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Application of different testing methods for evaluating effects of hydrated lime in bituminous mixes

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Abstract

Hydrated lime has been known to be one of the most effective and durable additives in increasing moisture resistance of asphalt mixes. Indirect Tensile Strength (ITS) test is probably the most widely used testing method for evaluating moisture resistance of bituminous mixes. However, this determines resistance of mixes under certain testing conditions that may not be similar to field conditions. In this research, in addition to ITS, two other tests that are normally used for other testing purposes, have been adopted. These were Marshall and Wheel Tracking (WT) tests which are commonly used for mixing design and determination of deformation resistance of mixes respectively. Asphalt Concrete (AC) mix samples, containing various amounts of hydrated lime (ranging from 1 to 2%), were prepared and were compacted in both cylindrical and slab molds. The former samples were used for Marshall and ITS testing purposes and the latter samples were used for WT testing. The above tests were carried out, both at dry and wet conditions and at two different temperatures with the aim of evaluating moisture resistance and temperature susceptibility of mixes. The results indicated that the above testing methods are appropriate for evaluating moisture resistance of AC mixes.

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Keywords: Hydrated lime; Indirect Tensile Strength; Wheel Tracking; Marshall Quotient

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1. Introduction

Bituminous mixes that are subjected to continuous moisture conditions and heavy traffic loading, deteriorate almost rapidly [1]. From the late 1970s, researchers confirmed that moisture causes stripping of mixes which will later on result in other distresses and finally to complete pavement disintegration [2 and 3]. In the latter research, it was shown that moisture damage in a bituminous mix resulted in 25% decrease in mix modulus and 60% increase in wheel tracking; plus 30% reduction in fatigue life of mixes [3].
The application of hydrated lime in bituminous mixes has widely been used as one of the most effective methods of preventing or reducing moisture damages [4]. In a research that was performed on mixes containing hydrated lime, it was shown that these mixes are some 20 to 25% more durable than those containing original fillers of the aggregates [5]. Although Indirect Tensile Strength (ITS) test is the most widely used testing method for evaluating moisture resistance of bituminous mixes, however, some researchers found Wheel Tracking (WT) also to be appropriate as it simulates field conditions properly [6 and 7]. In the latter research, samples were kept in water for four hours at 40^{o}C before being tested under WT testing. In another research using this testing method, a parameter named “WT Index” was defined as the ratio between WT depths under saturated condition to that under dry condition [8]. In a more recent research, the effectiveness of hydrated lime and WT test, performed at 50^{o}C on wet samples was reconfirmed [9]. It should be noted that hydrated lime has well been known to be a filler that imparts chemical bonding with aggregates [10].
With regard to using Marshall testing and WT testing results of mixes containing lime or cement, it was shown that WT and Marshall Quotient values were effective in determining mix properties against moisture damage [11].

2. Materials

Aggregates were taken from a local source in Tehran and a continuous grading was selected within percentage passing sieve sizes shown in Table 1. Physical properties of the aggregates were determined using standard aggregate testing methods reported in Table 2. The results in this table indicate that these could be classified as good to medium quality aggregates. The binder used in all mixes was a 60/70 penetration grade Iranian bitumen. Mixes were prepared using hydrated lime in the amounts of 0, 1.0, 1.5 and 2% as a replacement to the mineral filler of aggregates. For each mixing combination, the optimum binder contents were determined [12]. In replacing the hydrated lime, it was controlled that the F/B ratios of mixes lay within the specification limit of 0.6 to 1.2.

Table 1. Selected grading within the specification limits

Sieve size (mm)	19	12.5	4.75	2.36	0.3	0.076
Standard limits (%)	100	90-100	44-74	28-58	5-21	2-10
Passing materials (%)	100	95	59	43.5	11.5	6

Table 2. Aggregates physical testing results

Testing method	Standard	Limit		Result (%)
		Minimum	Maximum	
Los Angeles abrasion after 500 rpm	ASTM C 131	-	25	29
Materials weight decrease by sodium sulfate	ASTM C 88	-	8	0.62
Fractured particles at one face	ASTM D 5821	60	-	91
Flaky particles	ASTM D 4791	-	15	25
Sand equivalent	ASTM D 2419	50	-	69

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3. Testing Results

Using the above mentioned mix compositions at their optimum binder contents, samples were prepared for Marshall, Indirect Tensile and Wheel Tracking tests. The results of each of these testing methods are reported as it follows.

