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Moisture Susceptibility on Asphalt Mix and the Effect of Anti-Stripping Additives

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Abstract— The damage due to moisture can be result in asphalt pavements either due to stripping or the softening of asphalt, both of which result in loss of ability to resist traffic- induced stresses which is mainly occur due to the loss or destruction of bond between the aggregate and the asphalt. This study is aimed to determine the effect of moisture on different graded bitumen mixture i:e open graded mixture and dense graded mixture and the effect of anti-stripping agent(lime) in hot mix asphalt(HMA). Moisture susceptibility of asphalt mixture can be determined by different tests indirect tensile strength test, Retained Marshall stability value and boiling water test with varying the percentage of lime content from 0% to 2.5%.The results indicates that the addition of hydrated lime increases the moisture resistance value to some extent and also provide larger strength as compare to the other mixes without addition of lime and more over the dense graded mix provide more effective value than open graded mixes.

Keywords indirect tensile strength test, Retained Marshall stability value and boiling water test, hot mix asphalt, anti-stripping agent.

1. Introduction

India has a very large road network with majority of the network having flexible pavements. Generally the Hot mix asphalt roads are used now-a-days which provide more comfort and flexibility to the road users. Most of pavements shows different types of failures such as rutting, cracking stripping, disintegration, deformation which occur as a result of traffic loading, variation in temperature and water damages and poor construction practice. From all types of failure stripping is the most common failure, directly related to the penetration of moisture into the pavement and loss of bonding between the bitumen and aggregate. There are numerous factors which can enhance the moisture sensitivity problems in asphalt pavements and some of these are moisture-sensitivity aggregate, asphalt binder sensitivity, presence of water and traffic, pavement design consideration and material production issues etc. There are different modes of moisture transport among them three main modes are: (1) infiltration of surface water, (2) capillary rise of subsurface water and (3) permeation or diffusion of water vapour. Infiltration of water from the surface is the main source of moisture in the pavement and is directly related to rainfall, drainage conditions and material properties.

A moisture damage mechanism consists of the following steps:

- Moisture transport: processes by which moisture in either a liquid or vapour state infiltrates the asphalt mixture as well as the asphalt binder or mastic and reaches the asphalt binder–aggregate interface.
- Response of the system: as a response of the system the change in the internal structure of loss of load carrying capacity of the material occurs.

Moisture related problems are mainly due to two types of failure i:e adhesive failure and cohesive failure. Moisture in asphalt mixtures promotes the generation of cracks in the material. Crack growth in asphalt mixtures can occur either within the binder or at the binder–aggregate interface. The bond within the binder is termed as cohesive bond and the bond between the aggregate and binder is termed as adhesive bond.

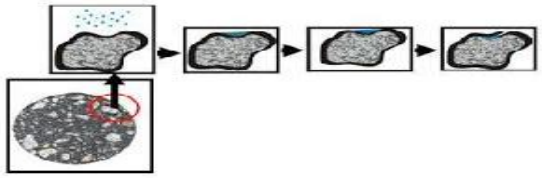

Fig 1: Moisture damage mechanism

2. Scope and objective

The main objective of this research is "*to evaluate the effects of aggregate and its properties on stripping and moisture susceptibility of Hot Mix Asphalt to study the effect of anti-stripping additives.* To accomplish this, the laboratory test will be initiated to evaluate the effect of aggregate properties on stripping and moisture susceptibility of HMA and than different percentage of anti-stripping additive i:e hydrated lime is added with the HMA to analyse the increase in strength and bitumen coating percentage.

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3. Material and experimental testing

- Aggregate of open graded and dense graded
- Asphalt binder: VG-30
- Anti-stripping additives lime
- Mixes: bituminous concrete

3.1 Aggregate

Aggregates are granular mineral particles; the aggregate used should be strong, tough, durable, and has the ability to be crushed into bulky particles without many flaky particles. In addition to gradation requirements, the aggregate are also required to possess the strength to carry and transmit the applied loads. Aggregate should be minimal plasticity the presence of clay fines in bituminous mix can result in problems like swelling and adhesion of bitumen to the rock which may cause striping problem clay lumps and foible particle should be limited to utmost 1% . The gradation table for open graded and dense graded mix are taken from **MORTH** specification. The physical properties of aggregate are shown in (**table 1)** after testing in IS testing methods.

