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# Moisture Sensitivity Performance of Hot Mix Asphalt Mixture Incorporating Fly Ash Geopolymer (FAG) Asphalt Binder

Hazirah Bujang[1,*], Mohamad Yusri Aman[2], Mohammad Nasir Mohamad Taher[2], Sinatu Sadiah Shapie[3]

[1] Spatial Technology for Civil Engineering (STFORCE), Department of Civil Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, 84600 Panchor, Johor, Malaysia
[2] Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia
[3] Civil Engineering Department, Politeknik Melaka, 75250 Plaza Pandan Malim, Melaka, Malaysia

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**ABSTRACT**

In Malaysia, Hot Mix Asphalt (HMA) is widely used in asphalt production. HMA is a mixture of asphalt and aggregates that give durability to the road surface for pavement. Due to vehicles excessive traffic loadings that cause road surface damage, this pavement technology frequently undergoes maintenance and rehabilitation work. This study used recycled material as a modified binder and showned the best result in increasing stiffness and better rutting performance with high percentages of additives. This research focuses on the effect of FAG additive on asphalt mixture performance evaluation according to SuperpaveTM mixes design method. The procedures were specified according to the American Association of State Highway and Transportation Officials (AASHTO), American Society for Testing and Materials (ASTM), British Standard (BS) and Malaysian Standard (MS). The granite aggregate type was produced by a local quarry with conventional asphalt binder grade 80/100 and 60/70. Incorporation FAG in modified asphalt binder as levels of 0, 3, 5, 7, 9, and 11% by mass of asphalt binder. The performance of moisture sensitivity showed low moisture damage susceptibility for the mixture based on consistent values of TSR, in which all the specimens met the minimum TSR threshold of 80%. The optimization findings indicated that 9% of fly ash geopolymer might be the ideal content for modifying the asphalt binder. Overall, research findings suggest that using geopolymers may have improved some of the characteristics of asphalt binder and the performance of asphalt binders in pavement applications. Thus, the outcomes of this research were significantly used for further performance test and analysis on the asphalt mixture.

## 1. Introduction

Environmental conditions and frequent traffic might cause pavement degradation, eventually resulting in fatigue cracking over its service life [1]. Therefore, the exploration of the material fatigue performance needs to be accounted. Fatigue cracking damage is an indication that the service life of

* *Corresponding author.*
*E-mail address: hazirahb@uthm.edu.my*

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the pavement may be improved after a thorough analysis of the properties and evolution of the material. In addition, Qiu *et al.,* [2] stated that asphalt mixture is a composite material with a complicated failure process. A typical flexible pavement structure in Malaysia consists of Hot Mix Asphalt (HMA) surface course, unbound granular base and sub-base overlying the subgrade. Typically, the surface course using HMA technology consists of wearing and binder layers, with different aggregate gradations.

Currently, HMA technology is considered the best material for use as a road surface which is generated at temperatures between 160 and 180 degrees [3]. A high temperature is crucial to ensure the appropriate binder coat and compress the aggregate completely [4]. HMA is mainly utilized in flexible pavement and is created by combining various amounts of aggregate with asphalt binder [5,6]. The qualities of the asphalt binder affect how well the HMA pavement performs. Additionally, environmental conditions such as high temperatures and dampness play a role. The structural performance of the pavement was impacted by these circumstances. Therefore, the use of additives in HMA technique will improve the structural performance of asphalt pavement [7].

Inorganic substances called geopolymers create a long-range, covalently bound non-crystalline skeleton. According to Tang *et al.,* [8], applying geopolymer can make asphalt less viscous and ensure that particles are completely coated. In this way, binder modification using geopolymers improves the performance of asphalt, increases the sustainability of asphalt binders, and reduces the environmental effect of roadways [9-11]. Additionally, various industrial wastes, including coal gangue, fly ash, tailings, and slag, can be employed as raw materials for synthesizing geopolymers [12]. In other words, the creative use of geopolymers as HMA additives is anticipated to open new opportunities for recycling industrial waste and enhance the performance of asphalt mixtures made with various binder grades. In terms of making better use of solid waste resources and boosting environmental protection, both are very significant.

