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Effect of Hydrated Lime on Moisture Susceptibility of Asphalt Mixtures

Dr. Mohammed Qadir Ismael*
Assistant Professor
University of Baghdad-Civil Eng. Dept.
Baghdad, Iraq
dr.mohammed.t@coeng.uobaghdad.edu.iq

Ahmed Hussein Ahmed
M.Sc. Researcher
University of Baghdad-Civil Eng. Dept.
Baghdad, Iraq
ahmedsumair1@yahoo.com

ABSTRACT

Moisture induced damage can cause a progressive deterioration in the performance of asphalt pavement by the loss of adhesion between asphalt binder and aggregate surface and/or loss of cohesion within the binder in the presence of water. The objective of this paper is to improve the asphalt mixtures resistance to moisture by using hydrated lime as an anti-stripping additive. For this purpose, two types of asphalt binder were utilized; asphalt grades (40-50) and (60-70) with one type of aggregate of 19.0 mm aggregate nominal maximum size, and limestone dust as a mineral filler. Marshall method was adopted to find the optimum asphalt content. Essentially, two parameters were determined to evaluate the moisture susceptibility, namely: The Index of Retained Strength and the Tensile Strength Ratio. The hydrated lime was added by 1.0, 1.5, and 2.0 percentages (by weight of aggregate) using the saturated surface dry method. It was concluded that using hydrated lime will improve the moisture damage resistance. This was adopted as the value of tensile strength ratio increased by 24.50 % and 29.16% for AC (40-50) and AC (60-70) respectively, furthermore, the index of retained strength also increased by 14.28 % and 17.50 % for both asphalt grades. The optimum hydrated lime content founded to be 1.5 %.
Keywords: asphalt pavement, moisture susceptibility, hydrated lime, tensile strength.

تأثير الجير المطفأ على تحسس الرطوبة للخلطات الاسفلتية

الخلاصة

ان الضرر الناتج عن الرطوبة يسبب تدهورا سريعا في أداء التبليط الاسفلتي نتيجة لفقدان التلاصق بين الرابط الاسفلتي وسطح الركام او لفقدان التماسك ضمن الرابط بوجود الماء. ان الهدف من المقالة هو تحسين مقاومة الخلطات الاسفلتية للرطوبة باستخدام الجير المطفأ. تم لهذا الغرض استخدام نوعان من الرابط الاسفلتي وهما اسفلت تدرج (40-50) و (60-70) مع نوع واحد من الركام بمقاس اقصى 19.0 مم وغبار حجر الكلس كمادة مالئة. تم اعتماد طريقة مارشال لتحديد نسبة الاسفلت المثلى. تم بشكل أساسي إيجاد معاملين لتقييم تحسس الرطوبة وهما: مؤشر مقاومة الانضغاط المتبقية ونسبة مقاومة الشد. تم إضافة الجير المطفأ بنسب 1.0، 1.5 و2.0 من وزن الركام باستخدام طريقة السطح الجاف المشبع. تم الاستنتاج بان استخدام الجير المطفأ سيحسن مقاومة ضرر الرطوبة. واعتمد هذا لان قيمة نسبة مقاومة الشد ازدادت بنسب 24.50 و29.16 للسمنت الاسفلتي (40-50) والسمنت الاسفلتي (60-70) بالتعاقب، بالإضافة لذلك، فان مؤشر مقاومة الانضغاط المتبقية أيضا ازدادت بنسب 14.28 و17.50 لكلا تدرجي الاسفلت. لقد وجد ان قيمة الجير المطفأ المثالية هي 1.5 %.

الكلمات الرئيسية: التبليط الاسفلتي، تحسس الرطوبة، الجير المطفأ، مقاومة الشد

*Corresponding author
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1. INTRODUCTION

For most societies, if not all, highways networks play a vital role in the economic and social development. In Iraq, due to the rapid social changes within the last years, the number of vehicles has an enormous growth rate, furthermore, highways pavement suffers from dramatically more loads due to the absence of transportation alternatives for goods and passengers in these days. Thus, more studies are required to overcome this progressive demands for constructing and rehabilitation roads considering the consumption of billions of dinars every year in this field. In general, most of highways in Iraq are constructed using asphalt concrete pavement. The fact is that highways do not last for the designed period because of many factors that contribute to the asphalt pavements performance, one of these factors is the moisture damage which is considered as one of the most important factors that reduce the asphalt pavement structural capacity causing different distresses to develop in pavement and reduce its life cycle, thus, highway engineers make more effort towards the improvement of the asphalt pavement resistance to moisture. Different additives were tested to perform as anti-stripping agents, some of these materials made a significant improvement in asphalt pavement moisture resistance as stated by **Perez and Pasandin, 2017**.

