Enhancing the Moisture Resistance in Asphalt Mixtures Using Epoxy Resin

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Received: 2 June 2025 | Revised: 22 June 2025 and 12 July 2025 | Accepted: 16 July 2025

 DOI: https://doi.org/10.48084/etasr.12476

ABSTRACT

Moisture damage is a critical issue that deteriorates the asphalt pavement, diminishes the road's longevity, and increases the likelihood of road failure. This study investigates the impact of epoxy resin, recognized for its strong adhesive properties, on the moisture resistance of asphalt mixtures by incorporating three ratios: 5%, 10%, and 15%. The Marshall, Tensile Strength Ratio (TSR), and Index of Retained Strength (IRS) tests were conducted to assess the influence of the epoxy resin on the asphalt performance. The results indicated that the Marshall characteristics, as well as the asphalt mixture's water resistance were enhanced. A 10% epoxy resin ratio was found to be the optimum content. The Marshall stability improved by 37.86 %, the TSR by 9%, and the IRS by 6.58%, relative to the original mixture. Epoxy resin supports the environmental sustainability by increasing the pavement resilience, which reduces the maintenance and reconstruction needs, lowers the carbon emissions, minimizes waste, and encourages the efficient use of resources.

Keywords-epoxy resin; epoxy-modified asphalt; moisture susceptibility; moisture damage resistance

I. INTRODUCTION

The condition of roads serves as a critical indicator of a nation's progress and development. The resilience and efficiency of pavements greatly affect the road quality. One of the most significant challenges in maintaining the asphalt pavements is moisture-induced damage. This may result in bleeding and peeling due to inadequate adhesion of bitumen, poor bonding between the asphalt binder and aggregates, and the accumulation of water within the mixture [1]. Moisture damage can also appear as a delamination or deterioration of the surface layer, and such disintegration can escalate rapidly, resulting in potholes that severely compromise the road safety [2]. The primary cause of these issues is the detachment of the asphalt binder from the aggregates or the degradation of the internal structure of the asphalt mixture due to water exposure.
Studies have focused on improving the moisture resistance of asphalt mixtures to enhance the pavement durability and reduce the maintenance requirements. One promising approach is replacing traditional asphalt binders with epoxy resin. Epoxy resins are known for their excellent adhesion properties, chemical durability, mechanical strength, and environmental benefits. As the epoxy, asphalt, and aggregate transition from liquid to solid, their adhesive strength improves, and this bond can form within hours or days, depending on the type of epoxy used and its curing rate. This process significantly enhances the bond between the materials [3]. Epoxy resin has been shown to enhance the lifespan of asphalt pavements, promoting a sustainable infrastructure development and mitigating the environmental impact of the road construction and maintenance [4]. Moreover, bio-epoxy resins derived from vegetable oils have been investigated as environmentally friendly alternatives to conventional epoxy resins. These bio-based materials not only reduce the reliance on petroleum, but also help lower the carbon emissions, while maintaining similar mechanical and chemical properties to traditional epoxies [5]. The addition of epoxy resin to asphalt mixtures has been explored, focusing on the effects of the varying resin content. Specifically, research indicates that adding 4% epoxy resin significantly enhances the moisture resistance, with the TSR improving by 11.3% for mixtures containing limestone aggregate and 21.5% for mixtures with silica aggregate [6]. Another study on 100% Reclaimed Asphalt Pavement (RAP) mixtures revealed that adding epoxy resin (at concentrations between 0.5% and 2%) significantly improves fatigue life, low-temperature fracture resistance, and moisture resistance. The fatigue life of mixtures with 2% epoxy resin increased to 415,000 cycles, and the TSR improved from 40% to 88-89% with 1% epoxy resin, showing substantial benefits for RAP mixtures [7]. The effect of adding epoxy resin to an asphalt mixture modified with Waterborne Epoxy Resin (WER) has also been studied. The best performance was achieved with 20% epoxy resin and TETA (E20-T), showing the highest resistance to deformation and water damage. The indirect tensile ratio increased by 24.65%,

indicating improved moisture resistance. However, increasing the epoxy content above 20% reduced the low-temperature crack resistance. Therefore, it is indicated that 20% epoxy resin significantly enhances the moisture resistance, improving the asphalt surface quality [8].