## 2. Methodology

A crush aggregate was dried, and sieved into a selected size range according to Superpave$^{TM}$ gradation. The sample was batching approximately 1200g for one sample. The batched aggregates were then pre-heated in the oven for a period of at least 4 hours at the desired mixing temperature. The bitumen grade penetration 60/70 and 80/100 was heated to simulate the aging condition. The laboratory mixing apparatus such as a mixer bowl, scoop, mould, and tray was also pre-heated in the oven to avoid binder from being rammed.

### *2.1 Mixing and Compaction Temperature*

During the mixing process, the aggregate was heated in the oven for 4 hours at temperature 160°C and the binder heated for 2 hours. Each 1100 g batched aggregate was mixed using a 20L heavy-duty mixer as shown in Figure 1(a) with 160°C for 3 minutes until they became well coated mixture. Before compaction, the mixes and mould were heated in oven for 2 hours. Subsequently, the mixing was poured into the mould in three layers and each layer were tamping using spatula with 15 times at the edge and 10 times at the middle. The specimens were compacted in a mould using Superpave gyratory compactor with 100 gyrations as shown in Figure 1(b).


(a) (b)

**Fig. 1.** Figure mixing and compaction sample (a) 20L heavy-duty mixer (b) Superpave gyratory compactor

### *2.2 Moisture Sensitivity Test*

Moisture damage also known as stripping is a common problem occurs to asphalt Pavement. Modified Lottman Test (AASHTO T283, 2007) procedures was used to evaluate the potential susceptibility of mixture to the water damage [13-15]. The advantage of this test is that the physical and mechanical properties of mixture, water/traffic action and pore pressure effect can be considered. Three specimens were selected as a control and tested without moisture conditioning and known as dry sample. Before run the test, the dry sample was precondition in incubator at 25°C for 2 hours.

The wet subsets were condition by saturating with water 55%-80% saturation level for 24 hours and was place in the 25°C water bath for 2 hours with a 25 mm of water above the surface of specimen. Next followed by a freeze subset by wrapped specimens in plastic bag with containing 10 ml distilled water and place specimen in freezer temperature -18°C for 16 hours. Then immerse specimens at 60°C in water bath for 24 hours. After that, remove plastic and place at room temperature 25°C for 2 hours.

The specimen was tested for indirect tensile strength (ITS) by loading the specimen at a constant rate of 50.0 mm/minutes with vertical deformation at 25°C and measure the force required to break the specimen. To determine the tensile strength ratio (TSR) the ITS of condition specimen is compare to the control specimen in order. The ITS value must not less than 80% and the TSR is calculated using the following Eq. (1):

$$\text{TSR} = \frac{S1}{S2} \quad (1)$$

where:
TSR = The Tensile Strength Ratio (TSR)
S1 = The average tensile strength of the dry subset (kPa)
S2 = The average tensile strength of the conditions subset (kPa)

## 3. Results

### *3.1 Moisture Sensitivity Evaluation*

Through this research, the AASHTO T283 (AASHTO, 2007) procedures were used to obtained the indirect tensile strength (ITS) and tensile strength ratio (TSR) [16-18]. These procedures limit the mixture shall be compacted to 7.0% ± 0.5 air voids. The air voids can be reached by adjusting the number of gyrations, adjusting foot pressure, number of tamps, levelling or adjusting the number of revolutions.

#### *3.1.1 Tensile Strength of Dry Subsets*

Figure 2 shown the specimens tensile strength data for dry subsets formed at a mixing temperature of 165 °C. Based on three specimens, the ITS values were averaged. As a comparison, the control of HMA mixture were prepared and all specimens were tested by using indirect tensile strength equipment. According to the results shown in Figure 2, all specimens examined under dry conditions exhibit higher tensile strengths compared to those specimens tested under wet conditions.

