EVALUATION OF HYDRATED LIME EFFECTS ON ASPHALT MIXTURE DURABILITY AGAINST MOISTURE: A CASE STUDY IN IRAN

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ABSTRACT

Aggregate stripping is a failure which mostly occurs in asphalt pavements in conditions with high degree of moisture accompanied by hydrophilic aggregates. The use of lime is a recognized way to mitigate this problem and in this research, we aimed to investigate the lime effect by performing laboratory tests on various aggregates and different percent of Hydrated Lime additive to figure out the changes in some principal HMA design factors. Test results have been use in one of the major road construction projects in Iran, with aggregates susceptible to premature stripping. ASTM D3625 is used as a primary evaluation of aggregate tendency to striping and AASHTO T283 for examining the indirect tensile strength of asphalt mixtures. Evaluation of asphalt mixture durability against moisture is done by TSR ratio, MRR and fatigue index. Results in our tests in a real project show the capabilities of Hydrated Lime additives against the stripping phenomena.

Keywords: Hydrated Lime additive, stripping, fatigue, MRR index

1. INTRODUCTION

Roads are the national assets of every country that provide connectivity between different regions. Management and roads maintenance are useful for all over the country. Hence, researchers have done many studies to determine distress reasons and treatment and maintenance methods. Stripping is one of the main distresses that occur in hot mix asphalt pavements. It has been an important problem these years that very much fund has been spent on that [1]. Since stripping is caused by water, it is important to analyze how the asphalt to aggregate interaction changes in the presence of water [2]. Although cohesion (the bonds between asphalt molecules) plays a part in moisture damage, the emphasis is more on the adhesion (the bonds between asphalt and aggregate) rather than cohesion. Active adhesion is the formation of bonds between asphalt and aggregate in presence of water. In other words, for asphalt to have active adhesion, it should have a higher affinity to the aggregate surface compared to water so that it can displace water from the aggregate surface [3]. The standard definition of stripping is the breaking of the bond between asphalt and aggregate by the action of water [4]. Several definitions for stripping have been presented that the definition "the decreasing of adhesion between asphalt cement and mineral aggregate caused by partition of asphalt coating from aggregate surface in the presence of water" is the best that has been expressed by Hosla. Here, the effects of hydrated lime on the strength, quality and composition of hot mix asphalt of Surface and Binder layers at severe humid weather conditions have been evaluated.

2. MATERIALS

2.1 Aggregates

Aggregates consist of inorganic polar compounds and differ widely in properties. Aggregates such as quartz, granite and sandstone have a high percent of silicon dioxide (SiO_2). The surfaces of these siliceous aggregates have silanol (SiOH) groups, which are weakly acidic. Aggregates such as marble and limestone have a high percent of calcium carbonate in them. Calcium carbonate is a base and this gives a weak basic character to its surface. Thus, the surface of aggregates can be either acidic or basic depending on the composition of the aggregates [3]. Also, aggregates chemical composition, mineralogy, surface texture, porosity and shape can be effective on the adhesion quality of aggregate to asphalt thin film [5, 6]. Aggregates used in asphalt mixture layers should absorb asphalt binder as well as possible so that aggregate particles hold each other and the mix become stable. Whatever the asphalt film adhere better to the aggregate particles, the pavement structure will be more stable and its stability and durability increases, so mineral aggregates play the main role in asphalt. In addition to the concern that dust weakens asphalt to aggregate bonds (adhesion), there is also concern that clay promotes the inclusion of water within the mixture, leading to weakened asphalt to asphalt bonds (cohesion). Plastic fines are another way to describe the clay present in an aggregate. The amount of plastic fines or clay can be inferred from the plasticity index (PI) [3]. In this case study, the crashed siliceous aggregates with the properties presented in tables 1 and 2, have been used. With respect to utilization of these aggregate in Surface and Binder layers, their gradation are presented in table 3.

