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Water Damage Evaluation of Fly Ash Geopolymer Modified Binder in Asphalt Mixture

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Abstract: Moisture damage has been a major concern for many years. It will cause stripping and accelerated the formation of potholes. Moisture are required to cause this type of damage in both liquid and vapour form, entering the pavement through infiltration of surface water by tire action, irrigation or repetitive traffic loading. In this study compacted specimens are the most common approach for checking the resistance to moisture of mixtures. The testing procedures for compact samples consist of indirect, adjusted tensile measurements (Lottman AASHTO T-283). This study are conduct to evaluate the effect of moisture on superpave mix design mixture with additive material Fly Ash Geopolymer (FAG). The material used in this study are granite aggregate and fly ash geopolymer. For the ITS value, the highest ITS value for the specimens used 9% of FAG. The highest ITSR value for the specimens used 3% of FAG. The ITSR result also shows that all the value comply with the AASHTO T-283. It can be conclude that the used of FAG in asphalt mixture with 60/70 bitumen grade can increased the resistance to moisture sensitivity.

Keywords: Water Damage, Moisture Sensitivity Test, Superpave, Fly Ash Geopolymer, Optimum Bitumen Content

1. Introduction

The building industry leads to a large annual growth in waste production. The total waste created throughout the world from construction and demolition (C&D) was about 3 billion tonnes, and will continue [1]. Because of those sustainable practices become a major focus concerning utilizing the waste materials due to the extensive use of natural resources in the construction and pavement projects. In addition, increasing costs of the raw materials for civil engineering applications prompted engineers and researchers to look for the industrial wastes as alternative resources. One of the well-known waste materials is fly ash geopolymer. The interest in the introduction of new technology for the manufacturing of high potential geopolymer-based products has stepped up since 1979, when

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Davidovits first used the term "geopolymers" as a new class of three-dimensional aluminum-silicates materials.

Road paving is the combination of gravel, combined with asphalt or concrete set up for vehicle and foot transportation on a specified route. In the past it comprised solely of gravel and stone, but afterwards high-quality materials like asphalt binding materials and concrete replaced these pitfalls. Today, pavement design is an important component for preserving optimum infrastructure performance in cities and providing road users with security. Roads are separated into paved or dirt roads. The historic use of dirt roads was largely weak in development for the mobility, transit, hunting and other activities. Asphalt or concrete paved roads also require regular maintenance, to ensure usage, accessibility and safety and to maintain them. Despite the expensive building and maintenance expenses of paved roads, they offer high speed surface and simple mobility, which are very essential for our contemporary and rapid moving age. The surface of the road, however, deteriorate and thereby impacts riding quality and safety of users. Therefore it becomes vital to apply an important monitoring system to adequate maintenance operations depending on the type of distress.

The all-weather service environment for paved asphalt guarantees the consistency of the natural environment for its surface layers. Several common issues on the floor surface arise from extreme service conditions. Water can penetrate the asphalt paving internal structure in a number of means, directly causing damage to humidity. Precipitation is the primary cause of road surface water from which cracks, vacancies and joint or road shoulder edges can penetrate the internal structure of asphalt pavement. The continuous process ensures asphalt flooring is still dynamically breathable [2], while the vapor can shift temperatures into liquid water and can rebound within an asphalt floor. Liquid water may be flow through the connected void canals within the pavement system. The resultant excess water pressure in the water maintained field speeds up asphalt film stripping and ultimately contributes to damage to humidity in raveling or potholes. In addition, the water infiltrating all asphalt surface depths will assess the top surface of the foundation and dissolve fine aggregates under vehicle loading.

Compact specimens are the most common approach for checking the resistance to moisture of mixtures. Testing procedures for compact samples consist of indirect, adjusted tensile measurements (Lottman AASHTO T-283). A wheel-tracking test is another humidity testing on compacted asphalt specimens. The most significant such test is the Hamburg wheel-tracking system which, since its repetitive loading period and moisture susceptibility are detected, has gained popularity as a moisture susceptible test [3]. Another test that can be used is (Immersion-compression (AASHTO T 165). Since the conditioned samples are put in water, equivalent to a modified Lottman test, instead of broken tensile, a compressive strength test without containment is used. Precision is not strong, and samples with visible signs of removal will give a force ratio of approximately 1.0.