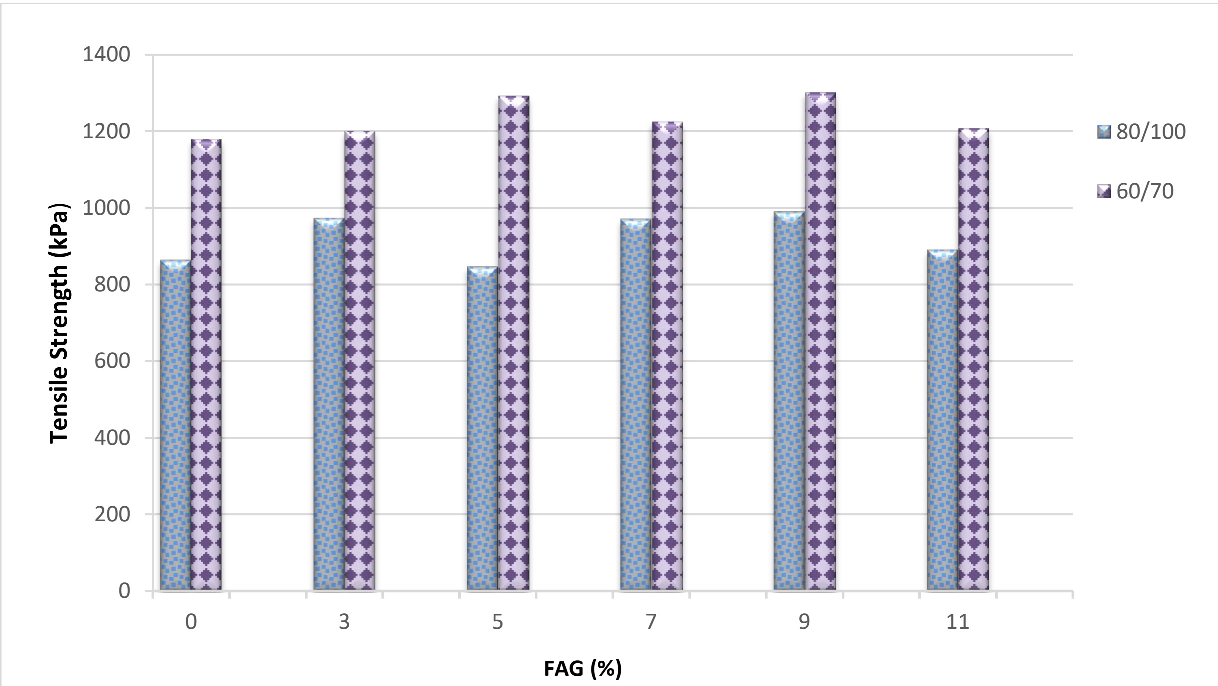


**Fig. 2.** Tensile strength of dry subsets

The strength of the dry subsets typically show varies results as the FAG content increases [19]. Dry specimens of asphalt binder grades 80/100 and 60/70 had tensile strengths that varied between 847 kpa and 990 kpa and 1178 kpa and 1300 kpa, respectively. It demonstrates that specimens with 9% FAG were able to reach a better tensile strength. Incorporating 9% FAG into asphalt binder grade 80/100 and 60/70 improve the tensile strength 14.6% and 10.4% compared to the control mixtures. It was discovered that the tensile strength was considerably impacted by FAG content. This result shows that dry specimen mixes with 9% FAG content have greater tensile strength.

### *3.1.2 Tensile Strength of Wet Subsets*

Figure 3 illustrates the effect of FAG on tensile strength in wet conditions. Overall trend shows that the tensile strength of wet specimen gradually increased with increases of FAG content. In general, the data did show the improvement of tensile strength in the mixture under wet conditions. The tensile strength evaluations for wet specimens of asphalt binder grades 80/100 and 60/70 were obtained in the ranges of 787 kPa to 927 kPa and 1024 kPa to 1194 kPa, respectively. The higher tensile strength of wet specimens was achieved with 9% FAG compare to control specimens. In compared to the control specimens, the tensile strength of 9% FAG for asphalt binder grades 80/100 and 60/70 has dramatically increased by about 17.8% and 16.6%, respectively. This observation shows that the bulk specific gravity of the specimens contributes to the higher tensile strength [20].

