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Examine the Temperature assessment of Foamed Warm Mix Asphalt

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Abstract- Warm Mix Asphalt (WMA) has the potential to reduce the application temperature of Hot Mix Asphalt (HMA) and improve workability without compromising the performance of asphalt pavement. This promises various benefits, e.g., a reduction in greenhouse gas emissions, decreased energy consumption and costs, improved working conditions, better compaction, extended paving season, higher reclaimed asphalt content, earlier opening to traffic, etc. These benefits as well as the potential concerns are discussed in this chapter. Mix design considerations and possible specializations of WMA technologies are summarized. Different WMA production technologies are reviewed with an emphasis on practical applications.

Keywords- Warm Mix Asphalt, Hot Mix Asphalt, Bulk Specific Value, Additives, Moisture Deterioration

I. INTRODUCTION

An Overview of Moisture Deterioration About 90% of India's 64-millionkilometer-long road system is made from asphalt. Even though the total length of the country's highway system is 1.42 million kilometers, or 2.21 percent of the road system, it carries 40 percent of all traffic (North 2020). There are 60.37 million kilometers of roadways besides state highways. High-traffic roads, such as expressways, national highways, state highways, and other important roads, are often built with bituminous concrete (BC), a thick combination. Keeping this road system functional has always been the biggest obstacle. Bituminous or asphalt pavements deteriorate for a variety of reasons. Premature failure is directly related to the asphalt pavement's performance, making the moisture resistance of asphalt mixes a crucial factor. Excess water in the pavement is a leading cause of early collapse (Essayed and Lindly, 1996). Accordingly, there is a global problem with asphalt pavements being damaged by moisture (Yilmaz and Sargin, 2012).

To boost the asphalt mixes' overall performance, several additives are being included in the binder and the mixture. The following are several researchers' definitions of moisture damage in asphalt mixtures: According to the Asphalt Institute (1981), "the phenomenon is known as stripping and results when moisture causes a loss of bond between the aggregate and the asphalt binder." Loss of the adhesive bond between the asphalt cement and the aggregate surface and/or loss of the cohesive resistance inside the asphalt cement, largely from the action of water, leads to the increasing functional degradation of a pavement mixture (Kiggundu and Roberts 1988). Damage caused by moisture in asphalt may be characterized as a decline in the material's mechanical characteristics (Bhasin et al., 2007).

When water is present in asphalt mixes, it causes a loss of strength and durability known as "moisture-induced damage" (MID). "Continued dislodging of aggregate as a result of moisture induced weakening and mechanical damage caused by traffic load" (Kringos and Scarpas, 2008) is a prevalent form of failure. Damage, in a broad sense, is the extent to which a system loses its ability to perform its intended functions. When used to describe asphalt mixes, the term "moisture damage" refers to any deterioration in the material's mechanical qualities caused by the presence of moisture in either liquid or vapor form.

Different ways of moisture transport led to the development of moisture damage, which in turn leads to adhesive and cohesive failures (Caroo et al., 2008). Moisture damage, as defined by Kumar and Anand (2012), occurs when moisture penetrates the pavement's microstructure and weakens its mechanical qualities. The foregoing criteria make it abundantly evident that traffic loads cause the mechanical characteristics of asphalt mixes to deteriorate in the presence of moisture, leading to the progressive dislodging of aggregates due to adhesive and cohesive failures.

The asphalt mixture, regardless of its composition, will be prone to moisture-induced deterioration over time even without the application of mechanical loads because the presence of moisture itself has an unfavorable influence on material properties. It is possible that the anxiety would not have manifested without the presence of water or that it would not have manifested until a later stage of service life (Kringos and Scarpas, 2008).

In Figure 1.1, we see some of the potential pathways for water to penetrate the pavement. Water can move through the asphalt because of its porous structure (Lottman 1971; Krishnan and Rao 2001). Ingress through the surface and shoulders, upward capillary movement, freeze/thaw cycles, and variations in water table level all contribute to the occurrence of water in the pavement system. When water condenses or evaporates, it travels through the asphalt mixture microstructure via the network of air gaps and fractures that connects those (Shakiba et al., 2017).

In addition, the proportion of air spaces is at its highest when the asphalt 3 pavement is exposed for vehicle movement following construction or overlay, which may facilitate water infiltration. Moisture in asphalt mixes can be caused by several factors, including improper compaction, insufficient drying of aggregate, aggregate dirtiness, improper drainage, and improper aggregate-binder chemistry. Several distresses in asphalt mixes are initiated and spread, mostly due to moisture. Moisture also hastens the breakdown of asphalt pavement, which can lead to a host of problems, including rutting, fatigue, raveling, or a combination of these. If this deterioration is significant enough, it might cause stripping. Table 1.1 details some of the possible causes of flexible pavement discomfort due to water.

