Journal of Building Technology, 2025, Volume 7, Issue 1
DOI: 10.32629/jbt.v7i1.3771
ISSN Online: 2717-5103
ISSN Print: 2705-1390

Benefits of Adding Hydrated Lime to Asphalt Mixtures: A Review

Karina Kikut Cruz, M.Sc. Alejandra Baldi, M.Sc. Ana Luisa Elizondo Salas

LanammeUCR, University of Costa Rica, Costa Rica.

Abstract: Hydrated lime is used as an additive for asphalt mixtures, since it enhances the properties of the material in a unique way, enabling a longer service life. In this study, several scientific articles were analyzed in order to understand some of the methods employed of adding hydrated lime to the asphalt mixtures, as well as the optimum amount of hydrated lime that will significantly improve the material's response towards diverse factors. It was found that the researchers usually add hydrated lime in percentages ranging between 1%-2% in weight of aggregates. Also, in the case of asphalt modified with hydrated lime, the material is stiffer and more resistant to moisture damage. Finally, after this literature review, it is concluded that adding 1.5% of hydrated lime resulted in the most promising properties being obtained in most of the studies considered.

Key words: asphalt; hydrated lime; moisture damage; asphalt matrix

1. Introduction

Hydrated lime is a compound that has been widely studied in recent years as an aggregate in the asphalt matrix due to the benefits it provides. This additive is also known as a filler; according to Little and Petersen (2005), a filler can be defined as "any particle added to asphalt with a size smaller than 74 μm." The authors also explain that hydrated lime is added to asphalt due to its exceptional properties, such as particle size, roughness, and surface energy, among others.

There are several reasons why this material is used as an aggregate, one of which is the crack resistance it adds to asphalt. According to Rasouli, Kavussi, Qazizadeh, and Taghikhani (2018), hydrated lime can improve the properties of asphalt mixtures in three ways: by improving crack resistance, improving resistance to permanent deformation, and reducing the stiffness rate due to oxidation.

Furthermore, hydrated lime is a commonly used additive due to the properties it provides to asphalt to resist moisture damage, which is one of the causes of premature failure of asphalt mixtures. Therefore, over the years, attempts have been made to test asphalt's sensitivity to moisture. Some studies attribute this sensitivity to fracture parameters, surface energy, diffusion coefficients, and adhesion characteristics. The reason hydrated lime is used is because it increases the adhesive bonding characteristics between the aggregate and the asphalt (Kim, Lutif, Bhasin, and Little, 2008).

Because hydrated lime has been widely used to mitigate moisture damage to asphalt, a literature review was conducted to understand the properties of lime, methods for adding it to the asphalt matrix, and the tests performed on the asphalt mixture once this compound has been added.

It is also important to highlight that moisture damage is one of the main problems facing asphalt in Costa Rica, given that this country has a tropical climate with six months of the rainy season. Costa Rica also has only one asphalt, so this article aims to provide a literature review of the use of lime to mitigate these problems, including how to modify it, the optimal quantities, and the improvements in mechanical properties that can be expected.

The objective of this study is to gain a comprehensive understanding of the lime application technique in asphalt mixtures and asphalt mastics, so that it can be applied in Costa Rica.

2. Development and Discussion

2.1 Optimal hydrated lime content in asphalt mixtures

Zamora and Mora (2019) used briquettes with a mass of 1 kg each, of which 47.45 g corresponded to the filler, and the latter did not contain hydrated lime. Subsequently, the filler was replaced 100% with hydrated lime and 50% with hydrated lime; dry traction, wet traction, and wear tests were performed. From the tests, the authors determined that the optimal percentage of filler replacement with hydrated lime was 2.387% of the total weight of the mixture.

On the other hand, Bastidas, De Carvalho, and Lucena (2015) conducted a study with asphalt samples modified with 0% lime, 10% lime, 15% lime, and 20% lime. Mixtures with higher percentages of lime tended to settle and produce a heterogeneous mixture. Based on the study, the authors propose using 0.96% hydrated lime and 3.84% pure asphalt; these data arise from the fact that the effective asphalt content is reduced by 20% by the addition of lime. This 20% translates to 0.3% of the optimal asphalt content in dense concrete.

