Effect of Lime Addition Methods on Performance Related Properties of Asphalt Concrete Mixture

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ABSTRACT

In the recent years, some of the newly constructed asphalt concrete pavements in Baghdad as well as other cities across Iraq showed premature failures with consequential negative impact on both roadway safety and economy. Frequently, load associated mode of failure (rutting and fatigue) as well as, occasionally, moisture damage in some poorly drained sections are the main failure types found in those newly constructed road.
In this research, hydrated lime was introduced into asphalt concrete mixtures of wearing course in two methods. The first one was the addition of dry lime on dry aggregate and the second one was the addition of dry lime on saturated surface dry aggregate moisturized by 2.0 to 3.0 percent of water. For each type of addition, five different percentages of lime as a partial replacement of ordinary limestone mineral filler were used; these were; 1.0, 1.5, 2.0, 2.5, and 3 percent by weight of aggregate besides a control mixture that did not contain lime. Marshall Mix design method was used and the performance properties of moisture damage, resilient modulus, permanent deformation and fatigue characteristics were evaluated using indirect tensile strength, uniaxial repeated loading and repeated flexural beam tests. Also, VESYS5W software was implemented to evaluate the pavements performance in terms of rut depth and fatigue area for a typical pavement structure. The main conclusion withdrawn from this research revealed that the use of 2.5 percent hydrated lime in dry addition method and wet addition method showed an improved fatigue and permanent deformation characteristics, lower moisture susceptibility and high resilient modulus.
Key Words: Asphalt, Hydrated Lime, Moisture Damage, Permanent Deformation, Fatigue, VESYS5W.

تأثير طرق اضافة النورة المطفئة على خصائص الاداء لخلطات الخرسانة الاسفلتية

لوحظ في السنوات الاخيرة في بعض رصفات الخلطات الاسفلتية في بغداد و مدن العراق الاخرى ظهور فشل مبكر و ما قد يترتب علية من اثار سلبية على الناحيتين الاقتصادية و الامان للطريق والتي غالباً ماتكون الاحمال المصحوبة بالفشل (التخدد و الكلل) و احياناً ما تكون مصحوبة بالدور المخرب للماء (الرطوبة) والتي هي احد الاسباب الرئيسية الموجودة في طبقات التبليط المرصوفة حديثاً. في هذا البحث تم اضافة مادة النورة المطفأة الى خلطات المزيج الاسفلتي والتي تمثل الطبقة السطحية من خلال اتباع طريقتين للاضافة , الاولى باضافة نورة جافة الى الركام الجاف و الثانية باضافة نورة جافة الى ركام رطب السطح (مشبع بنسبة 2.0-3.0%) بالماء وذلك بأستخدام خمس نسب مختلفة كنسب استبدال جزئية من المادة المالئة (الفلر) و هي 1.0,1.5,2.0,2.5,3.0 من وزن الركام الكلي , وكذلك تم عمل مزيج أعتيادي خالي من المادة المضافة النورة لغرض مقارنة النتائج . ولغرض تحقيق اهداف هذا البحث فقد تم استخدام طريقة مارشال في تصميم بالاضافة الى الخصائص التي من خلالها يتم تقييم الاداء و التي تشتمل على الضرر المصاحب للماء ,معامل المرونة الاسترادادي , التشوهات الدائمية و عمر الكلل , حيث اشتمل البرنامج المختبري على تقييم هذه الخصائص من خلال استخدام فحص الشد غير المباشر , فحص الحمل المتكرر للاسطوانة والعتبات الاسفلتية التي تم تهئيتها باشكال و ابعاد لتغطية البرنامج العملي لهذا البحث , اضافة الى ذللك تم استخدام برنامج VESYS 5W و الذي تم اختياره لتقييم الاداء للخلطات الاسفلتية من خلال احتساب عمق التخدد و مساحة التشققات للكلل لمنشأ تبليط اسفلتي تقليدي .النتائج و الاستنتاجات المترتبة على هذا البحث اظهرت بأن استخدام نسبة 2.5% بالطريقة الجافة و

الطريقة الرطبة يمكن ان تؤدي الى تحسين خصائص مقاومة الكلل و التشوهات الدائمية بالاضافة الى تقليل الحساسية تجاه الدور المخرب للماء واظهار قيم عالية لمعامل المرونة الاسترداد.