Table 1: Properties of aggregate

Property	Test value	MORTH Specification
Aggregate Impact Value(%)	22.6	Max 30%
Aggregate Crushing value (%)	25	
Aggregate Abrasion Value (%)	26	Max 30 %
Flakiness and Elongation Index(%)	28.20	Max 30%
Water Absorption value (%)	0.5	Max 2%
Specific Gravity	2.77	2.6-2.9
Stripping Value	2.5	5

3.2 Bitumen

Bitumen is derived from fractional distillation of petroleum. Naturally occurring bitumen is commonly known as asphalt. Bitumen is basically a hydrocarbon. Less than 10% by weight is due to atoms of sulphur, nitrogen, and oxygen which are attached to the hydrocarbon molecules. Carbon content in bitumen is 80-87% by weight. Asphalt binder VG30 is used in this research work. Grade of bitumen used in the pavements should be selected on the basis of climatic conditions and their performance in past. The physical properties of bitumen are shown in (**table 2)** after testing in IS testing methods.

Table 2: Properties of bitumen

Characteristics	Values	Ref. Is no.
Absolute viscosity at 60° c, poises, (min)	2400	IS 1206(part 2)
. Kinematic viscosity at 135° c, cst, (min)	350	IS 1206(part 3)
Flash point °c (min)	220	IS 1209
Solubility in trichloroethylene, percent,(min)	99.0	IS 1216
. PENETRATION AT 25 °C,100 g, 5s, 0.1mm	50-70	IS 1203
Softening point, °c,(min)	47	IS 1205
Tests on residue from rtfot 1. Viscosity ratio at 60°c,(max) 2. Ductility at 25°c , cm,(min)	 4.0 40	 IS 1206(part 2) IS 1208

3.3 Anti-stripping agent

Lime is calcium containing anti-stripping agent. Application dosage of 1% to 2.5% in mixes by weight of bitumen, as recommended that with the addition of hydrated lime additives, resistance of mixes against stripping were increased appreciably.

4. Experimentation

For moisture susceptibility test here three experiments are conducted by taking both open graded mix and dense graded mix after finding out the optimum binder content by Marshall sample according to ASTM D1559.

1. Retain Marshall stabilility
2. Indirect tensile strength test
3. Texas boiling test

4.1 AASHTO T283 (modified lottman test)

AASHTO T283 Modified Lottman test (ITS) is used to determine moisture sensitivity of compacted asphalt samples after subjecting them to wet condition or saturation conditions. In this research the optimum bitumen content of the mix was determined to be 5.78% for open graded mix and 6.3% for dense graded mix by weight of the mixture.

In ITS test the load is applied vertically on a cylindrical sample on its diametric plane. Failure usually occurs in the form of splitting along the diametric plane.

This test is performed on compacted specimens to reach an air void content in the mix ranging from 6% to 8%. Ten specimens were prepared for each type of gradation i:e for open graded mix and for dense graded mix , applying Marshall Hammer. The specimens were divided into two groups of dry and wet samples with varying lime content from 0% to 2.5%.

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Five specimens were tested in dry conditions, while five others were tested after conditioning these to water saturation conditions of 50–80%. The group of unconditioned specimens were kept in water bath at 25^0C for 2 h and then tested. The group of conditioned specimens were kept in water bath at 25^0C for 24hr by keeping the water level above the specimen at least 20mm. The specimens were tested under ITS at 2 in./min loading rate. ITS values of the samples were calculated using the following equation:

$$ITS = \frac{2P}{\pi DT}$$

where, ITS is the indirect tension strength (kPa), P is the failure loading (kN), T and D are samples thickness (m) and diameter (m) respectively.

Moisture susceptibility of the compacted specimens was evaluated upon determining Tensile Strength Ratio (TSR) of the samples from the following equation:

$$TSR = \frac{F_2}{F_1}$$

Where F_2 is the average ITS of the wet specimens(conditioned specimen) and F_1 is the average ITS of the dry specimens(unconditioned specimen). A minimum of 0.8 in TSR is required in order to prevent failure according to MORTH specification.