This study investigates the impact of epoxy resin on the asphalt mixture performance, with a focus on enhancing the moisture resistance and extending the pavement longevity. Asphalt samples with epoxy resin concentrations of 5%, 10%, and 15% were subjected to various tests, including penetration, softening point, flash point, and dynamic rheometer testing. The results for the moisture resistance of the modified asphalt mixes were compared to those of a control mix, without epoxy resin. The primary objective is to extend the service life of asphalt pavements by mitigating common pavement issues, including the rutting and stripping caused by moisture infiltration. This study aims to optimize the epoxy resin ratios for real-world applications by evaluating the impact of varying epoxy concentrations on the asphalt's resistance to moisture-induced deterioration. The results will help create more moisture-resistant asphalt materials, which will increase the lifespan of roads, lower the maintenance costs, and improve the pavement performance in general under damp conditions.

II. MATERIAL CHARACTERIZATION

Every material used is locally obtained and has been assessed to meet the requirements of the Iraqi Specification for Roads and Bridges (SCRB R/9, 2003).

A. Asphalt Cement

This study utilizes asphalt cement sourced from Dura Refinery, and characterized by a penetration grade of 40–50.

TABLE I. PROPERTIES OF ASPHALT CEMENT

Test	ASTM	Value	SCRB
Penetration (25˚C, 100 g, 5 s)	D5	43	40-50
Softening point °C	D36	52	-
Ductility at 25 °C	D113	135	>100
Specific gravity at 25˚C	D70	1.043	-
Flash point (Cleveland open cup) °C	D92	248	>232
Residue from TFOT			
Retained penetration of residue, % (25°C, 100 g, 5 s)	D5	64	>55
Retained ductility (25˚C, 5 cm/min), cm	D113	72	>25

TABLE II. AGGREGATE GRADATION FOR THE BASE LAYER IN ACCORDANCE WITH SCRB R9/2003

Sieve size	Sieve opening (mm)	Specification passing range (%)	Selected gradation
$1\frac{1}{2}$"	37.5	100	100
1"	25	90-100	95
3/4"	19	76-90	83
1/2"	12.5	56-80	68
3/8"	9.5	48-74	61
No.4	4.75	29-59	44
No.8	2.36	19-45	32
No.50	0.3	5-17	11
No.200	0.075	2-8	5

B. Fine and Coarse Aggregates

Al-Samarra Complex for Asphalt Paving was the local source for the coarse (retained between the 25 mm and 4.75 mm sieves) and fine (retained between No. 4 and No. 200 mm sieves) crushing aggregates used in the base course. The basic properties of the aggregates were established in the lab.

TABLE III. PHYSICAL CHARACTERISTICS OF COARSE AGGREGATES

Test	ASTM	Value	SCRB
Water absorption, %	C127	0.48	-
Bulk specific gravity	C127	2.54	-
Abrasion test (Los-Angeles), %	C131	14	≤ 30
Soundness in magnesium sulfate, %	C88	1.3	≤ 18
Degree of crushing, %	D5821	94	≥ 90

TABLE IV. PHYSICAL CHARACTERISTICS OF FINE AGGREGATES

Test	ASTM	Value	SCRB
Water absorption, %	C128	0.82	-
Bulk specific gravity	C128	2.59	-
Plasticity index	D4318	0.96	≤ 4
Sand equivalent	D2419	92	≥ 45
Clay lumps and friable particles, %.	C142	0	≤ 3

C. Mineral Filler

Limestone dust was incorporated into the asphalt mixture as a filler. It is a crucial component, since it enhances the hardening of the asphalt binder. Fillers are substances that pass through No. 200 sieve with a pore size of 0.075 mm.

TABLE V. PHYSICAL PROPERTIES OF MINERAL FILLER

Test	ASTM	Value	SCRB
% Passing sieve no. 200	D242	96	70% min
Bulk specific gravity	C-188	2.96	-

D. Epoxy Resin

Epoxy resin is a thermosetting polymer consisting of two main components: resin and hardener. When mixed, a chemical reaction (hardening) occurs, producing durable, tough, and environmentally resistant material. The epoxy resin selected for this research can withstand the temperature of the asphalt mix while maintaining its non-toxic and environmentally friendly properties throughout its service life.