2. Materials and Methods

This section outlines the design process, the experiment preparation and the laboratory test to study the influence of asphalt mixtures on a creep module constructed with aggregates like granite. Testing will be carried out in the Advanced Highway Laboratory of Tun Hussein Onn Malaysia University. All experiments were carried out in accordance with the standard and method set.

2.1 Material preparation

- **Granite**
  Granite is a light-coloured plutonic rock that is most frequently found in mountainous areas in the continental crust. It consists of gross quartz grains (10-5%), sodium feldspar and potassium feldspar. More than 80 percent of the rock contains these minerals. Granite aggregate that used in this study are obtain from advance highway laboratory in UTHM.
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- **Fly ash geopolymer**
  The geopolymer is ceramic-like and, in terms of its chemical composition, similar to zeolite, but has an amorphous structure. It can harden easily at ambient temperatures and obtain

mechanical strength and excellent longevity. Due to the properties, fly ash geopolymer that are used in this study as an additive material to increase the performance of the asphalt mixture. The concentration of fly ash geopolymer that are used in this study is as much as 0%, 3%, 5%, 7%, 9% and 12%.

- **Asphalt binder**
  Asphalt binder are material used as a binder for the aggregate to stick together. Binder plays an important role in avoiding common asphalt mixture-related distress, such as fatigue cracking and rutting. For example, binders with adequate adhesion and cohesion will greatly obstruct the isolation and separation of aggregates from the pavement surface. The grade of asphalt binder used in this laboratory test is 60/70. This material will be obtained from the advance highway laboratory UTHM.

2.2 Methods

2.2.1 Specific Gravity (SG) and Water Absorption (ASTM C 127)

Specific aggregate gravity test are performed to assess the material strength or quality, whereas the water absorption test determines the ability of the raw and fine aggregates to hold water. The main aim of this test is to measure the material's strength or quality. Specific gravity and water absorption values for aggregates are recommended. With an average of around 2.68, the specific gravity of the aggregates usually used in road building varies between around 2.5 and 30. Water uptake per unit by weight should be no more than 0.6.

2.2.2 Flakiness and Elongation Index (ASTM D4791)

Flaccidity index theory when they have a thickness of less than 0.6 of their medium size, aggregate particles are described as flaky. The flakiness index of an aggregate sample is obtained by dividing the flaky particles into a proportion of the mass of the tested sample. This test is not relevant for the aggregation of the 6.30mm strainer and the elongation index and 63.0mm strainer. When they have a larger dimension of more than 1.8 of their medium sieve size, aggregate particles are classed as elongations. The elongation index may be obtained by dividing the elongation particles into a percentage of the test mass. The test does not apply to material passing a seal of 6.30 mm or kept with a seal of 50 mm.

Conduct the analysis of the sieve on the provided sample. The aggregates are then organized into a number of very narrow clusters of particles. Each group (fraction) is weighed and thickness checked by passing each particle through a predetermined thickness slot along the lower dimension, on the corresponding aperture of the thickness gauge. Every fraction is recorded for the weight of the particles crossing the thickness gage. It’s flaky particle weight. The flakiness index is computed as a percentage of the total sample weight by expressing the weight of the flaky particles. For elongated particles, the lengths of the particles are much bigger than the two other dimensions and the largest dimension of the particles is 1.8 times the mean. The mixes have an extended particle limit of 45%. If the elongated particles are more than 45%, the aggregate is regarded unwanted for the intended application and the elongation index is the weight percentage of the elongated particle in a sample. The elongated index is determined as a percentage of the total weight of the sample by expressing the weight of elongated particles. The BS-1241 requires an index of flakiness of no more than 30 percent regardless of the overall size.

2.2.3 Aggregate Impact Value (AIV) (BS 812)

Due to the acceleration of the vehicle on the surface, the aggregates are subject to impact, resulting in them being broken down into smaller parts. The aggregates should therefore have sufficient strength to withstand their disintegration as a result of their effect. These characteristics are calculated by the impact value of the test. This test used to evaluate the effect value and evaluation of the appropriateness of the aggregates used in paving construction in roads. The test procedure includes screening the aggregate by means of IS sieves of 12.5mm and 10.0mm. The test material consists of aggregates passing through a filter of 12.5 mm. Then, the measuring cylinder fills just one over three depths. The material then compacts with the ring end of the tamping rod in the cylinder by providing twenty five soft blows. There are also two layers added and the procedure repeated till the cylinder is complete and the aggregates are removed. Then determine to the closest gram the net weight of the aggregates. Rest the impact machine on the level plate, block, or floor without wedging or packing to make it rigid and vertical guiding columns. The test sample must be compacted with 25 soft strokes with a tamping rod by attaching a cup securely to the base of the machine with the whole test sample in it. Then raise the hammer to 380 mm above the aggregate surface on its bowl to allow the hammer to fall freely on the aggregate sample. Fifteen strikes between subsequent falling occur at an interval of not less than one second. Take the pulverized compound from the cup and sew it with 2.36 mm IS sieves until no more significant quantities pass within one minute. Weighting of the fraction to 1gm precision in the sieve. It weighs the fraction kept in the sieve.