BACKGROUND

The related mechanisms and reactions involved in the change of the performance of lime-modified HMA mixtures are not totally understood. Nevertheless, when hydrated lime is added to HMA, a portion of the lime forms insoluble salts with the highly polar molecules of the asphalt, which could otherwise react in the mixtures to form water-soluble soaps that promote stripping (National Lime Association 2003). Dispersion of the tiny hydrated lime particles throughout the mixture makes it stiffer and tougher, reducing the likelihood that the bond between the asphalt cement (AC) binder and the aggregate will be broken mechanically. Furthermore, a portion of the hydrated lime can reduce the viscosity-building polar components in the AC binder and thus improve the long-term oxidative aging characteristics of HMA (Huang et al. 2002). The structure of hydrated lime consists of differently sized proportions. The smaller fraction of lime increases binder film thickness, enhances binder viscosity, and improves binder cohesion leading to increased adhesion between the aggregates and binder, which reduces mixture segregation (Mohammad et al 2000). The larger fraction performs as a filler to increase the indirect tensile strength and resilient modulus and improve (i.e., decrease) both the indirect tensile creep slope and the fatigue slope (with higher number of cycles to failure of HMA) (Kennedy and Ping 1991, Mohammad et al 2000, Sebaaly 2006). It has also been reported that the addition of lime to HMA improves its resistance to rutting (Little and Epps2001, Al-Suhaibani 1992, Shahrour and Saloukeh 1992). Hydrated lime replacement with lime stone or bag house fine dust or any other has gained a considerable recognition due to its efficient effect on both pavement and cost manifest and it benefits into decreasing maintenance and respire in current and newly constructed pavement section. The reasons why hydrated lime is so effective in asphalt mixtures lie in the strong interactions between the major components, i.e. aggregate and bitumen, and the combination of 4 effects, two on the aggregate and two on the bitumen. Hydrated lime modifies the surface properties of aggregate, allowing for the development of a surface composition (calcium ions) and roughness (precipitates) more favorable to bitumen adhesion. Then, hydrated lime can treat the existing clay particles adhering to the aggregate surface, inhibiting their detrimental effect on the mixture. Also, hydrated lime reacts chemically with the acids of the bitumen, which in turns slows down the age hardening kinetics and neutralizes the effect of the "bad" adhesion promoters originally present inside the bitumen, enhancing the moisture resistance of the mixture. Finally, the high porosity of hydrated lime explains its stiffening effect above room temperature. The temperature dependence and the kinetics of the stiffening effect might explain why hydrated lime is not always observed to stiffen asphalt mixtures and why it is more efficient in the high temperature region where rutting is the dominant distress (European Lime Association 2011). The various ways to add hydrated lime, i.e., into the drum, as mixed filler, dry to the damp aggregate, as lime slurry, with or without marination are described. No definitive evidence demonstrates that one method is more effective than the other, in general, contractors and (or) transportation departments have adopted one or more of three popular techniques in dry, wet, and slurry state. The three techniques along with a brief description of each and the major pros and cons of each are listed in Table 1 (Button and Epps 1983).

OBJECTIVE

1. To evaluate and compare the addition of hydrated lime in both wet and dry method on the laboratory performance-based properties of asphalt mixtures.

2. To determine the optimum content of hydrated lime for use in both methods to improve the performance of asphalt mixtures.
3. To compare the performance-based properties between hydrated lime modified asphalt mixture and control mixture.
4. To study the effectiveness of hydrated lime based on the long-term performance analysis by employing VESYS5W software.

MATERIAL CHARACTERIZATION

The materials used in this work, namely asphalt cement, aggregate, and fillers were characterized using routine type of tests and results were compared with state corporation for roads and bridges specifications (SCRB, R/9 2003).

