place on the top of the samples was highlighted with white color to facilitate monitoring the crack propagation during the test.

3.3. Materials and Methods

In this research, coarse aggregate with the maximum 19 mm natural gravel size and 2.64 kg/m^3 specific gravity, fine aggregate, and asphalt binder were mixed at 150 °C to provide HMA or WMA. There was also limestone aggregate, which was graded using Iran Highway Asphalt Paving Code (2003) limitations. Also, aggregates with a grain size of 12-0 mm were used in sand asphalt construction. Asphalt mixture was designed based on AASHTO T27, which comprised of bitumen penetration grade AC 60-70 (that fit to PG 64-22) with an optimum binder content of 4.55% by weight of HMA or WMA and 7% by weight of sand asphalt for each design. This study used PReSBox shear compression device to construct samples. The layers' average air void content was about 4%±0.5, the maximum specific weight was 2500kg/m^{3,} and the apparent density was 2400kg/m^2. Table 1 demonstrated the samples' name and specifications, which were used in this paper.

Table1. Name and Specifications of Asphalt overlays.

Row	**Asphalt slabs naming**	**Number of test repetitions**	**Sample Specifications**
1	R[4]	3	Reference sample (5 cm thick HMA overlay)
2	R.G[5]	3	Reinforced sample with geogrid (5 cm thick HMA overlay)
3	2SP[6]	3	Modified sample with 2 percent sasobit (5 cm thick WAM overlay)
4	1SP	3	Modified sample with 1 percent sasobit (5 cm thick WAM overlay)
5	1SP.G	3	Modified sample with 1 percent sasobit (5 cm thick WAM overlay) + reinforced with geogrid
6	2SP.G	3	Modified sample with 2 percent sasobit (5 cm thick WAM overlay) + reinforced with geogrid
7	R.SA[7]	3	Reference sample (5 cm thick HMA overlay) + 3 cm thick Sand asphalt
8	R.G.SA	3	Reinforced sample with geogrid (5 cm thick HMA overlay) + 3 cm thick Sand asphalt
9	2SP.SA	3	Modified sample with 2 percent sasobit (5 cm thick WAM overlay) + 3 cm thick Sand asphalt
10	1SP.SA	3	Modified sample with 1 percent sasobit (5 cm thick WAM overlay) + 3 cm thick Sand asphalt
11	1SP.G.SA	3	Modified sample with 1 percent sasobit) + geogrid +3 cm thick Sand asphalt
12	2SP.G.SA	3	Modified sample with 2 percent sasobit + geogrid + 3 cm thick Sand asphalt
Tack coat amount (kg/m2) for each sample			
Reference (Reference samples without geogrid)			0.3
With geogrid (100 KN/m – (Glass grid))			0.42

---

[4] Reference

[5] Geogrid

[6] Sasobit percent

[7] Sand asphalt

The following two materials were used in this study:

I. Geogrid: Glass grid, having tensile strengths of 100kN/m and 2% strain. The grid size was 30×30 mm.

II. Sasobit: a synthetic wax, melting point 98°C, less than 0.1 mm penetration grade at 25°C and the viscosity of the melted wax is about 12 mP in 135 °C[38].

4. Results and Discussion

In this section, data analysis was conducted to study the influence of effective parameters on the specimens. The reinforced, modified, and reference samples were tested under cyclic loading at various temperatures to evaluate the reflective cracking.

According to the recorded documentation, the fatigue life of the reference samples at 40 °C and 10 Hz was between 7500 and 8000 loading cycles in the bending mode. Compared to the same specimens at 20 °C, a significant decrease in fatigue life (up to 3 times greater than the reduction in fatigue life) has been achieved. This decrease in the fatigue life indicated changes in the properties of asphalt against temperature rises. In other words, with increasing temperature, changes occurred in asphalt, which reduced the adhesion of bitumen and aggregate. Figure 4 represents the fatigue life against the type of samples.