TABLE VI. PHYSICAL PROPERTIES OF EPOXY RESIN

Pigment	Colorless transparent
Density (g/cm³)	1.07+0.05
Viscosity (Pa·s)	1200+100
Operating time (100g, 25°C) (min)	40+ 5
Maxing ratio (by volume)	1:1
Temperature range (°C)	10-185

III. MIXTURE PREPARATION

The components are measured and preheated in a kiln before being added to the asphalt cement. The temperature of the asphalt cement increases to about 170°C [9]. First, the dry materials are mixed, then the heated asphalt is added, and finally, the epoxy resin. The ingredients are thoroughly mixed until the desired consistency is reached, and the necessary tests are then performed.

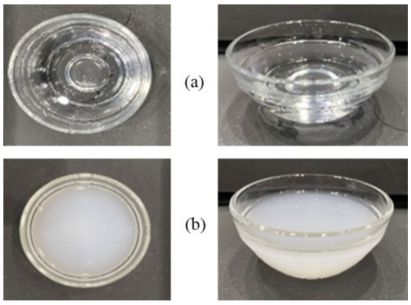

Fig. 1. Epoxy resin before (a) and after (b) hardening.

IV. EXPERIMENTAL METHODOLOGY

A. Marshall Test

This test determines the Optimal Asphalt Content (OAC), stability, flow, density, and Air Void (AV) of an asphalt concrete mixture using cylindrical specimens of 10.16 cm (4 inches) in diameter and 6.35 cm (2.5 inches) in height [10]. The bulk specific gravity and density were calculated using the ASTM D-2726 standards. The AV percentage for each specimen was calculated in line with ASTM D3203. The Marshall stability and flow parameters of each specimen were assessed using the ASTM D6927 technique [11].

Fig. 2. Marshall test.

B. Tensile Strength Ratio Test

This test analyzes the influence of moisture on the asphalt mixes, regardless of the presence of anti-stripping additives [12]. This test meets the standards given in ASTM D-4867. Initially, four Marshall specimens were created without any additives using the working mixture recipe [13]. To achieve AVs of 7 ± 1%, the specimens were empirically prepared with stroke counts of 40, 50, 60, and 70. Following the determination of the number of strokes, four sets of Marshall specimens were created, each including six examples. The first set was made without any additives, and the next three sets contained epoxy resin at concentrations of 5%, 10%, and 15%. Each set was then divided into two groups, with three specimens assigned to each group. The first group was treated to a water bath at 25°C for 30 min. The Indirect Tensile Strength (ITS) of each unconditioned sample was measured, and the average ITS was derived using three samples. To remove the air content, the second group was placed in a vacuum vessel filled with distilled water and heated to 25°C. The samples were then placed in a freezer at -18°C for 16 h. The thawing cycle began after the freeze cycle by immersing the samples in a water bath kept at 60°C for 24 h [14]. The samples were then removed and transported to a separate water bath set to 25°C for 1 h during which the ITS of these conditioned samples was measured according to ASTM D-6931 12 [15]. The minimum TSR value, as specified in ASTM D-4867-09, is 80%:

$$ITS = \frac{2000p_{max}}{\pi tD} \quad (1)$$

$$TSR = \frac{ITScon}{ITSuncon} \quad (2)$$

where P represents the maximum load necessary to fail the specimen (N), t represents the specimen's thickness (mm), D represents its diameter, ITScon denotes the conditioned indirect tensile stress (kPa), and ITSuncon denotes the unconditioned indirect tensile stress.

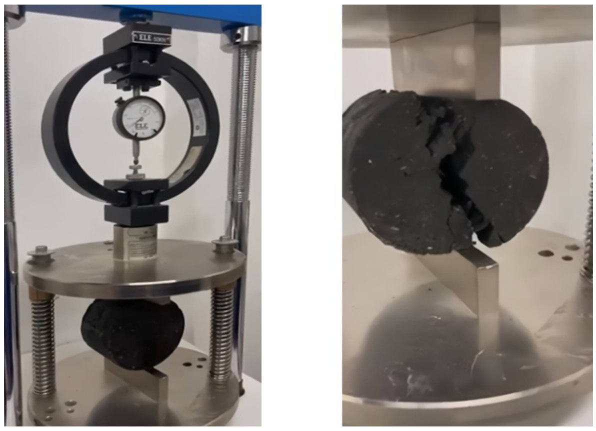

Fig. 3. TSR test.