Table 1: The results of quality experiments on aggregates

Experiment	Standard ASTM	Unit	Binder	Surface
Abrasion by los angeles in 500 rpm	C 131	%	B/25	B/22
Materials weight decrease by sodium solfat (salt cake)	C88	%	0.4 -1.7	0.3-0.9
Percent of fracture in one front	D 5821	%	99	99
Percent of fracture in two fronts	D 5821	%	97	98
Flakiness	BS 812	%	13	18
Sand equivalent	D2419	%	61	70
The maximum size	D 8	mm	25	19
Impact Value	D 5784	%	6.9	7.1

Table 2: Aggregate properties value in project

	Coarse Aggregate	Fine Aggregate	Filler
Apparent Specific gravity, kg/cm^3 ASTM C128	2.559	2.575	2.716
Water absorption, % ASTM C127	1.1	1.4	-

Table 3: Sieve test result

Seive size (mm) / Type of layer	25	19	12.5	9.5	4.75	2.36	0.3	0.076
Passing Percent (Binder)	100	95	-	73	55	36	12	5
Passing Percent (Surface)	100	100	95	-	61	42	11	7.2

2.2 Bitumen

Bitumen is a mixture of many organic compounds which are mostly hydrocarbons varying widely in structure and molecular weight [7]. It is oily nonpolar material in comparison to inorganic material such as aggregates. In addition to hydrocarbons, bitumen also contains certain amounts of polar organic compounds. Adhesion between bitumen and aggregate particles is a result of linkage between bitumen polar compounds and aggregates polar surface. Whereas bitumen is affected by the environment conditions, only the bitumen polarity is not adequate for good adhesion in the mixture [8]. Also, high level of water can infiltrate in to the bitumen film and mainly change the bitumen rheological properties [9]. In this research project, the AC85-100 bitumen of Tabriz refinery is used and its properties are presented in table 4.

Table 4: The properties of pure asphalt (Type of asphalt: 85-100 Tabriz petroleum)

Specific Gravity @25ºC	Loss of Weight	Penetration @25ºC	Softening point (R & B) ºC	Viscosity in 3 Temp. (cst)			PI	PVN
				120 ºC	135 ºC	160 ºC		
ASTM D70	**ASTM D1754**	**ASTM D5**	**ASTM D36**	**ASTM D2170**			-	-
1.003	0.2	99	45.9	514	260	102	-0.5	-0.9

2.3 Filler

If it is inevitable to use aggregates susceptible to stripping, it is necessary to use antistripping agents in asphalt mixture to reduce the risk of stripping. With respect to the severe humid weather conditions associated with this project (Tabriz-Zanjan freeway), we had the two options: 1) treatment with liquid antistripping additive 2) treatment with active fillers such as hydrated lime , cement to decrease the risk of stripping damage in this project. So laboratory tests were necessary to indicate that the selected option will be beneficial for decreasing the risk of stripping. Liquid antistripping additives and lime are used generally. If it is not necessary to use these additives or if they use mistakenly, it may have negative effects on pavement performance. To obtain proper results, it's necessary to use actual bitumen and aggregate samples during laboratory tests. One of the most prevalent antistrip additives is hydrated lime that effectively decreases asphalt mixtures stripping susceptibility. Hydrated lime can improve aggregates surface chemical properties [2]. Lime as a multi purpose additive in addition to reducing moisture susceptibility and its ability in controlling stripping, can decrease rutting and cracking and increase durability and strength against oxidation and aging [2].

The mechanism of lime is not well known. However lime addition for minimizing moisture susceptibility in asphalt mixtures is an accepted alternative. Lime is available in different forms which from hydrated lime ($CaOH_2$) and active lime (CaO) are effective for avoiding stripping of asphalt mixtures; nevertheless the first one is more prevalent. With respect to effectiveness and accessibility of hydrated lime, this material was used in Tabriz-Zanjan freeway project to prevent stripping of aggregates. Hydrated lime content required for decreasing moisture susceptibility of hot mix asphalt usually ranges between 1-2.5 weights percent of dry aggregates. Adding hydrated lime to hot mix asphalt mixtures usually increases the optimum asphalt content by 0.1-0.3 percents. Addition of dry lime to asphalt binder before mixing with aggregate is not examined [3]. In this project optimum lime content was determined as 1.0 percent according to AASHTO test method.