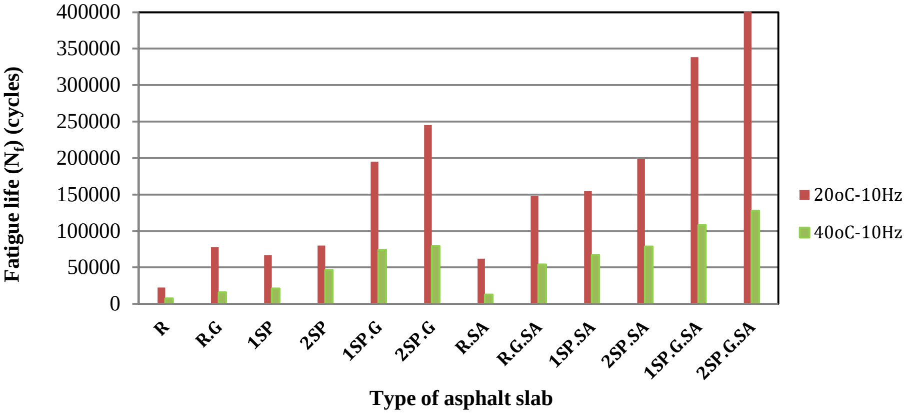


Fig. 4. The number of life cycles of different samples at 20 and 40^{0}c and load frequency 10 Hz.

Figure 4 showed that increasing the percentage of sasobit and using a geogrid interlayer reduced the time of the crack motion to the overlay surface, which improved the samples fatigue life at 20 °C up to almost three times. However, the sasobit modified samples had a better performance than geogrid reinforced ones at 40 °C. It was about six times improvement in fatigue life for modified samples, while a 2.5 times enhancement occurred in the reinforced specimens.

According to the fatigue life diagram in figure 4, the tolerance of reference samples with sand asphalt layer, reinforced with geogrid with sand asphalt layer and modified by sasobit with a sand asphalt layer (R.SA, R.G.SA, 1SP.SA) were 2.75, 6.5 and 8.8

times at 20 °C, 1.7, 7.2 and 10.5 times at 40 °C more than the fatigue life of the reference specimens. The results showed that the sand asphalt layer under the overlay could reduce the stress concentration on reflective cracks due to the increased thickness, and the fatigue life of samples increased by creating a uniform surface for overlays.

The combined system (2SP.G.SA) showed the best performance in fatigue failure. This anti-cracking system improved fatigue life about 15 to 19 times at 20°C and about 14 to 17 times at 40 °C. Based on the results, it is obvious that this system is the optimum way to improve the performance of asphalt overlays and their lifetime against the premature reflective cracks because it is capable of increasing the overlay thickness, layer stiffness, and tensile strength while reducing stress concentration on the crack areas.

Based on the image processing results, in all types of samples, cracks moved from the bottom to the top of the overlay. They first propagated as hairline type (microcrack) and then converted to one or two macro-cracks. The cracks in the reinforced, modified, and combined slabs at 20 °C launched slowly farther away from the beneath crack and then joined other cracks and achieved the middle depth of overlay. After that, the width of several branches of the cracks increased during the loading process.

However, image processing in these tests showed that in contrast to the temperature of 20°C, the cracks at 40 °C in reference samples moved from the top and down to the middle of the overlay. This change in crack growth pattern is due to the increased temperature and weakness of the adhesion of aggregate and asphalt binder. In addition, it should be noted that failures and fractures in asphalt overlays at high temperatures caused the top-down cracks as well.

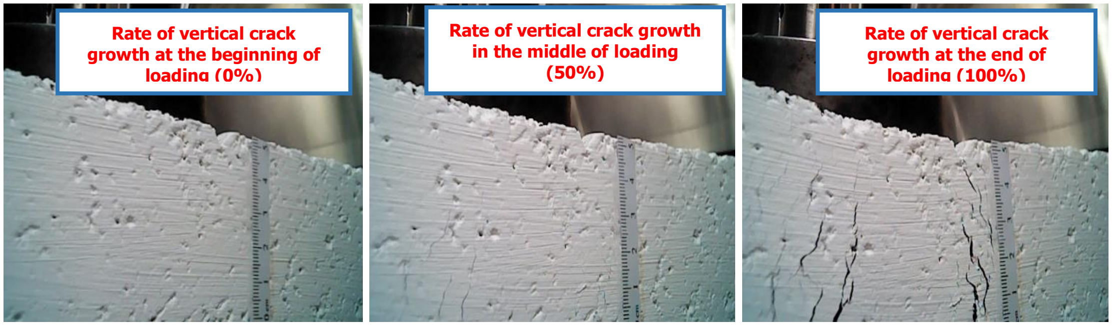


Fig. 5. Monitoring the trend and rate of cracks growth in various stages of loading.