2.2.4 Superpave mix design (AASHTO TP4 and AASHTO PP2)

The construction process of the Superpave mix was planned to replace the Hveem and Marshall methods. The mass analysis typical to the Hveem and Marshall methods provides the basis for the Superpave mix design process. The Superpave method connects asphalt binder and aggregate collection to the mixing design phase and also considers traffic and atmosphere. The Hveem and Marshall compacting devices have been replaced by a gyro compactor and the compacting effort in the mixing design is related to the planned traffic. This section consists of a short history of the construction process of the Superpave mix accompanied by a general description of the current method. This overview stresses basic principles and reasoning for particular practices.

2.3 Testing method

2.3.1 Moisture Sensitivity Test

Several separate methods are used to determine the susceptibility of the asphalt mixture to moisture. The best known test protocol among the highway agencies is AASHTO T-283, with its numerous changes. AASHTO T-283 was used as a benchmark for comparison in this study. More than one hundred specimens have been prepared and evaluated for examination. Twelve specimens were split into two sets for each test (dry and conditioned sets). The outcomes of AASHTO T 283 are expressed in terms of the tensile strength ratio (TSR). Figure 1 show the moisture sensitivity test machine that are used for the test. This experiment are conducted to make a comparison between dry sample and wet sample with an additive. This experiment was focused on evaluation of effectiveness of fly ash geopolymer in asphalt mixture against moisture damage. The indirect tensile strength (ITS) for each sample was calculate using the following equation$\Sigma t = \frac{2000P}{ntD}$.

Figure 1: Moisture Sensitivity Test Machine

3. Results and Discussion

3.1 Flakiness Index and Elongation Index

Percentages of flaky and elongation particles dictate the particle form of aggregates. Particles with flaky and elongation are considered undesirable since they create pavement weakening. In concrete floors of cement, rounded particles are chosen since the workability of concrete increases. Regarding granular base distances, regular particle forms are preferred because of the higher stability that better interlocking requires. The flakiness index result for the aggregate as shown in table 4.1 are 19.00%. The standard provide by the JKR are must less than 25%. Then, the elongation index result are 10.00% and there are no specification provided by JKR for elongation index. So that, the flakiness and elongation index result are pass the JKR specification.

Table 1: Flakiness Index and Elongation Index result

Properties	JKR Specification Requirement	Results
Flakiness Index	Less than 25%	19.00%
Elongation Index	Not Stated	10.00%

3.2 Aggregate Impact Value Test

The property of a material to resist the impact is known as toughness. Due to a movement of vehicles on the road the aggregate are subjected to impact resulting in their breaking down into smaller pieces. The aggregate should therefore have sufficient toughness to resist their disintegration due to impact. This characteristic is measured by impact value test. The aggregate impact value is a measure of resistance to a sudden impact or a shock, which may differ from its resistance to gradually applied compressive load. The result of aggregate impact value is recorded in table 2. The percentage value of aggregate impact value must follow the JKR Standard Specification which is the aggregate impact value must not less than 10% and must not more than 30%. In this study, the percentage value of aggregate impact value is 25.05% which is comply with the JKR specification.

Table 2: Aggregate Impact Value Test Result

Properties	**AIV**
JKR Specification Requirement	Not less than 10% and Not more than 30%
Result	25.05%

3.3 Specific Gravity (SG) and Water Absorption Test

This test is done to measure the strength or quality of the material while water absorption test determines the water holding capacity of the coarse and fine aggregates. The main objective of these test is to, to measure the strength or quality of the material.

3.3.1 Coarse Aggregate Specific Gravity and Water Absorption

The particular gravity test helps to identify the aggregate. The absorption of water offers a sense of aggregate strength. More water absorption aggregates are more porous and are typically regarded improper until shown to be acceptable on the basis of strength, impact and hardness tests. As shown in table 3, the specific gravity result for course aggregate are 2.509. The water absorption result for course aggregate are 0.620 follow the JKR specification which is must not exceed 2%. So that the aggregate that had been test can be used in asphalt mixture.

