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The Assessment of Stiffness Modulus Characteristic of Asphalt Concrete With The Existing Moisture – A Review

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Abstract: Moisture damage is one of the major problem that contribute to asphalt concrete (AC) distress due to the loose of stiffness modulus characteristic. The presence of moisture in AC had affect the strength of adhesive and cohesive properties of bitumen and mixture component. Due to this problems, the bond between AC mixture becomes weak and lead AC to manifest distress such as stripping, rutting and raveling. This study was conducted by reviewing the previous research journal that related with this issue and the main objective is to evaluate the stiffness modulus characteristic of AC with and without moisture effect. Besides that, this study also evaluated the capability of additive in AC mixture to resist the effect of moisture. The comparison between stiffness modulus result from Indirect Tensile Stiffness Modulus (ITSM) test for conditioned and unconditioned sample has been made. In order to categorize the most susceptible or resistant to moisture AC mixture, the Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR) value has been identified. Based on the result of comparison of ITS and TSR ratio, it showed that the use of additive in AC mixture indicated the improvement and relatively resistance to moisture. From ITSM test result, it shows that the stiffness modulus characteristic of AC mixture reduced with the presence of water. This result was similarly with the AC mixture sample with additive. In order to approach a better understanding and improvement for the study, it is possible to recommend for the future investigation, it should consider the reliability and repeatability of the test result. The assessment and evaluation of moisture damage resistance of AC mixture supposed to be in the range of the optimum value of additive that been mixed in the AC mixture. With the comprehensive assessment and analysis, it will provide a guidance for the industry to produce stable, durable and moisture resistance AC mixture.

Keywords: Asphalt Concrete, Indirect Tensile Stiffness Modulus, Indirect Tensile Strength, Tensile Strength Ratio

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1. Introduction

Road is defined as a route or a way which is one of the most important transport element in the world that play roles in economic system and country development [1]. The road construction should follow the standard specification design in order to achieve the demand and requirement of high quality transport network. Therefore, road pavement is design based on the factor such as traffic loading, material and environment condition.

Moisture damage is one of the major problem that contribute to AC distress due to the loose of stiffness modulus characteristic [2]. According to Abtahi [3], the presence of moisture in AC had affected the strength of adhesive and cohesive properties of bitumen. Therefore, to overcome this problem, many researches had been conducted to study the parameter which helps to improve the AC design. There are many factors that contribute to moisture damage of AC such as mixture design, production, construction and climate factor [4].

Modification of AC mixture design is one of the approach taken to improve AC pavement. There are many researches of various types of material added to AC mixed design and tested to identify the different strength and effectiveness in improving AC stiffness. The rutting resistance and modulus characteristics of AC can be improved after the use of styrene butadiene styrene an an additive in AC mixture [5]. The other improvement of moisture resistance and moisture susceptibility of AC mixture is been revealed when it been mixed with Hydarated Lime and Portland Cement [6].

The combination of styrene butadiene styrene and hydrated lime as additive in AC mixed can affect mechanical properties of AC especially the moisture damage resistance [7]. Besides that, others type of additives such as nano-silica, polyster resin, paraffin wax, polyethylene and Evo therm also can improve the AC mechanical properties and characteristic [8, 9 and 10]. Therefore, this study focus to investigate the effect of water to the stiffness characteristic of AC and the capability of additive in AC to resist the effect of moisture.

2. Literature

The framework of the activities is according to the scope and objective in order to satisfy the goal of the study. The strategies to find previous researched paper was conducted through searching in few publication databases such as Web of Science Direct, Research Gate and Google Scholar. All selected paper will be screened through eligibility and exclusion criteria. Only the related papers were selected for analysis. Data that collected from journal and articles were based on the effect of moisture to the stiffness modulus of AC and the capability of additive in AC to resist effect of moisture. Hence, the results that obtained were refering to these reliable sources collected data.