Based on the results and the analysis of the diagram in figure 5, by increasing the percentage of sasobit and using an interlayer geogrid, the crack arrival time to the surface of overlay decreased, which improved the samples fatigue life at 20 °C almost 3 times. While the sasobit effects on overlay fatigue life improvement at 40 °C is higher than geogrid reinforced samples, this increase in fatigue life vs. the reference samples was up to 5.5 times for sasobit and approximately 2.5 times for geogrid reinforced. Accordingly, it can be said that the effect of the sasobit in tropical regions is clearly evident in the improvement of the asphalt overlay performance in reflective cracking retardation. In other words, increasing the amount of modulus and rigidity (tensile strength) of the overlay, which was modified by sasobit or reinforced with geogrid, had a significant effect on overlay performance in reflective growth retardation. It should be noted that the increase in environmental temperature influences the flow rate of tack coat and overlay and geogrid adhesion, adversely.

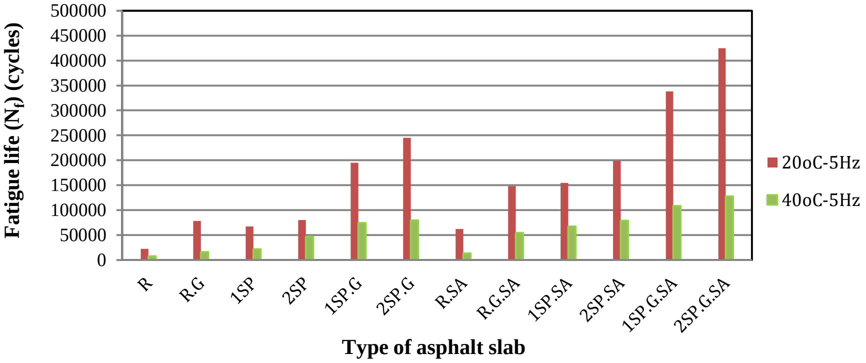


Fig. 6. The number of life cycles of different samples at 20 and 40^0c and load frequency 6 Hz.

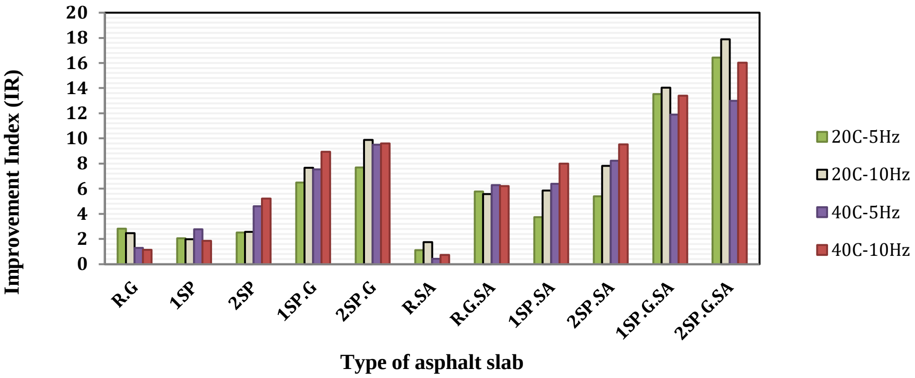


Fig. 7. Improvement index of different samples vs. reference samples.

