



# **Assessment of Moisture Resistance and Mechanical Behavior of Hydrated Lime Modified Asphalt Mixtures**

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**ABSTRACT:** Pedestrian the effect of hydrated lime on the performance characteristics of Hot Mix Asphalt (HMA), with particular emphasis on strength properties and moisture susceptibility. An experimental program was conducted using the Marshall mix design method to determine the optimum binder content, followed by the preparation of lime-modified asphalt mixtures with varying lime percentages. The optimum bitumen content for the conventional mix was determined as 5.0%, corresponding to maximum stability and desired volumetric properties. The performance of conventional and modified mixes was evaluated using Marshall Stability, Indirect Tensile Strength (ITS), and Tensile Strength Ratio (TSR) tests. The results indicate that the addition of hydrated lime significantly improves the performance of asphalt mixtures. Marshall Stability increased from 12.0 kN for the conventional mix to 14.8 kN at 1.5% lime content, representing an improvement of approximately 23%. Similarly, the ITS values under dry and wet conditions increased from 0.80 MPa to 1.05 MPa and from 0.60 MPa to 0.90 MPa, respectively. The TSR value improved from 75.0% to 85.7%, indicating enhanced resistance to moisture-induced damage. The study demonstrates that hydrated lime improves adhesion between binder and aggregates, enhances mechanical strength, and reduces moisture susceptibility. The optimum lime content was found to be 1.5%, at which maximum performance improvement was achieved without adversely affecting volumetric properties. The findings suggest that the incorporation of hydrated lime is an effective approach to improve the durability and service life of asphalt pavements.

**KEYWORDS:** Hot Mix Asphalt, Hydrated Lime, Marshall Stability, Moisture Susceptibility, Indirect Tensile Strength, Tensile Strength Ratio

## **I. INTRODUCTION**

Hot Mix Asphalt (HMA) pavements are subjected to a wide range of traffic loads and environmental conditions, requiring materials and design approaches that satisfy stringent engineering performance criteria. The primary objective of HMA mix design is to determine the optimal combination of asphalt binder and aggregates that ensures long-term durability and structural performance of the pavement system. This process involves a series of laboratory-based procedures aimed at establishing appropriate material proportions. These procedures include selecting suitable aggregate sources to achieve the desired gradation and determining the type and content of asphalt binder required for effective cohesion and stability.

Well-designed asphalt mixtures are expected to perform satisfactorily over extended service periods under varying loading and environmental conditions. However, several forms of pavement distress can compromise performance prematurely. One of the most common issues is the stripping of aggregates from the asphalt binder, which weakens the structural integrity of the pavement. Additionally, rutting often develops during the early stages of pavement life, further affecting serviceability.

Moisture plays a critical role in accelerating pavement deterioration through two primary mechanisms. First, it infiltrates the interface between the asphalt binder and aggregates, weakening the adhesive bond between these key

components. Second, moisture can penetrate the asphalt binder itself, reducing its cohesive strength and leading to softening. Both mechanisms significantly compromise pavement integrity and reduce its effective service life.

Moisture-induced damage can severely diminish the expected design life of HMA pavements. Once deterioration begins, there is a substantial loss in internal strength, which manifests in various forms of distress such as rutting and raveling. Furthermore, fatigue cracking may occur when the pavement structure is excessively stiff or when the structural layers are insufficient to withstand applied traffic loads. This type of cracking is often associated with repeated tensile stresses within the pavement, commonly exacerbated by heavy vehicle loads, shear stresses from traffic movement, and rapid temperature fluctuations.

Over the past several decades, research has demonstrated that hydrated lime can effectively improve the performance of asphalt mixtures. It reacts with acidic components of the bitumen, leading to beneficial modifications that mitigate moisture damage and enhance the overall durability of the pavement.

## II. LITERATURE SURVEY

### 2.1 Overview of Hot Mix Asphalt Performance

Hot Mix Asphalt (HMA) is one of the most commonly used materials in flexible pavement construction due to its durability, adaptability, and cost-effectiveness. The performance of HMA pavements is largely governed by their ability to withstand traffic loads and environmental conditions without significant deterioration. According to Huang Yang H., pavement performance is typically evaluated in terms of resistance to rutting, fatigue cracking, and environmental damage.

In recent years, increasing attention has been directed toward durability-related issues, particularly moisture-induced damage, which has been identified as a major contributor to premature pavement failure (Kandhal P. S. & Rickards I. J.). This has led to extensive research on understanding the underlying mechanisms and identifying effective mitigation strategies.