2.1 Searching of reading material

The search strategies for research paper was conducted through a schematic literature search in few publication databases Web of Science Direct, Research Gate and Google Scholar. All of this databases are widely used in engineering research paper. Three main search categories were identified:

i. Capability Additive in Asphalt Concrete
ii. Moisture Damage of Asphalt Concrete
iii. Stiffness Modulus of Asphalt Concrete

Figure 2.1 shows the flowchart of the searching process and the results. After removal of unsuitable an unrelated paper, 7 papers were identified as journals or articles. Through eligibility and exclusion criteria the title and abstract of which relate to these paper was assessed. Only the related paper that fulfill eligibility were used and included for further analysis

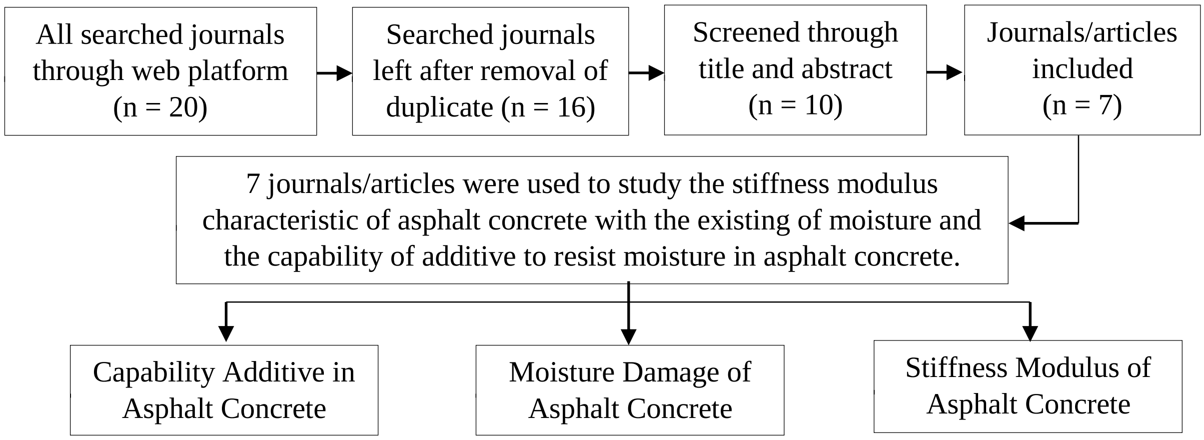


Figure 2.1: Flow chart of searching reading material process

2.2 Inclusion and exclusion criteria

Seven paper journals/articles were finally eligible. The research paper was extracted and divided into different categories by refering to the relevant information. The main category was "The Stiffness Modulus Characteristic of Asphalt Concrete with The Existing of Moisture" and "The Capability of Additive To Resist Moisture In Asphalt Concrete". Each category then divided into sub categories which is "Capability Additive in Asphalt Concrete", "Moisture Damage of Asphalt Concrete" and "Stiffness Modulus of Asphalt Concrete". Others relevant strength value were also extracted and analyzed. There are some paper not including the exact values and only presented result in diagram. For the paper investigating various parameter, similar parameter was chosen and kept constant. Table 2.1 shows the inclusion and exclusion criteria for the searched journal.

Table 2.1: Inclusion and exclusion criteria of reading material

Criteria	Eligibility criteria	Exclusion criteria
Language	• English language	• Non-English language
Literature type	• Journal • Articles	• Others document type than research paper (e.g. books, books-section, review)
Title/abstract keyword	• Asphalt concrete • Moisture damage • Additive capability • Stiffness modulus	• Non - Asphalt concrete - Moisture damage - Additive capability - Stiffness modulus
Timeline	2000-2020	Others than 2010-2020

3. Results and Discussion

According to the reading materials, the performance of AC been observed and evaluated based on the Indirect Tensile Stiffness Modulus (ITSM), Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR). There was a various type of additive that been used to evaluate the effectiveness in improving AC characteristic. Table 3.1 shows the data of tensile strength and stiffness modulus of asphalt concrete from the total of 7 journals of different author and year of publication. The comparison of strength between AC under conditioned and unconditioned been made to identify the effect of moisture. All of this data was presented using bar chart and linear graph to show the comparison.