Table 3: Course Aggregate Specific Gravity and Water Absorption Result

Test	Result
Specific gravity (SG)	2.509
Water Absorption	0.620

3.3.2 Fine Aggregate Specific Gravity and Water Absorption

Water absorption result for fine aggregate as shown in table 4 are 0.786. The result are followed the JKR specification which is the water absorption for aggregate must not exceed 2%. The specific gravity result for this test is 2.577. The aggregate that had been test can be used in the asphalt mixture because the aggregate passed the specific gravity and water absorption JKR specification.

Table 4: Fine Aggregate Specific Gravity and Water Absorption Result

Test	Result
Specific gravity (SG)	2.577
Water Absorption	0.786

3.4 Optimum Bitumen Content Determination

The Optimum Bitumen Content (OBC) was determined by using Superpave mix design. The sample are divided into 0% FAG as a control specimens, 3%, 5%, 7%, 9% and 11% FAG as a specimens with an additive. The OBC was selected using 4% air void at Ndesign = 100 gyration. The graph asphalt content versus % Air Void, %VMA, %VFA and Dust Propotion was construct to determine the OBC. As shown in table 3.5 the OBC are 5.69%, 5.03%, 5.12%, 5.28% and 6%. All the criteria must be consider before OBC determination but there are no specification provided for OBC determination.

Table 5: Optimum Bitumen Content Result

Mix Properties	0%	3%	5%	7%	9%	11%	Criteria	Status
% Air Void	4	4	4	4	4	4	4	Pass
% VMA	18	18.7	18.5	18	19.4	18.9	min 14	Pass
% VFA	76	79	78	80	76.9	79.3	65-75	Not Pass
Dust Propotion	0.51	0.585	0.605	0.62	0.63	0.63	0.6-1.2	Pass
% Gmm @ Ndes = 100	93.8	96.8	96.4	95.9	92.3	92.8	96	Pass
OBC	5.69	5.03	5.12	5.28	6	6	-	-

3.5 Effect of Fly Ash Geopolymer on Indirect Tensile Strength

Figure 2 shows the Indirect Tensile Strength (ITS) result for compacted sample compared with Fly Ash Geopolymer (FAG) percentages which is 0%, 3%, 5%, 7%, 9% and 11%. From the bar chart, the value of ITS for the dry condition higher than the wet condition. Specimens incorporating with 9% of FAG exhibit a higher ITS value in dry and wet condition compared to other specimens with 0%, 3%, 5%, 7% and 11%. For using a 9% of FAG, the ITS value is 1648.483 for the dry specimens and decrease to 1409.068 for the wet specimen. While the ITS value for the specimens with 3% of FAG shows the lowest value which is 1119.212 for the dry specimen and decrease to 1029.446 for the wet sample.