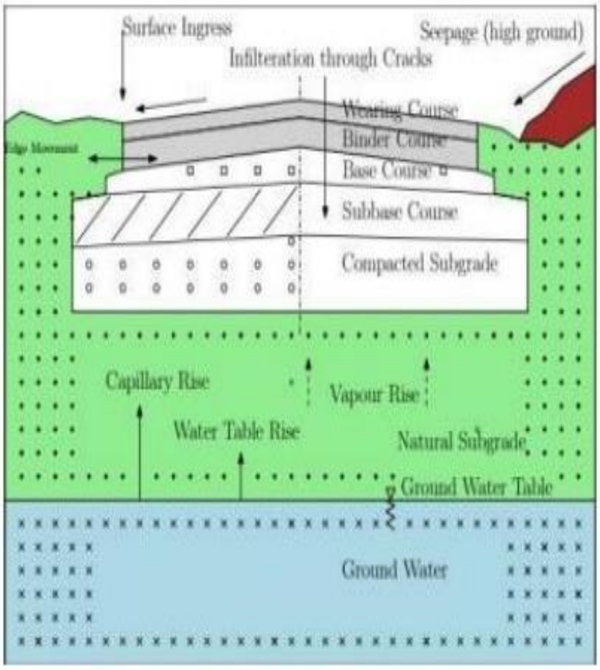
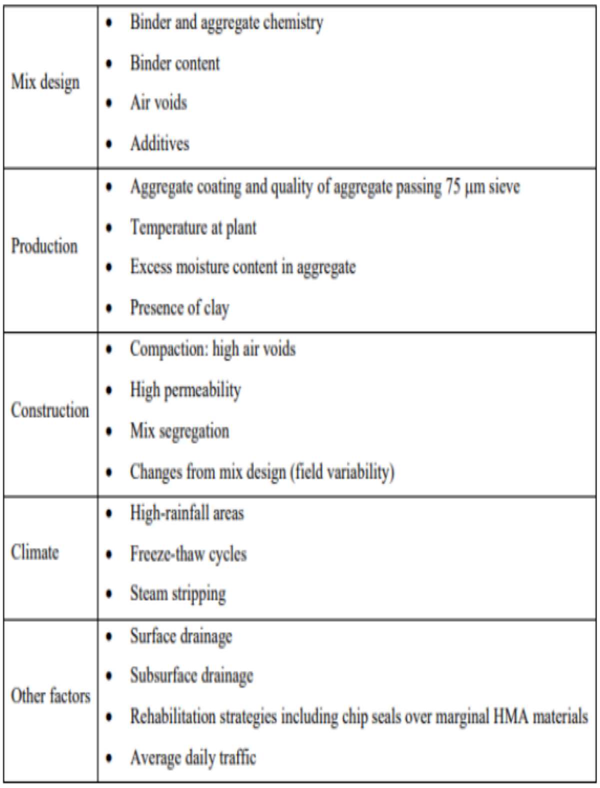


Fig 1. Possible sources of water entering the pavement.

Since 1930 (Terrel and Shute 1989), asphalt mixes have been tested in the lab using a variety of moisture sensitivity tests to see how well they perform in wet conditions. Despite years of research, the issue of moisture-induced degradation in asphalt mixes has yet to be resolved. (Tarefder and Zaman 2009) for more than seventy years.

There are two ways to lessen the impact of moisture on asphalt roads. By sealing the seams and making the surface layer impermeable, water is kept out of the pavement system. Both approaches have limitations; therefore, scientists all around the world arelooking for better ways to lessen the impact of moisture on asphalt.

Table 1. Factors contributing to moisture induced distresses.



Mix design	• Binder and aggregate chemistry • Binder content • Air voids • Additives
Production	• Aggregate coating and quality of aggregate passing 75 μm sieve • Temperature at plant • Excess moisture content in aggregate • Presence of clay
Construction	• Compaction: high air voids • High permeability • Mix segregation • Changes from mix design (field variability)
Climate	• High-rainfall areas • Freeze-thaw cycles • Steam stripping
Other factors	• Surface drainage • Subsurface drainage • Rehabilitation strategies including chip seals over marginal HMA materials • Average daily traffic

II. LITERATURE REVIEW

The Background on the role of these additions in warm mixes is provided before getting into the specifics of one such addition based on surfactants. Next, we'll go over the research on the effects of moisture on asphalt mixtures like hot mix asphalt and warm mix asphalt. The literature on antistripping additives and lime will be examined next. The different methods for assessing moisture damage on compacted asphalt mixtures are described after a brief history of the indirect tensile strength test and the fatigue test.

A literature analysis on the topic of employing a fatigue test to assess the level of moisture damage in asphalt mixtures is also provided. Finally, a review of relevant literature is presented to emphasize the gaps in knowledge and direct future study.

Hot-Mix Additives:
Why They Matter Increased asphalt mixture workability and reduced working temperatures during mixing, laying, and compaction are only two of the many reasons why WMA binders are increasingly being used in pavement construction across the world. The reduced binder aging

period has been found to increase the fatigue life of WMAs compared to HMAs (Hurley and Prowell, 2006; Roja and Krishnan, 2016). However, at lower mixing and compaction temperatures, moisture damage due to retained residual moisture in the aggregates is more likely to occur (Prowell et al., 2007). The addition of WMA to the asphalt mixture delays binder aging and increases its susceptibility to moisture. Therefore, studying how WMA additives affect asphalt mixture performance is necessary. Chemical additions will not diminish binder viscosity in a heated mix, although organic additives and foaming technologies are well known for doing so. As a result, we decided to investigate Evotherm, a surfactant-based warm-mix ingredient.

Evotherm is a surfactant-based warm-mix additive. The emulsion based Evotherm (Evotherm ET) was introduced in 2005. Evotherm ET technology is a high-residue emulsion because its total asphalt content is 70% by weight. When aggregate, asphalt binder, and chemical additive are heated together, the water evaporates, leaving behind only the binder and chemical additive. The dispersed additive technique, also known as Evotherm DAT, was then implemented. This strategy used far less water than the emulsion approach. The chemical additive solution was pumped directly into the asphalt line at the mixing plant. Then the third generation of the well-liked heating system, Evotherm 3G, was released. Without using any water, the chemical ingredient was incorporated into the asphalt mixture. The approach became significantly simpler to implement (NCHRP 691, 2011).