Table 3.1: Indirect Tensile Strength (ITS) and Indirect Tensile Stiffness Modulus (ITSM) of previous research

Author (year)	Type additive	Percentage additive (%)	ITS (kPa) Mixed Additive		ITS (kPa) Control Sample		TSR (%)		ITSM (MPa) Control Sample	
			Conditioned	Unconditioned	Conditioned	Unconditioned	Mixed Additive	Control Sample	Conditioned	Unconditioned
Yan et al., (2020)	Rubberised (R)	18%	-	-	-	-	89	87	-	5000
	Styrene-Butadiene-Styrene (SBS)	18%	-	-	-	-	93		-	5500
	Polyymer fiber (PF)	18%	-	-	-	-	86		-	6000
Behiry, (2013)	Portland cement (PC)	-	790	810	600	620	98	97	-	-
	Hydrated Lime (HL)	-	1220	1240			98		-	-
Kok & Yilmaz, (2009)	Styrene-Butadiene-Styrene (SBS)	2	500	690	500	650	72	77	-	1170
		4	520	710			73		-	1300
		6	550	820			67		-	1610
	Hydrated Lime (HL)	2	550	690			80		-	900
	Styrene-Butadiene-Styrene with Hydrated Lime (SBSHL)	2	560	700			80		-	1210
		4	610	750			81		-	1400
		6	770	870			89		-	1880
Moghadas Nejad et al., (2013)	High density Polyethylene (HDPE)	0.48	900	1100	810	1050	82	77	990	1185
	Low density Polyethylene (LDPE)	0.48	880	1090			81		970	1100

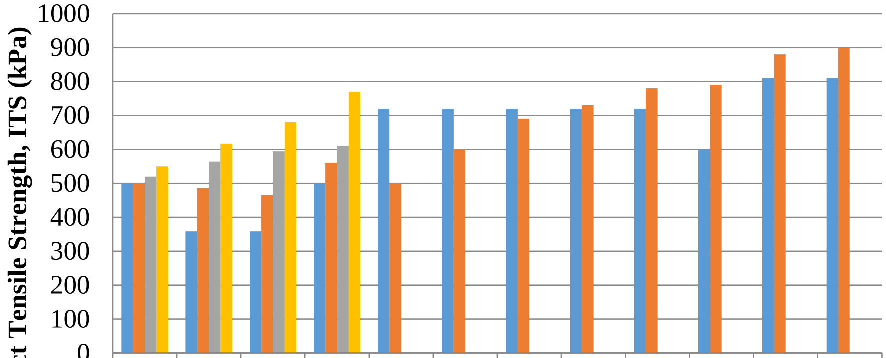
Table 3.1: (continued)

Author(s) (year)	Type additive	Percentage additive (%)	ITS (KPa) Mixed Additive		ITS (KPa) Control Sample		TSR (%)		ITSM (MPa) Control Sample	
			Conditioned	Unconditioned	Conditioned	Unconditioned	Mixed Additive	Control Sample	Conditioned	Unconditioned
Taherkhani & Tajdini, (2019)	Nano-silica (NS)	2	465.1	612	359	560	76	64	-	1473
		4	594	707			84		-	1845
		6	680	765			89		-	2293.7
	Hydrated Lime (HL)	1.5	486	635			77		-	1579
		2	564	683			83		-	1924
		2.5	617	714			86		-	2199
Yu et al., (2018)	Evotherm-DAT (EDAT)	0.5	500	680	720	850	74	85	-	1500
	Evotherm-3G (E3G)	0.5	690	750			92		-	2000
	Sasobit (SAS)	3	730	900			81		-	2750
	Paraffin Wax (PW)	1.5	600	800			75		-	2080
Ahmedzade& Yilmaz, (2008)	Polyster Resin (PR)	0.75	780	800	720	760	98	95	-	1986.5