ASPHALT CEMENT

The asphalt cement used in this work is of 40-50 penetration grades. It was obtained from the Dora refinery, south-west of Baghdad. The asphalt properties are shown in Table 2.

AGGREGATE

The aggregate used in this work was crushed quartz obtained from Amanat Baghdad asphalt concrete mix plant located in Taji, north of Baghdad, its source is Al-Nibaie quarry. This aggregate is widely used in Baghdad city for asphaltic mixes. The coarse and fine aggregates used in this work were sieved and recombined in the proper proportions to meet the wearing (W) course gradations as required by SCRB specification (SCRB, R/9 2003). Routine tests were performed on the aggregate to evaluate their physical properties. The results together with the specification limits as set by the SCRB are summarized in Table 3. Tests results show that the chosen aggregate met the SCRB specifications; while, gradation curve for the aggregate are shown in Figures 1 and Table 4.

MINERAL FILLER

The filler is a non-plastic material passing sieve No.200 (0.075mm). In this work, the control mixes were prepared using limestone dust as mineral filler at a content of 7 percent; this content represented the mid-range set by the SCRB specification for two types of mixes IIIA for wearing course. Hydrated lime has been known to be a promising potential material for pavements due to its unique physical/chemical/mechanical characteristic. The use of hydrated lime has been recommended by SRCB with a rate of 1.5% by weight of aggregates, as an anti-stripping additive for HMA pavements. This study used hydrated lime in two different forms (dry lime added to dry aggregates and dry lime added to wet aggregate) prior to asphalt mixing in five different content (1.0% , 1.5%, 2.0% 2.5% and 3.0%) by weight of aggregate as a limestone dust replacement. The limestone dust and hydrated lime were obtained from lime factory in Karbala governorate, south east of Baghdad. Tables 5 and 6 illustrate the basic physical and chemical properties of hydrated lime and limestone dust used for this study.

LIME ADDITION TECHNIQUES AND SPECIMEN FABRICATION

One of the main objectives of this research is to study the effect of lime addition method on a mixture's mechanical properties, noticing that hydrated lime was added by the weight of aggregate as a mineral filler replacement. For the lime modified mixes, two methods were performed in terms of introducing lime into the aggregate. For the first method, called "dry method", dry hydrated lime by total aggregate weight is added following the normal procedure for adding mineral filler into the mixture. The second method, "wet method", introduces the hydrated lime to wet aggregate at a moisture content of 2–3% over SSD condition. Five different content of hydrated lime (1, 1.5, 2.0, 2.5 and 3.0) % was added with both methods by weight of aggregate as the amount of filler reduced; 20 of the 22 mix designs were modified using hydrated lime aggregates treatment method. Each mix was designed with the same blend of aggregates to avoid variability due to physical and mineralogical characteristics of the aggregates. The dry method follows the normal procedure for preparing the general mix after consideration of the variability in hydrated lime and mineral filler content. Wet hydrated lime method involves spreading hydrated lime onto the aggregate that has been wet to approximately 2 to 3% over its SSD. Dry aggregate blends were moisturized with an addition of 3.0% water by weight of total aggregates. Dry hydrated lime at a different rate (from 1.0% to 3.0%) by the total dry weight of aggregate was then mixed with the wet aggregates for 10 minutes to produce evenly distributed lime-water films on the aggregate surfaces. The lime-treated aggregates were then oven dried for four hours to eliminate all water before the addition of the asphalt binder. The mixtures replaced with hydrated lime in the form of wet method were not marinated for 48hours. This procedure was elaborated based on a study by McCann and Sebaaly (2003). They evaluated behavior of different lime application methods such as with and without 48 hours marinating process of lime-aggregate mixtures and found no statistical difference behind the marination process. In fact, a 48 hour marination time was used to allow for any pozzolanic reaction that might occur between the aggregates and lime. The steps for wet hydrated lime addition method are shown in Figures (2, 3,4and 5).