3.1. Marshall Test

In addition to performing standard Marshall testing for determining the optimum binder contents of mixes, a new process was carried out in this research in order to investigate the susceptibility of mixes against moisture damage and high temperature variations (i.e. within temperature ranges of 45 and 60°C). A series of samples were prepared with the composition of mixes at optimum binder contents and were compacted in similar conditions as in Marshall Standard procedure. A set of compacted samples were kept in dry condition at room temperature. These were then set in water at 60°C or 45°C accordingly, for 30 minutes before being tested under Marshall Apparatus. The second sets were kept in water for 48 hours at 60°C or 45°C. Then these were kept at room temperature for 48 hours before being tested under Marshall testing.

The idea for the above testing procedure was to test samples for both moisture and temperature susceptibility characterization within the normal Marshall Apparatus capabilities. In addition to the conventional parameters, Marshall Quotient which is the ratio between Marshall Stability and Marshall Flow was determined for all the samples. Among the various parameters determined in performing the above testing (e.g. specific gravity, voids, and voids in mineral aggregates) only the three parameters shown in Tables 3 and 4 were recognized to be the key parameters that definitely show the role of hydrated lime in mixes. Table 3 shows the results at 60°C and Table 4 shows those at 45°C.

With reference to the results reported in the above tables, it can be seen that neither the samples that had poor stabilities (such as the control samples) nor those that had high stability and poor flow values were desirable for pavements. In fact, the first mixes would not resist against deformation and the second mixes would be too stiff which will make these prone to cracking under fatigue conditions in the field. Hence, comparing the data in the above mentioned two tables, it can be concluded that samples containing 1.5% hydrated lime could meet the required criteria.

Table 3. Major Marshall Parameters and Marshall Quotient values tested at 60°C

Mix Type			Flow (mm)		Stability (Kg)	
	Dry Condition	Saturated Condition	Dry Condition	Saturated Condition	Dry Condition	Saturated Condition
Control (0% hydrated lime)	758	675	4.85	5.75	156	117
Containing 1% hydrated lime	824	772	4.30	5.25	191	147
Containing 1.5% hydrated lime	843	797	4.05	4.85	208	164
Containing 2% hydrated lime	868	817	4.25	5.10	204	160

Table 4. Major Marshall Parameters and Marshall Quotient values tested at 45°C

Mix Type	Stability (Kg)		Flow (mm)		Marshall Quotient (Kg/mm)	
	Dry Condition	Saturated Condition	Dry Condition	Saturated Condition	Dry Condition	Saturated Condition
Control (0% hydrated lime)	1001	852	5.50	6.50	182	131
Containing 1% hydrated lime	1020	958	5.05	6.15	202	156
Containing 1.5% hydrated lime	1051	1024	4.30	5.20	244	197
Containing 2% hydrated lime	1075	1049	4.40	5.45	244	192

In order to be more specific on the conclusions with Marshall testing and to get maximum benefits from the various data that were obtained using this method, two other parameters were determined. These were namely Retained Stability and Retained Marshall Quotient parameters. The first is the ratio between Marshall Stabilities at saturated and dry conditions and the second is the ratio between Marshall Quotient parameters at saturated and dry conditions. Table 5 reports the results. As it can be seen in this table, the highest values correspond again with mixes containing 1.5% hydrated lime.

Table 5. Retained Marshall Stability and Marshall Quotient at 45 and 60°C

Mix Type	Test temperature: 45°C		Test temperature: 60°C	
	$\frac{Stability_{saturated}}{Stability_{dry}}$	$\frac{Marshal\ Quotient_{saturated}}{Marshal\ Quotient_{dry}}$	$\frac{Stability_{saturated}}{Stability_{dry}}$	$\frac{Marshal\ Quotient_{saturated}}{Marshal\ Quotient_{dry}}$
Control (0% hydrated lime)	0.851	0.72	0.891	0.75
Containing 1% hydrated lime	0.939	0.77	0.937	0.77
Containing 1.5% hydrated lime	0.974	0.81	0.945	0.79
Containing 2% hydrated lime	0.976	0.79	0.942	0.79

3.2. Indirect Tensile Test

Standard Indirect Tensile Strength (ITS) testing was performed on all samples with the above mentioned mix compositions. Testing was performed both on dry and saturated samples and in addition to ITS values, Tensile Strength Ratio (TSR) of the samples was determined too. Table 6 reports the results. As it can be seen on mixes containing zero or little amount of hydrated lime, TSR values were quite low. Upon increasing the hydrated lime content, TSR values were increased. However, with increasing more the level of this filler (in this case above 1.5%), TSR values were decreased again. This might indicate that at low hydrated lime levels the effects of this filler is quite low. In contrast, at high level contents, mixes become too stiff, making these prone to cracking. Hence, it can be concluded that this testing method could also be considered as an effective method for determination of the optimum amount of hydrated lime to be used in mixes.