3.1 Comparison of ITS result for conditioned specimens.

As mentioned before, ITS is a test to determine the tensile strength properties of AC which can be further related to the determine the moisture susceptibility of AC through TSR between conditioned and unconditioned specimens. Figure 3.1 shows the value of ITS for each conditioned specimens of mixture with and without additive and the different type of additive used with different percentages amount of additive. It was observed that the most ITS value for specimen with additive are higher than the control specimen without additive mixture except for the EDAT, PW and E3G additive. The ITS value for the specimens mixed with this additive was lower than the control specimens.

This problem is due to the additive which was not evaporated completely during mixing process with high dosage in the AC mixture [9]. Besides that, the temperature during mixed process also influenced the additive performance and would affected the ITS result. For the specimens which mixed with SBS, SBSHL, HL and NS at the left hand side of the bar chart, its shows that the value of ITS are significantly improved with the increasing of additive content. Besides that, other additives such as SAS, PR, PC, LDPE and HDPE also shows the improvement of ITS value in single mixed ratio of additive used. This improvement showed that different additive ratio used had a result to the improvement of ITS value.



	SBS (2,4, 6%)	HL(1.5, 2,2. 5%)	NS(2,4, 6%)	SBS HL(2,4, 6%)	ED AT(0.5 %)	PW(1.5 %)	E3G (0.5 %)	SAS (3%)	PR(0.75 %)	PC(NS)	LDP E(0. 48%)	HD PE(0.48 %)
Control Specimens	500	359	359	500	720	720	720	720	720	600	810	810
Mixed Additive Specimens	500	486	465	560	500	600	690	730	780	790	880	900
	520	564	594	610								
	550	617	680	770								

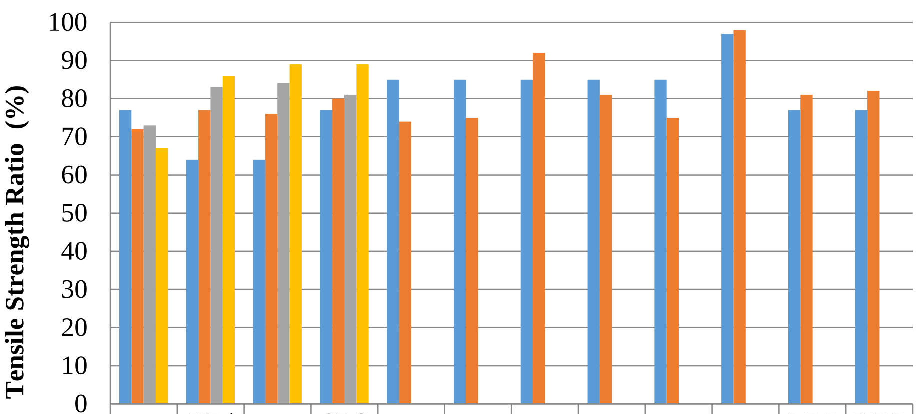
Figure 3.1: Indirect Tensile Strength (ITS) (kPa) for control mixture and mixture with additive (conditioned)

3.2 Comparison of TSR result

In order to categorize the specimens of AC is susceptible or resistant to moisture, the TSR value need to be identified. AC mixture which having TSR value of 80 % and above are relatively good resistance to moisture damage and if the value of TSR is less than 80 % the AC considered as moisture susceptible mixture [6]. Therefore, minimum acceptable TSR value for AC as a resistance mixture to moisture damage is 80 % and above. Based on Figure 3.2, its shows the value of TSR for each specimen that mixed with and without additive were compared. The figure also shows the different type of additive used with different type of ratio have different TSR value result. The used of additive in AC mixed such as HL, NS, SBSHL, E3G, PC, LDPE and HDPE indicated the improvement in TSR value compared with the control specimens.