### 2.2 Mechanisms of Moisture-Induced Damage

Moisture damage in asphalt mixtures is primarily associated with the intrusion of water into the pavement structure, leading to the weakening of the asphalt–aggregate bond. Little Dallas N. and Jones David R. explained that moisture damage occurs due to both adhesive failure and cohesive failure mechanisms.

Adhesive failure refers to the loss of bonding between the asphalt binder and aggregate surface, whereas cohesive failure occurs within the asphalt binder itself due to the presence of water. Hicks R. G. highlighted that these failures are influenced by aggregate mineralogy, binder chemistry, and environmental conditions such as temperature and humidity.

### 2.3 Factors Affecting Moisture Susceptibility

Several factors contribute to the moisture susceptibility of HMA mixtures. Roberts Freddy L. emphasized that aggregate characteristics, including surface texture and mineral composition, significantly influence adhesion properties. Hydrophilic aggregates tend to have weaker bonding with asphalt binder, increasing the risk of stripping. Binder properties also play a crucial role. Read James and Whiteoak David reported that the chemical composition of bitumen affects its interaction with aggregates and its resistance to moisture damage. Additionally, air void content and compaction quality are critical parameters. Higher air voids increase permeability, allowing water to penetrate more easily into the mixture, thereby accelerating deterioration.

### 2.4 Role of Hydrated Lime in Asphalt Mixtures

Hydrated lime has been widely recognized as one of the most effective additives for improving moisture resistance in asphalt mixtures. Little Dallas N. demonstrated that hydrated lime enhances the chemical bonding between asphalt binder and aggregates by reacting with acidic components in the binder.

Similarly, Epps Jon A. reported that lime treatment modifies aggregate surface properties, making them more resistant to moisture-induced debonding. These chemical interactions improve adhesion and reduce the likelihood of stripping.

### 2.5 Performance Improvements with Hydrated Lime

Numerous studies have confirmed that the incorporation of hydrated lime significantly enhances the performance of asphalt mixtures. According to Kennedy Thomas W., lime-treated mixtures exhibit improved resistance to rutting and fatigue cracking.

Experimental investigations by Little Dallas N. and Epps Jon A. have shown that hydrated lime increases Tensile Strength Ratio (TSR), indicating improved resistance to moisture damage. Additionally, lime-treated mixtures demonstrate better aging resistance due to reduced oxidation of the asphalt binder.

Laboratory tests such as Marshall Stability, Indirect Tensile Strength (ITS), and moisture susceptibility tests consistently support these findings, highlighting the superior performance of lime-modified mixtures compared to conventional asphalt mixes.

### 2.6 Research Gaps and Future Scope

Despite the extensive research on hydrated lime, several gaps remain. Kandhal P. S. noted that the effectiveness of lime treatment varies depending on factors such as dosage, method of application, and aggregate type. Furthermore, most studies are limited to laboratory conditions, with insufficient long-term field performance data. Future research should focus on optimizing lime content, evaluating performance under diverse climatic conditions, and exploring its interaction with modified binders and recycled materials.

### 2.7 Summary

The literature clearly demonstrates that moisture-induced damage is a critical issue affecting the durability of HMA pavements. The use of hydrated lime has proven to be an effective solution for improving moisture resistance and overall pavement performance. However, further research is required to standardize its application and ensure consistent results in field conditions.

## III. EXPERIMENTAL OBSERVATION

### 3.1 General

This study adopts an experimental methodology to evaluate the effect of hydrated lime on the performance characteristics of Hot Mix Asphalt (HMA). The research focuses on analyzing the influence of lime modification on mechanical properties and moisture susceptibility of asphalt mixtures under controlled laboratory conditions. A systematic approach was followed to ensure accuracy, consistency, and reliability of results.

### 3.2 Materials

The materials used in this investigation include aggregates, bitumen, and hydrated lime.

**Aggregates:** Aggregates were selected in accordance with standard specifications to achieve the required gradation and mechanical strength. Physical properties such as specific gravity, water absorption, impact value, and abrasion resistance were determined prior to mix preparation.

**Bitumen:** Bitumen of appropriate grade was used as the binding material. The binder was tested for its fundamental properties, including penetration, softening point, ductility, and viscosity to ensure suitability for pavement applications.

**Hydrated Lime:** Hydrated lime was used as an additive to improve adhesion between bitumen and aggregates and to enhance resistance against moisture-induced damage.

### 3.3 Mix Design Procedure

The Marshall Mix Design method was adopted to determine the optimum binder content and evaluate the performance of asphalt mixtures. A series of specimens were prepared with varying bitumen contents. For each mix, key parameters such as Marshall Stability, flow value, air voids, voids in mineral aggregate (VMA), and voids filled with bitumen (VFB) were determined. The optimum binder content was selected based on standard criteria, ensuring a balance between strength, durability, and workability of the mix.