2. BACKGROUND

Moisture sensitivity in asphalt pavement is a global issue affecting the performance and cycle life of asphalt pavement mixtures and can basically be defined as the loose of adhesive bonding between asphalt binder and aggregate surface and/or loose of cohesion within the binder or aggregate. Asphalt pavement sensitivity towards moisture is a complex phenomenon contributed by many factors including but not limited to physical and chemical properties for the binder and aggregate as well as the design procedure and construction quality. Moisture damage in asphalt pavement can lead to many distresses within asphalt structure such as bleeding, cracking, rutting, raveling and localized failures as reported by **Hicks, et al., 2003**. To demonstrated this distress, **Kiggunda** and **Roberts, 1988**, referred to six mechanisms behind moisture damage in asphalt pavement mixtures which are: detachment, displacement, spontaneous emulsification, pore pressure, hydraulic scour, and pH instability and the effects of environment or climate on asphalt-aggregate materials system that may have a significant effect on moisture damage. Several theories tried to explain the adhesion bond between asphalt binder and aggregates including: mechanical theory, chemical reaction theory, surface energy theory, and molecular orientation theory while no one of these theories provides full explanation of the mechanism by which adhesion works as declared by **Hicks, 1991**. To improve asphalt pavement resistance to moisture damage, many steps must be considered, among these, is the addition of anti-stripping agents. Anti-stripping agents are basically classified into two groups; those added to the asphalt binder which are usually chemical liquids called "Liquid Anti-Stripping Agents" and those added directly to the aggregate like: lime, fly ash, Portland cement, flue dust, polymers, cement Klein, and many others as illustrated by **Epps, et al., 2003**. The primary goal of adding anti-stripping agents is to reduce asphalt mixtures moisture sensitivity by improving the bond between the asphalt binder and the aggregate. Another important consideration when using anti-stripping additives is its ability to maintain good HMA properties, *i.e*, the additive must not negatively affect other desirable properties of the HMA in addition to its ability to improve HMA resistance to moisture as reported by **Sebaaly, 2007**. Lime has been widely used both as filler and additive to resist moisture in asphalt mixtures.

Three major forms of lime are used with asphalt mixtures according to **Hunter and Ksaibati, 2002**; Hydrated Lime ($Ca(OH)_2$), Quick lime (CaO), and Dolomitic Lime (CaO.MgO). In this paper, Hydrated Lime ($Ca(OH)_2$) was used as anti-stripping, thus the term (lime) refers to

Hydrated Lime in this paper. The National Lime Association, **NLA, 2003**, suggested that the lime may be added by a content ranged from 1.0 to 2.0 % by dry weight of total aggregate in different ways; dry lime to dry aggregate, dry lime to wet aggregate, lime slurry to dry aggregate, or mixed with asphalt. The mechanism by which lime acts as anti-stripping agent is not fully understood, **Selim, 1997**, assumed a chemical interaction involved between the calcium in the lime with the silica in the aggregate and found that lime has proven to work effectively with different types of aggregate. Lime is considered to be very chemically active in nature which makes it effective to reduce moisture damage in asphalt pavements. In the same direction, the mechanical characteristics of lime were also approved by **Huang, et al., 2010**, when they studied the effect of the lime particle fineness when lime was used as anti-stripping additive with asphalt mixtures, they pulverized a commercially available lime into smaller particle by using abrasion machine with different revolution speeds, then a concentration of 1.0 % of the pulverized lime was added to the asphalt mix and tested for moisture damage. The results showed an increase of TSR's values.

3. MATERIAL CHARACTERIZATION

Asphalt cement, aggregate, and filler used in this work have been characterized using routine type of tests and the results were compared with the State Corporation for Roads and Bridges Specifications, **SCRB, 2003**.

3.1 Asphalt Cement

Two types of asphalt cement were used in this work. Asphalt cement grade (40-50) which was obtained from Al-Durrah Refinery and asphalt cement grade (60-70) which was obtained from Al-Sheaba Refinery. Physical properties of both asphalt cement types are listed in **Table 1** and **Table 2**. All tests results meet the **SCRB R/9, 2003** specification.

3.2 Coarse Aggregate

The coarse aggregate (crushed) was brought from the hot mix plant of Amant Baghdad. The source of the aggregate was from Al-Nibaee quarry. According to **SCRB R/9, 2003** specifications, the sizes of coarse aggregate ranged between 3/4 in. (19 mm) and No.4 sieve (4.75mm). A routine physical tests were conducted to investigate the aggregate properties which are listed in **Table 3**.