Consequential, in order to determine the optimum percent of bitumen in asphaltic specimens a triplicate number of specimens for each asphalt content by Marshall design method (ASTM D6926-2010a) were prepared for 10 mix of 11 treated with hydrated lime by aggregate treatment. The specimen prepared for this study, have the diameter of 100mm and height of 63 mm for Marshall and tensile strength ratio (ASTM- D-4867-96), Table 7 list Marshall for lime modified and control mixes. Specimens were compacted using Marshall standard compaction with 75 blows per each face, only for tensile strength the blows was less in order to produce HMA with targeted air voids between 6-8% to accelerate the potential damage of moisture in specimen and simulate the actual filed. Superpave Gyratory Compactor (AASHTO 2004) was used to fabricate HMA specimens with 50 gyrations of sample 101.1 mm diameter and 203.3mm height to quantify the effect of hydrated lime on rutting potential. Also compacted rectangular prismatic beams 76 mm (3 in) x 76 mm (3 in) x 381 mm (15 in) were produced by means of static compaction using a "double plunger" arrangement, using compressive machine device, and pressed in compressive machine under the gradual application of a static load for 2 minutes according to (ASTM-D1074-96), to promote homogeneity, the mixture is generally "rodded" or "spaded" prior to compaction, and the mold is made "free floating" by using a "double plunger" arrangement.

INDIRECT TENSILE TEST

The moisture susceptibility of the asphalt concrete mixtures was evaluated according to (ASTM- D-4867-96). The result of this test is the indirect tensile strength (ITS) and tensile strength ratio (TSR). In this test, a set of specimens were prepared for each mix according to Marshall procedure and compacted to 7±1 % air voids using different numbers of blows per face that varies from (34 to 49) according to the hydrated lime replacement rate. The set consisted of six specimens and divided into two subsets, one set (control) was tested at 25°C and the other set (conditioned) was subjected to one cycle of freezing and thawing then tested at 25°C. The test is shown below in figure 6. Involved loading the specimens with compressive load at a rate of (50.8mm/min) was acting parallel to and along the vertical diametrical plane through 0.5 in. wide steel strips which are curved at the interface with specimens. These specimens failed by splitting along the vertical diameter. The indirect tensile strength which is calculated according to (Eq.1) of the conditioned specimens (ITS_c) is divided by the control specimens (ITS_d), which gives the tensile strength ratio (TSR) as the following (Eq.2).

$$ITS = \frac{2P}{\pi t D} \tag{1}$$

$$TSR = \frac{ITS_c}{ITS_d} \tag{2}$$

where
ITS= Indirect tensile strength
P = Ultimate applied load
t = Thickness of specimen
D = Diameter of specimen other parameters are defined previously

UNIAXAIL REPEATED LOADING TEST

The uniaxial repeated loading tests were conducted for cylindrical specimens, 101.6 mm (4 inch) in diameter and 203.2 mm (8 inch) in height, using the pneumatic repeated load system (Albayati 2006), shown below in fig. (7). In this test, repetitive compressive loading with a stress level of 20 psi was applied in the form of rectangular wave with a constant loading frequency of 1 Hz (0.1 sec. load duration and 0.9 sec. rest period) and the axial permanent deformation was measured under the different loading repetitions. All the uniaxial repeated loading tests were conducted at 20°C, 40°C and 60°C as shown in figure (8). The permanent strain (ε_p) is calculated by applying the following equation:

$$\varepsilon_p = \frac{p_d \times 10^6}{h} \tag{3}$$

where
εp= axial permanent microstrain, pd= axial permanent deformation
h= specimen height
Also, throughout this test the resilient deflection is measured at the load repetition of 50 to 100, and the resilient strain (εr) and resilient modulus (Mr) are calculated as follows (Huang 2004):

$$\varepsilon_r = \frac{r_d \times 10^6}{h} \tag{4}$$

$$M_r = \frac{\sigma}{\varepsilon_r} \tag{5}$$

where
εr= axial resilient microstrain
rd= axial resilient deflection
h= specimen height
Mr= Resilient modulus
σ = repeated axial stress
εr= axial resilient strain

The permanent deformation test results for this study are represented by the linear log-log relationship between the number of load repetitions and the permanent microstrain with the form shown in Eq.6 below which is originally suggested by Monismith et. al., (1975) and Barksdale (1971).