Lesueur, Petit, and Ritter (2013) state that the typical amount of lime added to the asphalt mixture is in the range of 1% to 1.5% by mass of dry aggregates. If lime were used as a typical binder, its content should be 5% by mass based on dry aggregates; this percentage corresponds to 20% - 30% by mass or 10% - 15% by volume of hydrated lime. Likewise, in 2011, the European Lime Association compiled a comparative table of the amount of hydrated lime added to asphalt by country, as well as the method of addition. Based on this, it was determined that the percentage of hydrated lime added ranges from 1% to 3.5%, and this is added neat or mixed with the filler (EuLa, 2011).

For their part, Han, Dong, Yin, Liu, and Liu (2020) focused on finding the optimal amount of hydrated lime, as well as its ideal fineness, for the asphalt mixture. This study concluded that the optimal lime content is 10%. It was also discovered that the lime content should be controlled to ensure a level between 3% and 10% to maintain the appropriate rheological properties of the asphalt.

Little and Epps, on the other hand, conducted a study on the use of hydrated lime, from its history to the methods of adding it to the asphalt matrix. The authors explained that dry lime can be added as dry or wet aggregate; and the studies they compiled used between 1% and 3% hydrated lime (National Lime Association, 2006).

According to the literature review, it was concluded that, while hydrated lime is added to asphalt in various percentages, the most commonly used percentages are between 1% and 2% of the aggregate weight.

2.2 Use of hydrated lime to improve the performance of asphalt and asphalt mixtures

Kim et al. (2008) analyzed asphalt mixtures to which 1% hydrated lime was added, varying the lime concentration, which was added in slurry form. These concentrations were 0.33, 0.22, and 0.13 percent. All mixtures were tested for moisture damage, susceptibility, fracture, and surface free energy, among others. The results are reported collectively; therefore, the optimal percentage of hydrated lime to be added is not reported; however, an improvement in asphalt properties is observed with 1%.

In the case of the study by Kollaros, Kalaitzaki, and Athanasopoulou (2017), it focused on the investigation of fillers for asphalt mixtures, as well as their dosage. The fillers tested were added after passing a No. 200 sieve and lime. The filler content was varied between 2%, 4%, 6%, and 8%, and stability, void, and deformation tests were performed. The addition of lime improved all of the aforementioned tests; maximum stability was achieved with 4% filler, while deformation was achieved with 2%.

Rasouli et al. (2018) used specimens with hydrated lime content by mass between 1% and 2%. They performed fatigue tests and determined that the modification increased the hardness of the asphalt mixture and improved the elastic properties of the mixture. The authors found that adding a percentage greater than 1.5% hydrated lime could lead to a gradual decrease in the flexibility of the mixture and an excessive increase in hardness.

Moon, Falchetto, Wang, Riccardi, and Wistuba (2017) analyzed the effect of adding hydrated lime to the asphalt mixture as part of the filler, varying the added percentages as follows: 5%, 10%, and 20% by volume of fine aggregate. They analyzed the performance of the mixtures at low (10°C and -6°C) and high (28°C and 70°C) temperatures. The authors found that at low temperatures, the mixture properties were not significantly affected. At high temperatures, however, there was an improvement in the mixture properties with both types of filler.

Gutiérrez (2017) performed tests other than those discussed above by adding hydrated lime to the asphalt in the fine aggregate and performing three tests on the samples: sand equivalent, determination of specific weight, and particle size analysis. The hydrated lime was added in proportions of 1%, 1.5%, and 2%. The 1.5% yielded the best results, as this amount provided the greatest stability for the mixture.

On the other hand, it is common to add lime directly to asphalt to evaluate its response to chemical aging, which is a significant factor affecting asphalt and reducing its useful life. It is also difficult to quantify in order to understand its progress. This is due to the difficulty in sampling aged asphalt, as the first few centimeters or millimeters of the asphalt layer must be extracted, which are sometimes mixed with lower layers that are not representative of chemical aging (EuLA, 2011).

Therefore, the effect of modification with hydrated lime and dolomitic hydrated lime on the aging index obtained at 60°C was tested (EuLA, 2011). Among the results obtained, a decrease in the susceptibility to chemical aging of asphalt was observed through a gradual increase in viscosity. Likewise, a decrease in carbonyl formation was observed in the modified asphalt; this effect occurs at temperatures above 88°C. Furthermore, a 10% hydrated lime neutralized most of the acids in the asphalt (EuLA, 2011).