C. Index of Retained Strength Test

The measurement of the IRS is used to prevent the moisture degradation. The lowest permitted IRS is 70% [15]. Mixtures with a diminished IRS are more susceptible to moisture degradation. A compaction apparatus is utilized to compress the prepared mixture. Specimens of 101.6 x 101.6 mm (4 x 4 inches) in diameter and 100 mm in height were prepared. Before the specimens' compressive strength was measured at a loading rate of 5.08 mm/min, they had been chilled for a whole day [16]. The IRS assessment employs:

$$IRS = \frac{S1}{S2} \times 100 \quad (3)$$

where S1 is the compressive strength of the submerged specimens, and S2 is the compressive strength of the dry specimens.

Fig. 4. IRS test.

V. RESULTS AND DISCUSSION

A. Marshall Test

The addition of 5, 10, and 15% of epoxy resin affected the mixtures, as shown in Figure 5.

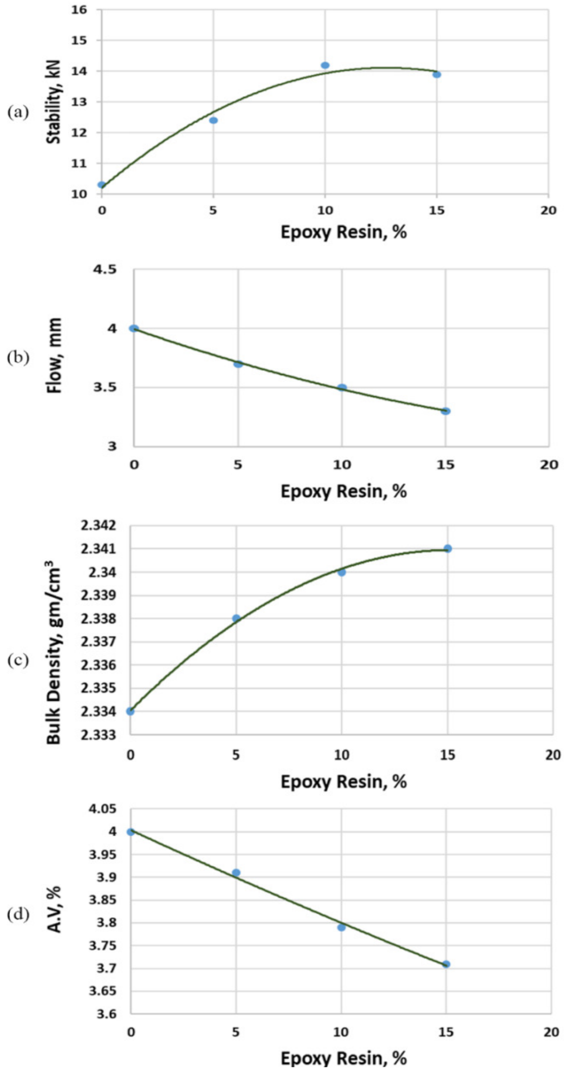

Fig. 5. The effect of epoxy resin: (a) stability, (b) flow, (c) density, (d) AV.

The test results indicated that 5% epoxy resin increased the stability of the mix by 20.39%, reduced the flow by 7.5% and AV by 2.25%. It also increased the Voids in the Mineral Aggregate (VMA) by 0.75% and Voids Filled with Asphalt (VFA) by 1%. By using 10% of epoxy resin, the stability improved by 37.86%, VMA by 1.76%, and VFA by 2.31%, whereas the flow decreased by 12.5% and AV by 5.25%. Finally, 15% of epoxy resin led to a 34.95% increase in stability, 3.52% in VMA, and 3.5% in VFA, while the flow and AV decreased by 17.5% and 7.25%, respectively. The measurements for each mix are detailed in Table VII.