3.3 Fine Aggregate

The fine aggregate (river and crushed sand) is the part of asphalt mixtures that passes sieve No.4 (4.75mm) and retained on sieve No.200 (0.075mm) according to **SCRB R/9, 2003.** It was brought from the same hot mix plant of Amant Baghdad and consists of hard, tough, grains, free of injurious amount of clay, loam or other deleterious substances. The physical properties of fine aggregate are listed in **Table 3**.

3.4 Mineral Filler

Filler is a material passing sieve No. 200 (0.075 mm). It is thoroughly dry and free from lumps or aggregations of fine particles. It was decided to use limestone dust as filler in preparing the asphalt mixture due to its availability and relatively lower cost. It was brought from lime factory at Karbala province. The physical properties are shown in **Table 4.**

Table 1. Physical properties of asphalt cement grade (40-50).

Test	Unit	ASTM No.	Pen. Grade	SCRB Specs.
Penetration @ (25°C, 100 gm, 5 sec)	1/10 mm	D-5	42	40 – 50
Softening Point.(Ring & Ball)	°C	D-36	49	----
Specific Gravity @ 25℃	-----	D-70	1.04	----
Ductility @ (25℃, 5 cm/min)	cm	D-113	>100	>100
Flash Point, (Cleveland Open Cup)	°C	D-92	280	>232

Table 2. Physical properties of asphalt cement grade (60-70).

Test	Unit	ASTM No.	Pen. Grade	SCRB Spec.
Penetration @ (25°C, 100 gm, 5 sec)	1/10 mm	D-5	63	60 – 70
Softening Point.(Ring & Ball)	°C	D-36	43	----
Specific Gravity @ 25℃	-----	D-70	1.01	----
Ductility @ (25℃, 5cm/min)	cm	D-113	>100	>100
Flash Point, (Cleveland Open Cup)	°C	D-92	280	>232

Table 3. Physical properties of Al-Nibaee aggregate.

Property	ASTM No.	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity	C-127 & C-128	2.584	2.604
Apparent Specific Gravity	C-127 & C-128	2.608	2.664
Percent Water Absorption	C-127 & C-128	0.57	1.419
Percent Wear(Los Angeles Abrasion)	C-131	13.08%	--------

Table 4. Physical properties of mineral filler.

Property	**Limestone**
% Passing No.200	100
Bulk sp. gr.	2.69

3.5 Additive

To improve the ability of asphalt mixtures to resist the harmful effect of moisture presence, the hydrated lime was used as anti-stripping additive. Lime was added at 1.0, 1.5, and 2.0 % by weight of aggregate using SSD method (*i.e.* adding dry lime to wet aggregate). Water was added with 5.0 % , by weight of aggregate, to the aggregate without mineral filler, then lime was added and properly mixed with the aggregate and then left to dry in an oven for 2 hours at 150℃. After drying, the mineral filler was added to the combination and mixed with desired asphalt content. Chemical properties of hydrated lime are listed in **Table 5**.

Table 5. Chemical properties of hydrated lime

Property	Percent	I.Q.S Standard
CO_2	1.75	≤ 5%
Mg + CaO	72.1	≥ 64%
MgO	0.39	≤ 5%
Fe_2O_3	0.21	$Fe_2O_3 + Al_2O_3 + SiO_2 \leq 5\%$
Al_2O_3	0.00	
SiO_2	2.80	
SO_3	0.32	

4. EXPERIMENTAL WORK

The experimental work phase was started by Marshall test to find the optimum asphalt content for asphalt cement grade (40-50) and asphalt cement grade (60-70). In order to evaluate the potential of asphalt mixture to resist the damage effect of moisture, two parameters were determined, namely: Tensile Strength Ratio (T.S.R) and Index of Retained Strength (I.R.S). For the purpose of determining these parameters, the indirect tensile strength and compressive tests were employed.

4.1 Marshall Method

This test measures the resistance of asphalt mixtures specimens to plastic flow when loaded on the lateral surface by means of Marshall apparatus according to **ASTM (D-6927)**. This method includes the preparation of cylindrical specimens which were 101.6 mm in diameter and 63.5 mm in height. The tested specimens were evaluated for Marshall stability, flow value, percent of air voids (AV) and percent of voids in mineral aggregate (VMA). The optimum asphalt content for AC (40-50) was 5.0 % and 4.8 for AC (60-70), test results are listed in **Table 6**.