Table 6. Results of Indirect Tensile Strength testing

Mix Type	Indirect Tensile Strength (Kpa)		TSR (%)
	Dry Condition	Saturated Condition	
Control (0% hydrated lime)	534	192	36
Containing 1% hydrated lime	597	401	67
Containing 1.5% hydrated lime	617	509	83
Containing 2% hydrated lime	614	480	78

3.3. Wheel Tracking Test

Wheel tracking test was performed on slab samples of 300*300*50 mm size. Two sets of samples were prepared for dry and wet testing conditions. Dry samples were kept in WT Environmental Chamber for 5 hours at 40 or 60°C before being tested under AASHTO T324 testing method. Samples for wet testing were similarly kept in water at the above temperatures and time period. The amount of loading in WT testing was kept 705 N and was applied in 8000 cycles at the rate of 26.5 rpm. The results are reported in Tables 7 and 8.

Table 7. Results of Wheel Tracking test at 40°C in dry and wet conditions

Mix Type	Rut depth (mm)		Rutting rate (mm/h)	
	Dry condition	Wet condition	Dry condition	Wet condition
Control (0% hydrated lime)	2.74	4.58	0.117	0.319
Containing 1% hydrated lime	2.45	3.99	0.122	0.168
Containing 1.5% hydrated lime	2.18	3.24	0.098	0.104
Containing 2% hydrated lime	1.82	3.14	0.110	0.104

Table 8. Results of Wheel Tracking test at 60°C in dry and wet conditions

Mix Type	Rut depth (mm)		Rutting rate (mm/h)	
	Dry condition	Wet condition	Dry condition	Wet condition
Control (0% hydrated lime)	9.97	18.37	0.882	2.574
Containing 1% hydrated lime	8.84	15.40	0.652	2.562
Containing 1.5% hydrated lime	6.99	13.25	0.643	1.355
Containing 2% hydrated lime	5.69	13.20	0.788	1.610

As it can be seen in these tables, at both testing temperatures, the rutting depths were decreased with increasing level of hydrated lime used in mixes. The rate of decrease was more pronounced at 60°C testing temperature, compared with 40°C. The rate of variations can clearly be seen in Figures 1 and 2 for the results obtained in the two testing temperatures. Within the level of variation of hydrated lime in mixes in this research (i.e. from 1 to 2%), mixes containing greater amounts of hydrated lime showed lower rates of decrease in wheel tracking. This could show the positive role of using hydrated lime in mixes. However, comparing these results with those obtained using ITS and Marshall testing, no optimum values could be determined in WT testing for the hydrated lime to be used in mixes (i.e. within 1 to 2% ranges of hydrated that were applied in this research).

4. Conclusions

Based on the results obtained from Marshall, Indirect Tensile and Wheel Tracking tests that were performed on asphalt concrete mixes, the following conclusions could be drawn:

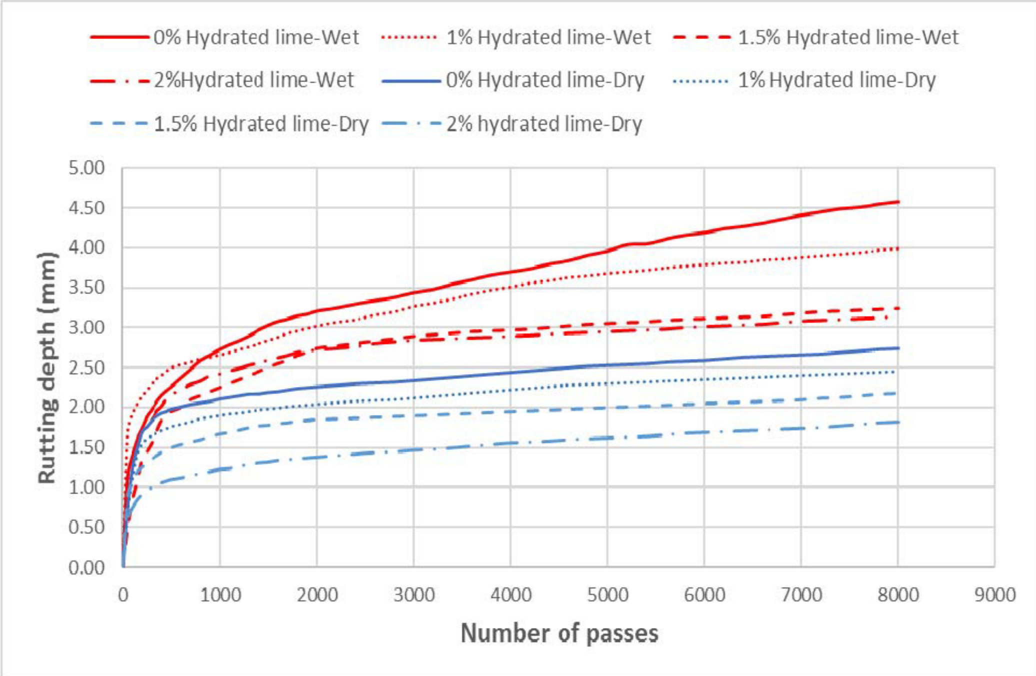

Fig. 1. Wheel track testing results at 40°C on both dry and wet conditioned samples

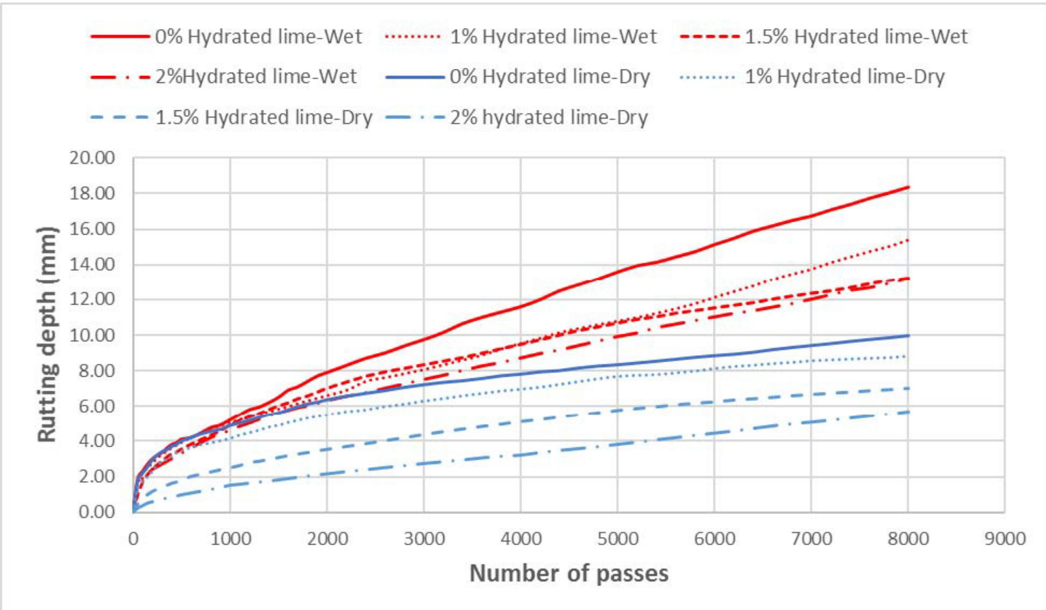

Fig. 2. Wheel track testing results at 60°C on both dry and wet conditioned samples

1) Marshall testing, in addition to its conventional purpose use of mixing design can be used to evaluate moisture resistance characteristics of mixes too. With this regard Marshall Quotient parameters of the saturated and dry samples was recognized to be an appropriate parameter.

2) Indirect Tensile testing, in addition of being a suitable testing method for evaluating moisture resistance of mixes, can also be used to determine the optimum amount of hydrated lime to be used in mixes.
3) Wheel tracking, performed on dry and wet samples can also be a suitable testing method for evaluating moisture resistance of mixes. With increased amounts of hydrated lime in mixes, rut depths were decreased. The rate of decrease was more pronounced on wet samples containing higher amounts of hydrated lime, tested at 60^{o}C. This again confirms the use of hydrated lime in reducing moisture damages of mixes.
4) Although both ITS and Marshall testing results, as adopted in this research, could be used for determination of the optimum amount of hydrated lime to be used in mixes; wheel tracking test, applied on mixes containing the amounts of hydrated lime used in this research, cannot be used for this purpose.

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