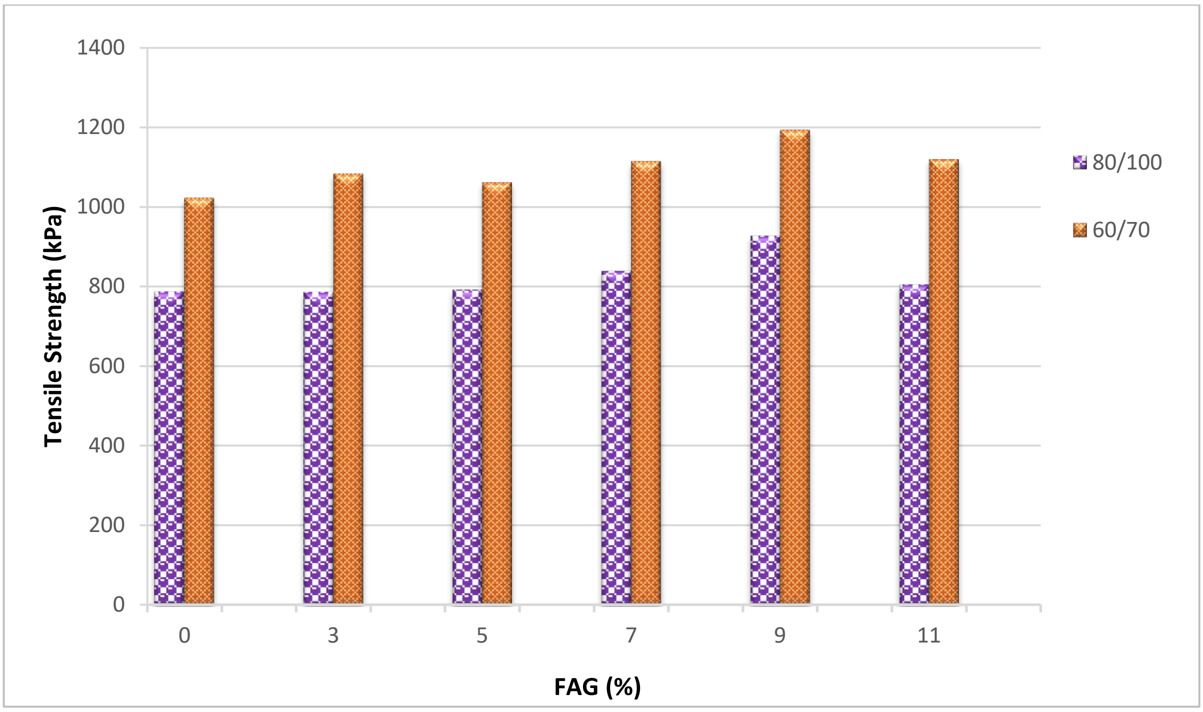


**Fig. 3.** Tensile strength of wet subsets

### *3.1.3 Tensile Strength Ratio (TSR) Value of the Specimens*

Tensile strength ratio (TSR) values for control and modified specimens tested at 25ºC are represented graphically in Figure 4. The specimens were categorised into two groups namely wet and dry subsets, and the ratio of the wet to dry subset was computed to obtain TSR. The graph exhibits low moisture damage susceptibility for the mixture based on consistent values of TSR which all the specimens met the minimum TSR threshold of 80%.  Particularly, the 9% FAG mixture for asphalt binder grades 80/100 and 60/70 has a considerable impact on moisture susceptibility, with computed TSR values reaching 94% and 92% greater over control specimens. For a mixture that could resist moisture susceptibility, a TSR value of 80% and higher is strongly recommended [21].

