

INFLUENCE OF HYDRATED LIME ON THE PROPERTIES AND PERMANENT DEFORMATION OF THE ASPHALT CONCRETE LAYERS IN PAVEMENT

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Abstract

Flexible or asphalt concrete pavement is the paving system most widely adopted all over the world. It has been recognized that there are many different types of the factors affecting the performance and durability of asphalt concrete pavement, including the service conditions, such as: the variation of temperature from mild to extremes and the repeated excessive axle loading as well as the inadequate quality of the raw materials. All of these when combined together are going to accelerate the occurrence of distresses in flexible pavement such as permanent deformation and fatigue cracking. As the result, there has an urgent need to enhance the ability of asphalt concrete mixture to resist distresses happened in pavement. Use of additives is one of the techniques adopted to improve pavement properties. It has been found that hydrated lime might be one of the effective additives because it is widely available and relatively cheap compared to other modifiers like polymers. This paper presents an experimental study of the hydrated-lime modified asphalt concrete mixtures. Five different percentages of the hydrated lime additive were investigated, namely (1, 1.5, 2, 2.5 and 3 percent). The hydrated lime additive was used as partial replacement of limestone filler by total weight of the aggregate. The designed Hot Mix Asphalt (HMA) concretes are for the application of three pavement courses, i.e. Surface, Leveling and Base. These mixtures are designed and tested following Marshall procedure and uniaxial repeated loading to evaluate permanent deformation at different temperatures of 20°C, 40°C and 60°C. The experimental results show that the addition of hydrated lime as a partial replacement of ordinary limestone mineral filler results a significant improvement on mechanical properties and the resistant to permanent deformation of the designed asphalt concrete mixtures.

Keywords: Asphalt concrete, Additives, Mineral filler, Hydrated lime, Permanent deformation.

1. INTRODUCTION

Heavy and repeating traffic loads as well as the variation of environmental temperatures are of course the two of the main factors causing the development of distresses, such as fatigue cracking, moisture damage and permanent deformation, in pavements (Albayati, 2012). Using additives has been found to be one of the effective techniques to improve pavement durability. Recently, the use of hydrated lime, i.e., calcium hydrate ($\text{Ca}(\text{OH})_2$), as mineral filler and anti-stripping material has raised more and more interest. Hydrated lime has a wide range of particle size distribution and proportion. Its large particles can act as filler to enhance the stiffness of the asphaltic mixture, while the small particles can increase the asphalt viscosity to improve its cohesion (Mohammad et al., 2000). Previous studies (Albayati 2012, Little et al. 2006, Sebaaly et. al. 2001, Albayati and Ahmed 2013) have found that asphalt concretes with added hydrated lime showed a reduction of hardening age, and increase of flexural stiffness and resilient modulus at moderate and high temperatures. These studies also found that the modified asphalt concretes have improved durability, including the ability to resist permanent deformation, fatigue failure (alligator), thermal cracking, as well as moisture ingress. Hydrated lime as a partial conventional filler substitute also displayed a significant effect on the volumetric properties of the concrete mixtures. Meanwhile a high hydrated lime content corresponds a high asphalt content for the mixtures of optimum properties. For example, it was found that a high asphalt content of 5.34% achieved optimum concrete properties when the added hydrated lime content was 3%, while a low asphalt content of 4.73% achieved an optimum state at 0% hydrated lime content (Albayati, 2012). Satyakumar et al. (2013) studied three types of mineral fillers including hydrated lime. They found that adding 1.5% of hydrated lime by the total weight of specimens increases stiff modulus up to 55%, while, in the similar way, adding the same percentage of the other two mineral fillers (fly ash and phosphogypsum) showed less increase in stiffness. Al-Suhaibani (1992) studied the properties of the asphalt concretes with added hydrated lime and compared with other types of fillers locally available in Saudi Arabia. It was showed that the hydrated lime enhances the resistance to permanent deformation (rutting). The hydrated lime as a filler added in the asphalt concrete will decrease the chance of hot mix asphalt (HMA) to deform at high temperature, especially at the beginning of service life when the asphalt is on its highest susceptibility to rut. This is due to that hydrated lime stiffens the asphalt film coating on the aggregate surface and

enhances the bonding between aggregates and asphalt (Satyakumar et. al., 2013). Using hydrated lime to modify asphalt concrete for practical pavement applications, more information and experimental data are still needed for the sake of the development of design standards. So far, there haven't had sufficient studies on the combined effects of the mixtures with varied hydrated lime contents under a wide range of the variation of temperature and for different applications. This paper presents an experimental study on the mechanical properties of asphalt concrete with five different percentages of the hydrated lime as partial replacement of the conventional limestone filler. Concrete mixtures are designed for the application of three pavement courses, i.e. Surface or Wearing, Leveling or Binder and Base. Experiments, including the Marshall test and the uniaxial repeated loading test, are conducted to evaluate the resistance to plastic flow and the permanent deformation at three different temperatures of 20°C, 40°C and 60°C. The obtained experimental results are compared and discussed.

2. EXPERIMENTS

2.1. Raw Materials and Mixture

The component materials that used in this research are asphalt cement, aggregates, and fillers (limestone dust and hydrated lime). The physical properties of the asphalt cement and aggregate are listed in Table 1 and 2 respectively. The aggregates (coarse and fine) were sieved and recombined in deferent proportions in terms of the Wearing (Surface), Leveling (Binder) and the Base course gradation specified by Iraqi State Corporation for Roads and Bridges specification (SCRB, R/9 2003).