### 3.4 Preparation of Modified Mixes

To study the effect of hydrated lime, asphalt mixtures were prepared with different percentages of lime content. The lime was incorporated in a controlled manner to ensure uniform mixing with aggregates and binder.

Separate sets of specimens were prepared:

Conventional mix (without lime)

Lime-modified mixes (with varying lime content)

This allowed a comparative evaluation of performance characteristics.

### 3.5 Sample Preparation

Aggregates were heated to the required temperature before mixing. Bitumen was also heated to achieve proper viscosity for coating. The heated aggregates and binder were thoroughly mixed, followed by the addition of hydrated lime. The mixture was compacted using a standard number of blows on each side to prepare cylindrical specimens. All samples were prepared under controlled conditions to maintain uniformity.

### 3.6 Laboratory Testing

The prepared specimens were subjected to the following laboratory tests:

Marshall Stability and Flow Test: This test was conducted to evaluate the load-bearing capacity and deformation characteristics of the asphalt mixtures. Stability indicates resistance to deformation, while flow represents flexibility.

Indirect Tensile Strength (ITS) Test: This test was performed to assess the tensile strength of the mixtures, which is an important parameter for evaluating cracking resistance.

Moisture Susceptibility Test (TSR): The resistance of asphalt mixtures to moisture damage was evaluated using the Tensile Strength Ratio (TSR). This test compares the strength of conditioned (wet) and unconditioned (dry) samples.

Volumetric Analysis: Parameters such as air voids, VMA, and VFB were calculated to understand the internal structure and durability characteristics of the mixtures.

### 3.7 Data Analysis

The test results were analyzed to compare the performance of conventional and lime-modified asphalt mixtures. The effect of varying lime content on stability, strength, and moisture resistance was evaluated. Graphs and tabular comparisons were used to identify trends and relationships between different parameters. The optimum lime content was determined based on maximum performance improvement without compromising other properties.

### 3.8 Quality Control and Reliability

All experimental procedures were carried out in accordance with standard testing methods. Multiple specimens were tested for each mix condition to ensure repeatability and minimize experimental errors. Proper control of temperature, mixing, and compaction was maintained throughout the study to ensure consistency in results..

## IV. EXPERIMENTAL RESULTS

### 4.1 General

This chapter presents the experimental results obtained from laboratory testing of conventional and hydrated lime-modified Hot Mix Asphalt (HMA). The performance of the mixtures was evaluated in terms of Marshall properties, tensile strength, and moisture susceptibility. A comparative analysis was carried out to assess the effect of varying hydrated lime content on the behavior of asphalt mixtures.

### 4.2 Marshall Mix Design Results

Marshall mix design was conducted to determine the optimum bitumen content for the conventional mix. The variation of stability, flow, density, and air voids with bitumen content was analyzed. It was observed that the stability of the mix initially increased with an increase in bitumen content, reached a maximum value, and then decreased. This behavior indicates that an optimum binder content exists at which the mix achieves maximum load-bearing capacity. Similarly, flow values showed a gradual increase with increasing bitumen content, indicating improved flexibility of the mix. The air voids decreased with higher binder content due to better filling of void spaces. Based on the standard criteria, the optimum bitumen content was determined by considering:

Maximum stability  
Maximum density  
Desired air voids

The selected optimum binder content ensured a balance between strength, durability, and workability.

#### **4.3 Effect of Hydrated Lime on Marshall Properties**

The Marshall properties of asphalt mixtures modified with hydrated lime were evaluated and compared with the conventional mix. An increase in stability was observed with the addition of hydrated lime up to a certain percentage, beyond which the stability showed marginal variation or reduction. This indicates that hydrated lime improves the stiffness and load-bearing capacity of the mix when used in optimum proportion. Flow values for lime-modified mixes were slightly lower compared to the conventional mix, suggesting improved resistance to deformation. The reduction in flow indicates that the mixture becomes more stable and less susceptible to excessive deformation under load. Volumetric properties such as air voids and VMA showed minor variations with the addition of lime, indicating that the modification did not adversely affect the internal structure of the mix.

#### **4.4 Indirect Tensile Strength (ITS) Analysis**

The Indirect Tensile Strength (ITS) test was conducted to evaluate the tensile strength of asphalt mixtures under dry and wet conditions. The results indicated that:

Dry ITS values increased with the addition of hydrated lime

Wet ITS values also improved significantly compared to the conventional mix

This improvement can be attributed to enhanced bonding between the binder and aggregates due to the presence of hydrated lime. The increased tensile strength suggests better resistance to cracking and improved structural integrity.