Asphalt Blends' Vulnerability to Moisture Degradation It is also possible for asphalt mixtures to absorb moisture in the form of liquid and/or gas. However, whereas relative humidity differential is more critical for vapor moisture transport, air void structure has a significant influence on liquid moisture transfer (Chen et al. 2004, Masad et al. 2006a, Arambula et al. 2007). Vapor dispersion, even though the impermeable dense-grade asphalt mixtures, causes blisters, which are more prevalent in the summer than the monsoon and are mostly dependent on-air temperature and humidity (Sasaki et al., 2006).

Water vapor entering the asphalt binder weakens the binding between the binder and the 17 aggregate (Hung et al., 2017). The film thickness of an asphalt binder and its moisture diffusion coefficient have major impacts on moisture transport inside an asphalt binder. Several experimental and analytical techniques are used to determine the rate of water movement through asphalt binder (Vasconcelos et al., 2010) and fine aggregate mix (Vasconcelos et al., 2011). It's an antioxidant that plays nicely with asphalt's fine clay. When hydrated lime is added to a binder, it stiffens the binder, reduces the negative impacts of the oxidized product, and reduces the risk of stripping, as observed by Little et al. (2006) and Rasouli et al. (2018).

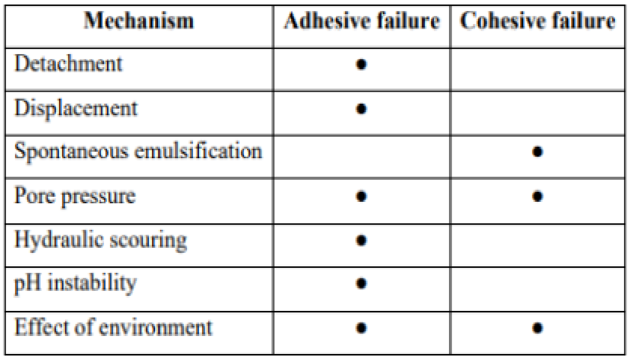
III. MECHANISMS OF WATER DAMAGE

The effects of moisture on asphalt mixes may be broken down into two categories: physical and mechanical. The physical process is characterized as the mastic weakening and Erosion breaks the aggregate-and-asphalt connection. When a road is subjected to traffic stress, pore water pressure develops mechanically (Kringos and Scarpas, 2008).

Detachment, displacement, spontaneous emulsification, pore pressure, hydraulic scouring, pH instability, and environmental influence are all mechanisms that contribute to the stripping process. Table 1.2 summarizes the possible causes of failure due to adhesive or cohesive forces. Water damage is not caused by a single mechanism but rather by a collection of processes that happen all at once or over time. When wheel loads are applied, the moisture already existing in the spaces becomes compressed and produces an abnormally high force.

Applying five-wheel loads repeatedly causes peeling. Both "adhesion" (weakening of the link between the aggregate surface and the asphalt layer) and "cohesion" (weakening of the asphalt itself) have been implicated as causes of moisture degradation in asphalt mixes. Table 1.3 details the hypotheses that explain the process of moisture damage, whereas Table 1.4 details the most current research studies that explain the mechanism of moisture-induced damage.

Table 2.Mechanisms related to adhesive and cohesive failure.

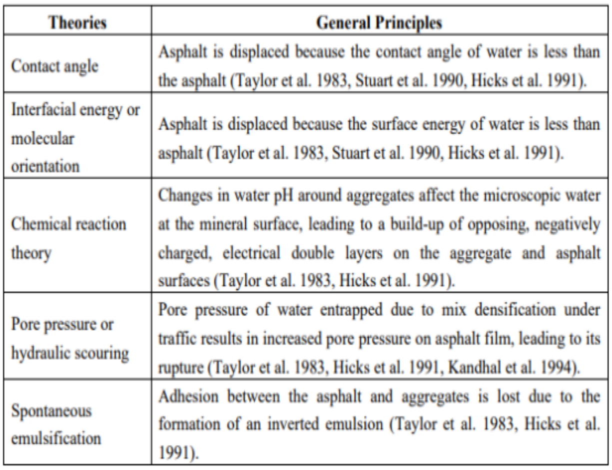


Mechanism	Adhesive failure	Cohesive failure
Detachment	•	
Displacement	•	
Spontaneous emulsification		•
Pore pressure	•	•
Hydraulic scouring	•	
pH instability	•	
Effect of environment	•	•

Many elements, including asphalt mixture type and usage, binder properties, aggregate characteristics, environment, traffic, construction procedures, and the use of an appropriate antistripping agent, contribute to the complexity of the stripping problem.

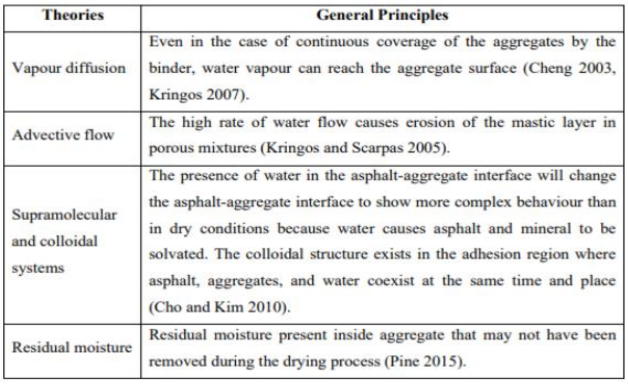
The most common reason for stripping is hydraulic scouring (Pinkham et al., 2012). Depending on asphalt chemistry, asphalt rheology, aggregate surface chemistry, and physical qualities, moisture damage may be explained as an asphalt-aggregate interaction issue (Kanitpong and Bahia, 2003).

Table 3. Theories explaining moisture damage mechanisms.