The physical properties and chemical composition of hydrated lime and limestone are presented in Tables 3 and 4, respectively. Control mixes were prepared using limestone dust as the only mineral filler with the content of 7%, 6% and 5% of the total weight of the mixes. The three percentages are in the mid of the range suggested by the SCRB (R/9 2003) for the three types of applications, i.e.: IIIA, II and I for Wearing, Leveling and Base course, respectively.

Other sample mixes took five different hydrated lime percentages by the total weight of the aggregates, namely 1.0, 1.5, 2.0, 2.5 and 3.0%. The hydrated lime was used to replace the same weight of the limestone dust filler. Hydrated lime were added into the mixtures following the normal procedure. Each

mixture has the same aggregate gradation to avoid the variation in physical and mineralogical characters. The hydrated lime contents for the mixtures of the Wearing, Leveling and Base course are listed in the Table 5.

2.2. Experimental Procedure

2.2.1 Marshall Mix Design, Preparation and Test

The mix design and preparation followed the Marshall method as summarized in the manual series No. 2 of Asphalt Institute (AI, 1981) and according to the standard ASTM-D-1559. The asphalt cement percentages by the total weight of the specimens are in the range of 4.3 – 5.5 for the Wearing course, 4.0 – 5.2 for the Leveling course, and 3.7 – 4.9 for the Base course, respectively. Three specimens were made for each percentage. The property results take the average value of the tests of the three. Mixes with an interval of 0.3% in each range were studied. The air void percentage (ASTM D3203), bulk density and specific gravity (ASTM D2726) and the maximum (theoretical) specific gravity (no voids in mix) (ASTM D2041) were calculated in terms of the following definition:

$$AV = \frac{G_{mm} - G_{mb}}{\frac{G_{mm}}{W_a}} \quad (1)$$

$$G_{mb} = \frac{G_{mm}}{W_{ssd} - W_w} \quad (2)$$

$$G_{mm} = \frac{A}{A+B-C} \quad (3)$$

where, AV is the voids in the specimen (%), G_{mm} is the theoretical maximum specific gravity of loose mixture excluding the air voids (g/cm^3), G_{mb} is the bulk specific gravity of the compacted specimen (g/cm^3). W_a is the weight of specimen in air (g), W_{ssd} is the weight of saturated surface dry specimen (g), and W_w is the weight of specimen in water (g), A is the weight of dry sample in air (g), B is the weight of flask filled with water only at 25°C (g), and C is the weight of flask filled with water and specimen at 25°C (g).

2.2.2. Permanent Deformation Test

Uniaxial repeated loading test was conducted for the cylindrical specimens, which are 101.6 mm (4 inches) in diameter and 203.2 mm (8 inches) in height. A stress amplitude of 138 kPa (20 psi) and up to 10,000 times of

repetition was applied in a rectangular wave form with a constant frequency of 1 Hz (0.1 seconds of load duration followed by 0.9 seconds of rest time). The axial permanent deformation was recorded using Linear Variable Differential Transducer (LVDT). The deformation was measured at the upper face of the specimen. The permanent axial deformation were recorded after 1, 2, 10, 100, 500, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10000 times of repetition, respectively, until the specimens failed. The permanent strain is calculated according to the following definition:

$$\varepsilon_p = \frac{p_d * 10^6}{h} \quad (4)$$

Where, ε_p is the axial permanent strain, p_d is the axial permanent deformation, h is the specimen initial height. Throughout the test the resilient deflection is measured at each load repetition of 50 to 100, and then resilient modulus is calculated in terms of the definition below:

$$M_r = \frac{\sigma}{\varepsilon_r} \quad (5)$$

where, ε_r is the axial resilient strain, r_d is the axial resilient deflection, h is the specimen original height, M_r is the resilient modulus, σ is the repeated axial stress. The permanent deformation results are represented in terms of relationship between the permanent strain and the repetition number of load following the description of the Eq. (6) originally suggested by Barksdale (1972) and Monismith et al. (1975), which is a linear function in the form of log-log display

$$\varepsilon_p = aN^b \quad (6)$$

where, ε_p is the permanent strain, N is the number of stress applied, a and b are intercept and slope of the relationship respectively.

2.3. Specimen Nomenclature

Nomenclature (as the mixture shown in Table 5) were made for the designed mixes in terms of the name of the pavement course application and the hydrated lime content. The name of each type of specimens consists of three components, i.e.: the first letter refers to the nature of samples (C means control, H means hydrated lime modified), the numerical figure in the middle indicates the percentage of the added hydrated lime, and the last letter refers to the type of application i.e.: Wearing (W), Leveling (L) or Base (B) course.

3. RESULTS AND DISCUSSION

3.1. Optimum Asphalt Content (OAC)

The data shown in Tables 6-8 indicate that the mixtures with added hydrated lime appear to have a higher asphalt content than the control mixture. The mixtures of H3W, H3L and H3B have the OAC values of 5.3%, 5% and 4.7%, respectively, which are higher than that of the mixtures of less hydrated lime contents. The three control samples for the W, L and B course have the lowest OAC values, which are 4.9%, 4.6% and 4.3%, respectively. The increase of the asphalt cement for the hydrated lime modified mixtures can be attributed to the relatively high specific surface area of hydrated lime, which is about 1.6 times of that of the limestone dust. The high surface area attracts more asphalt cement particles to achieve a more thorough hydration process (Al-Suhaibani et al. 1992, Shahrour and Saloukeh 1992).