Besides that, the specimens mixed with additive HL, NS and SBSHL show that TSR values are significantly improved with the increasing of additive content. In addition, the combination of multiple additive added into AC mixture also could improve the tensile strength and moisture resistance ability. Similar research also found that the combination of SBS and HL in AC mixture show the high TSR value [7]. The TSR value increased from 80 to 89 % with the increment of 2 to 6 % of additive and it shows that the AC mixture is relatively resistance to moisture. On the other hand, the specimens with the additive such as SBS, EDAT, PW, SAS and PR shows the lower result of TSR if compared with control specimens. This shows that this type of additive was not effective in certain AC design ratio. This problem occurs for certain bitumen grades, due to the temperature heat during mixed process and the evaporation of additive was not complete during mixing process which directly influence the reult of ITS and TSR [9].

The specimen with PC additive mixed shows the highest TSR value among others type of additive. The result of 98% of TSR shows that this specimens was categorised as relatively high resistance to moisture. PC additive is an anti-stripping agent which react with aggregate and strengthen the bond between aggregate interface and bitumen. When the high polar molecule of aggregate reacts with anti-striping agent and form insoluble salt which no longer absorb water [10]. Through this situation, aggregate and bitumen bonding improves and reduce moisture damage in AC. By adding PC in AC mixture, it become an effective agent for emulsion mixture that reduce moisture susceptibility in AC and increased the tensile strength [6].



	SBS(2,4,6%)	HL(1.5,2,2.5%)	NS(2,4,6%)	SBSHL(2,4,6%)	EDAT(0.5%)	PW(1.5%)	E3G(0.5%)	SAS(3%)	PR(0.75%)	PC(NS)	LDPE(0.48%)	HDPE(0.48%)
Control Specimens	77	64	64	77	85	85	85	85	85	97	77	77
Mixed Additive Specimens	72	77	76	80	74	75	92	81	75	98	81	82
	73	83	84	81								
	67	86	89	89								

Figure 3.2: Tensile Strength Ratio (%) for control mixture and mixture with additive

3.3 Comparison of ITSM result

Figure 3.3 shows the relationship of different type of additive and percentage used to measure the stiffness modulus strength of AC. The specimen test was conducted according to European Standard EN 12697-26, Annex C standardized procedure of Indirect Tensile Stiffness Modulus test [7]. Based on Figure 3.3, it shows that the AC mixture with highest 18% of additive which is PF, SBS, and R results the higher stiffness modulus among others additive content. The PF additive gave the result of the highest stiffness strength value followed by SBS and R [5]. It is also showed that stiffness modulus value was significantly been improved with the increasing of additive content. This also been supported by the study which show the result of additive content SBS, SBSHL and NS at 2%, 4% and 6% had increased the stiffness modulus value as the additive content increased [7 and 11].

Additive of HL also show the same cases at 1.5%, 2% and 2.5% of additive content. In the range of 3% to 6% of additive content, SAS additive shows the highest stiffness strength at 3% of content compare with SBS, SBSHL and NS at 4% and 6% content. This result shows that the used of SAS as an additive was more effective in AC mixture between the range of additive content. With the situation of the AC mixture for the conditioned and unconditioned situation which mixed with NS, HL, LDPE and HDPE additive, it shows that the ITSM value for conditioned specimens are lower than the unconditioned specimen. From this result, it was clearly shows that the presence of moisture will directly affected the stiffness modulus value of AC even it consist of an additive in the mixture.