Table 6. Marshall test results for wearing course

O.A.C (%)	Stability (kN)	Flow (mm)	Bulk Density gm/cm^3	Air Voids (%)	V.M.A (%)	V.F.A (%)
Asphalt Cement Grade (40-50)						
5.0	11.5	3.3	2.351	4.0	14.2	72.0
Asphalt Cement Grade (60-70)						
4.8	9.8	2.8	2.333	4.0	14.9	73.0
SCRB (R/9) Specification for Surface Course						
4 - 6	Min. 8 kN	2 - 4	-----	3 - 5	Min. 14	-----

4.2 Indirect Tensile Strength Test

The moisture susceptibility of the bituminous concrete mixtures was evaluated according to **ASTM (D-4867)**. The result of this test yields the indirect tensile strength (I.T.S) value and the tensile strength ratio (T.S.R). For his test, a set of asphaltic specimens were prepared for each mix according to Marshall procedure and compacted to 7±1 % air voids using trial mixtures as shown in **Fig. 1**. This high targeted air voids content is not meant to mimic the actual field conditioning process but to accelerate the moisture damage in a manner that can be measured under laboratory conditions. The set consists of six specimens and was divided into two subsets, one set (control) was tested at 25°C and the other set (soaked) was conditioned at 60℃ water for 24 hours and then tested at 25°C. The test involved loading the specimens with a compressive load at a rate of 50.8 mm/min which acting parallel to and along the vertical diametric plane through 12.5 mm wide steel strips that was curved at the interface with the specimens. These specimens failed by splitting along the vertical diameter. The indirect tensile strength (I.T.S) value is calculated according to Eq. (1), while the value of tensile strength ratio (T.S.R) is determined by Eq. (2).

$$I.T.S = \frac{2\,P}{\pi\,t\,D} \qquad (1)$$

$$T.S.R = \frac{ITS\ s}{ITS\ d} \qquad (2)$$

where:

I.T.S= indirect tensile strength
P = ultimate applied load
t = thickness of specimen
D = diameter of specimen
$I.T.S_s$ = indirect tensile strength for soaked specimens
$I.T.S_d$ = indirect tensile strength for dry specimens

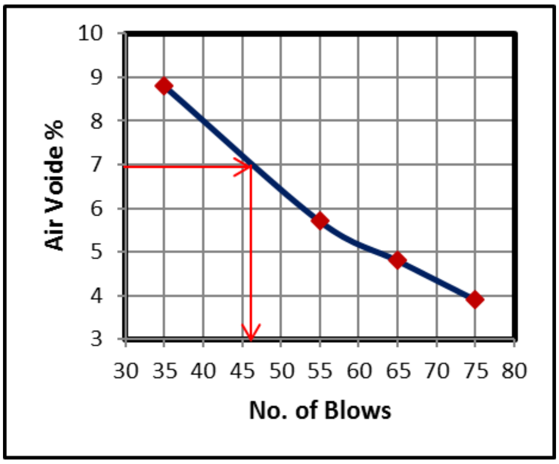


Figure 1. Relationship between No. of blows and air voids.

4.3 Index of Retained Strength Test

This test covers measurement of compressive strength loss resulting from the action of water on compacted asphaltic mixtures. This procedure is fully covered by **ASTM (D-1075)**. Six cylindrical specimens with a dimensions of (101.6 mm *101.6 mm) were prepared according to **ASTM (D-1074)**. The mixtures were compressed at top and bottom under an initial pressure of 1MPa (150 psi) to set the mixture against the sides of the mold, after that, the required pressure of 20 MPa (3000 psi) was applied for a two minutes and the specimen was left to cool at room temperature for 24 hours as demonstrated by **Ismael** and **Al-Harjan, 2018**. The specimens were extruded from the molds and the bulk specific gravity was obtained following the procedure described in test method **ASTM (D-2726).** The set of six specimens was sorted into two groups of three specimens so that the average bulk specific gravity was approximately the same for both groups. One set was tested in dry condition by storing in air bath for 4 hours at 25±1˚C before applying an axial load at a rate of 5.08 mm/min and the failure load was recorded as **S_1.** The second group was immersed in water path for 24 hours at 60˚C and was transferred to another water path at 25 ˚C for 2 hours to bring the specimens to the test temperature before applying the same load rate and the failing load was recorded as **S_2.**

The index of retained strength is calculated using the following formula:

Index of Retained Strength (IRS), %=(S2 /S_1) ×100 (3)

(min.70% according to SCRB-R/9, 2003)