TABLE VII. EFFECT OF EPOXY RESIN ON MARSHALL PROPERTIES FOR ASPHALT MIXTURE

	Mix with epoxy resin			**Control mix**
Asphalt content (%)	4.31	4.27	4.18	4.35
Epoxy resin (%)	5	10	15	0
Stability (kN)	12.4	14.2	13.9	10.3
Flow (mm)	3.7	3.5	3.3	4
Density (g/cm³)	2.338	2.340	2.341	2.334
AV (%)	3.91	3.79	3.71	4.00
VMA (%)	16.04	16.20	16.48	15.92
VFA (%)	75.62	76.60	77.49	74.87

B. Tensile Strength Ratio Test

The addition of epoxy resin to the asphalt mixtures increased the dry and wet tensile strength. Therefore, TSR increased by 5.5% and 9% with the incorporation of 5% and 10% epoxy resin, respectively. However, 15% of epoxy resin achieved a lower increase of 8.08%. The rise in the tensile strength results from the tougher bond between the binder and the combined particles. Enhancing the molecular weight of the epoxy resin may improve the composite's properties, leading to higher strength and decreased resistance to degradation upon exposure to water.

TABLE VIII. RESULTS OF THE ITS RATIO

	Epoxy resin %	**Dry ITS (kPa)**	**Wet ITS (kPa)**	**TSR (%)**
Control mix	0	1,534	,1232	80
Mix with epoxy resin	5	1,598	1,354	84
	10	1,603	1,404	87
	15	1,648	1,431	86

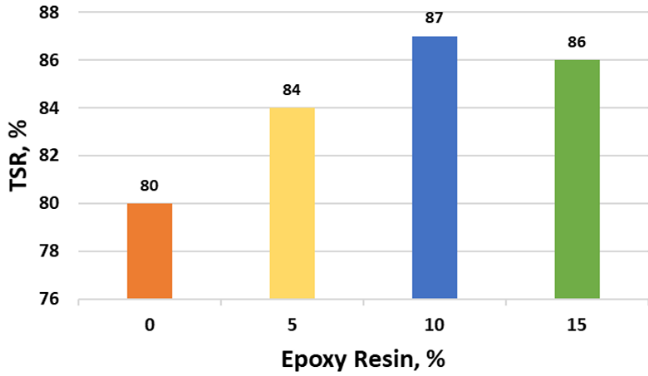

Fig. 6. The ITS ratio and the impact of the epoxy resin content.

C. Index of Retained Strength Test

IRS increased by 4.17%, 6.41%, and 7.45% with the addition of 5%, 10%, and 15% of epoxy resin, respectively. These results are associated with a reduction in the moisture susceptibility of the asphalt mixture, as the moisture resistance increases with greater IRS.

TABLE IX. RESULTS OF THE COMPRESSIVE STRENGTH TEST

	Epoxy resin %	Dry compressive strength (kPa)	Wet compressive strength (kPa)	IRS (%)
Control mix	0	4885	3729	76
Mix with epoxy resin	5	5367	4268	79
	10	5534	4495	81
	15	6087	4993	82

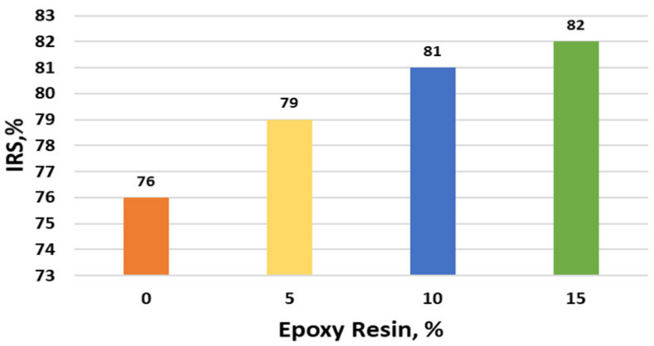

Fig. 7. The effect of the epoxy resin content on the compressive strength.

VI. CONCLUSIONS

The Indirect Tensile Strength (ITS) and compressive strength of hot-mix asphalt were tested after the incorporation of epoxy resin at 5%, 10%, and 15% by weight of asphalt in the mixture. The asphalt mixes were assessed using moisture damage resistance tests. The experimental data resulted in the following conclusions:

1. The Marshall stability test results show a clear improvement in the stability of the asphalt mixtures with the addition of epoxy resin. The stability increased from 10.3 in the control mixture to 12.4 with 5% epoxy (20.39% increase), to 14.2 with 10% epoxy (37.86% increase). However, at 15% epoxy, the stability slightly decreased to 13.9, displaying a 2.11% reduction compared to 10%. Since the epoxy resin enhances the bond between the aggregates and the binder, the stability is increased. At 15%, however, the stability somewhat declined, most likely due to excessive epoxy breaking the binder-aggregate bond and increasing the mixture's brittleness.
2. The Marshall flow test results indicate a reduction in the flow values of the modified asphalt mixtures with the incorporation of epoxy resin. The flow value of the control mixture was 4.0, which decreased to 3.7 with 5% epoxy resin (7.5% reduction). With 10% epoxy, the flow value further decreased to 3.5 (12.55% reduction), and at 15% epoxy, the flow value dropped to 3.3 (17.5% reduction). Given that the epoxy resin increases the stiffness and improves the bond between the binder and particles, the flow values decrease. Greater resistance to deformation under load is exhibited by a decrease in the flow, which results from the mixture being less flexible as the epoxy resin content increases.
3. The Air Void (AV) content in the asphalt mixture decreased with the addition of epoxy resin. The control mixture had an AV content of 4.0%, which decreased to 3.91% with 5% epoxy resin (2.25% reduction), to 3.79% with 10% epoxy resin (5.25% reduction), and to 3.71% with 15% epoxy resin (7.25% reduction). Due to the mixture's enhanced compaction and denser structure, the AV content decreases as the epoxy resin content increases. By filling the spaces between the particles, the epoxy resin reduces the air gaps and enhances the asphalt mixture's overall density and stability.
4. The addition of epoxy resin to asphalt mixture significantly improved the wettability and adhesive properties of the asphalt mixture, as demonstrated by the increase in the Tensile Strength Ratio (TSR). The TSR value of the control mixture was 80.34%, which increased to 84.75% with the addition of 5% epoxy resin. With 10% epoxy resin, the TSR reached 87.57%, representing the highest improvement, and at 15% epoxy resin, the TSR slightly decreased to 86.83%. Since the epoxy resin enhances the adhesion between the aggregates and the asphalt binder, it increases the mixture's resistance to moisture damage and raises the total stiffness ratio. The TSR value did, however, marginally decline at higher epoxy concentrations (15%), most likely due to the excess epoxy reducing the mixture's flexibility and bonding effectiveness.
5. The incorporation of epoxy resin also resulted in a significant increase in the Index of Retained Strength (IRS). The IRS value of the control mixture was 76.34%, which increased to 79% with the addition of 5% epoxy resin, to 81% with 10% epoxy resin, and reached 82% with 15% epoxy resin. The highest IRS value of 82% was achieved with the addition of 15% epoxy resin, representing a notable improvement over the control mixture. The improved bonding between the epoxy resin and the aggregates and asphalt binder enhances the mixture's overall cohesiveness and resistance to tensile stresses, thereby increasing the IRS.
6. Previous research has indicated that the optimum quantity of epoxy resin proposed for application is 10%.

REFERENCES

[1] S. F. Mohammed and M. Q. Ismael, "Effect of Polypropylene Fibers on Moisture Susceptibility of Warm Mix Asphalt," *Civil Engineering Journal*, vol. 7, no. 6, pp. 988–997, Jun. 2021, https://doi.org/10.28991/cej-2021-03091704.

[2] S. K. Ugla and M. Q. Ismael, "Evaluating the Moisture Susceptibility of Asphalt Mixtures Containing RCA and Modified by Waste Alumina," *Civil Engineering Journal*, vol. 9, pp. 250–262, Dec. 2023, https://doi.org/10.28991/CEJ-SP2023-09-019.

[3] X. Liu, C. Zhou, D. Feng, H. Tang, Y. Xu, and X. Fan, "Influence of moisture in aggregates on properties of cold-mixed resin asphalt mixture," *Construction and Building Materials*, vol. 120, pp. 232–240, Sep. 2016, https://doi.org/10.1016/j.conbuildmat.2016.05.113.

[4] Y. Haibara and H. Ge, "Effects of Epoxy Resin System and Ingredient Content on the Properties of Asphalt and Its Mixtures," *Journal of Materials in Civil Engineering*, vol. 37, no. 1, Jan. 2025, Art. no. 04024440, https://doi.org/10.1061/JMCEE7.MTENG-18561.