Additionally, the experiment conducted by Aragão, Lee, Kim, and Karki (2010) focused on analyzing the effects of hydrated lime on asphalt to improve crack resistance. The amount of hydrated lime was varied in the following proportions: 0.5%, 1.0%, 1.5%, 2.0%, and 3.0% by weight of dry aggregate. The tests performed corresponded to dynamic modulus, fatigue strength, and permanent deformation. Once again, an improvement in the hardness of the asphalt mixture was observed, as well as an improvement in the fatigue strength of the samples. Adding hydrated lime contents greater than 2% to the mixture did not show any additional improvement in its properties.

Lesueur et al. (2013) compiled a bibliography on asphalt modification with hydrated lime, concluding that this additive increases asphalt durability. This increased durability is achieved through the improvement that hydrated lime provides to properties such as resistance to moisture damage, resistance to chemical aging, and mechanical properties (modulus of strength, strength, and fatigue, among others). Han et al. (2020), for their part, performed surface free energy tests, the technical properties of lime, and the mechanical properties of modified asphalt. They found that increasing the fineness of the lime also increases asphalt adhesion and that adding hydrated lime increases asphalt viscosity and hardness.

In 2005, Little and Petersen (2005) conducted a study that focused on comparing the addition of lime and hydrated lime to the rheology of the asphalt matrix. Hydrated lime was added as a filler at a ratio of 20%, and mechanical tests were performed. It should be noted that the aforementioned 20% hydrated lime by mass corresponds to the typical 1% in pavement mixtures. It was discovered that lime provides asphalt with important characteristics, one of which is hardness, which makes the asphalt mixture resistant to fractures or cracks. It is worth noting that asphalt modified with hydrated lime showed better characteristics than asphalt modified with lime.

2.3 Use of hydrated lime to mitigate moisture damage in asphalt mixtures

As mentioned above, hydrated lime provides various properties to asphalt, making it more resistant to adverse factors such as moisture. Later, we will delve into the advances made in the use of hydrated lime to mitigate moisture damage in Costa Rica.

Moisture damage consists of the infiltration of moisture or water into the asphalt, causing separation between it and the aggregates. Caro, Masad, Bhasin, and Little (2008) define it as: "the degradation of the mechanical properties of a material due to the presence of moisture in a liquid or vapor state." According to Kim et al. (2008), this type of damage generates various signals in the material, such as cracking and permanent deformation of the asphalt. There are several mechanisms for studying and understanding moisture damage; Caro et al. (2008) explain that these mechanisms are based on two steps: moisture transport and system response. The first is to understand how moisture reaches the asphalt, and the second corresponds to how the internal structure of the material has been modified. Some manifestations of moisture in asphalt include cracking, stripping, crumbling, and hydraulic erosion of the asphalt mixture (Caro et al., 2008).

Kim et al. (2008) begin their research by delving into premature asphalt damage caused by moisture and the emergence of techniques to reduce this type of damage. One of the most widely used techniques to reduce moisture damage in asphalt mixtures is the addition of hydrated lime, as it is known to improve the adhesive compatibility between the aggregate and the asphalt. There are various ways to add hydrated lime to asphalt, for example, adding it to dry aggregates or to wet aggregates, among others. The reason hydrated lime reduces moisture damage in asphalt is that it adds calcium ions to the aggregate surface, giving both the aggregate and the asphalt a better affinity to resist moisture damage. Lime reacts with water and carbon dioxide in the air, forming calcium carbonate, resulting in a hard mineral surface and improved adhesion between the aggregate and asphalt (Han et al., 2020).

Kim et al. (2008) conducted two laboratory tests that evaluated moisture damage, asphalt susceptibility, material properties, and the potential for fracture. Their main conclusions were that mixtures containing hydrated lime performed better in the following ways: 1) increased stiffness; 2) increased strength and hardness, which provide greater resistance to moisture degradation; and 3) improved adhesion between the asphalt and the aggregate, which provides greater resistance to cracking.