Theories	General Principles
Contact angle	Asphalt is displaced because the contact angle of water is less than the asphalt (Taylor et al. 1983, Stuart et al. 1990, Hicks et al. 1991).
Interfacial energy or molecular orientation	Asphalt is displaced because the surface energy of water is less than asphalt (Taylor et al. 1983, Stuart et al. 1990, Hicks et al. 1991).
Chemical reaction theory	Changes in water pH around aggregates affect the microscopic water at the mineral surface, leading to a build-up of opposing, negatively charged, electrical double layers on the aggregate and asphalt surfaces (Taylor et al. 1983, Hicks et al. 1991).
Pore pressure or hydraulic scouring	Pore pressure of water entrapped due to mix densification under traffic results in increased pore pressure on asphalt film, leading to its rupture (Taylor et al. 1983, Hicks et al. 1991, Kandhal et al. 1994).
Spontaneous emulsification	Adhesion between the asphalt and aggregates is lost due to the formation of an inverted emulsion (Taylor et al. 1983, Hicks et al. 1991).

Table 4. Recent literature related to moisture damage mechanisms.



Theories	General Principles
Vapour diffusion	Even in the case of continuous coverage of the aggregates by the binder, water vapour can reach the aggregate surface (Cheng 2003, Kringos 2007).
Advective flow	The high rate of water flow causes erosion of the mastic layer in porous mixtures (Kringos and Scarpas 2005).
Supramolecular and colloidal systems	The presence of water in the asphalt-aggregate interface will change the asphalt-aggregate interface to show more complex behaviour than in dry conditions because water causes asphalt and mineral to be solvated. The colloidal structure exists in the adhesion region where asphalt, aggregates, and water coexist at the same time and place (Cho and Kim 2010).
Residual moisture	Residual moisture present inside aggregate that may not have been removed during the drying process (Pine 2015).

Water can still reach the aggregate surface via diffusion even if the binder completely covers it, as demonstrated by studies and modeling (Kringos, 2007). Binder dependence of this diffusion was also demonstrated (Cheng et al., 2003). Most aggregates have a high concentration of carboxylic acids and 2-quinolone type compounds (responsible for adhesion feature of asphalt binder) adsorbed on their surfaces, and these chemicals are easily washed away by water. Water readily displaces the sulfoxides that are adsorbed in large quantities on the aggregate surface (Huang et al., 2005a).

1. Additives against Stripping:

Due to water's greater affinity for aggregate than asphalt, asphalt mixes are more vulnerable to moisture. The asphalt mixture benefits from an anti-stripping ingredient because of its sensitivity to moisture. Only a small handful of anti-stripping additives, including polyphosphoric acid and hydrated lime, are employed with asphalt mixes. These include liquid anti stripping additives (liquid amines and diamines, liquid polymers), solid anti stripping additives (Portland cement and fly-ash), and polyphosphoric acid.

Lime has been used historically as an antistripping agent. Lime is commonly used as an antistripping component in asphalt mixtures (Boyes 2011, Huang et al., 2005a). In comparison to other mineral fillers, hydrated lime has a significantly higher relative concentration of reactive chemical functionality because of its low molecular weight and strong reactivity. Calcium salt is formed when the strong base of hydrated lime combines with the carboxylic acid and other comparable functional groups in asphalt. These acidic components (representing around 5% of total asphalt) are removed from the asphalt phase by adsorption onto the surface of hydrated lime (Little and Petersen, 2005).

These hydrated lime interactions have positive outcomes, such as decreased stripping and increased resistance to rutting, but they also have negative outcomes, most notably decreased fatigue resistance. The binding strength between asphalt and aggregate is improved by the addition of hydrated lime, making the asphalt mixture more resistant to moisture. Adding lime to HMA slows down the oxidation process and mitigates the damage caused by oxidation by-products (Little et al., 2006).

2. Additives for Hot-Mix Asphalt:

Since Warm Mix Asphalt (WMA) can achieve the necessary workability for mixing and compaction even at reduced temperatures compared to Hot Mix Asphalt (HMA), it is seeing widespread application across the world. Organic additives, chemical additives, and foaming technologies make up the broad categories of WMA technologies. The mixing temperature of asphalt with aggregate can be decreased by using organic additives that reduce the binder viscosity.

In a similar vein, different foaming methods do reduce the binder's viscosity by a factor of 8 while simultaneously increasing its volume. Chemical additives, on the other hand, have negligible effects on viscosity but act as a surfactant to lower frictional forces at the aggregate/asphalt interface and thus lower the mixing temperature of asphalt with aggregate by 20–40 C. As of 2011 (Bonaquist), there were around 20 different WMA additions sold in the USA. After agreeing to do so in Paris (UNFCCC 2017), several countries are now actively striving to reduce their emissions of greenhouse gases.

WMA-Foam, Aspha-min, Sasobit wax, Advera WMA, and Evotherm are the five primary WMA technologies that have developed and are utilized for construction across the world (Kuang, 2012).

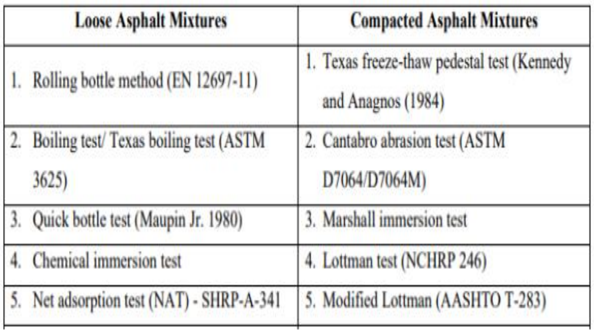
Chemical warm mix additives have been widely preferred by several researchers around the world because, unlike organic additives and foaming technologies, they do not significantly alter the binder viscosity during mixing or compaction. As emulsifiers and surfactants, chemical additives improve binder coating over aggregates by decreasing internal friction between the two (Li et al. 2016, Pereira et al. 2018).