Furthermore, in this paper, another parameter called the IR[8] was used to evaluate the performance of the modifiers and geogrid in the simple or combined asphalt slabs, and their performance is compared with reference samples[39].

$$IR = \frac{N_f^{th} - N_f^{NT}}{N_f^{NT}} \times 100 \qquad [39]$$

$$N_f^{NT} = unreinforced\ sample\ fatigue\ life$$

$$N_f^{th} = reinforced\ sample\ fatigue\ life$$

As shown in Figure 7, the best performance is related to the combined samples (1SP.G.SA & 2SP.G.SA) at 20 and 40 °C with frequencies of 5 and 10 Hz, which improved the resistance of systems by about 12 to 18 times compared to reference samples. Subsequently, other combined samples without a sand asphalt layer at a temperature of 20 and 40 °C had the best performance, respectively. Obviously, increasing sasobit percentage improved the performance of the overlay against reflective cracks even at high temperatures.

---

[8] Improvement Ratio

According to figure 8, the highest rate of crack growth at all temperatures was about the reference samples. Also, increasing frequency and temperature in the reinforced, modified, and combined samples and in reference samples increase this rate. Obviously, asphalt combination samples (1SP.G.SA & 2SP.G.SA) have shown the best performance in reducing the rate of crack penetration in asphalt overlay at all temperatures.

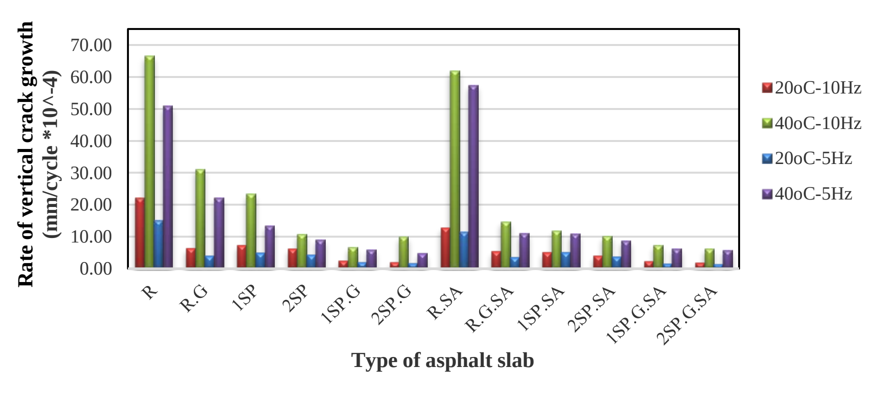


Fig. 8. Rate of vertical crack growth of different samples.

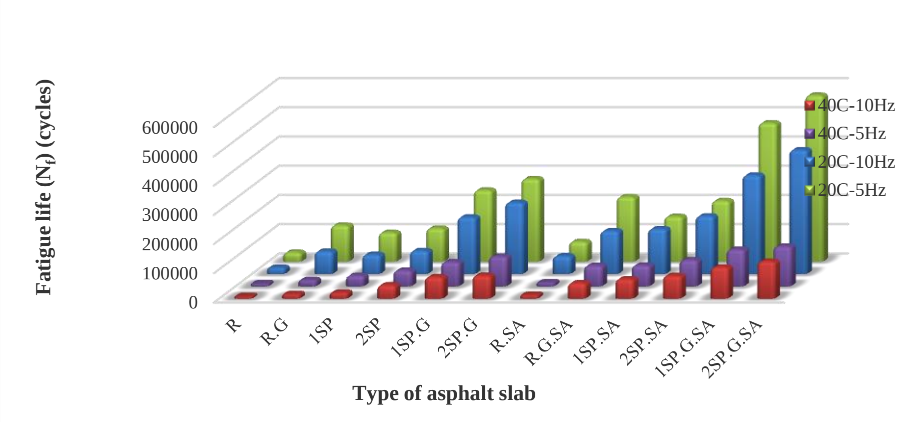


Fig. 9. Number of life cycles of different samples under different traffic loading in the bending mode at different temperatures.

Based on figure 9, the highest fatigue life is related to samples tested at 20 ° C and 5 Hz frequency. A part of this increase is related to the performance of the sasobit and geogrid at low temperatures, and the other part is about the increase in the strength of asphalt beams at lower temperatures and lighter loading.

The effect of sasobit on the improvement of reflective cracking retardation in asphalt overlays was studied. According to the results, improvement of the modulus of the top and down layers can be considered as a fundamental parameter affecting the growth of reflective cracks and the efficiency of asphalt overlays, especially at high temperatures. Such enhance in modulus could happen due to granulation changing, the use of other polymer additives, and so forth.