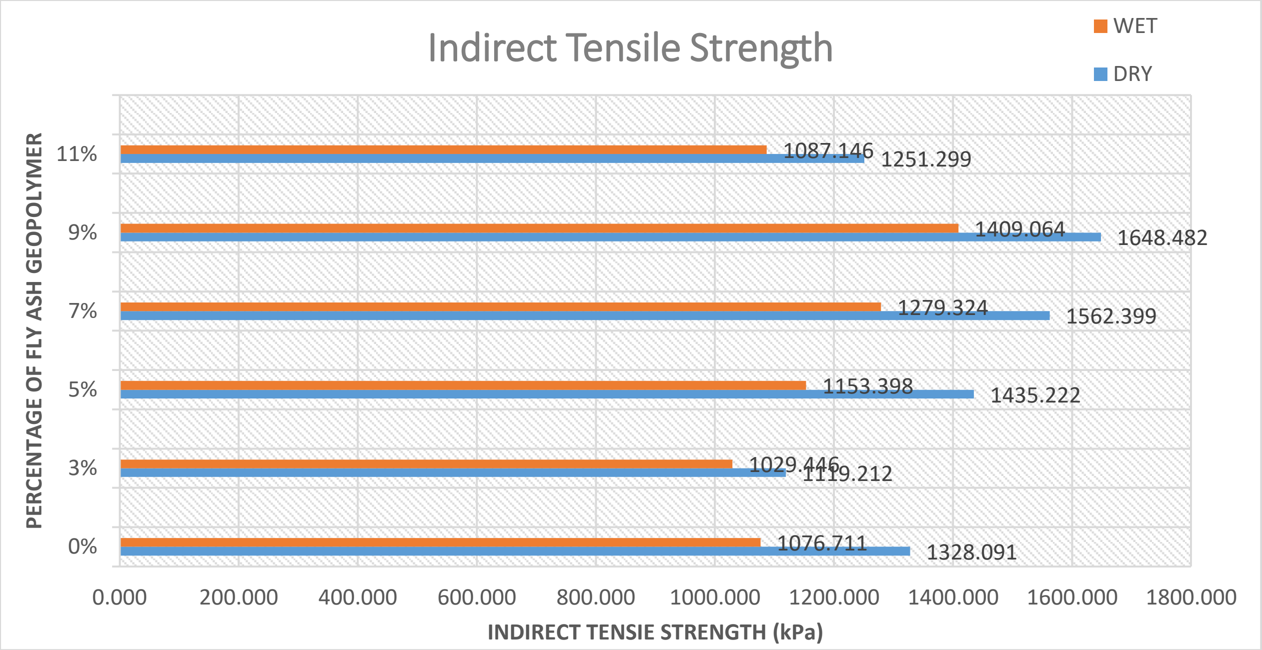

Figure 2: Effect of Fly Ash Geopolymer on Indirect Tensile Strength

3.6 Effect of Fly Ash Geopolymer on Resistance of Moisture Sensitivity

From The Indirect Tensile Strength Ratio (ITSR) test was perform to measure the effectiveness of FAG on asphalt mixture with 60/70 grade of bitumen due to water damage. Figure 3 shows the average ITSR, which is defined as the ratio ITSR for wet specimen over dry specimen. The graph shows that for the specimens with 3% FAG are the highest value of ITSR compared to the other specimens mixes with 0%, 5%, 7%, 9% and 11% FAG. The lowest ITSR value are 5% FAG. By using 3% FAG, the ITSR value is 92.013. While using 5% FAG the ITSR value are 80.429. According to AASHTO T-283 procedure, the ITSR for water sensitivity must be at least 80%. It can be seen that, all the specimens had more than 80% values and complies with the AASHTO T-283 specification requirement.