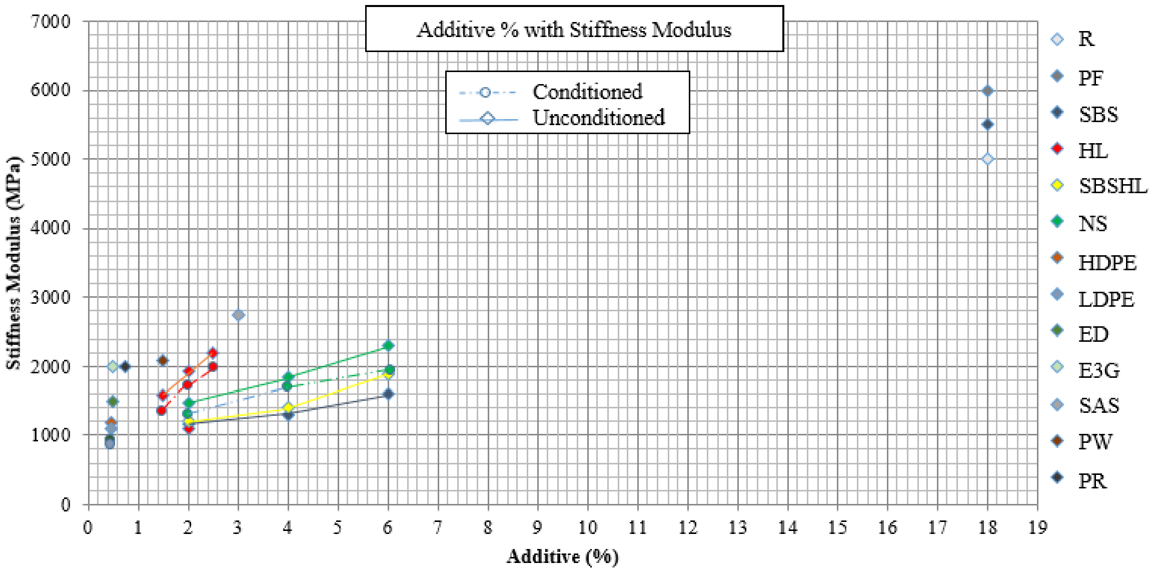


Figure 3.3: Relationship between the stiffness modulus value (kPa) with content of additive in AC mixture (%)

4. Conclusion and Recomendation

From the result and discussion, it showed that by adding the additive was able to enhance the performance of AC mixture in resisting the effect of moisture with an appropriate amount of additive that been used. Besides that, it also found that the results of conditioned and unconditioned of sample with additive and without additive indicated that moisture contributed an effect to the ITS and stiffness modulus value of AC. In this study, it was summarized that AC mixture with additive showed the improvement of the ITS value if compared with the control mixture which without having any additive.

Additives such as SBS, SBSHL, HL, NS SAS, PR, PC, LDPE and HDPE showed the improved value of ITS with the increasing of additive content except for the EDAT, PW and E3G additive. This problem occured due to the certain bitumen grades, the temperature heat during mixed process and the evaporation of additive which not fully completed during the mixing process. AC mixture with the used of 6% NS additive showed the highest improvement of ITS value. The other improvement of ITS value also been demonstrated from the AC mixture with the additive of 5 % HL and 6 % SBSHL. Therefore, it can be concluded that in this study, the used of additive in the AC mixture improved and increased the ITS value.

Stiffness modulus of AC mixture was influenced with the present of moisture. The result of ITSM of AC mixed under conditioned and unconditioned specimens showed that the stiffness modulus of conditioned sample had much lower value than the unconditioned sample. It clearly showed that the presence of moisture in AC directly able to reduce the stiffness modulus of AC even with there additive been used in the AC mixture. The moisture kept weakening the bond of aggregate and bitumen and reduced the adhesion and cohesion of the mixture. However, by adding the additive in AC mixture, it showed that the effect of moisture in reducing the stiffness modulus value can be reduced.