IV. EVALUATIONS OF VULNERABILITY TO MOISTURE

Asphalt mixes can be tested for their susceptibility to moisture by means of moisture susceptibility evaluations. Predicting the likelihood of long-term stripping and assessing the efficacy of anti-stripping additives, which are applied to the asphalt binder, aggregate, or asphalt mixture, may be done with the use of moisture susceptibility test findings. Numerous studies have been conducted throughout the years to determine how susceptible an asphalt mixture is to moisture degradation. The hypothesis that pore pressure growth within the specimen or the interaction of water at increased temperature at the asphalt-aggregate interface, or both, were responsible for the moisture damage was established (Lottman 1978). Water dissolves asphalt at room temperature and higher (Lottman 1982).

Damage from moisture affects aggregates of all sizes, but it is particularly harmful to fine aggregates, which serve as the asphalt mixture's underlying matrix (Kennedy et al., 1982). The damage caused by moisture to asphalt mixes may be quantified using the AASHTO T283 (2014) moisture susceptibility test, which is utilized in India (MoRTH 2013). The moisture sensitivity test, which has been refined throughout time for use on either loose or compacted asphalt mixes (Table 1.5), assesses damage on a global scale without isolating individual causes. The results of these tests are averaged so that they may be compared across different settings.

Table 5. Tests conducted on loose and compacted asphalt mixtures.



Loose Asphalt Mixtures	Compacted Asphalt Mixtures
1. Rolling bottle method (EN 12697-11)	1. Texas freeze-thaw pedestal test (Kennedy and Anagnos (1984)
2. Boiling test/ Texas boiling test (ASTM 3625)	2. Cantabro abrasion test (ASTM D7064/D7064M)
3. Quick bottle test (Maupin Jr. 1980)	3. Marshall immersion test
4. Chemical immersion test	4. Lottman test (NCHRP 246)
5. Net adsorption test (NAT) - SHRP-A-341	5. Modified Lottman (AASHTO T-283)

This article discusses the additional tests that have been developed over time to assess the effects of moisture damage on asphalt mixes. The adhesive strength between aggregate and binder, as well as the cohesive strength of the binder itself, may be determined with the use of pneumatic adhesive tensile testing equipment. When a pulling force is applied between the metal plates holding the specimens in place, the amount of force needed to break the specimens apart may be recorded. Asphalt mixes' sensitivity to moisture may also be estimated by calculating the surface free energy of the aggregate and binder. The aggregate surface free energy is measured with the use of a Universal Sorption Device (USD). The surface free energy of asphalt is calculated using the Dynamic Wilhelmy Plate Method (DWPM), while the heat of immersion of the aggregates in water is measured using a microcalorimeter in US dollars.

V. REASONS FOR CONDUCTING RESEARCH

Two basic problems were presented by Tarfeder and Zaman (2010) but have yet to be resolved. Is it possible to foretell whether moisture will cause damage? How can harm caused by moisture be reduced?

After construction is complete, the pavement is used by vehicles, so it's important to know how asphalt mixes react to repeated wheel loads. The asphalt pavement's wearing course is subjected to direct, repetitive loading. Most India's high-traffic roads employ bituminous concrete (BC), a dense-graded asphalt mixture, as their wearing course. Understanding the fatigue response of asphalt mixes after the compacted specimen is damaged by moisture is important since the worn course is immediately subjected to wheel loads in the presence of moisture during the monsoon.

A similar asphalt combination with more moisture accessibility should show more wear and tear. Some research suggests that damage is not necessarily proportional to the amount of moisture that is accessible and that TSR can vary even when the specimen is compressed at the same air voids (Tarefder and Ahmad 2015a, Tarefder and Ahmad 2015b, Ahmad et al. 2018). It's possible that ITS readings will fluctuate due to chemical reactions that occur during freeze-thaw cycles or pore pressure cycles at high temperatures. If the binder becomes stiffer because of chemical modifications, the TSR should increase because of the low stripping (Ahmad et al., 2018). Heating aggregate and asphalt to around 160 °C to create a workable asphalt mixture is an energy-intensive process used to make HMA.

This results in the temporary aging of the binder due to the loss of volatile factions. WMA technology is used to create usable asphalt mixes at lower temperatures, reducing the amount of energy required to do it. About 20–40 C cooler than HMA, WMA combinations are created. As a result, WMA will age more slowly than HMA and harden less quickly. It is anticipated that WMA will have a longer fatigue life than HMA. However, WMA is more susceptible to moisture damage than HMA is when moisture is present. Hydrated lime was once used to reduce the effects of moisture on HMA and WMA.

Since hydrated lime is also an active filler, it can make the unconditioned asphalt mixture more rigid. Therefore, improved performance across the board is predicted for conditioned asphalt mixes made with hydrated lime. The fatigue performance of HMA and WMA treated with lime after being conditioned with moisture is also anticipated.

VI. PURPOSES AND AIMS

Following are some of the goals of this study:

- Determine if the indirect tensile strength ratio test is a reliable method for determining how susceptible asphalt mixes are to moisture.
- Second, we want to see how flexural stiffness and energy dissipation change over time and how much of a role warm mix addition, hydrated lime, and moisture conditioning play.
- The third objective is to determine how much water and hydrated lime affect the fatigue life of hot mix asphalt and warm mix asphalt. The addition of hydrated lime to hot mix asphalt and warm mix asphalt has been studied to determine its impact on viscoelastic dissipation and damage-induced dissipation.