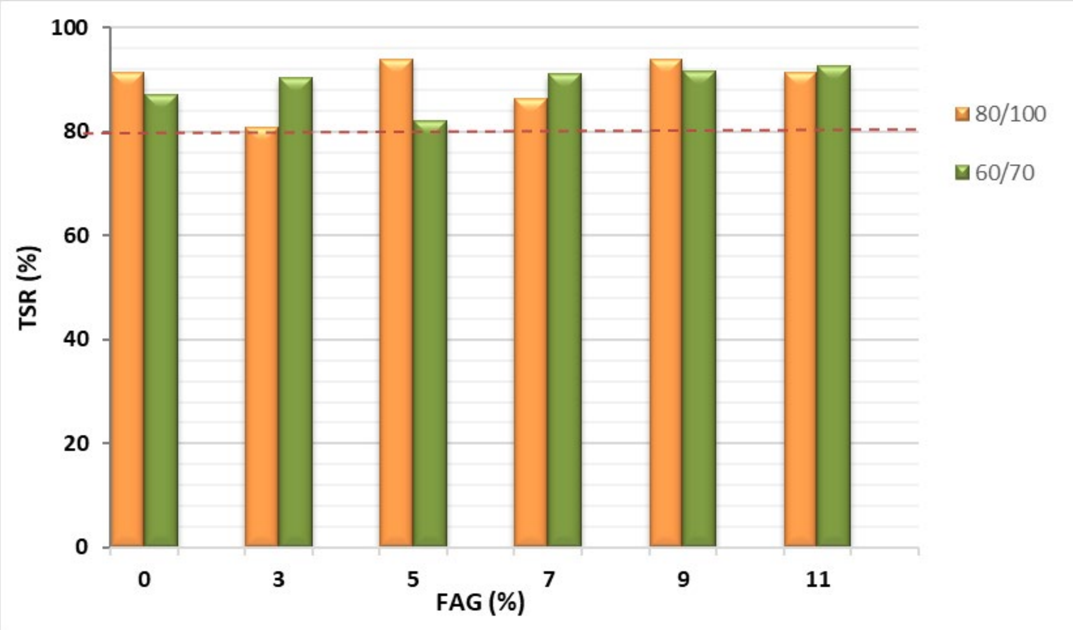


**Fig. 4.** Tensile strength ratio (TSR) value of the specimens

## 4. Conclusions

The experiment data show the effect of FAG on moisture sensitivity for all samples enhanced gradually by the increased of the FAG content. Generally, the strength of dry and wet subsets for asphalt binder grade 80/100 and 60/70 were exhibited higher tensile strength compare to the control specimen. It shows that a higher tensile strength was achieved by specimens with 9% FAG, thus improve the tensile strength compared to the control mixtures. The TSR of the asphalt binder grade 80/100 and 60/70 specimens met the minimum TSR threshold of 80%. The TSR met the minimum TSR threshold of 80% indicated that the specimen resistance to moisture damage. This observation shows that the bulk specific gravity of the specimens contributes to the higher tensile strength.

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## References

[1] Karimi, Mohammad M., Ehsan Ahmadi Dehaghi, and Ali Behnood. "A fracture-based approach to characterize long-term performance of asphalt mixes under moisture and freeze-thaw conditions." *Engineering Fracture Mechanics* 241 (2021): 107418.

[2] Qiu, X., Y. J. Wang, Q. Yang, J. X. Xu, and W. H. Cheng. "Assessment of fatigue damage in asphalt mixture using an acoustic emission approach." In *IOP Conference Series: Materials Science and Engineering*, vol. 542, no. 1, p. 012051. IOP Publishing, 2019. https://doi.org/10.1088/1757-899X/542/1/012051

[3] Omranian, S. R., M. O. Hamzah, G. S. Mounik, K. P. Reddy, Y. M. Kapadia, and S. Y. Teh. "Laboratory investigation on warm mix asphalt incorporating organo-silane additive." In *IOP Conference Series: Earth and Environmental Science*, vol. 463, no. 1, p. 012068. IOP Publishing, 2020. https://doi.org/10.1088/1755-1315/463/1/012068

[4] Arshad, A. K., E. Shaffie, F. Ismail, W. Hashim, and N. S. F. Mustapa. "Warm Mix Asphalt Surfacing Performance for Different Aggregate Gradations with Cecabase RT Additive." In *IOP Conference Series: Earth and Environmental Science*, vol. 498, no. 1, p. 012019. IOP Publishing, 2020. https://doi.org/10.1088/1755-1315/498/1/012019