Where:
S_1 = compressive strength of dry specimens (group 1)

S_2 = compressive strength of immersed specimens (group 2)

5. TEST RESULTS AND DISCUSSION

5.1 Marshall Test

The addition of hydrated lime as an additive to the asphalt mixture caused an increase in Marshall stability by (2.6, 8.69, and 4.34) % for asphalt grade 40-50 and by (7.14, 13.26. and 9.18) % for asphalt grade 60-70. As noticed, the maximum increment in stability occurred at 1.5 % of lime content. This increase was accompanied by a reduction in flow values by (12.10, 15.15, and 21.20) % for asphalt grade 40-50 and by (3.57, 10.71, and 14.28) % for asphalt grade 60-70. The air voids in asphalt mixtures decreased with the addition of lime, whereas, it decreased by (2.5, 5.0 and 8.75) % for asphalt grade 40-50 and by (0.0, 2.5, and 5.0) % for asphalt grade 60-70. The values of bulk density for asphalt mixtures containing hydrated lime were slightly increased with the increase of lime content. The justification of these behaviors can be attributed to the fact that addition of hydrated lime increased the fine materials in the asphalt mixtures, subsequently, the air voids decreased despite the fact that these materials absorbed more asphalt. The reduction in air void values causes the bulk density to increase resulting in an obvious growing increment in Marshall stability.
The test results are gathered in **Tables 7** and **8** and graphically presented by **Figs 2** and **3**.

Table 7. Effect of hydrated lime on Marshall properties for asphalt grade (40-50).

	Lime (%)	**Stability kN**	**Flow mm**	**B.D (gm/cm3)**	**A.V (%)**	**V.M.A (%)**	**V.F.A (%)**
Control Mix	0.0	11.5	3.3	2.351	4.00	14.20	72.0
Hydrated Lime	1.0	11.8	2.9	2.353	3.90	14.17	72.49
	1.5	12.5	2.8	2.355	3.80	14.08	73.02
	2.0	12.0	2.6	2.359	3.65	14.00	73.56

Table 8. Effect of hydrated lime on Marshall Properties for asphalt grade (60-70)

	Lime (%)	Stability kN	Flow mm	B.D (gm/cm^3)	A.V (%)	V.M.A (%)	V.F.A (%)
Control Mix	0	9.80	2.8	2.333	4.0	14.90	73.0
Hydrated Lime	1.0	10.5	2.7	2.332	4.0	14.75	72.88
	1.5	11.1	2.5	2.334	3.9	14.66	73.40
	2.0	10.7	2.4	2.337	3.8	14.57	73.92