3.2. Density

The effect of the addition of hydrated lime on the unit mass of the compacted mixes is shown in Figure 1. It can be seen that the unit mass tends to decrease as the lime content increases. There are two reasons may related to the decrease. The first one is due to the low density of hydrated lime (2.43 gm/cm^3) compared with that of the replaced limestone dust (2.71 gm/cm^3), while the second one is attributed to the increase of air voids. Generally, the addition of mineral filler tends to increase the viscosity and makes the mixture more stiff. As a result, the degree of compaction may decrease with the increase of hydrated lime content (Fayadh 1987, Al-Suhaibani et al. 1992, Shahrour and Saloukeh 1992, Baig 1995, Tayh and Jabr 2011, Sengul et al. 2011).

3.3. Marshall Stability

Figure 2 shows the influence of added hydrated lime on the stability of the mixtures. It can be seen that the maximum stability corresponds to 2% hydrated lime addition for course W, 2.5% for course L and 2.5% for course B. The result is attributed to the fact that hydrated lime is finer than limestone dust. The replacement of the limestone with hydrated lime increases the stiffness of the mixture. On another hand, because the addition of hydrated lime increases the viscosity of the asphalt cement (Kim et al. 2003, Little and Petersen 2005 and

Zeng and Wu 2008), a low percentage of hydrated lime has the effect on the improvement of the binding capacity of the mixture. However, when the hydrated lime content is too high, the increase of air voids will result in the decrease of the stability. The results show that the maximum stability value has been increased by 24%, 9% and 20%, with respect to the control mix, for the mixes H2W, H2.5L and H2.5B, respectively. This finding is in agreement with the results of some previous research work (Al-Suhaibani et al. 1992, Albayati 2012, Shahrour and Saloukeh 1992, Baig 1995, Kok and Yilmaz 2009, Tayh and Jabr 2011).

3.4. Resilient Modulus

The resilient modulus can be worked out in terms of the Eq. (5) using the recorded stress-strain relationship. The resilient modulus at different temperatures with respect to the addition of hydrated lime for the course W, L and B mixes are presented in Figure 4. It can be seen that relatively high resilient modulus has been achieved by the mixtures of the added hydrated lime with a content in the range of 1.0 to 3.0% at the three temperatures of 20°C, 40°C and 60°C. However, in general, the modulus decreases with the increase of temperature. In detail, the modulus increases with the added content of hydrated lime for all the three types of course mixtures at the low temperature of 20°C. However, for the W and L mixtures, the modulus shows a decrease with the increase of temperature at the high hydrated lime content. In general, the properties will deteriorate with the increase of temperature.

3.5. Permanent Deformation

3.5.1. Effect of Hydrated Lime on Permanent deformation

Figures 5-7 show the permanent deformation of the mixtures under a repeated loading. It can be seen that the addition of hydrated lime improves the capability of the mixtures to resist the deformation at the three studied temperatures, particularly at the middle temperature of 40°C for the mixtures of W and L. For all of these mixtures, the permanent deformation shows an approximately linear relationship with the number of the repetition of the applied load. It means that the addition of the hydrated lime improves the mechanical behavior by increasing the stability of the mixture. The improvement is in correlation with the properties observed above. Little and

Petersen (2005) pointed out that hydrated lime is chemically inactive at low temperature, and, as a result, it helps to develop a significant rutting resistance. The results from Figs. 5-7 show that at a relatively low temperature, such as 20°C, the permanent strain is low for all the mixtures and the effect of the variation of the hydrated lime content is not significant, however, at a relatively high temperature, such as 40°C and 60°C, the hydrated lime content displays an effective influence, particularly, at 40°C and for the course W and L, the effect of the hydrated lime content is more pronounced.

3.5.2. Models' parameters and Number of repetition to Failure

Based on the model Equation (6), Table 9 demonstrates the permanent deformation model parameters; intercept (a) and slope (b) for Wearing, Leveling and Base courses at 20°C, 40°C and 60°C for a series of hydrated lime addition percentages. The table shows also the coefficient of determination of each equation and the number of repetitions to failure for each mixture. In general, it can be seen that there is a reduction in intercept (a) by addition of HL and the slope (b) of the linear trend decreases with the increase of the hydrated lime with a variety in the influence due to change in mixture type and temperature of the test. The repetitions to failure increased as a result of HL modification in intermediate and high temperatures (40°C and 60°C).

4. CONCLUSIONS

The follow conclusions can be drawn from the results.

1. The addition of hydrated lime will enhance the Marshall properties as well as increase the demand of asphalt cement. The addition of 2%, 2.5% and 2.5% hydrated lime displays the most effective improvement on the Marshall properties for the Wearing, Leveling and Base mixtures, respectively.
2. The addition of hydrated lime up to 2.5% will increase resilient modulus for all the mixes at the temperature of 20°C, 40°C and 60°C. However, over 3% hydrated lime addition shows a slight decrease in stiffness. It can be concluded that the temperature has a significant influence on the HMA properties.
3. The addition of hydrated lime up to 2.5% results in a considerable improvement on the fatigue performance of asphalt concrete mixes, which become more durable and resistant to distresses.