It should also be noted that in this research, all samples were only loaded in bending mode. Considering the effect of shear mode or the effect of a combination of shear and bending modes in the fatigue life of multilayer asphalt slabs, it should be kept in mind that the performance of the multi-layer asphalt systems offered in this study will certainly be less than its real value.

5. Conclusion

This work evaluated the methods of rehabilitating, repairing, and strengthening of asphalt overlays with laboratory studies. Accordingly, the performance of reinforced overlays with geogrid and modified by a polymer additive “sasobit” has been evaluated separately and in combination with the reference control samples. Finally, the following results have been extracted:

1. The combination samples (1SP.G.SA & 2SP.G.SA) illustrated a better performance in increasing fatigue life and reducing crack propagation than other samples. In other words, increasing the amount of modulus and rigidity (tensile strength) of the overlay by modifying it with sasobit or using geogrid had a significant effect on improving the overlay performance and the retardation in the growth of reflective cracks.
2. The results showed that there are some hairline and micro-cracks in the crack initiation stage. Subsequently, these cracks turned into a macro form. Moreover, the crack propagation in the reference sample is usually a single-branch with a large crack width form exactly from the top of the crack, while in reinforced and modified samples, due to the reduction of stress concentrations, the hairline cracks expanded slowly on the overlays.
3. Based on the image processing results, the trend of the crack propagation in the reinforced and unreinforced samples varied significantly at different temperatures and frequencies. Typically, at low temperatures and frequencies (20 °C), the cracks grew from down to the top, and the width of the cracks was lower. However, the cracks at 40 °C in reference samples, moved from both top and down to the middle of the overlay. These cracks originated in the form of micro-crack, and after reaching the middle of the overlay, they expanded rapidly and became macro-crack.
4. The change in the crack propagation is due to an increase in the temperature and lack of the adhesion between aggregate and asphalt binder. In other words, it should be noted that failures and fractures in AC overlays occurred at high temperatures because of underlying reflective cracks and top-down cracks. Moreover, the cracks grew rapidly to reach the overlay’s surface at this temperature.
5. The vertical rate of crack propagation in the sasobit modified or geogrid-reinforced overlays are much lower than the reference samples. Furthermore, with an increase in temperature from 20 to 40 °C, the crack growth rate increased from 1.7 to 4.9 times. The sample of asphalt slabs with 2% sasobit, reinforced with interlayer geogrid with or without asphalt sand layers, had the lowest crack growth rate.

6. It was observed that the amount of crack propagation rate at all temperatures in the reference samples had the highest value. Moreover, this rate was increased by increasing frequency and temperature in the reinforced, modified, combined, and control samples. However, the best performance at all frequency and temperature conditions was related to, the combined samples (1SP.G.SA & 2SP.G.SA)
7. The best performance in the IR index was associated with the combined samples (1SP.G.SA & 2SP.G.SA) up 3 inches of gravel pavement at 20 and 40°C and 5 and 10 Hz frequencies, which was improved the system resistance by 12 to 18 times compared to the reference samples.
8. The highest fatigue life was related to the samples, which were tested at 20 °C and 5 Hz frequency (equivalent to average traffic load). A part of this increase was about the performance of sasobit and geogrid at low temperatures, and the other part was about the increase in the resistance of asphalt beams at lower temperatures and lighter loading.
9. The results of this study indicated that the geogrid reinforcement and polymer additives such as sasobit had a significant effect on retarding reflective cracking in asphalt pavements. Accordingly, the proposed methods for reinforcing asphalt overlays were used to reduce the life cycle cost and increase the service life by reconstruction, rehabilitation, repair and maintenance.

REFERENCES

[1] Moghaddas Nejad F, Asadi S, Fallah S, and Vadood M, (2016) “Statistical-experimental study of geosynthetics performance on reflection cracking phenomenon,” Geotext. Geomembranes, vol. 44, no. 2, pp. 178–187.