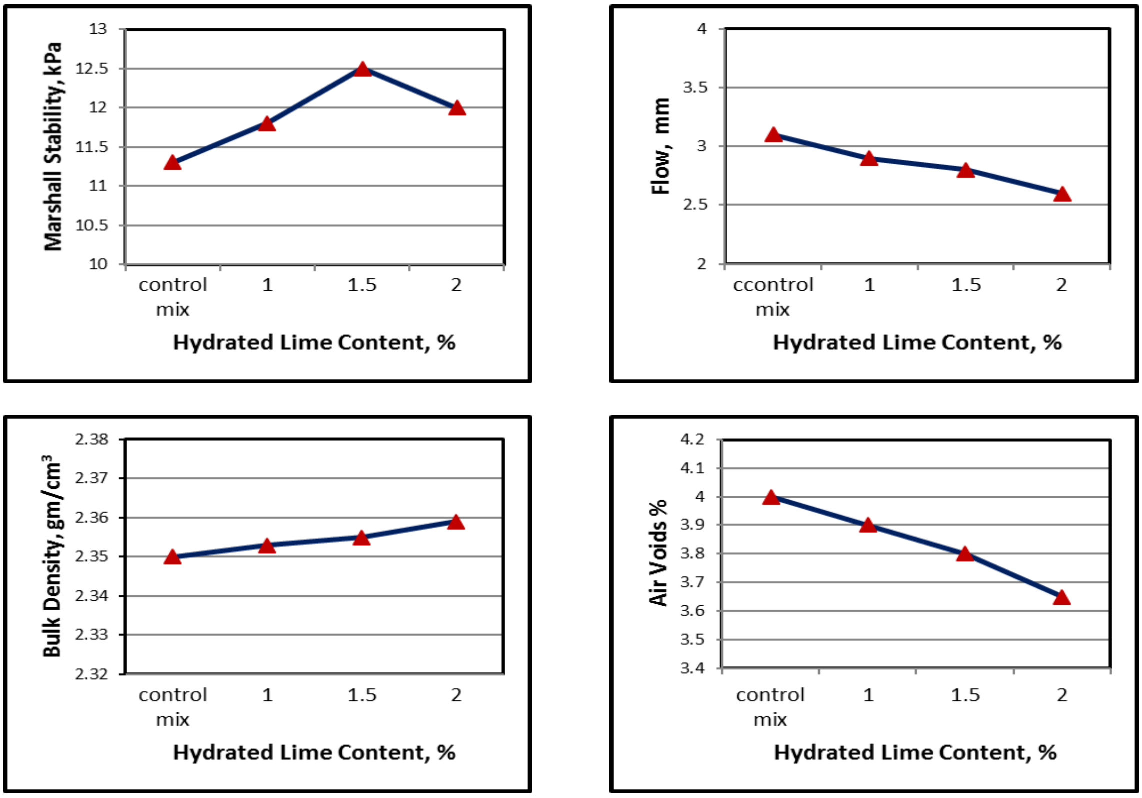
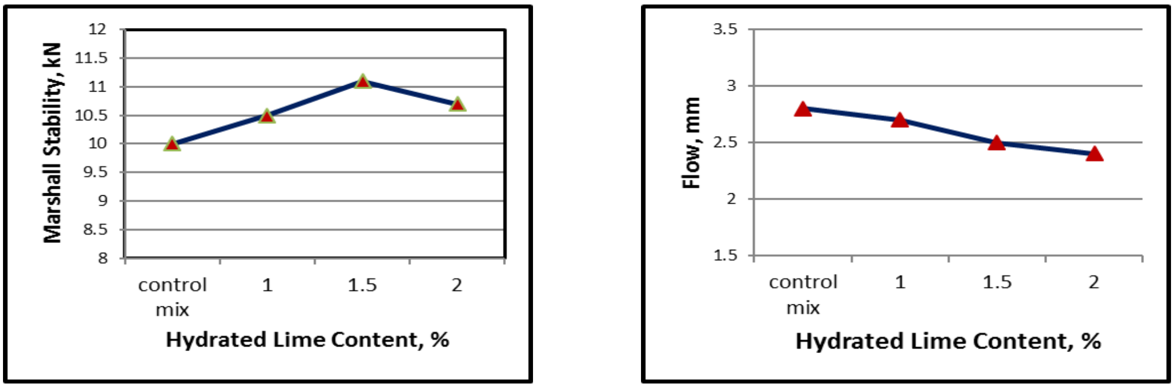
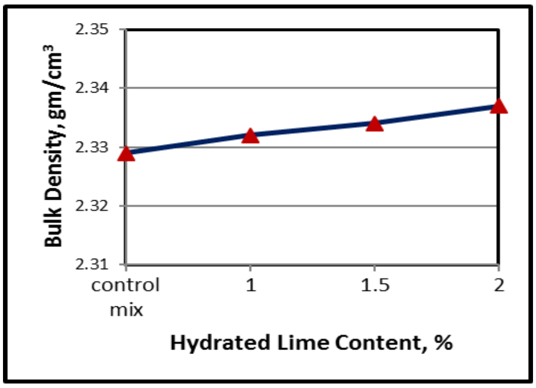


Figure 2. Effect of hydrated lime on Marshall Properties for asphalt grade (40-50).





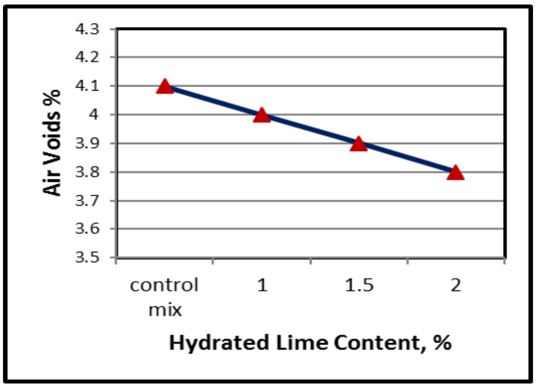


Figure 3. Effect of hydrated lime on Marshall Properties for asphalt grade (60-70).