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

where
εp= permanent strain
N=number of stress applications
a= intercept coefficient
b= slope coefficient

FLEXURAL BEAM FATIGUE TEST

Within this study, third-point flexural fatigue bending test was adopted to evaluate the fatigue performance of asphalt concrete mixtures using the pneumatic repeated load system, this test was performed in stress controlled mode with flexural stress level varying from 5 to 30 percent of ultimate indirect tensile strength applied at the frequency of 2 Hz with 0.1 s loading and 0.4 s unloading times and in rectangular waveform shape. All tests were conducted as specified in SHRP standards at 20°C (68°F) on beam specimens 76 mm (3 in) x 76 mm (3 in) x 381 mm (15 in) as shown in figure (9) prepared according to the (ASTM-D1074-96). In the fatigue test, the initial tensile strain of each test has been determined at the 50th repetition by using (Eq.7) shown below and the initial strain was plotted versus the number of repetition to failure on log scales, collapse of the beam was defined as failure, the plot can be approximated by a straight line and has the form shown below in (Eq. 8).

$$\varepsilon_t = \frac{\sigma}{Es} = \frac{12h\Delta}{3L^2 - 4a^2} \qquad (7)$$

$$N_f = k_1(\varepsilon_t)^{-k2} \qquad (8)$$

where
ε_t = Initial tensile strain
σ =Extreme flexural stress
Es =Stiffness modulus based on center deflection.
h =Height of the beam
Δ =Dynamic deflection at the center of the beam.
L = Length of span between supports.
a =Distance from support to the load point (L/3)
N_f = Number of repetitions to failure
k_1 = fatigue constant, value of Nf when = 1
k_2 = inverse slope of the straight line in the logarithmic relationship

TEST RESULTS AND DISCUSSION

EFFECTS OF HYDRATED LIME ON MOISTURE SUSCEPTIBILITY

Based on the data shown in Figure 10, it appears that the examined hydrated lime contents and addition method have influence on the moisture susceptibility of the asphalt concrete mixes. The figure clearly demonstrates that both hydrated lime addition methods contributed to an increase in TSR and the general observation shows that wet method seems to be more effective than dry methods. TSR has gained a considerable increasing by 4.2%, 5.9%, 10.9%, 12% and 9% by dry method with respect to ascending amount of lime replacement as compared to the control mix. While, it took a similar manner by acquiring a gain in TSR of wet method by 3.4%, 6%, 18.8%, 20.8% and 19.8%. These results indicated the affirmative data that confirm the role of hydrated lime as a superior anti striping agent. The improvement in increasing in TSR can be attributed to improve in the adhesion between aggregate and asphalt cement due to the presence of hydrated lime by interacting with carboxylic acids in the asphalt and forming insoluble salts that are readily adsorbed at the aggregate surface (Plancher et al. 1977; and Hicks 1991). Implementing of these phenomena on local Iraqi paving materials can be discussed as follow: the aggregate used in this study was brought form Al-Nibaie quarry, which is Quartzite and classified as acidic aggregate and the improvement showed by altering the surface chemistry of acidic aggregate, causes a basic coating, and develops a strong bond between aggregate and acidic asphalt binder. Such bonding developed between asphalt binder and aggregate results in mitigate moisture damage in the asphalt mixtures. The effect of wet method of hydrated lime replacement was significant and even more impressive when the mixes replaced with dry hydrated lime to wet aggregate, this could be explained by fact that wet replacement of hydrated lime on 3% SSD provides better coverage and allows for proper application as compared to that add dry hydrated lime to dry aggregate. These advantages are possible because moisture ionizes lime and helps distribute it on the surface of the aggregate. Also visual inspection for tested specimens show more broken aggregates on the split faces which reflect higher bonding strength of the binder.