[5] Azarhoosh, Ali Reza, Fereidoon Moghadas Nejad, and Ali Khodaii. "Nanomaterial and fatigue cracking of hot mix asphalt." *Road Materials and Pavement Design* 19, no. 2 (2018): 353-366. https://doi.org/10.1080/14680629.2016.1261724
[6] Jitsanigam, Peerapong, Wahidul K. Biswas, and Martyn Compton. "Sustainable utilization of lime kiln dust as active filler in hot mix asphalt with moisture damage resistance." *Sustainable Materials and Technologies* 17 (2018): e00071. https://doi.org/10.1016/j.susmat.2018.e00071
[7] Bujang, H., M. Y. Aman, T. N. Arumugam, and M. N. M. Taher. "Physical Characterization of Modified Asphalt Binder with Differing Fly Ash Geopolymer Contents." *International Journal of Integrated Engineering* 15, no. 1 (2023): 331-338. https://doi.org/10.30880/ijie.2023.15.01.030
[8] Tang, Ning, Zhaoxue Deng, Jian-Guo Dai, Kaikai Yang, Chongyang Chen, and Qing Wang. "Geopolymer as an additive of warm mix asphalt: Preparation and properties." *Journal of cleaner production* 192 (2018): 906-915. https://doi.org/10.1016/j.jclepro.2018.04.276
[9] Hamid, Abdulrahman, Hamed Alfaidi, Hassan Baaj, and Mohab El-Hakim. "Evaluating fly ash-based geopolymers as a modifier for asphalt binders." *Advances in Materials Science and Engineering* 2020 (2020): 1-11. https://doi.org/10.1155/2020/2398693
[10] Milad, Abdalrhman, Ahmed Suliman B. Ali, Ali Mohammed Babalghaith, Zubair Ahmed Memon, Nuha S. Mashaan, Salaheddin Arafa, and Nur Izzi Md. Yusoff. "Utilisation of waste-based geopolymer in asphalt pavement modification and construction—A review." *Sustainability* 13, no. 6 (2021): 3330. https://doi.org/10.3390/su13063330
[11] Hamid, Abdulrahman, Hassan Baaj, and Mohab El-Hakim. "Temperature and Aging Effects on the Rheological Properties and Performance of Geopolymer-Modified Asphalt Binder and Mixtures." *Materials* 16, no. 3 (2023): 1012. https://doi.org/10.3390/ma16031012
[12] Sun, Qi, Shuo Tian, Qingwei Sun, Bing Li, Chang Cai, Yajie Xia, Xing Wei, and Qianwen Mu. "Preparation and microstructure of fly ash geopolymer paste backfill material." *Journal of Cleaner Production* 225 (2019): 376-390. https://doi.org/10.1016/j.jclepro.2019.03.310
[13] Abuawad, Ibrahim MA, Imad L. Al-Qadi, and James S. Trepanier. "Mitigation of moisture damage in asphalt concrete: Testing techniques and additives/modifiers effectiveness." *Construction and Building Materials* 84 (2015): 437-443. https://doi.org/10.1016/j.conbuildmat.2015.03.001
[14] Iskender, Erol. "Evaluation of mechanical properties of nano-clay modified asphalt mixtures." *Measurement* 93 (2016): 359-371. https://doi.org/10.1016/j.measurement.2016.07.045
[15] Vargas-Nordcbeck, Adriana, Fabricio Leiva-Villacorta, José Pablo Aguiar-Moya, and Luis Loria-Salazar. "Evaluating moisture susceptibility of asphalt concrete mixtures through simple performance tests." *Transportation Research Record* 2575, no. 1 (2016): 70-78. https://doi.org/10.3141/2575-08
[16] Boz, Ilker, Jhony Habbouche, and Stacey Diefenderfer. "The Use of the Indirect Tensile Test to Evaluate the Resistance of Asphalt Mixtures to Cracking and Moisture-Induced Damage." In *Airfield and Highway Pavements 2021*, pp. 104-114. 2021. https://doi.org/10.1061/9780784483510.010
[17] Tarefder, Rafiqul A., and Mohiuddin Ahmad. "Evaluating the relationship between permeability and moisture damage of asphalt concrete pavements." *Journal of Materials in Civil Engineering* 27, no. 5 (2015): 04014172. https://doi.org/10.1061/(ASCE)MT.1943-5533.0001129
[18] Iskender, Erol. "Evaluation of mechanical properties of nano-clay modified asphalt mixtures." *Measurement* 93 (2016): 359-371. https://doi.org/10.1016/j.measurement.2016.07.045
[19] Chen, Shikun, Shengqian Ruan, Qiang Zeng, Yi Liu, Mingzhong Zhang, Ye Tian, and Dongming Yan. "Pore structure of geopolymer materials and its correlations to engineering properties: A review." *Construction and Building Materials* 328 (2022): 127064. https://doi.org/10.1016/j.conbuildmat.2022.127064
[20] Gardete, Dinis, Luís Picado-Santos, Silvino Capitão, and Rosa Luzia. "Asphalt mix design: Discussion on the bulk specific gravity procedure influence on the results obtained from empirical, volumetric, and performance-based methods." *Construction and Building Materials* 342 (2022): 127870. https://doi.org/10.1016/j.conbuildmat.2022.127870
[21] Das, Bhaskar Pratim, and Anjan Kumar Siddagangaiah. "Moisture damage analysis based on adhesive failure in asphalt mixtures." *International Journal of Pavement Engineering* 23, no. 8 (2022): 2554-2564. https://doi.org/10.1080/10298436.2020.1862840