4.2 Boiling water test

Boiling water test (ASTM D 3625) is used to evaluate the adhesiveness characteristics of aggregate particles with bitumen (using a visual rating i:e eye estimation of the degree of stripping after test conditioning).

Coarse aggregate of size 6.5–9.5 mm were coated with binder containing hydrated lime and the anti-stripping additive. An amount of 250 g of loose aggregate were boiled for 10 min. After drain out water, the blends were placed on a white paper to estimate the stripping visually. Images were also taken from different samples using a digital camera. The shots were then transformed into digital images, containing white and black pixels .The stripped areas or uncovered parts of the aggregate particles are recognized by white pixels. The images were then cropped to define the exact stripped areas. Finally, in order to obtain the exact numbers of white pixels and the amount of stripped areas can be easily found out by using, MATLAB and AUTOCAD softwares.

4.3 *Retained marshall stability test*

Retained Marshall Stability test (RMS) is used to determine moisture sensitivity of compacted asphalt samples after subjecting them to saturation conditions. In this research the optimum bitumen content of the mix was determined to be 5.78% for open graded mix and 6.3% for dense graded mix by weight of the mixture.

RMS testing is consisted of loading a cylindrical sample with Marshall Machine and the stability value is recorded. Ten specimens were prepared for each type of gradation i:e for open graded mix and for dense graded mix , applying Marshall Hammer. The specimens were divided into two groups of dry and wet samples with varying lime content from 0% to 2.5%. Five specimens were tested in dry conditions, while five others were tested after conditioning these to water saturation conditions of 50–80%.

The group of unconditioned specimens were kept in water bath at 60^0C for 30min and then tested. The group of conditioned specimens were kept in water bath at 60^0C for 24hr.The specimens were tested under Marshall Machine. The retained stability is given by:

$$RMS = \frac{F_2}{F_1}$$

where F_2 is the stability value of the wet specimens(conditioned specimen) and F_1 is the Stability value of dry specimen

5.Results and analysis

5.1 Retained marshall stability

Open graded mix

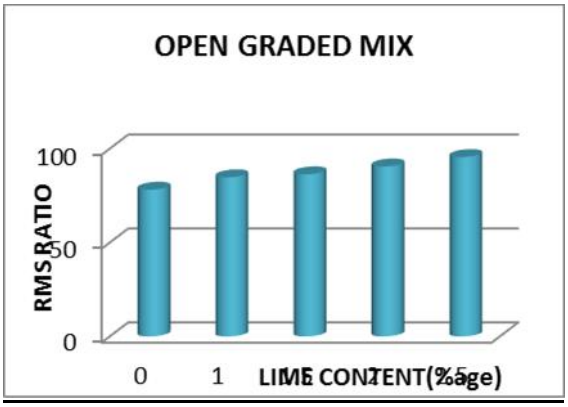
Bitumen content	Dry Condition	Wet Condition	Ratio
5.5%	175	138	78.80
6%	198	157	79.29
6.5%	179	140	78.21
7%	164	125	76.21

Average ratio for mix without lime

$$\frac{78.80+79.29+78.21+76.21}{4} = 78.1275$$

Open graded mix using lime

Lime Content	Wet Condition	Dry Condition	Ratio
1%	100	118	84.74
1.5%	120	139	86.33
2%	134	148	90.50
2.5%	150	157	95.50



Dense graded mix

Bitumen content	Dry Condition	Wet Condition	Ratio
5.5%	232	179	77.10
6%	280	219	78.20
6.5%	205	167	81.4
7%	190	160	84.2