[5] R. Auvergne, S. Caillol, G. David, B. Boutevin, and J.-P. Pascault, "Biobased Thermosetting Epoxy: Present and Future," *Chemical Reviews*, vol. 114, no. 2, pp. 1082–1115, Jan. 2014, https://doi.org/10.1021/cr3001274.

[6] H. Bahmani, H. K. Sanij, and F. Peiravian, "Estimating Moisture Resistance of asphalt mixture containing epoxy resin using Surface Free Energy Method and Modified Lottman test," *International Journal of Pavement Engineering*, vol. 23, no. 10, pp. 3492–3504, Aug. 2022, https://doi.org/10.1080/10298436.2021.1904236.

[7] A. Elnihum, Q. Lu, M. Alharthai, M. Alamri, C. Chen, and A. Elmagarhe, "Evaluation of an Asphalt Mixture Containing a High Content of Reclaimed Asphalt Pavement (RAP) Materials with Epoxy Asphalt," *Sustainability*, vol. 16, no. 12, Jan. 2024, Art. no. 4988, https://doi.org/10.3390/su16124988.

[8] L. Wang, Z. Zhang, W. Liu, M. Wu, J. Shi, and K. Yan, "Effects of Epoxy Resin Value on Waterborne-Epoxy-Resin-Modified Emulsified Asphalt Mixture Performance," *Applied Sciences*, vol. 14, no. 4, Jan. 2024, Art. no. 1353, https://doi.org/10.3390/app14041353.

[9] A. M. da S. Lopes, I. M. Silva, O. de Medeiros Melo Neto, L. C. de F. L. Lucena, T. M. de Sousa, and M. das V. do Nascimento, "Assessment of the Effects of Temperature, Ultraviolet Radiation, and Moisture on the Properties of Asphalt Mixtures," *Transportation Research Record*, Apr. 2025, https://doi.org/10.1177/03611981251327220.

[10] K. A. Kaaf and V. T. Ibeabuchi, "Marshall Asphalt Mix and Superior Performance Asphalt Mix in Oman: A Comparative Study," *Engineering, Technology & Applied Science Research*, vol. 13, no. 6, pp. 12258–12263, Dec. 2023, https://doi.org/10.48084/etasr.6206.

[11] N. J. Mahdi, A. E. Jehad, O. F. Rajab, and T. Akhlaghi, "Evaluation of the impact of moisture damage on warm mix asphalt containing zeolite and hydrated lime," *AIP Conference Proceedings*, vol. 3249, no. 1, Oct. 2024, Art. no. 060019, https://doi.org/10.1063/5.0236460.

[12] S. A. R. Al Nuaimi and S. I. Sarsam, "Assessing the Influence of Moisture Damage under Repeated Load on Multilayer Interface Bond Strength of Asphalt Concrete," *Journal of Engineering*, vol. 26, no. 11, pp. 21–42, Nov. 2020, https://doi.org/10.31026/j.eng.2020.11.02.

[13] T. L. Nguyen, V. P. Le, Q. P. Nguyen, G. B. Dang, and M. H. N. Nguyen, "Performance Evaluation of Asphalt Mixtures with Rediset LQ-1200 Additive," *Engineering, Technology & Applied Science Research*, vol. 14, no. 4, pp. 15724–15728, Aug. 2024, https://doi.org/10.48084/etasr.7848.

[14] V. B. Le, H.-B. Tran, and V. P. Le, "Laboratory evaluation of resistance to moisture damage in carbon nanotubes modified hot mix asphalt mixtures," *Transportation Research Procedia*, vol. 85, pp. 185–190, Jan. 2025, https://doi.org/10.1016/j.trpro.2025.03.150.

[15] H. Wu *et al.*, "Multi-scale analysis on fracture behaviors of asphalt mixture considering moisture damage," *Construction and Building Materials*, vol. 416, Feb. 2024, Art. no. 135234, https://doi.org/10.1016/j.conbuildmat.2024.135234.

[16] M. Q. Ismael, Z. A. Sahib, and A. H. Rasheed, "Utilizing Waste Engine Oil and Soft Binder as Additives to Mitigate the Moisture Damage of Asphalt Mixtures," *Engineering, Technology & Applied Science Research*, vol. 14, no. 6, pp. 17604–17612, Dec. 2024, https://doi.org/10.48084/etasr.7451.