3. EXPERIMENTAL TEST

In this research, Marshall Specimens were prepared according to ASTM D1559 test method. Mixing and compaction temperatures for asphalt mixtures of Surface and Binder layers were determined using viscosity-temperature curves of bitumen as presented in table 5.

Table 5: Compaction and mixing temperature

Type of Layer	Mixing Range Temperature	Compaction RangeTemperature	Compaction Effort in 7±1%Voids
Surface	143-149	132-137	37 blows
Binder	143-149	132-137	42 blows
Asphalt Institute Recommends for viscosity	170 ± 20 centistokes	280 ± 30 centistokes	-

Tests for evaluating bituminous mixtures are classified in two groups: test on loose (uncompacted) mix and test on compacted mix. Test on uncompacted asphalt mixtures are suitable for bitumen coated aggregates in presence of water. The main advantages of this test are simplicity, inexpensiveness. In this project, the boiling water test according to ASTM D3625 standard test method was used for evaluating the effects of hydrated lime on hot mix asphalt production process. In this test, loose mix is placed in boiling water for 10 minutes. Then visual observation is made of retained bitumen coating on the aggregate. The results of this test are presented in table 6.

Table 6: Texas boiling test (ASTM D3625)

Layer Type	Result	Standard
Surface	Between 10 to 15 %	ASTM D3625
Surface Modified	Between 5 to 10 %	ASTM D3625
Binder	More than 20%	ASTM D3625
Binder Modified	Between 5 to 10 %	ASTM D3625

Evaluating compacted asphalt mixtures strength against moisture damage according to AASHTO T283 standard test method, is the most prevalent test method for determining hot mix asphalt moisture susceptibility. This test is a combination of Lottman, Tunnicliff and Root test methods and is similar to Lottman test method. Modified Lottman test procedure determines indirect tensile strength ratio, TSR. This is the ratio of the average tensile strength of the conditioned samples divided by the average tensile strength of the unconditioned samples. AASHTO T 283 allows specimens that are compacted using Marshall Apparatus, California Kneading Compactor, Superpave Gyratory Compactor, or U.S. Corps of Engineers Gyratory Testing Machine. The minimum allowable tensile strength ratio is 0.7 [10]. Nevertheless, the proposed minimum ratio is considered as 0.8. The test results of Surface and Binder layers asphalt mixture either containing or not containing the lime are presented in table 7.

Table 7: Test results of TSR value

Layer	Optimum binder %	Situation	Lottman AASHTO T283				
			Specific Weight	Void	Sat %	ITS	TSR
Surface	6.0	Dry	2213	7.3	70	408	67
		Sat	2217	7.0		274	
Surface Modified	6.1	Dry	2221	6.9	64	477	80
		Sat	2223	6.8		380	
Binder	5.4	Dry	2139	7.2	77	424	47
		Sat	2141	7.1		201	
Modified Binder	5.5	Dry	2143	6.8	73	450	66
		Sat	2149	6.6		295	

For further assessment and evaluation of hydrated lime effects, the Marshall Stability test was performed according to ASTM D1075 (AASHTO T165) standard test method. Preparing and conditioning procedures for two set of specimens are similar to immersed compression test, but the Marshall stability is determined instead of compressive strength in this test [11]. The test results of Surface and Binder layers asphalt mixture either containing or not containing the lime are presented in table 8.

Table 8: Test results of Marshall

Layer	Situation	Stability				
		Specific Weight	Stability	Sat/Dry	Flow	Q
Surface	Dry	2263	1128	73	12.0	3.69
	Sat	2270	824		12.9	2.51
Surface Modified	Dry	2290	1071	89	10.5	4.0
	Sat	2289	958		11.3	3.33
Binder	Dry	2196	1196	76	12.4	3.78
	Sat	2201	916		12.9	2.79
Modified Binder	Dry	2212	1104	92	12.9	3.36
	Sat	2212	1019		13.0	3.08

As it is obvious in table 8, specific gravity of modified specimens for Surface and Binder is increased and Marshall Stability ratio is increased more than 20 percent compared to not modified mixtures. Also, with respect to the minimum allowable Marshall Stability and acceptable flow ranges in Iranian regulation, the "Q" parameter should be greater than 2.68. According to the data presented in table 8, the "Q" parameter after adjustment has an ascending trend.