Average ratio for mix without lime

$$\frac{77.1+78.2+81.4+84.2}{4} = 80.225$$

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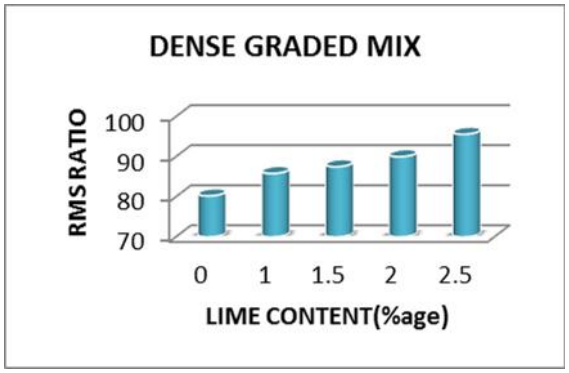
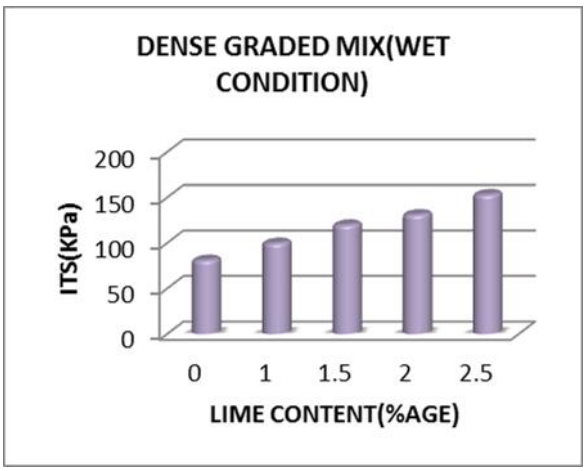
Dense graded mix using lime

Lime Content	Wet Condition	Dry Condition	Ratio
1%	109	127	85.82
1.5%	126	144	87.50
2%	144	160	90.00
2.5%	196	205	95.60





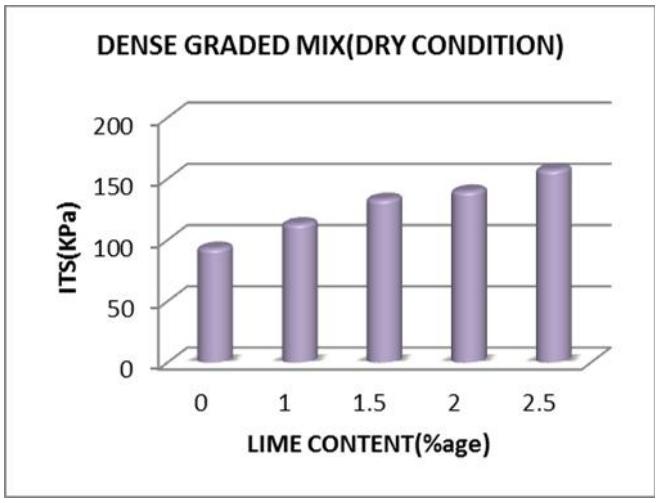
Open graded mix (dry condition)

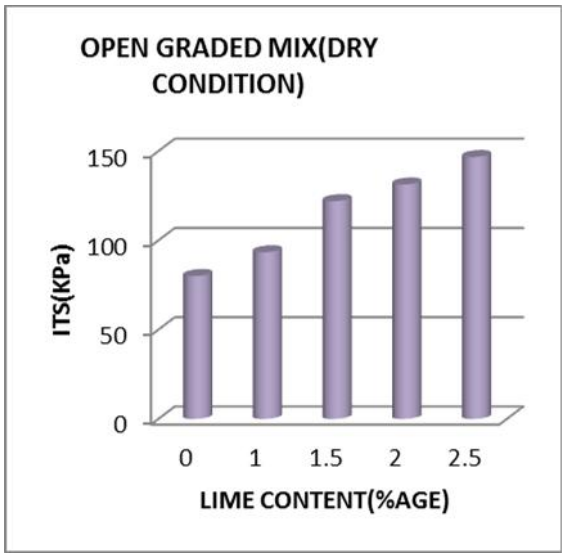
Lime content	Dia of specimen	Ht. Of specimen	Division reading	Load (kg)	Stress (kpa)
0%	10.1	6.3	12	80.004	80.044
1%	10.1	6.3	14	93.338	93.384
1.5 %	10.1	6.2	18	120.006	122.002
2%	10.1	6.4	20	133.34	131.322
2.5 %	10.1	6.3	22	146.674	146.747

5.2 Indirect tensile strength

Dense graded mix (dry condition)

Lime content	Dia of specimen	Ht. Of specimen	Division reading	Load(kg)	Stress (kpa)
0%	10.1	6.3	14	93.338	93.384
1%	10.1	6.3	17	113.339	113.395
1.5%	10.1	6.4	20	133.34	133.407
2%	10.1	6.3	21	140.007	140.077
2.5%	10.1	6.4	24	160.008	157.587





Dense graded mix (wet condition)