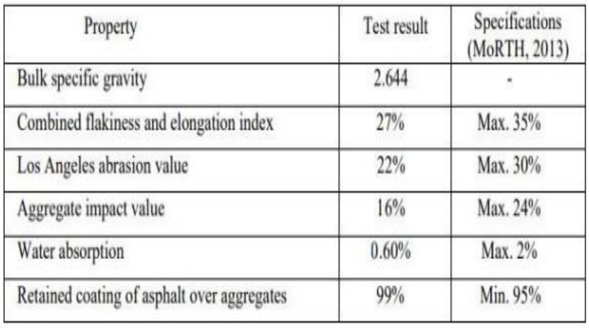
VII. LIMITATIONS

This study's scope is restricted to the following: The bituminous concrete used in all the trials in this study has a Grade II density. Three different asphalt binder types are employed in the current investigation: (1) VG30, an unaltered binder; (2) hydrated lime, a common antistripping addition; and (3) Evotherm, a commercial warm mix additive. The indirect tension test and the four-point beam bending fatigue test are two of the performance tests considered in this investigation.

1. Materials and Fabrication of Specimen:

Overview Materials for research and production of compacted asphalt mixes are discussed in this chapter. The research uses asphalt of VG30 quality and aggregate from two different suppliers. To make warm mix asphalt, a surfactant-based warm mix additive is combined with hydrated lime to increase the material's resistance to water.

Table 6. Properties of Aggregates from Warangal Quarry.



Property	Test result	Specifications (MoRTH, 2013)
Bulk specific gravity	2.644	-
Combined flakiness and elongation index	27%	Max. 35%
Los Angeles abrasion value	22%	Max. 30%
Aggregate impact value	16%	Max. 24%
Water absorption	0.60%	Max. 2%
Retained coating of asphalt over aggregates	99%	Min. 95%

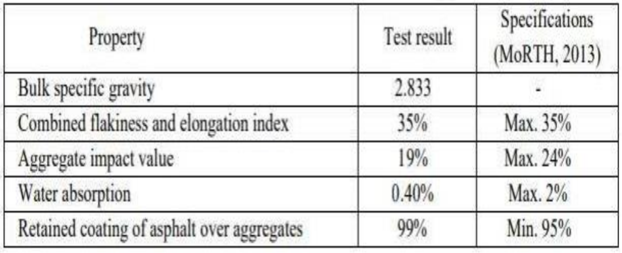
Marshall Compaction and a shear box compactor were used to create BC gradation-2 mixes, which were then used to create cylinder and beam examples. The air void content of the Marshall specimens was reduced to 7 0.5%, while the shear box specimens were reduced to 4 0.5%. In this experiment, we created and evaluated four different mixtures: VG30, VG30-WMA, VG30-L, and VG30-WMA-L.

The HMA mixture without hydrated lime is denoted by the symbol VG30, the WMA mixture without hydrated lime by the symbol VG30-WMA, the HMA mixture with hydrated lime by the symbol VG30-L, and the WMA mixture with hydrated lime by the symbol VG30-WMA-L.

Sum Total: The research makes use of locally accessible granite aggregate from two different sources. To prepare Marshall specimens, aggregate from the Warangal quarry was analyzed for Aggregate from the Chennai quarry was put through indirect tensile strength and fatigue tests, and it was found to be suitable for use in making shear box beams. Tables 3.1 and 3.2 list the results of 29 standard aggregate tests conducted at the Warangal quarry and the Chennai quarry, respectively. According to the Ministry of Roads and Highways (2013), Bituminous Concrete (BC) Grading II should be used for wearing or profile-correcting courses; hence, this is what the research uses.

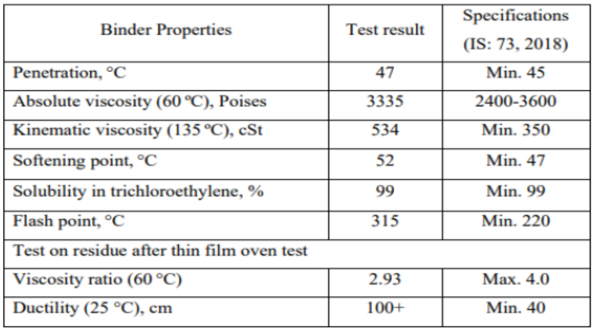
Bituminous concrete with a nominal maximum aggregate size of 13.2 mm was used in the investigation, as shown in Figure 3.1. As can be seen in Figure 3.1, the aggregates employed in the current study had a gradation that was both desirable and proportionately attained, making it a good fit for the mid gradation of bituminous concrete grade II. Coarse aggregate makes up 38% of the mix, while fine aggregate makes up 55%, and filler makes up 7%. Aggregates that are finer than a 75-m screen (5% of the filler fraction) and hydrated lime (2% of the filler fraction).

Table 7. Properties of Aggregate from Chennai Quarry.



Property	Test result	Specifications (MoRTH, 2013)
Bulk specific gravity	2.833	-
Combined flakiness and elongation index	35%	Max. 35%
Aggregate impact value	19%	Max. 24%
Water absorption	0.40%	Max. 2%
Retained coating of asphalt over aggregates	99%	Min. 95%

Table 8. Properties of VG30 binder.