4. At low temperature (20°C), the addition of hydrated lime shows a limited effect on the enhancement of the resistance to permanent deformation. However, at relatively high temperatures (40°C and 60°C), the effect of addition of hydrated lime becomes more clear and significant. It can be concluded that 2.5% of hydrated lime content will achieve an optimum mixture with a balance between rutting susceptibility, resistance to rutting, and workability.

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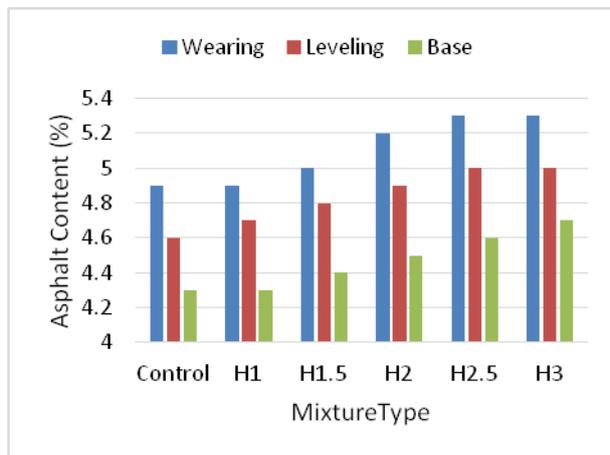


Figure 1. Hydrated lime influence on the asphalt content

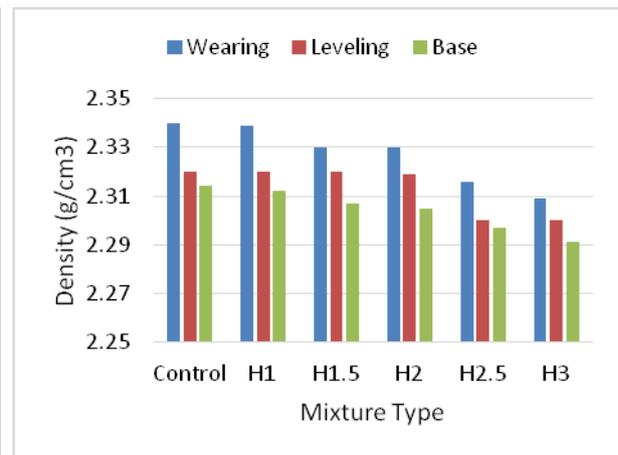


Figure 2. Hydrated lime influence on density

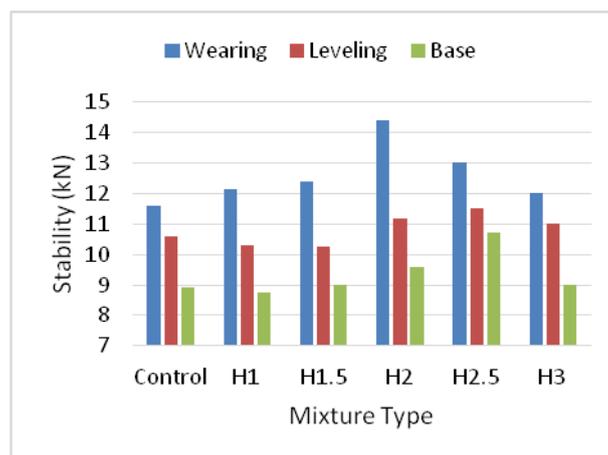


Figure 3. Hydrated lime influence on stability

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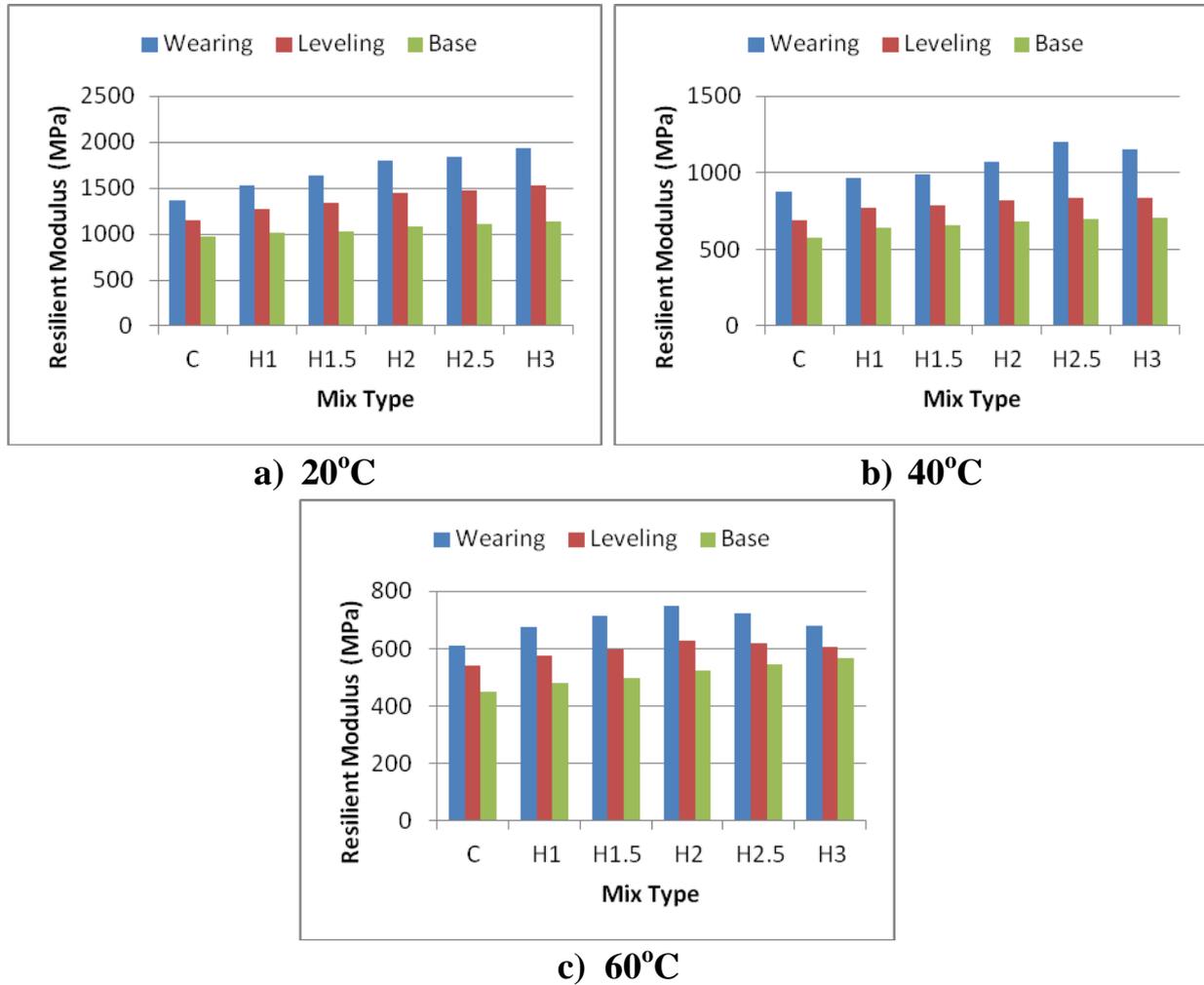