Lime content	Dia of specimen	Ht. Of specimen	Division reading	Load(kg)	Stress (kpa)
0%	10.1	6.2	12	80.004	81.335
1%	10.1	6.3	15	100.005	100.055
1.5%	10.1	6.3	18	120.066	120.066
2%	10.1	6.4	20	133.34	131.322
2.5%	10.1	6.3	23	153.341	153.418

Open graded mix (wet condition)

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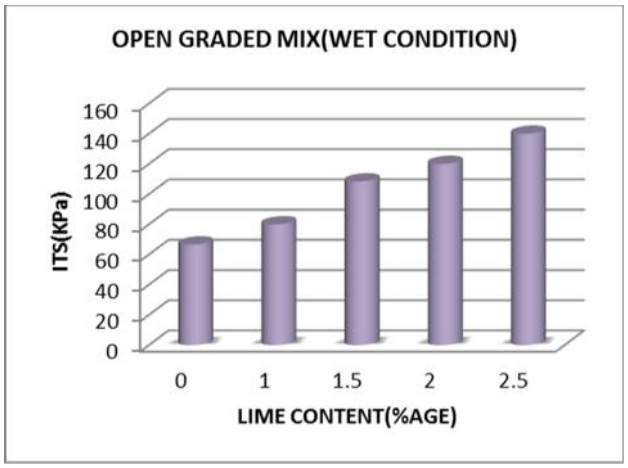
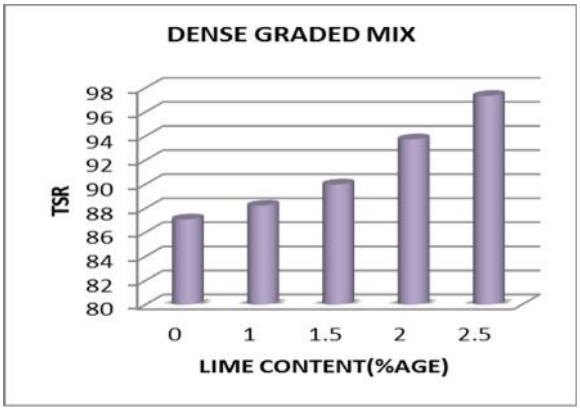
Lime content	Dia of specimen	Ht. Of specimen	Division reading	Load(kg)	Stress (kpa)
0%	10.1	6.3	10	66.67	66.70
1%	10.1	6.3	12	80.004	80.044
1.5%	10.1	6.2	16	106.672	108.446
2%	10.1	6.3	18	120.006	120.066
2.5%	10.1	6.3	21	140.007	140.077



5.3 Tensile strength ratio

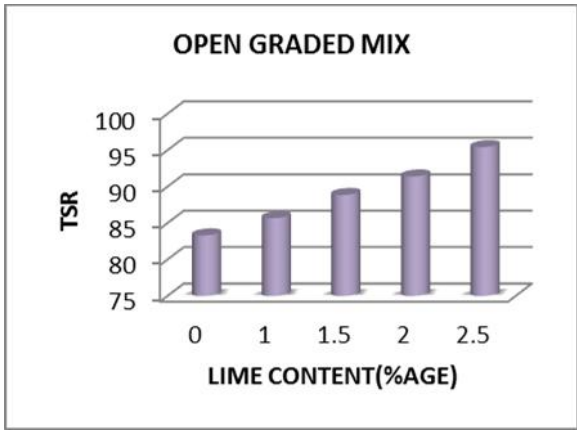
Dense graded mix

Lime content	Wet condition	Dry condition	Ratio
0%	81.335	93.384	87.09
1%	100.055	113.395	88.23
1.5%	120.066	133.407	89.99
2%	131.322	140.077	93.74
2.5%	153.418	157.587	97.35