#### **4.5 Moisture Susceptibility Analysis (TSR)**

Moisture susceptibility of asphalt mixtures was evaluated using the Tensile Strength Ratio (TSR). The TSR values for lime-modified mixes were higher than those of the conventional mix, indicating improved resistance to moisture-induced damage. The increase in TSR demonstrates that hydrated lime effectively reduces stripping and enhances durability. It was observed that:-

Conventional mix showed relatively lower TSR values

Lime-modified mixes exhibited significant improvement

Maximum benefit was achieved at optimum lime content

These results confirm that hydrated lime plays a crucial role in improving moisture resistance of asphalt mixtures.

#### **4.6 Overall Performance Evaluation**

Based on the experimental results, hydrated lime modification led to the following improvements:

Increased Marshall Stability

Reduced susceptibility to deformation

Enhanced tensile strength

Improved resistance to moisture damage

However, beyond the optimum lime content, no significant improvement was observed, indicating the importance of proper dosage.

#### **4.7 Discussion**

The improvement in performance of lime-modified mixtures can be attributed to both physical and chemical effects. Hydrated lime enhances adhesion between binder and aggregates, reduces moisture sensitivity, and improves stiffness of the mix. The results clearly demonstrate that the addition of hydrated lime leads to a more durable and stable asphalt mixture. The improved performance under wet conditions highlights its effectiveness in mitigating moisture-induced damage, which is one of the major causes of pavement failure.

The findings also indicate that proper mix design and optimization are essential to achieve maximum benefits from lime modification.

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**Table: 4.1 Marshall Stability Test Results (Conventional Mix)**

Bitumen Content (%)	Stability (kN)	Flow (mm)	Density (g/cc)	Air Voids (%)
4	8.5	2.5	2.3	5.5
4.5	10.2	2.8	2.34	4.8
5	12	3.1	2.38	4
5.5	11	3.5	2.36	3.5

**Table 4.2: Volumetric Properties of Conventional Mix**

Bitumen Content (%)	Air Voids (%)	VMA (%)	VFB (%)
4	5.5	15.5	64.5
4.5	4.8	15.8	69.6
5	4	16	75
5.5	3.5	16.5	78.8

**Table 4.3: Determination of Optimum Bitumen Content**

Criteria	Bitumen Content (%)
Maximum Stability	5
Maximum Density	5
4% Air Voids	5
<b>Optimum Bitumen Content</b>	<b>5</b>

**Table 4.4: Marshall Stability Results (Lime-Modified Mixes)**

Lime Content (%)	Stability (kN)	Flow (mm)	Density (g/cc)
0	12	3.1	2.38
1	13.5	3	2.39
1.5	14.8	2.9	2.4
2	14	2.8	2.39

**Table 4.5: Volumetric Properties of Lime-Modified Mixes**

Lime Content (%)	Air Voids (%)	VMA (%)	VFB (%)
0	4	16	75
1	3.8	16.2	76.5
1.5	3.5	16.4	78.7
2	3.6	16.6	78.3

### V. CONCLUSION

The present study evaluated the effect of hydrated lime on the performance characteristics of Hot Mix Asphalt (HMA) using Marshall mix design, Indirect Tensile Strength (ITS), and moisture susceptibility analysis. The conclusions are drawn based on experimental results and comparative evaluation of conventional and lime-modified mixes.

The optimum bitumen content for the conventional mix was determined as 5.0%, corresponding to maximum stability, maximum density, and approximately 4% air voids. At this binder content, the mix exhibited a stability of 12.0 kN, flow value of 3.1 mm, and air voids of 4.0%, indicating a balanced mix design in terms of strength and durability.

The incorporation of hydrated lime significantly influenced the Marshall properties of asphalt mixtures. Stability increased from 12.0 kN (0% lime) to 14.8 kN at 1.5% lime content, representing an improvement of approximately 23.3%. Beyond this level, a marginal decrease in stability was observed, indicating that excessive lime content does not contribute to further strength enhancement. Flow values decreased from 3.1 mm to 2.9 mm, reflecting improved resistance to deformation.

Volumetric analysis indicated that air voids decreased slightly with the addition of lime, while VMA and VFB remained within acceptable limits. This confirms that the inclusion of hydrated lime did not adversely affect the internal structure of the mix.

Based on overall performance evaluation, the optimum hydrated lime content was found to be 1.5% by weight of aggregates, at which maximum improvement in strength, durability, and moisture resistance was achieved.

The results clearly demonstrate that the addition of hydrated lime enhances adhesion between binder and aggregates, improves mechanical properties, and significantly reduces moisture susceptibility. Therefore, hydrated lime can be effectively used as a modifier in asphalt mixtures to improve pavement performance and extend service life.

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