The study also showed that most type of the additive used in AC mixed improved the TSR value if compared with the control specimens. The increment of moisture resistance also influenced from the amount of additive used in AC mixture. The increment amount of additive significantly indicated the improvement of TSR value and it able to change the AC mixture characteristic from moisture susceptible to the moisture resistance. Therefore, it was proved that by using the additive with the effective amount in AC mixture had improved the resistance of moisture damage.

4.1 Recomendation

In order to obtain a better understanding and improvement for the study, it is possible to recommend for the future investigation, it should consider the reliability and repeatability of the test result. Besides that, the study should observe and evaluate other parameters and variables with various performance tests. The assessment and evaluation of moisture damage resistance of AC mixture supposed to be in the range of the optimum value of additive that been mixed in the AC mixture. With the comprehensive assessment and analysis, it will provide a guidance for the industry to produce stable, durable and moisture resistance of AC mixture. It will prolong the lifespan of AC and reduce the cost of future AC pavement maintenance.

References

[1] U. J. Alengaram, B. A. Al Muhit and M. Z. Jumaat, “Utilization of oil palm kernel shell as lightweight aggregate in concrete - A review,” Construction Building Material, vol. 38, pp. 161–172, 2013, doi: 10.1016/j.conbuildmat.2012.08.026.

[2] E. A. Igwe, E. O. Ekwulo and C. G. Ottos, “Moisture Effect on Stiffness of Asphalt Concretes for Low Volume Roads: Comparative Study of Asphalt Institute and Witczak 1-40D Models,” International Journal of Constructive Research in Civil Engineering, vol. 2, no. 4, 2016, doi: 10.20431/2454-8693.0204002.

[3] S. M. Abtahi, M. Sheikhzadeh and S. M. Hejazi, “Fiber-reinforced asphalt-concrete - A review,” Construction Building Material, vol. 24, no. 6, pp. 871–877, 2010, doi: 10.1016/j.conbuildmat.2009.11.009.

[4] H. M. Hamada et al., “Properties of Concrete Containing High Volume Palm Oil,” International Journal of Civil Engineering, vol. 125, pp. 100–107, October 2011, doi: 10.1016/j.proeng.2015.11.119.

[5] J. Yan, et al., “Characterization and comparison of high-modulus asphalt mixtures produced with different methods,” *Construction Building Material*, vol. 237, pp. 117594, 2020, doi: 10.1016/j.conbuildmat.2019.117594.

[6] A. E. Behiry, “Laboratory evaluation of resistance to moisture damage in asphalt mixtures,” Ain Shams Engineering Journal, vol. 4, no. 3, pp. 351–363, 2013, doi: 10.1016/j.asej.2012.10.009.

[7] B. V. Kok and M. Yilmaz, “The effects of using lime and styrene-butadiene-styrene on moisture sensitivity resistance of hot mix asphalt,” *Construction Building Material*, vol. 23, no. 5, pp. 1999–2006, 2009, doi: 10.1016/j.conbuildmat.2008.08.019.

[8] P. Ahmedzade and M. Yilmaz, “Effect of polyester resin additive on the properties of asphalt binders and mixtures,” Construction Building Material, vol. 22, no. 4, pp. 481–486, 2008, doi: 10.1016/j.conbuildmat.2006.11.015.

[9] H. Yu et al., “Workability and mechanical property characterization of asphalt rubber mixtures modified with various warm mix asphalt additives,” Construction Building Material, vol. 175, pp. 392–401, 2018, doi: 10.1016/j.conbuildmat.2018.04.218.

[10] F. M. Nejad et al., “Influence of using polymeric aggregate treatment on moisture damage in hot mix asphalt,” Construction Building Material, vol. 47, pp. 1523–1527, 2013, doi: 10.1016/j.conbuildmat.2013.06.060.

[11] H. Taherkhani and M. Tajdini, “Comparing the effects of nano-silica and hydrated lime on the properties of asphalt concrete,” Construction Building Material, vol. 218, pp. 308–315, 2019, doi: 10.1016/j.conbuildmat.2019.05.116.