Mouillet, Séjourné, Delmotte, Ritter, and Lesueur (2014) recognize the use of hydrated lime to mitigate the effects of moisture on asphalt, as well as to reduce chemical aging of asphalt. Furthermore, it was found that adding lime increases the hardness of asphalt which directly impacts the mechanical properties of the material, to the point that North American agencies estimate that adding hydrated lime to the asphalt mix increases the durability of the material between 2 and 10 years (an increase of 20 - 50%).

Khattak and Kyatham conducted two studies in the same year. In the first, they evaluated the susceptibility of both the asphalt matrix and the asphalt mixture to moisture, modifying both with hydrated lime. The asphalt binder was modified with 20% hydrated lime; this was not used as a filler. The asphalt matrix was used with 10% asphalt binder content and fine aggregate passing a No. 8 sieve. Using the surface area method, the binder accounted for 18% - 20% by weight of the asphalt matrix. A positive viscoelastic response was obtained by modifying the mixture with hydrated lime, i.e., an increase in the dynamic modulus, G (Khattak and Kyatham, 2008a). In the second study, they focused on fine aggregate because it is more susceptible to moisture damage. The mixture was modified with hydrated lime, 20% for the binder. The asphalt matrix was composed in the same manner as explained above. Various tests indicate an improvement in the strength of the asphalt matrix, making it less susceptible to moisture damage (Khattak and Kyatham, 2008b).

Authors Little and Epps determined that hydrated lime reduces asphalt's sensitivity to moisture and improves adhesion between the aggregate and asphalt. Furthermore, this substance reduces oxidative aging and increases its resistance to fatigue. One study showed that adding hydrated lime can save $20/ton of asphalt mix and extend the material's useful life by 38% (National Lime Association, 2006).

It is important to mention the methods used to quantify moisture damage. Some of these are: HWTD (Hamburg Wheel Tracking Device), ITSR (Indirect Tensile Strength Ratio), Duriez, Cantabro, SATS (Saturation Ageing Tensile Stiffness), and Lottman, among others. It should be noted that there are still no studies determining which method is most appropriate for assessing moisture damage. A comparison of different aggregates (including hydrated lime) and different testing methods showed that hydrated lime performed better than other additives in the Lottman test. The HWTD test also shows that hydrated lime is more effective in improving asphalt's resistance to moisture damage (EuLA, 2011).

All of the studies reviewed determined that adding hydrated lime has a clear benefit on asphalt properties, increasing its hardness and resistance to moisture, and improving the characteristics of the asphalt matrix in general.

2.4 Use of hydrated lime in asphalt mixtures in Costa Rica

In Costa Rica, research has been conducted on the incorporation of hydrated lime as an aggregate in the asphalt matrix to mitigate moisture damage. Jiménez (2015) modified the asphalt binder with nanolime, using this nanometric size to achieve better interaction between the binder and lime particles. This research concluded that there is no improvement in asphalt performance (according to the Superpave methodology) when comparing the use of nanolime or conventional lime. Furthermore, according to the parameters of retained strength and loss of adhesion, lime-modified asphalts improved from 5% to 11%.

Similarly, Vargas (2016) evaluated the effects of adding lime and nanolime to hot-mix asphalt mixtures with nominal sizes of 9.5 mm and 12.5 mm. The samples underwent three tests: Diametral Tension, Hamburg Wheel, and Dynamic Modulus. The research showed that adding lime and nanolime reduces the percentages of optimal asphalt required, resulting in lower production costs. The sample that presented the most favorable results was the 12.5 mm lime-modified asphalt, which has greater resistance to moisture damage.

In 2016, a report on moisture damage in asphalt mixtures was prepared by the National Laboratory of Materials and Structural Models. The objective was to develop a methodology to quantify moisture damage in asphalt mixtures for Costa Rica conditions. The report's findings included improved resistance to moisture damage in lime-modified mixtures. It was also found that modifiers added to asphalt mixtures, such as SBS polymer or lime, affect the volumetric properties of the mixture (LanammeUCR, 2016).

In 2017, another report was conducted on moisture damage. The objective of this report was to comprehensively evaluate the susceptibility of various asphalt mixtures to moisture damage through component and cluster analysis. This report concluded that adding lime to asphalt mixtures improves resistance to moisture damage. It was also highlighted that modifying asphalt mixtures with SBS (polystyrene-butadiene-styrene) polymer and liquid anti-stripping agent (LTA) improves the material's performance against moisture damage and fatigue cracking (LanammeUCR, 2017).