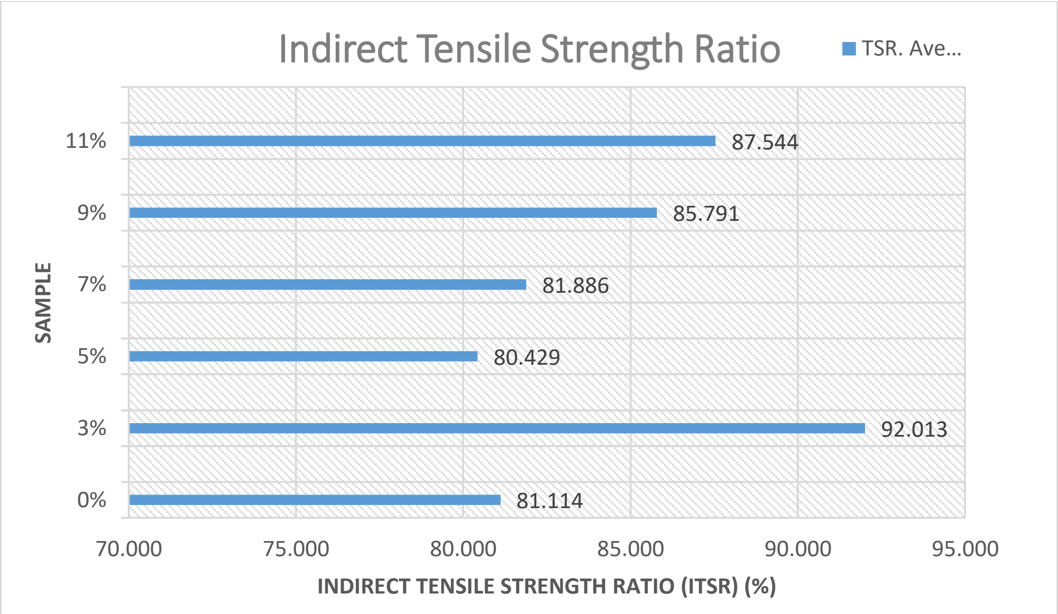

Figure 3: Effect of Fly Ash Geopolymer on Resistance of Moisture Sensitivity

4. Conclusion

Stripping mechanisms are complex and a number of ideas to explain humidity parameters in asphalt blends have been presented. Each theory has some merit, but this complex phenomenon might be hard to prove by itself. According to study, stripping was connected to several factors. Differences such as the combined design and building issues, the surroundings and weather conditions during construction are supposed to induce stripping. The objective of the project is to create a humidity sensitivity test. This ranges from fundamental observations of conditioned samples to more sophisticated conditioning and testing procedures. As the stripping potential was solely assessed by empirically based test techniques, none of the testing was useful in forecasting stripping potential. In this work, the AASHTO T-283 test technique was utilized to evaluate the moisture susceptibility of HMA mixes. One approach to enhance the performance of the asphalt pavement is to use FAG as an asphalt mix. This goes from basic observations of conditioned samples to more advanced conditioning and testing. Since the deletion potential was evaluated exclusively by empirical test procedures, none of the tests was helpful for estimating deletion potential. In this work, the test procedure for the moisture sensitivity of HMA mixtures was used using AASHTOT-283. FAG as an asphalt mix should be used as one way to improve the performance of the asphalt flooring. Then combine asphalt with the test mixtures and the brief oven with the aging. Further compress and analyze the volumetric of the test mixtures. The final is to pick the best test mixtures. The use of the FAG-modified binder in a combination also shows that the ITSR of the specimens is enhanced such that the mixture resists damage to water. Finally, this component may be utilized in the mix to improve the way performance and also to make the road user pleasant. There are also less costs to carry out repairs.

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References

[1] A. Akhtar, A.K. Sarmah, Construction and demolition waste generation and properties of recycled aggregate concrete: A global perspective, J. Clean. Prod. 186 (2018) 262–281.

[2] R. Luo, T. Huang, D. Zhang, R.L. Lytton, Water vapor diffusion in asphalt mixtures under different relative humidity differentials, Constr. Build. Mater. 136 (2017) 126–138.

[3] Leng, Z., Padhan, R. K., & Sreeram, A. (2018). Production of a sustainable paving material through chemical recycling of waste PET into crumb rubber modified asphalt. Journal of Cleaner Production, 180, 682–688. https://doi.org/10.1016/j.jclepro.2018.01.171.

[4] Ali, S. I. A., Yahia, H. A. M., Ibrahim, A. N. H., & Al Mansob, R. A. (2017). High temperatures performance investigation of geopolymer modified bitumen binders. Bearing Capacity of Roads, Railways and Airfields - Proceedings of the 10th International Conference on the Bearing Capacity of Roads, Railways and Airfields, BCRRA 2017, 417–422. https://doi.org/10.1201/9781315100333-60.

[5] Celauro, C., & Praticò, F. G. (2018). Asphalt mixtures modified with basalt fibres for surface courses. Construction and Building Materials, 170, 245–253. https://doi.org/10.1016/j.conbuildmat.2018.03.058.

[6] Khedmati, M., Khodaii, A., & Haghshenas, H. F. (2017). A study on moisture susceptibility of stone matrix warm mix asphalt. Construction and Building Materials, 144, 42–49. https://doi.org/10.1016/j.conbuildmat.2017.03.121.

[7] Ma, L., Varveri, A., Jing, R., & Erkens, S. (2021). Comprehensive review on the transport and reaction of oxygen and moisture towards coupled oxidative ageing and moisture damage of bitumen. *Construction and Building Materials*, *283*, 122632. https://doi.org/10.1016/j.conbuildmat.2021.122632.

[8] Naquib Alam, M., & Aggarwal, P. (2020). Effectiveness of anti-stripping agents on moisture susceptibility of bituminous mix. *Construction and Building Materials*, *264*, 120274. https://doi.org/10.1016/j.conbuildmat.2020.120274.

[9] Perez, A. P., Wåhlin, J., & Klein-Paste, A. (2015). Effect of surface roughness and chemistry on ice bonding to asphalt aggregates. Cold Regions Science and Technology, 120, 108–114. https://doi.org/10.1016/j.coldregions.2015.08.015.

[10] Salim, Ramadan A. (2019). Asphalt Binder Parameters and their Relationship to the Linear Viscoelastic and Failure Properties of Asphalt Mixtures. Asu.Edu. https://doi.org/hdl:2286/R.I.53877.