Figure 4. Hydrated lime influence on resilient modulus for W, L and B

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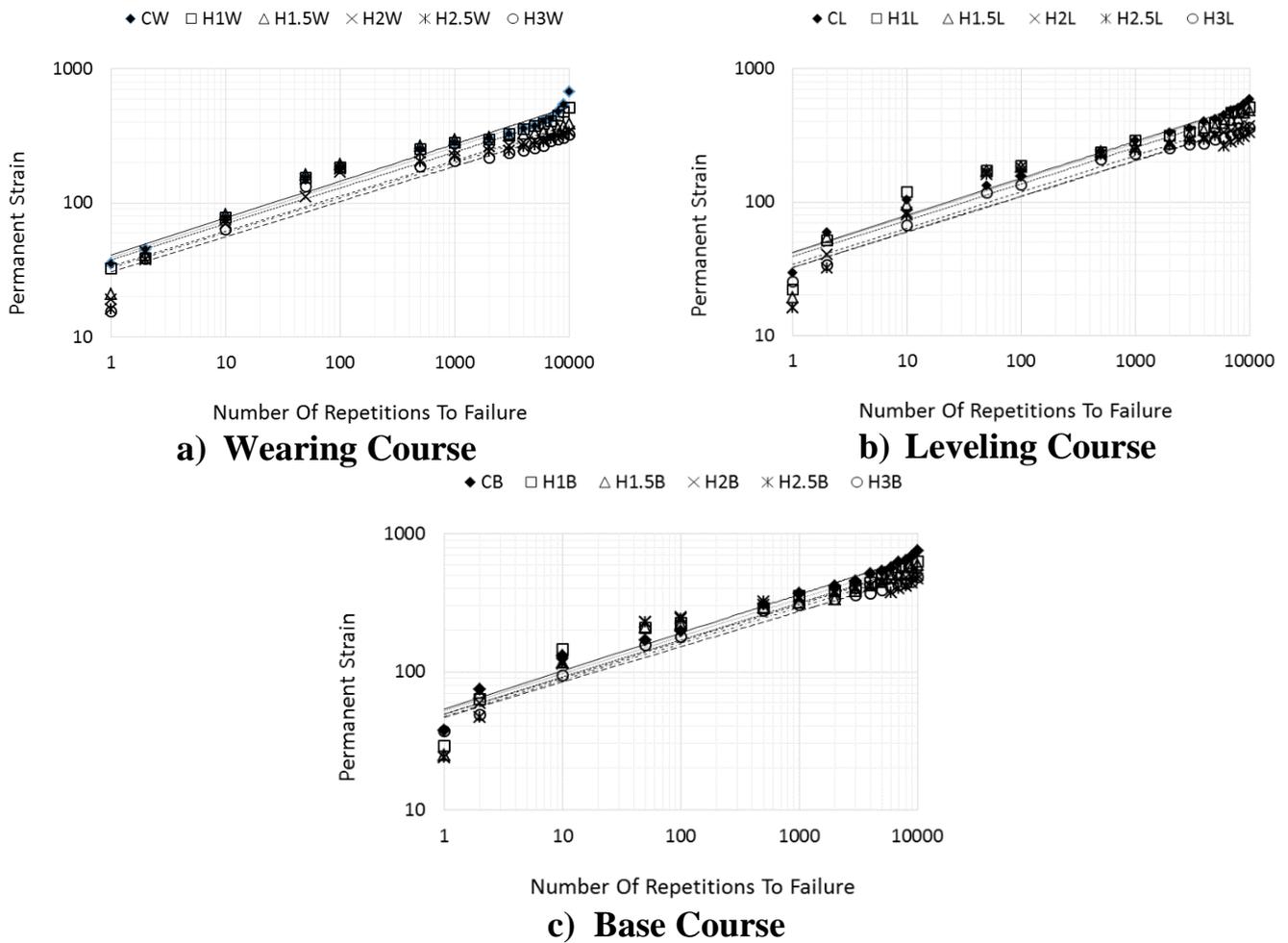