[2] Li Y and Metcalf J.B, (2004) “Fatigue Characteristics of Asphalt Concrete from Asphalt Slab Tests,” J. Mater. Civ. Eng., vol. 16, no. 4, pp. 306–314.

[3] Shenoy A, (2001) “Determination of the Temperature for Mixing Aggregates with Polymer-Modified Asphalts,” Int. J. Pavement Eng., vol. 2, no. 1, pp. 33–47.

[4] West R.C, Watson D.E, Turner P.A, and Casola J.R, (2010) “Mixing and compaction temperatures of asphalt binders in hot-mix asphalt,” Transportation Research Board.

[5] Xiao F, Wenbin Zhao F.B, and Amirkhanian S.N, (2009) “Fatigue behavior of rubberized asphalt concrete mixtures containing warm asphalt additives,” Constr. Build. Mater., vol. 23, no. 10, pp. 3144–3151.

[6] Ziari H, Babagoli F, and Akbari A, (2015) “Investigation of fatigue and rutting performance of hot mix asphalt mixtures prepared by bentonite-modified bitumen,” Road Mater. Pavement Des., vol. 16, no. 1, pp. 101–118.

[7] Behroozikhah A, Morafa S.H, and Aflaki S, (2017) “Investigation of fatigue cracks on RAP mixtures containing Sasobit and crumb rubber based on fracture energy,” Constr. Build. Mater., vol. 141, pp. 526–532.

[8] Scarpas A, De Bondt A.H, Molenaar A, and Gaarkeuken G, (1996) Finite elements modelling of cracking in pavements.

[9] Zhang Y, Luo X, Luo R, and Lytton R.L, (2014) “Crack initiation in asphalt mixtures under external compressive loads,” Constr. Build. Mater., vol. 72, pp. 94–103.

[10] Cleveland G, Button J, and Lytton R, (2003) Geosynthetics in flexible and rigid

pavement overlay systems to reduce reflection cracking.

[11] Li Y and Metcalf J.B, (2004) "Fatigue Characteristics of Asphalt Concrete from Asphalt Slab Tests," J. Mater. Civ. Eng., vol. 16, no. 4, pp. 306–314.

[12] Lytton R, (1989) "Use of geotextiles for reinforcement and strain relief in asphalt concrete," Geotext. Geomembranes.

[13] Amini F, (2005) "Potential applications of paving fabrics to reduce reflective cracking.,".

[14] Grabowski W and Pozarycki A, (2008) "Energy absorption in large dimension asphalt pavement samples reinforced with geosynthetics," Found. Civ. enviromental Eng.

[15] Canestrari F, (2018) "Advanced Interface Testing of Grids in Asphalt Pavements," Springer, Cham, pp. 127–202.

[16] Kim J and Buttlar W.G, (2002) "Analysis of Reflective Crack Control System Involving Reinforcing Grid over Base-Isolating Interlayer Mixture," J. Transp. Eng., vol. 128, no. 4, pp. 375–384, Jul.

[17] Fallah S and Khodaii A, (2015) "Evaluation of parameters affecting reflection cracking in geogrid-reinforced overlay," J. Cent. South Univ., vol. 22, no. 3, pp. 1016–1025.

[18] Khodaii A, Fallah S, (2009), "Effects of geosynthetics on reduction of reflection cracking in asphalt overlays," Geotext. Geomembranes.

[19] Zamora-Barraza D, Calzada-Pérez M.A, Castro-Fresno D, and Vega-Zamanillo A, (2011) "Evaluation of anti-reflective cracking systems using geosynthetics in the interlayer zone," Geotext. Geomembranes, vol. 29, no. 2, pp. 130–136.

[20] Xu Y, Williams D J, and Serati M, (2018) "Investigation of shear strength of interface between roadbase and geosynthetics using large-scale single-stage and multi-stage direct shear test," Road Mater. Pavement Des., pp. 1–24.

[21] Ling J, Wei F, Gao J, Zhang J, Tian Y, and Li Y, (2019) "New Test Method for Measuring Reflective Cracking in Hot-Mix Asphalt Overlay Pavements," Transp. Res. Rec. J. Transp. Res. Board, p. 036119811984104.