Table 9: Variation of TSR and Marshall Stability ratio value of Hydrated Lime percent in binder layer

Sample Number	1	2	3	4
Hydrated Lime %	0	33	50	67
Filler %	100	67	50	33
TSR Value %	47	60	61	66
Marshall Stability Ratio	76	80	81	92

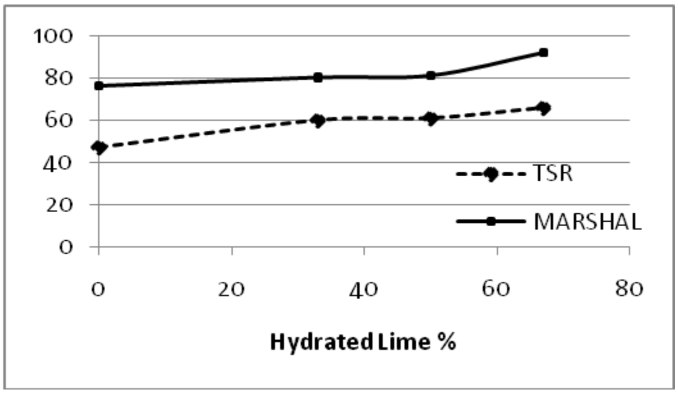

Figure 1: Variation of TSR and Marshall Stability ratio value of Hydrated Lime percent in binder layer

According to the data presented in table 9, increasing hydrated lime content leads to increase in TSR index, but does not satisfy the allowable minimum ratio. However we can say that the moisture susceptibility of hot mix asphalt materials is decreased and the lime has been effective. This ascending trend is visible in modified specimens Marshall Stability ratio as can be seen in figure 1. So increasing hydrated lime content in hot mix asphalt production results in decline of moisture susceptibility and increase of strength.

To analyze accurately the effects of adding lime in order to improve performance properties of asphalt mixtures, performance tests using UTM apparatus were performed [10]. Fatigue performance of asphalt mixtures was analyzed via performing indirect tensile fatigue tests to predict asphalt mixtures strength against cracking. This test was performed at three stress levels according to table 10.

Table 10: Fatigue test result

Stress (Kpa)	Number of Load Repeatation to Failure			
	Surface	**Surface Modified**	**Binder**	**Binder Modified**
75	59938	85623	21391	74850
100	28770	30123	11083	27708
150	11508	15165	4015	6568

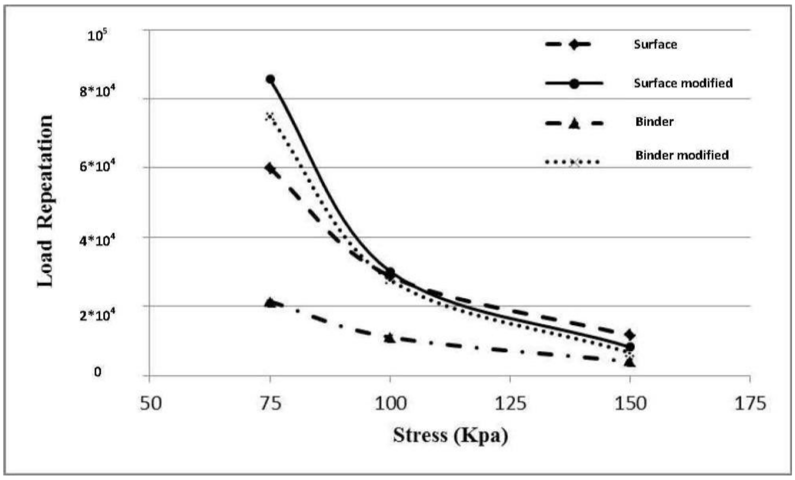

Figure 2: fatigue test result

As it can be seen in figure 2, increasing the stress level, increases the damages of pavement by fatigue mechanism, but the number of load repetition for fatigue destruction of asphalt pavements with hydrated lime is increased that lead to increasing in pavement serviceability life.