Figure 5. Influence of Hydrated Lime on Permanent Deformation at 20°C

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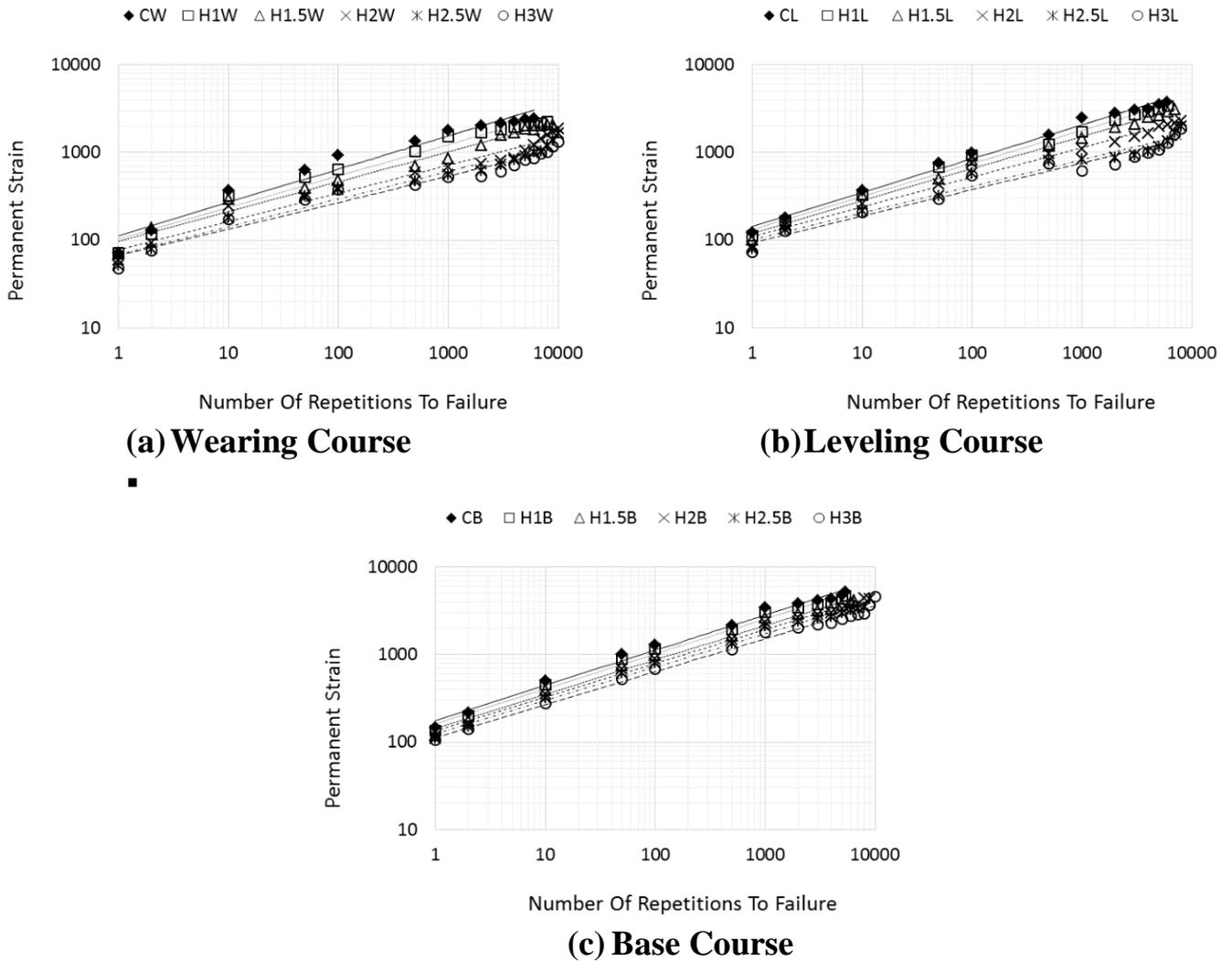