EFFECTS OF HYDRATATED LIME ON PERMANANET DEFORMATION

Permanent deformation manifests itself as primary distress due to the hot climate of Iraqi hot summer season. In this study the effect of hydrated lime has been quantified at a range of three temperatures 20°C, 40°C and 60°C representing the actual climate variation during the year in Iraq. The analysis of permanent deformation potential affected by the addition of hydrated lime are shown in figure 11 to 16 which are based on the data presented in tables 8 and 9. Examinations of the presented data suggest that the permanent deformation parameters intercept and slope generally improved with the use of hydrated lime. At lower temperature 20°C, the trend line of permanent deformation shows a narrow corridor between control and lime treated mixture with different rates for both dry and wet hydrated lime method. In other words , hydrated lime seems insignificant in reducing slope and intercept values as shown in tables 8 and 9 This can be attributed to the fact that, hydrated lime had minor effect at lower temperature in reducing the permanent deformation parameter slope and intercept and this was expected and indicated throughout the study of (Little and Petersen 2005). At intermediate and higher temperatures, hydrated lime showed a significant effect in improving rutting resistance by decreasing slope value, using dry method the slope value decreased as the amount of hydrated increased at 40°C and 60°C, mixes replaced with dry method at 2.5% at 40°C and 60°C exhibits a lower slope value by 18.4 % and 8.1% respectively. The addition of more hydrated lime beyond this percent may not represent best scenario as the time to failure for the 3.0% case was not different, while the same scenario using wet method, mixture with 2.5% exhibited lower slope value with 21.3% and 11.5% respectively at 40°C and 60°C compared to the control mix. As a summery from the test result it also appears that the addition of more than

2.5% for dry and wet hydrated lime did not improve the performance, as the time to failure for the 3.0% case was very similar to the time to failure of the 2.5% case, expect at lower temperature 20°C where hydrated lime acts as inert filler and less chemically active. The addition-reduction trend in permanent deformations of specimens of asphalt by percentage reduction of hydrated lime content was more impressive. So, additional hydrated lime content will have less negative effect on permanent deformation parameter of asphalt specimens. On the other hand, wet method seems to be more effective in reducing the slope value. In general, hydrated lime show a significant effect when using with both method in HMA mixture as limestone dust replacement in increasing the resistance to permanent deformation potential. Therefore in dry and hot environments similar to that of Iraq, where rutting failure controls the selection of asphalt concrete mixture, the use of wet hydrated lime replacement confirms that the rutting mode of failure in asphalt concrete pavement which is enhanced at hot summer temperature can be reduced to large extent with the introduction of hydrated lime to asphalt concrete mixtures.

RESILIENT MODULUS

Table 10 as well as figure 17 exhibits the variation of the resilient modulus values with both hydrated lime addition methods. Higher values of Mr are found with 1%, 1.5%, 2.0%, and 2.5% with dry and wet hydrated lime replacement as compared to control mix at 20°C, 40°C and 60°C respectively. It is observed that as the percentage of dry hydrated lime is increased the moduli increase for both hydrated lime methods at all three temperatures, indicating the mix is becoming stiffer. Also the Mr values for wet method show decrease in their values with 3.0% at 40°C and 60°C respectively. Comparison of Mr between dry and wet hydrated indicated that, in case of wet method, up to 2.0% can increase the modulus value and above percentage it will decrease the modulus tremendously at 40°C and 60°C. While mixes with dry hydrated lime replacement show a trend of increase due to hydrated lime replacement increase in the mix at all three temperatures, may be attributed to production of dry mixes. Also, it should be noted that at lower temperature using both method the Mr value increases as hydrated lime replacement increases and this easily explained the mixture to become stiffer at lower temperature.

EFFECT OF HYDRATED LIME ON FATIGUE PERFORMANCE

The fatigue characteristic curves for all mixtures are presented in Figures 18 and 19. The fatigue parameters k_1 and k_2 are shown in Table 11 and 12. Values of k_1 and k_2 can be used as indicators of the effects of hydrated lime on the fatigue characteristics of a paving mixture. The flatter the slope of the fatigue curve, the larger the value of k_2. If two materials have the same k_1 value, then a large value of k_2 indicates a potential for longer fatigue life. On the other hand, a lower k_1 value represents a shorter fatigue life when the fatigue curves are parallel, that is, k_2 is constant.