5.2 Tensile Strength Ratio

The addition of designated amount of hydrated lime to the asphalt mixtures increased both of dry and wet tensile strength values. Consequently, the values of T.S.R for both types of asphalt are elevated, whereas, the maximum increment of increase occurred at 1.5 % of lime content. As for using asphalt grade (40-50), herein, the maximum T.S.R value was increased by 24.50 % over the control mixture. In the same way, for mixtures fabricated by utilizing asphalt grade (60-70), the maximum T.S.R value was higher by 29.16 % over the control mixture. This improvement in moisture damage resistance might be scientifically interpreted by the effect of chemical action due to the presence of Ca^{++} that is available in the lime material which increased the bond between the aggregate surface texture and the film of asphalt cement. All the necessary data concerning this test are listed in **Tables 9** and **10** and demonstrated in **Figs. 4** and **5**.

Table 9. Indirect tensile strength ratio results for asphalt grade (40-50).

	Lime (%)	Dry I.T.S (kPa)	Wet I.T.S (kPa)	T.S.R (%)
Control Mix	0	2270	1713	75.5
Hydrated Lime	1.0	2504	1990	79.5
	1.5	2729	2561	94.0
	2.0	2632	2232	85.0

Table 10. Indirect tensile strength ratio results for asphalt grade (60-70).

	Lime (%)	Dry I.T.S (kPa)	Wet I.T.S (kPa)	T.S.R (%)
Control Mix	0	2376	1711	72
Hydrated Lime	1.0	2371	1866	79
	1.5	2667	2475	93
	2.0	2610	2301	88

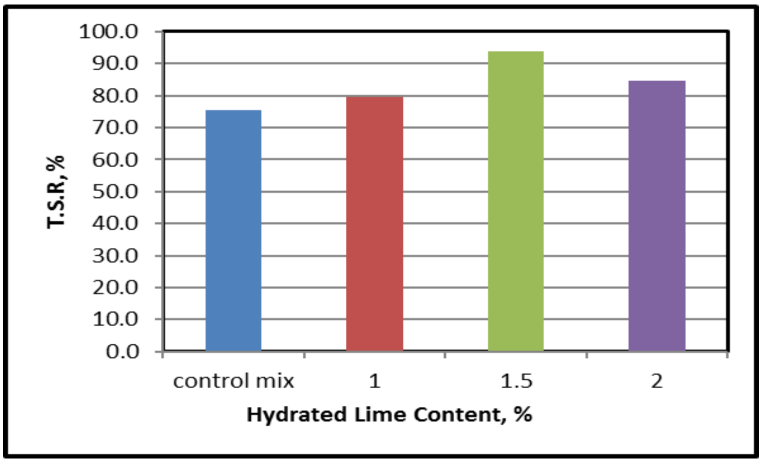


Figure 4. Effect of hydrated lime on T.S.R for asphalt grade (40-50).

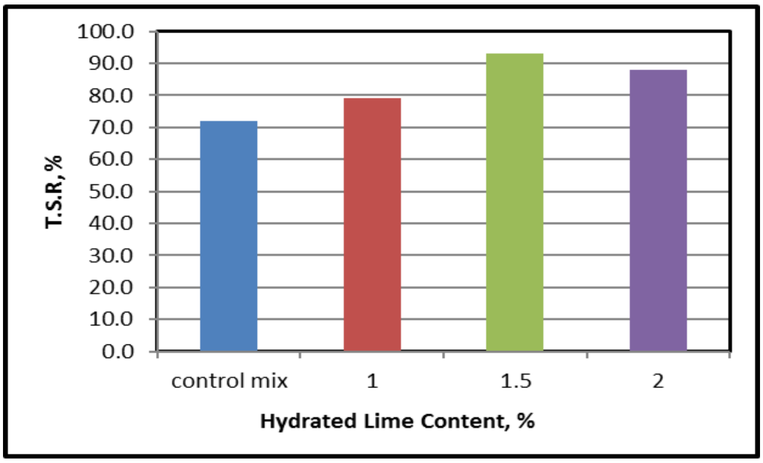


Figure 5. Effect of hydrated lime on T.S.R for asphalt grade (60-70).

5.3 Index of Retained Strength

Following the same trend of improvement as for tensile strength ratio, incorporating the hydrated lime in mixtures preparation enhance the values of dry and wet compressive strength. Hence, the magnitude of Index of Retained strength was also raised. The best results occurred at a percent of 1.5. The maximum increment of increase in I.R.S value was 14.28 % over the control mix for AC (40-50) while for AC (60-70) this value became 17.5 %. The justification of this behavior of improvement is similar to the previous interpretation. The output of this test are summarized in **Tables 11** and **12** and illustrated visually by **Figs. 6** and **7**.

Table 11. Index of retained strength test results for asphalt grade (40-50).