Binder Properties	Test result	Specifications (IS: 73, 2018)
Penetration, °C	47	Min. 45
Absolute viscosity (60 °C), Poises	3335	2400-3600
Kinematic viscosity (135 °C), cSt	534	Min. 350
Softening point, °C	52	Min. 47
Solubility in trichloroethylene, %	99	Min. 99
Flash point, °C	315	Min. 220
Test on residue after thin film oven test		
Viscosity ratio (60 °C)	2.93	Max. 4.0
Ductility (25 °C), cm	100+	Min. 40

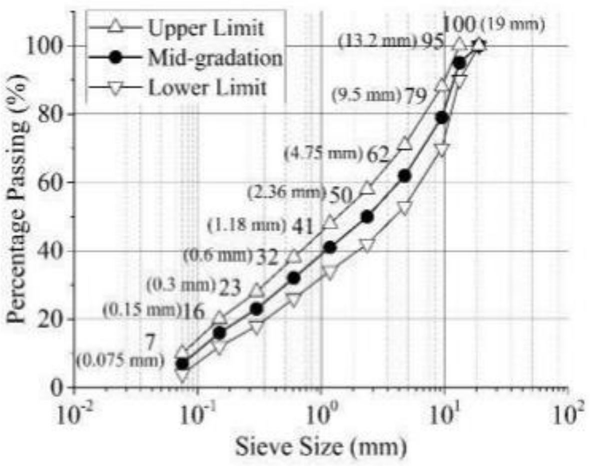


Fig 2. Aggregate gradation (BC grade II) (MoRTH, 2013)

2. Investigation by Way of Experiment:

Context: This chapter provides the approach needed to move forward with the desired goal. To conduct laboratory study, there are four different asphalt combinations:

- VG30,
- VG30-WMA,
- VG30-L, and
- VG30-WMA-L

The Marshall and beam samples were evaluated both before and after being exposed to moisture. Moisture resistance was measured using cylindrical Marshall Specimens subjected to ITS and TSR testing, and fatigue was measured using beam specimens subjected to load-deformation data recording. A sinusoidal load-deformation waveform was achieved by PID tuning. Stress- strain information was calculated using this information for the ongoing study.

In order to recreate moisture damage in the lab; the AASHTO T283 (2014) test technique is commonly used. This procedure is mandated for cylinder-shaped specimens. Indirect tension testing is performed on a specimen after it has been conditioned with moisture, and the failure load is compared to that of a control specimen in order to rank asphalt mixes. Saturating the specimen to the desired level (70–80%) is rather uncomplicated and can be completed in as little as 15–20 minutes when the specimen is compressed to in-place air gaps after construction (6–8%).

When trying to characterize the impact of moisture damage on fatigue characteristics, it is unclear if such an approach may be applied to assess the damage caused by moisture to a beam specimen. It is not easy to treat such specimens to the necessary degree of saturation since they are compressed to 4% air. It is also unclear how to fully saturate a prismatic beam with just 4% air space or how the addition of an additive would change the saturation level.

VIII. RETAINING MOISTURE

Conditioned in accordance with AASHTO T283 (AASHTO T283, 2014). Both sets of specimens were prepared to fall within the Marshall specimen's allowed range of 7.5% for air spaces. The first group of samples was evaluated straight out of the box. AASHTO T283 (2014) dictated the moisture conditioning procedure for the second batch of samples. Saturation was achieved by subjecting water-soaked specimens to a partial vacuum of 660 mm Hg for 5–10 minutes. The Marshall specimen was sealed in a desiccator to prevent drying out. According to Equations (4.1) and (4.2), the saturation level was determined by dividing the volume of the absorbed water by the volume of the air gaps.

Table 9. Details of data collected for study.

Asphalt mixture	Air voids range (%)	Duration (h)	No. of specimens	Degree of saturation (%)
VG30	4.1-4.5	3	3	68-82
VG30-WMA	3.8-4.5		8	75-82
VG30-L	3.9-4.3		4	68-74
VG30-WMA-L	3.5-4.6		8	67-81

Table 10. Effect of additive on the degree of Saturation (%).

Additive	VG-30				
	Mean	SD	f*	f	p
Control	76	7.9	3.1	2.1	0.12
Evotherm	78	4.0			
Lime	71	2.7			
Evotherm and lime	74	5.8			

Table 11. ITS Test matrix.

Conditioning	Test variables	Number of specimens			
	Temperature (°C)	VG30	VG30-WMA	VG30-L	VG30-WMA-L
Unconditioned	-	3	3	3	3
AASHTO T283 conditioned	-18 °C for 16h and 60 °C for 24h	3	3	3	3

Table 12. Precision for ITS test for VG30 (ASTM D6931, 2017) .

Specimen	Unconditioned		AASHTO T283 conditioned		
	ITS, kPa	SD	ITS, kPa	Saturation range	SD
VG30	1549	47.08	1037	71.7 - 73.2	64.3
VG30-WMA	1156	59.12	694	72.2 - 78.5	35.26
VG30-L	796	3.99	781	63.7 - 68	32.8
VG30-WMA-L	1179	33.15	1102	73.1-78	54.26

IX. CONCLUSION

The following results are obtained from the experimental studies that were conducted on HMA and WMA with and without hydrated lime on dry and moisture-conditioned specimens using the ITS test and the four-point beam bending test, respectively. Indirect tensile strength and tensile strength ratio are used to quantitatively evaluate the moisture sensitivity of asphalt mixtures, leading to the following conclusions: 1. indirect tensile strength tests were first performed in both dry and wet conditions to determine the impact of hydrated lime and warm mix additions on the tensile strength of asphalt mixes. Indirect tensile strength test results on cylindrical specimens subjected to a constant displacement rate of 50 mm/min show that while the tensile strength of the dry HMA specimen decreased after lime was added, the tensile strength of the WMA 98 specimen did not change.

While the addition of lime decreases the tensile strength of HMA specimens in moisture-conditioned samples, it increases the tensile strength of WMA samples. Therefore, when the stresses applied to the cylindrical specimens increased, the results of the tensile strength tests showed conflicting tendencies. This demonstrates that the relative impacts of lime and warm mix addition cannot be captured by using indirect tensile strength as a metric. Dry and wet indirect tensile strengths were used to determine the tensile strength ratio, which was then used to analyze the impact of hydrated lime and warm mix additives on the moisture resistance of asphalt mixes.