Figure 6. Influence of Hydrated Lime on Permanent Deformation at 40°C

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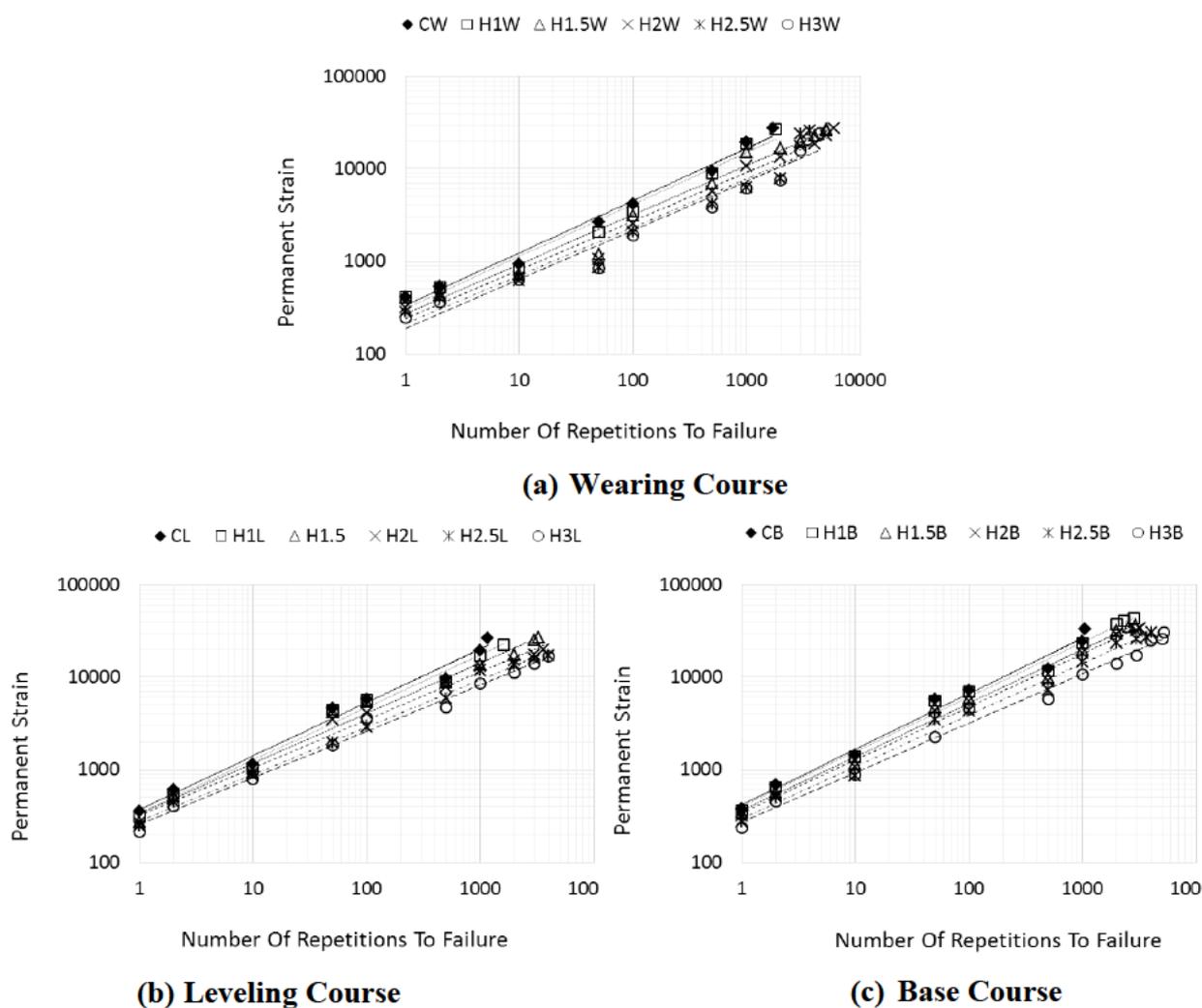


Figure 7. Influence of Hydrated Lime on Permanent Deformation at 60°C

Table 1. Physical Properties of Asphalt Cement 40/50

Tests	units	40/50 AC test results
Penetration (25C, 100gm, 5 sec). ASTM D5	1/10mm	42
Softening point (Ring & Ball). ASTM D36	°C	49
Specific gravity (25°C). ASTM D70	----	1.04
Flash Point (Cleveland open cup). ASTM D92	°C	293
Ductility (25°C, 5 cm/min). ASTM D113	cm	120
Residue after thin film oven test (ASTM D1754)		
Penetration (25C, 100gm, 5 sec). ASTM D5	1/10mm	25
Ductility (25°C, 5 cm/min). ASTM D113	cm	80

Table 2. Physical Properties for Aggregates

Property	Al-Nibaie aggregate		SCRB Properties limitations
	Coarse Aggregate	Fine Aggregate	
Bulk Specific gravity (g/cm³) (ASTMC127 and C128)	2.52	2.643	-----
Apparent Specific gravity (g/cm³) (ASTM C127 and C128)	2.55	2.68	-----
Percent water absorption (ASTM C127 and C128)	0.13	0.520	-----
Percent wear (Los-Angeles Abrasion) (ASTM C131)	19.0		30 Max
Fractured pieces, %	96		90 Min
Sand Equivalent (ASTM D 2419)		59	45 Min
Soundness loss by sodium sulfate solution,% (C-88)	4.12		12 Max

Table 3. Physical Properties of Hydrated Lime and Limestone

Material property	Hydrated lime	Limestone dust(filler)
Specific gravity(gm./cm ³)	2.43	2.71
Specific surface (m ² /Kg)	394	246
-100 Mesh (150 μm), %	100	100
-200 Mesh (75 μm), %	99	87

Table 4. Chemical Composition of Hydrated Lime and Limestone

Chemical composition	Limestone	Hydrated lime
% CaO	68.3	56.1
% SiO ₂	2.23	1.38
% Al ₂ O ₃	-	0.72
% Fe ₂ O ₃	-	0.12
% MgO	0.32	0.13
% SO ₃	1.2	0.21
% Loss On Ignition (L. O. I.)	27.3	40.65

Table 5. Filler Contents in the Mixtures for Different Applications

Hydrated Lime Content (%)	Wearing Course		Levelling Course		Base Course	
	Mixture	Limestone Content (%)	Mixture	Limestone Content (%)	Mixture	Limestone Content (%)
0	CW	7	CL	6	CB	5
1	H1W	6	H1L	5	H1B	4
1.5	H1.5W	5.5	H1.5L	4.5	H1.5B	3.5
2	H2W	5	H2L	4	H2B	3
2.5	H2.5W	4.5	H2.5L	3.5	H2.5B	2.5
3	H3W	4	H3L	3	H3B	2