On the other hand, a similar study was conducted at Lanamme in 2018, which concluded that the currently defined parameter used as an acceptance criterion for moisture damage does not distinguish whether the mixture is susceptible to this problem or not; this corresponds to the reality of pavements in Costa Rica. Similarly, the researchers concluded that adding lime to the asphalt mixture improves the material's resistance to moisture damage, especially when the mixture was subjected to a higher level of damage (LanammeUCR, 2018).

2.5 Methods for quantifying hydrated lime in the asphalt matrix

Many of the studies reviewed are based on the usual amount of hydrated lime added, as this technique has been extensively studied over the years. However, failure to quantify the amount of lime added could lead to sedimentation problems. Similarly, studies demonstrated that although hydrated lime benefits asphalt, this only occurs within a specific proportion range; exceeding this threshold wastes the compound without enhancing its properties.

One of the quantification methods is the American method, which uses Fourier Transform Infrared Spectroscopy (FTIR) to calculate the hydrated lime content in asphalt. The signal is easy to detect in the spectrum and occurs at wavelengths of 1390-1400 cm-1 (Mouillet et al., 2014).

Another quantification method is German; this method consists of three tests: the purity of the hydrated lime, the hydrated lime content in the mixture as a filler, and the lime recovery in the filler from an asphalt mixture. This test is based on titration of a sample in suspension with the product of interest using hydrochloric acid. The filler is collected after extracting the asphalt from the mixture. The titration suspension is obtained by dissolving 1 g of the collected filler in 150 mL of water, 10 mL of isobutanol, and 5 mL of a surfactant solution. This method was applied to asphalt samples 1.5 years after placement. Four samples were used, two of which contained 25% hydrated lime by mass, and the amount of hydrated lime after the test was higher in both samples. The authors determined that not all of the added hydrated lime was recovered due to reactions between the aggregates and the lime (Mouillet et al., 2014).

3. Conclusions

The literature review suggests that adding hydrated lime to the asphalt matrix improves the mixture's properties in terms of hardness and resistance to fatigue, oxidation, chemical aging, and moisture damage. Likewise, changes in the viscoelastic properties of asphalt are observed when hydrated lime is mixed in, improving its resistance to permanent deformation. Furthermore, based on the studies reviewed, it is inferred that the optimal amount of lime in the asphalt mixture is 1.5% by weight of aggregates to achieve better properties and for the material to resist moisture.

It is important to emphasize that the results obtained and the benefits found after the use of lime are linked to the objective of each study analyzed. That is, studies focused on analyzing the effect of lime on a certain property of the mixture or of asphalt modified with this material will present results related to that specific property. Therefore, readers are advised to exercise discretion, given that, although this additive is indeed beneficial for pavement, it could be perceived as a solution to all road deterioration.

It is recommended that further research can be conducted on the use of this additive in the asphalt matrix in Costa Rica to determine its viability and applicability on the country's roads.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Aragão, F., Lee, J., Kim, Y., y Karki, P. (2010). Material-specific effects of hydrated lime on the properties and performance behavior of asphalt mixtures and asphaltic pavements. Construction and Building Materials, 24(4), 538-544. doi: 10.1016/j. conbuildmat.2009.10.005

[2] Bastidas, J., De Carvalho, J., y Lucena, L. (2015). Optimización del contenido de asfalto modificado con cal hidratada en mezclas asfálticas densas. Revista Asfaltos y Pavimentos, 31, 55-64.

[3] Caro, S., Masad, E., Bhasin, A., y Little, D. N. (2008). Moisture susceptibility of asphalt mixtures, part 1: mechanisms. International Journal of Pavement Engineering, 9(2), 81-98. doi: 10.1080/10298430701792128

[4] EuLA (2011). Hydrated lime: a proven additive for durable asphalt pavements critical literature review. Recuperado de: https:// www.eula.eu/hydrated-lime-a-proven-additive-for-durable-asphalt-pavements-critical-literature-review-paper/

[5] Gutiérrez, L. (2017). Diseño de asfalto en caliente mejorado con el uso de cal hidratada en la Av. Camino Dibos, ICA, 2017. (Tesis de grado). Universidad César Vallejo, Lima.