Compared to the VG30 specimen, the VG30-WMA specimen has a lower tensile strength ratio, indicating that it is more vulnerable to moisture. Furthermore, both the VG30 and VG30-WMA specimens' tensile strength ratios are below the required limit of 80%, indicating extreme vulnerability to moisture. The tensile strength ratio for VG30-L and VG30-WMA-L specimens went over 80% when hydrated lime was added to both combinations because of the antistripping properties of hydrated lime. The VG30-L specimen has the highest moisture resistance overall, followed by the VG30 and VG30-WMA-L specimens. This demonstrates that the addition of hydrated lime to asphalt mixes increases the mixture's resistance to moisture, as measured by the tensile strength ratio.

Although the indirect tensile strength test is a fast method of measuring the impact of hydrated lime and warm mix additives on the moisture resistance of asphalt mixtures, it is not sensitive enough to distinguish between the effects of these two variables when the specimens are subjected to dry and wet conditions. c) The TSR is a pass/fail test, with the peak load being the only factor in determining whether or not asphalt mixes are susceptible to moisture. When conducting an indirect tensile strength test, the load is delivered in the diametrical direction, creating a consistent tensile stress along the diametrical plane vertically. This creates a biaxial stress condition. Another thing is that an indirect tensile strength test always results in some sort of permanent deformation of the specimen. Therefore, it is necessary to utilize a fatigue test, which faithfully records the incremental damage after each loading cycle, to assess the moisture susceptibility of asphalt mixes. In addition, the four-point bend fatigue test has been considered for the present investigation due to its ability to apply stress reversals, which is practically impossible in the indirect fatigue test, in which the specimen also undergoes 99 permanent deformations.

The specimen fails at a region of relatively uniform stress, and the condition of stress is uniaxial because a sinusoidal load is given at the third place in the four-point bend fatigue test, creating a uniform bending moment within the beam midspan. Second, at 800 microstrain, flexural stiffness and energy dissipation decrease at a faster rate than at 600 microstrains or 400 microstrains. The fatigue life is greatest at 400 microstrain, next at 600 microstrain, and finally at 800 microstrain. The dry lime-treated specimen demonstrated enhanced resistance to reduction in flexural stiffness and energy dissipation at 400 microstrains, but at higher strains (600 and 800 microstrain), the specimen demonstrated decreased resistance to these phenomena. The addition of hydrated lime, on the other hand, improved the condition of the specimens in contact with moisture across the board. This demonstrates that at greater strain levels, the positive impact of hydrated lime could only be observed in moisture-conditioned specimens.

Comparing the results of indirect tensile strength tests conducted on cylindrical specimens subjected to a constant displacement rate of 50 mm per minute, it is seen that while the tensile strength of dry HMA specimens decreased after the addition of lime, the tensile strength of WMA specimens did not change. Although the tensile strength of a conditioned HMA specimen decreases when lime is added, the tensile strength of a conditioned WMA specimen increases. The results of tensile strength tests performed on cylindrical specimens exposed to increased stresses show conflicting tendencies.

To determine the effects of warm mix addition, hydrated lime, and moisture conditioning on the development of flexural stiffness and energy dissipation, fatigue tests were performed on beam specimens subjected to four-point bending. This study's initial contribution is the invention of an appropriate approach to mimic moisture damage in beam specimens; this is necessary because there are currently no established test methods for this purpose.

- By contrasting the normalized flexural stiffness of the VG30 specimen with that of the VG30- WMA specimen, we may learn how the presence of the warm mix additive affects the behavior of the material over time with respect to flexural stiffness. There were two distinct slopes seen in the flexural stiffness curve, with the first being more gradual than the second. At 400 microstrains, it was found that the flexural stiffness of the VG30-WMA specimen decreased more gradually than that of the VG30 specimen during the early stage. In contrast to the VG30 specimen, the flexural stiffness of the VG30-WMA specimen was shown to decrease at a far faster pace during constant 100 loading. The stiffness of the VG30-WMA specimen decreased more quickly than that of the VG30 specimen at 600 microstrains. At 800 microstrains, the flexural stiffness variation is not noticeably different from what it was at 600 microstrains.

- By contrasting the normalized flexural stiffness of VG30 and VG30-L and VG30-WMA and VG30-WMA-L, we can examine the impact of hydrated lime on the development of flexural stiffness. The specimen treated with lime demonstrated greater resistance to loss of flexural stiffness and energy dissipation at 400 microstrains than the asphalt-mixed specimen without lime. But at higher strain levels (600 and 800 microstrain), the trend in the development of flexural stiffness and energy dissipation of lime-treated specimens shifted, with the lime-treated specimens displaying a greater rate of change in flexural stiffness and energy dissipation.
- The rate of decrease in flexural stiffness was greater in the moisture-conditioned samples than in the unconditioned dry samples. At 400 micro strains, the flexural stiffness of the VG30-WMAMC combination decreased much more quickly than that of the HMA mixture, as compared to the VG30-MC mixture. As a result, the WMA combination is more susceptible to the effects of moisture than the HMA mixture. While the dry specimen showed no improvement when lime was added, the flexural stiffness of the VG30-L-MC specimen decreased more gradually than that of the VG30-MC specimen. Hydrated lime's positive effect on moisture-conditioned VG30 and VG30-WMA specimens is seen across the board for all strain levels.
- In both the dry and moisture-damaged states, the flexural stiffness as a function of the number of cycles showed two-stage slopes for both WMA and HMA specimens with and without hydrated lime. The slope transition occurred at the number of cycles that resulted in a 50% reduction in initial flexural stiffness. Each specimen's energy dissipation curve had two distinct slopes, with the transition between them happening after the 50% initial flexural stiffness threshold had been reached.

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