[22] Gonzalez-Torre I, Calzada-Perez M A, Vega-Zamanillo A, and Castro-Fresno D, (2014) "Damage evaluation during installation of geosynthetics used in asphalt pavements," Geosynth. Int., vol. 21, no. 6, pp. 377–386.

[23] Norambuena-Contreras J, Gonzalez-Torre I, Fernandez-Arnau D, and Lopez-Riveros C, (2016) "Mechanical damage evaluation of geosynthetics fibres used as anti-reflective cracking systems in asphalt pavements," Constr. Build. Mater., vol. 109, pp. 47–54.

[24] Noory A, Moghadas Nejad F, and Khodaii A, (2019) "Evaluation of geocomposite-reinforced bituminous pavements with Amirkabir University Shear Field Test," Road Mater. Pavement Des., vol. 20, no. 2, pp. 259–279.

[25] Volpi F, (2017) "A capacitance-based solution to monitor absolute crack length in four-point bending test: Modelling and experiments," Sensors Actuators, A Phys., vol. 254, pp. 145–151.

[26] Norambuena-Contreras J and Gonzalez-Torre I, (2015) "Influence of geosynthetic type on retarding cracking in asphalt pavements," Constr. Build. Mater., vol. 78, pp. 421–429.

[27] Noory A, Nejad F.M, and Khodaii A, (2018) "Effective parameters on interface failure in a geocomposite reinforced multilayered asphalt system," Road Mater. Pavement Des., vol. 19, no. 6, pp. 1458–1475, Aug.

[28] Ogundipe O, Thom N, and Collop A, (2013) "Investigation of crack resistance potential of stress absorbing membrane interlayers (SAMIs) under traffic loading," Constr. Build. Mater..

[29] Pasetto M, Pasquini E, Giacomello G, and Baliello A, (2019) "Innovative composite materials as reinforcing interlayer systems for asphalt pavements: an experimental

study," Road Mater. Pavement Des., pp. 1–15.

[30] Saride S and Kumar V, (2019) "Reflection Crack Assessment Using Digital Image Analysis," Springer, Singapore, pp. 139–156.

[31] Zornberg J G, (2017) "Functions and Applications of Geosynthetics in Roadways," Procedia Eng., vol. 189, no. May, pp. 298–306,.

[32] Zofka A, Maliszewski M, and Maliszewska D, (2016) "Glass and carbon geogrid reinforcement of asphalt mixtures," Asph. Paving Technol. Assoc. Asph. Paving Technol. Tech. Sess., vol. 85, no. 0, pp. 717–744.

[33] Saride S and Kumar V, (2017) "Geotextiles and Geomembranes In fl uence of geosynthetic-interlayers on the performance of asphalt overlays on pre-cracked pavements," Geotext. Geomembranes, pp. 1–13.

[34] Sachs S, Vandenbossche J.M, Alland K, Desantis J, and Khazanovich L, (2016) "Effects of Interlayer Systems on Reflective Cracking in Unbonded Overlays of Existing Concrete Pavements," J. Transp. Res. Board.

[35] Habbouche J, Hajj E Y, Morian N E, and Sebaaly P E, (2017) "Reflective cracking relief interlayer for asphalt pavement rehabilitation : from development to demonstration," Road Mater. Pavement Des., vol. 0, no. 0, pp. 1–28.

[36] Sobhan K and Tandon V, (2008) "Mitigating Reflection Cracking in Asphalt Overlays using Geosynthetic Reinforcements," Road Mater. Pavement Des., vol. 9, no. 3, pp. 367–387.

[37] Khodaii A, Fallah S, and Moghadas Nejad F, (2009) "Effects of geosynthetics on reduction of reflection cracking in asphalt overlays," Geotext. Geomembranes, vol. 27, no. 1, pp. 1–8.

[38] Oelkers C, (2017) "The versatile additive for asphalt mixes - Sasobit,".

[39] Dizaj A B, Ziari H, and Nejhad M A, (2014) "Effects of Carbon Fibre Geogrid Reinforcement on Propagation of Cracking in Pavement and Augmentation of Flexible Pavement Life," Adv. Mater. Res., vol. 891–892, pp. 1533–1538.