[6] Han, S., Dong, S., Yin, Y., Liu, M., y Liu, Y. (2020). Study on the effect of hydrated lime content and fineness on asphalt properties. Construction and Building Materials, 244, 1-9. doi: 10.1016/j.conbuildmat.2020.118379

[7] Jiménez, M. (2015). Análisis del efecto de nano partículas de cal hidratada en el desempeño del ligante asfáltico. (Tesis de grado). Universidad de Costa Rica, San José.

[8] Khattak, M., y Kyatham, V. (2008a). Mechanistic characteristics of moisture damaged asphalt matrix and hot mix asphalt mixtures. Airfield and Highway Pavements 2008, Washington.

[9] Khattak, M., y Kyatham, V. (2008b). Viscoelastic behavior of hydrated lime-modified asphalt matrix and hot-mix asphalt under moisture damage conditions. Journal of the Transportation Research Board, 2057(1), 64-74. doi: 10.3141/2057-08

[10] Kim, Y., Lutif, S., Bhasin, A., y Little, D. (2008). Evaluation of moisture damage mechanisms and effects of hydrated lime in asphalt mixtures through measurements of mixture component properties and performance testing. Journal of Materials in Civil Engineering, 20(10), 659-667. doi: 10.1061/(ASCE)0899-1561(2008)20:10(659)

[11] Kollaros, G., Kalaitzaki, E., y Athanasopoulou, A. (2017). Using hydrated lime in hot mix asphalt mixtures in road construction. American Journal of Engineering Research (AJER), 6(7), 261-266.

[12] Lesueur, D., Petit, J., y Ritter, H. (2013). The mechanisms of hydrated lime modification of asphalt mixtures: a state-of-the-art review. Road Materials and Pavement Design, 14(1), 1-16. doi: 10.1080/14680629.2012.743669

[13] Little, D., y Petersen, C. (2005). Unique effects of hydrated lime filler on the performance- related properties of asphalt cements: physical and chemical interactions revisited. Journal of Materials in Civil Engineering, 17(2), 207-218. doi: 10.1061/ (ASCE)0899-1561(2005)17:2(207)

[14] Moon, K., Falchetto, A., Wang, D., Riccardi, C., y Wistuba, M. (2017). Mechanical performance of asphalt mortar containing hydrated lime and EAFSS at low and high temperatures. Materials, 10(7), 1-20. doi: 10.3390/ma10070743

[15] Mouillet, V., Séjourné, D., Delmotte, V., Ritter, H., y Lesueur, D. (2014). Method of quantification of hydrated lime in asphalt mixtures. Construction and Building Materials , 68, 348-354. doi: 10.1016/j.conbuildmat.2014.06.063

[16] National Lime Association (2006). The benefits of hydrated lime in hot mix asphalt. Recuperado de: https://www.scholarworks.unr. edu/handle/11714/4927

[17] Rasouli, A., Kavussi, A., Qazizadeh, M., y Taghikhani, A. (2018). Evaluating the effect of laboratory aging on fatigue behavior of asphalt mixtures containing hydrated lime. Construction and Building Materials, 164, 655-662. doi: 10.1016/j. conbuildmat.2018.01.003

[18] LanammeUCR (2016). Daño por humedad en mezclas asfálticas (Informe LM-PI-UMP-044-R3). Recuperado de: https://www. lanamme.ucr.ac.cr/repositorio/handle/50625112500/991

[19] LanammeUCR (2017). Daño por humedad en mezclas asfálticas (Informe LM-PI-UMP-044-R4). Recuperado de: https://www. lanamme.ucr.ac.cr/repositorio/handle/50625112500/977

[20] LanammeUCR (2018). Daño por humedad en mezclas asfálticas (Informe LM-PI-UMP-044-R5). Recuperado de: https://www. lanamme.ucr.ac.cr/repositorio/handle/50625112500/1710

[21] Vargas, M. (2016). Efecto en la resistencia al daño por humedad de la mezcla asfáltica en caliente al añadir cal y nano cal hidratada (Tesis de grado). Universidad de Costa Rica, San José.

[22] Zamora, F., y Mora, E. (2019). Influencia de la cal hidratada en mezclas asfálticas drenantes (Tesis de grado). Universidad Católica de Colombia, Bogotá.