Table 6. Marshall Design Properties for Wearing Course

Mixture	OAC %	Density, gm/cm ³	Gmm gm/cm ³	Stability KN	Flow mm	AV %	VMA %	VFA %
Control (CW)	4.9	2.34	2.439	11.6	3.25	4.018	14.22	71.74
H1W	4.9	2.339	2.437	12.13	3	4.01	14.18	71.7
H1.5W	5	2.33	2.428	12.4	2.8	4.08	14.4	72.4
H2W	5.2	2.33	2.431	14.4	3	4.14	14.68	72.74
H2.5W	5.3	2.316	2.42	13	2.8	4	15.2	71.47
H3W	5.3	2.309	2.41	12	2.6	4.1	15.4	71.2

AV=Air Voids; VMA=Voids in Mineral Aggregate; VFA=Voids in Aggregates Filled with Asphalt

Table 7. Marshall Design Properties for Leveling Course

Mixture	OAC %	Density, gm/cm ³	Gmm gm/cm ³	Stability KN	Flow mm	AV %	VMA %	VFA %
Control (CL)	4.6	2.32	2.426142	10.57	3.25	4.02	13.14	69.36
H1L	4.7	2.32	2.432	10.31	3.1	4.3	13.5	66
H1.5L	4.8	2.32	2.428	10.25	2.8	4.3	13.3	67
H2L	4.9	2.319	2.424	11.19	3	4.35	13.36	67.4
H2.5L	5	2.3	2.42	11.5	3	4.5	13.7	67
H3L	5	2.3	2.41	11	2.5	4.6	14	67

Table 8. Marshall Design Properties for Base Course

Mixture	OAC %	Density, gm/cm ³	Gmm gm/cm ³	Stability KN	Flow mm	AV %	VMA %	VFA %
Control (CB)	4.3	2.314	2.418251	8.9	2.92	4.29	14	69.35
H1B	4.3	2.312	2.415861	8.77	2.7	4.28	13.99	69.39
H1.5B	4.4	2.307	2.41	9	2.5	4.5	14.3	69
H2B	4.5	2.305	2.406	9.6	2.4	4.2	14.39	70
H2.5B	4.6	2.297	2.403	10.7	2.45	4.39	14.67	70.06
H3B	4.7	2.291	2.4	9	2.3	4.55	15	70.1

Table 9. Permanent deformation models' parameters for all mixtures at 20°C, 40°C and 60°C

Mixture	Model ($\epsilon_p = aN^b$) Parameters, Intercept (a) and Slope (b)						R ²			Number of Repetitions to Failure (N _f)		
	20°C		40°C		60°C		20°C	40°C	60°C	20°C	40°C	60°C
	a	b	a	b	a	b						
Control (CW)	40.825	0.2761	113.04	0.3785	332.11	0.567	0.9726	0.959	0.9862	10000	6050	1700
H1W	38.922	0.2758	103.85	0.358	307.71	0.5634	0.9725	0.9736	0.976	10000	8025	1800
H1.5W	37.598	0.2682	96.636	0.3409	273.54	0.5331	0.9149	0.9819	0.9766	10000	9000	5050
H2W	33.541	0.2632	77.959	0.3211	238.06	0.5285	0.9312	0.9654	0.9796	10000	10000	5900
H2.5W	32.561	0.2628	68.991	0.3151	211.08	0.5224	0.8952	0.9638	0.9413	10000	10000	3600
H3W	30.761	0.2619	66.6	0.3027	189.67	0.5288	0.8995	0.9594	0.9606	10000	10000	4425
Control (CL)	42.033	0.2771	144.46	0.3855	371.34	0.5785	0.9785	0.9914	0.9849	10000	5950	1155
H1L	41.449	0.2745	132.42	0.3772	343.23	0.569	0.9323	0.992	0.9847	10000	6000	1610
H1.5L	38.929	0.2729	120.44	0.3674	332.21	0.5442	0.9227	0.9931	0.9849	10000	7000	3242
H2L	34.104	0.2716	110.95	0.3372	319.65	0.5175	0.8996	0.983	0.9867	10000	8000	3609
H2.5L	32.435	0.2671	101.32	0.304	274.95	0.5108	0.8808	0.9642	0.9951	10000	8000	4000
H3L	32.476	0.2658	93.85	0.3024	255.23	0.5033	0.973	0.9563	0.9904	10000	8000	4000
Control (CB)	53.614	0.277	177	0.401	416.5	0.601	0.9785	0.9898	0.9845	10000	5400	1048
H1B	52	0.271	163.2	0.397	402.1	0.591	0.9379	0.9904	0.9913	10000	5400	2843
H1.5B	49.67	0.267	143.9	0.391	361.9	0.58	0.9245	0.9913	0.9916	10000	6472	2914
H2B	49.12	0.265	133.8	0.386	337.2	0.575	0.904	0.993	0.9915	10000	8000	3210
H2.5B	47.52	0.263	124.7	0.381	297.7	0.558	0.8822	0.9934	0.9912	10000	9000	4022
H3B	46.64	0.256	112.9	0.376	274	0.533	0.9772	0.992	0.9902	10000	10000	5209