In order to survey the effects of lime addition on asphalt mixtures resilient modulus, indirect tensile test according to ASTM D4123 was performed on compacted specimens. This test was performed at 25 centigrade with aload amplitude of 200 N per centimeters of specimen height at a frequency of 0.5 Hz. The loading width and pulse width were 100 ms and 1000 ms, respectively. The results of this test are presented in table 11.

Table 11 : Resiliant Modolus ASTM D4123

Layer Type	Height (mm)	Resilient Modulus (Mpa)	Deformation (µm)
Surface	68.6	835	14.58
Surface Modified	67.4	1153	10.65
Binder	71.9	1236	9.9
Binder Modified	72.3	1418	8.6

As it can be seen in table 11, the lime causes increase in resilient modulus and decrease in deformation of Surface and Binder layers asphalt mixtures and it is evident that the effects on Surface layer asphalt mixture are more than the other.

Not only moisture damage is an independent distress, but also can lead to other early and premature distresses such as thermal cracking, rutting, raveling, potholes and alligator cracking. Therefore, in order to assess the structural capacity and performance of pavement at project site moisture conditions, beside the TSR ratio, MRR ratio was determined. This index is the ratio of saturated resilient modulus to dry resilient modulus which is related to the samples prepared by

AASHTO 283 precedure. The minimum allowable resilient modulus ratio is 0.7 [2]. The laboratory test results of this ratio are presented in table 12.

Table12 : Resiliant modulus ASTM D4123

Layer Type		Height (mm)	Resilient Modulus (Mpa)	Deformation (µm)	MRR
Binder	Dry	74.8	1252	9.73	0.33
	Sat	74.3	412	29.24	
Binder Modified	Dry	75.0	2034	5.99	0.56
	Sat	75.7	1133	10.76	
Surface	Dry	74.6	1067	14.33	0.44
	Sat	74.2	470	43.06	
Surface Modified	Dry	75.3	1656	7.42	0.76
	Sat	75.9	1262	13.32	

4. CONCLUSIONS

Following results are obtained from the study of hydrated lime addition effects in Surface and Binder layers asphalt mixture of Tabriz-Zanjan freeway project:

1- Aggregates have a main part in asphalt mixtures. So with respect to the use of siliceous aggregates in this project and the plasticity of fine aggregates and workability of lime compared to the other options, utilization of lime was considered.
2- With respect to the presence of lime close to the project site, using that resulted in costs reduction of displacing the project materials with suitable aggregates.
3- In order to assess materials stripping, tests on compacted and uncompacted specimens were performed.
4- According to Texas Boiling Water test results, hydrated lime addition resulted in stripping reduction.
5- According to Modified Lottman test results, hydrated lime addition resulted in increasing of indirect tensile strength (ITS) of lime modified mixtures. Also, TSR index was increased and its value for Surface layer asphalt mixture became more than 80%.
6- For further assessment and evaluation of hydrated lime effects, the Marshall Stability test was performed according to ASTM D1075 (AASHTO T165) standard test method. Marshall Stability ratio is increased more than 20 percent compared to not modified mixtures and the "Q" parameter after lime treatment had an ascending trend.
7- Increasing hydrated lime content in hot mix asphalt production resulted in decline of moisture susceptibility and increase of strength.
8- To analyze accurately the effects of adding lime in order to improve performance properties of asphalt mixtures, performance tests using UTM apparatus were performed. Increasing the stress level, increased the damages of specimens by fatigue mechanism, but the number of load repetition for fatigue destruction of asphalt specimens with hydrated lime was increased that lead to increasing in pavement serviceability life.
9- The lime causes increase in resilient modulus and decrease in deformation of Surface and Binder layers asphalt mixtures and it is evident that the effects on Surface layer asphalt mixture are more than the other.
10- In order to assess the structural capacity and performance of pavements at project site moisture conditions, beside the TSR ratio, MRR ratio was determined. The results show that lime treatment increases MRR index.
11- With regard to the following table 13, we can see the variations in results of Surface and Binder layers asphalt mixture:

Table13: Variation in Rsults

Layer	Texas boiling test	TSR	Marshall Stability ratio	Flow	Q	Fatigue Resistance	MRR
Binder	↑	%19↑	↑	↓	↑	↑	↑
Surface	↑	% 40↑		↓	↑	↑	

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