	Lime (%)	Dry Compressive Strength. (kPa)	Wet Compressive Strength. (kPa)	I.R.S (%)
Control Mix	0	9247	7716	84
Hydrated Lime	1.0	11673	10578	91
	1.5	13412	12811	96
	2.0	12156	10336	85

Table 12. Index of retained strength test results for asphalt grade (60-70).

	Lime (%)	Dry Compressive Strength. (kPa)		Wet Compressive Strength. (kPa)	I.R.S (%)
Control Mix	0	7300		5833	80
Hydrated Lime	1.0	8944		7768	87
	1.5	10648		10031	94
	2.0	11301		9245	82

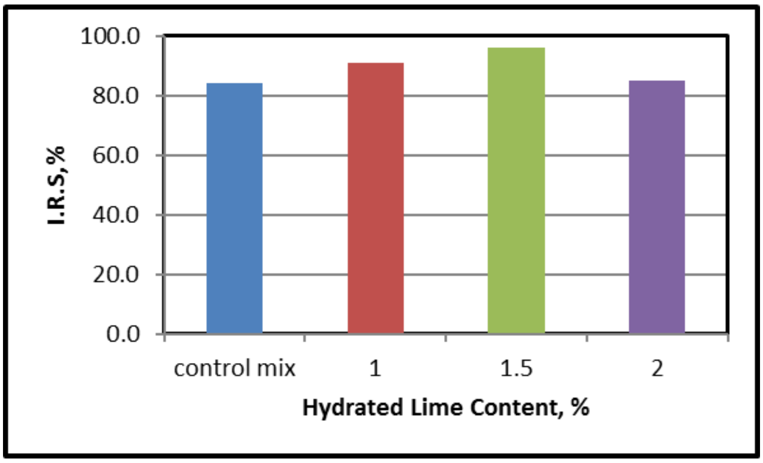


Figure 6. Effect of hydrated lime on I.R.S for asphalt grade (40-50).

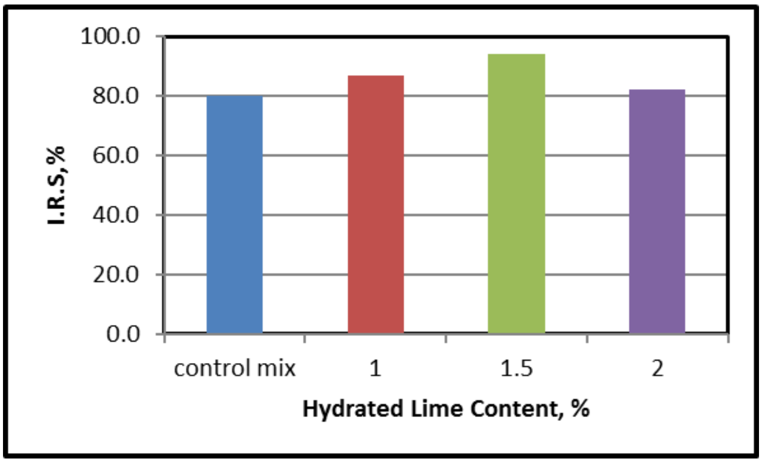


Figure 7. Effect of hydrated lime on I.R.S for asphalt grade (60-70).

6. CONCLUSIONS

- The addition of hydrated lime by three percentages (1.0, 1.5 and 2.0) by weight of aggregate using SSD method recorded an optimum content of 1.5 %. This magnitude increased the Marshall stability by 8.69 % and 13.26 % for AC (40-50) and AC (60-70) respectively.

- The air voids in asphalt mixtures decreased with the addition of hydrated lime. The higher value of reduction marked by 8.75 % for AC (40-50) at 2.0 % of lime content.

- Hydrated lime significantly increased the values of tensile strength ratio. The best results were recorded at 1.5 % lime content. At this point, the T.S.R values for modified mixtures overcome the control mixtures by 24.50 % and 29.16 % for AC (40-50) and AC (60-70) respectively.

- The index of retained strength value witnessed an enhancement by adding hydrated lime to the mixtures. At 1.5 % of lime content, the increment of increase in I.R.S value was 14.28 % over the control mix for AC (40-50) while for AC (60-70) this value became 17.50 %.

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10. NOMENCLATURE

ac	=asphalt cement, %
astm	=american Society for testing and material
av	=air voids, %
d	=diameter of specimen, mm
hma	=hot mix asphalt
i.t.s	=indirect tensile strength, kpa
p	=ultimate load failure, n
ssd	=saturated surface dry
t	=thickness of specimen, mm
t.s.r	=tensile strength ratio
irs	=index of retained strength, %
vma	=voids in mineral aggregate, %