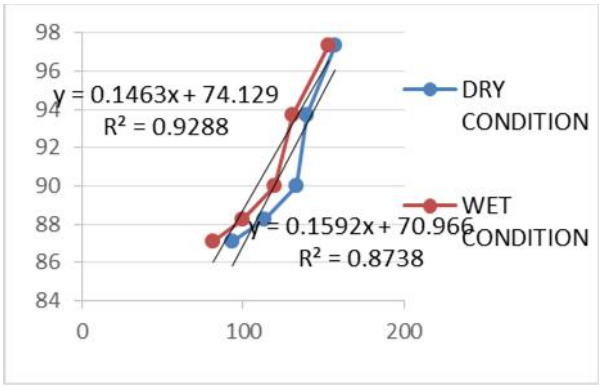


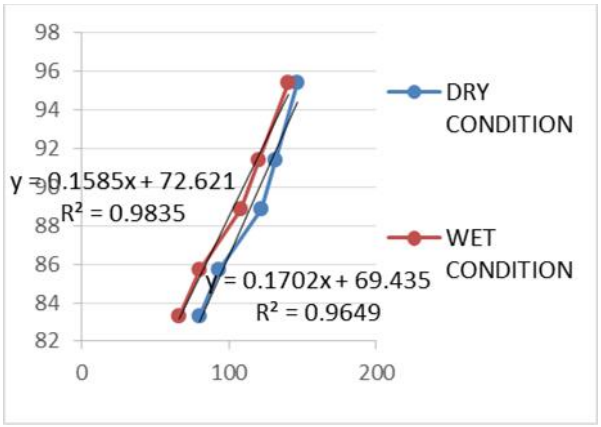
Open graded mix

Lime content	Wet condition	Dry condition	Ratio
0%	66.70	80.044	83.33
1%	80.044	93.384	85.71
1.5%	108.446	122.002	88.88
2%	120.066	131.322	91.42
2.5%	140.077	146.747	95.45



5.4 comparision graph between ITS and TSR





Correlation between ITS and TSR parameters were high, giving R^2-values of 0.87 and 0.92 for the wet and dry samples, of dense graded mixture respectively also presents correlation of data for hydrated lime treated mixes and also the correlation presenting R^2 value 0.983

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and 0.964 for open graded mixture. As it was shown in the results, the addition of hydrated lime has a strong impact on increasing strength of asphalt mixes in both wet conditioned and control mixes

5.5 Boiling water test

Mixture type	Coating amount after processing data after matlab (%)
No additive	91
1% lime	95
1.5% lime	96
2% lime	98
2.5% lime	99

Digital images of samples indicate that by adding lime the amount of white pixel will be reduced. These results, hence, show that the anti-stripping agent has worked properly in reducing the moisture susceptibility of mixes significantly Moreover, the maximum stripping percentage of all mixtures treated using anti-stripping additive was less than 5%. Among the various samples, mixtures containing no additive exhibited the highest percentage of adhesive failure with an average stripping of 9% .Conversely, it can be seen that the coverage in mixtures containing 2% and 2.5% hydrated lime was better than mixtures containing no lime.The amounts of coating were eventually maximized in hydrated lime treated mixtures (up to 99%), indicating better adhesive properties of this material. However, the results cannot be approved using this test only. More testing will be required.

6. Conclusion

Depending on the test program results the following points were concluded: Using hydrated lime as additive material has improved properties of asphalt concrete mixtures at different lime content. It was observed from the results that the Marshall Stability increases with the increase in hydrated lime content with maximum at (2.5%), this indicates the increase in strength due to additive which increases the stiffness and cohesive strength in the mixture.

According to Retained Marshall stability test, hydrated lime tends to reduce the effects of water and temperature on the cohesion and stiffness of mixtures. RMS value increases with increase in hydrated lime dosage. It was also observed that at (2.5%) hydrated lime content the RMS value was equal to (95.50%) for open graded mix and (95.60%) for dense graded mix. The addition of hydrated lime had improved the tensile strength for unconditioned and conditioned specimens; as a result the TSR values increase from (87.09% without addition of lime) to (97.35% with addition of lime) for dense graded mix and (83.33%) to (95.45%) for open graded mix which improves moisture damage resistance. The use of anti-stripping additives helps in increasing the additives properties of asphalt to aggregate which decreases the stripping value due to water susceptibility. From the result it can be concluded that by using (2.5%) hydrated lime we can get the maximum bitumen coating value of aggregate. Finally the use of hydrated lime as additive material improves the Marshall stability, reduce air voids, increases cohesive strength, and tensile strength, which makes asphalt mixtures more stiffness and durable against environmental effects, and the optimum hydrated lime content will be (2% to 2.5%) as indicate from the tests results.

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