From the figures listed previously, it is clearly shown that the dry method of replacement mixture with 2.5% show higher fatigue resistance accompanied by increasing in number of repetition and this clearly show by increasing in K2 than control mix value by 29% with respect to control mix. While a drastic reduction happened when the doze increase beyond threshold limits of 2.5% and result in decreasing k_2 value by 7% for 3.0%. This is due to the fact that the higher stiffness caused by increasing lime in the mix and supported by gradual increase in stiffness modulus effect. There is an indication that the k_2 value increases highly, and the k_1 values change correspondingly. It is worth noting here that all of the k_1 values ranging between 1.083303xE-8 to 7.7459xE-11is by using dry method. For wet method, the general trend was observed form figures and tables' results show synergistic effect to dry method by increasing the fatigue life to a point and then the extra amount will deteriorate the fatigue resistance. Mixture with 2.5% show longer fatigue resistance firstly by increasing in number of repetition and extending lower slope with flatter power trends and k_2 value for this mixture was increased by 31.4%. In comparing the effect of the two addition methods wet method extend the fatigue life better than dry methods, for the same percentage of lime content, the overall result for fatigue test showed that increasing trend in resistance to number of repetition as more hydrated lime was used, even if the better performance to fatigue damage was observed from the mixture with 2.5% for both dry and wet method. However, with more than 2.5% additional hydrated lime, no additional improvement in performance was observed.

PERFORMANCE ANALYSIS USING VESYS 5W SOFTWARE

Using **VESYS5W** software for analyzing pavement section consisted of a 150 mm asphalt concrete layer over a 400 mm base course layer with 10 million ESALs application during 20 years' service life, the present serviceability index trend line is abstracted from the output results of the software and the results are shown in figures 20 and 21. The figures clearly show that the pavement section which consists of asphalt concrete layer modified with 2.5 percent lime (wet application method) provide better performance as compared to the mixes with 2.5 percent lime (dry application method) or mix with 0 lime. The PSI values at the end of 20 years' service life are 11.8, 13.0and 6.6 for the pavement section with asphalt concrete layers containing 2.5 percent lime (wet), 2.5 percent lime (dry) and 0 lime, respectively. The PSI values in VESYS5W software reflect the effect of rutting and cracking for a pavement section during the design life.

CONCLUSIONS

The following conclusions and recommendations are based on the results of the laboratory tests and analysis presented in this study:

- The use of both hydrated addition methods exhibited a good resistance against the moisture damage, an increase in TSR is achieved by 4.2%, 5.3%, 5.9% 10.9%, 12% and 9.0% for dry hydrated lime replacement method and 3.4% , 6% , 18.8%, 20.8 and 19.8% for wet hydrated lime replacement method corresponding to 1.0, 1.5, 2.0 and 3.0 lime contents, respectively. This indicates that the wet addition method was more effective than the dry method in improving the resistance to moisture induced damage of asphalt concrete pavement modified with hydrated lime
- The permanent deformation parameters, slope and intercept, was significantly effected using dry and wet hydrated lime addition methods employing different percentages of hydrated lime and this effects is more pronounced at high testing temperatures. The lime modified mixed with 2.5 percent in dry method wet method result in a decrease in permanent deformation slope higher temperature of 40^{o}C and 60C as compared to control mixture with no lime.
- The dry addition method of hydrated lime as a filler substitute results in better elastic modulus as characterized by resilient modulus test in comparison with the wet addition method. The use

of 3 percent lime, respectively at 20°C, 40°C and 60°C test temperature improve the resilient modulus by 40.2, 35.2 and 21.9 percent in dry addition method whereas for wet addition method the corresponding values are 29.1, 29.8 and 22.4 percent as compared to control mixes with no lime.

- For both addition methods, the use of 2.5 percent hydrated lime as a filler substitute has improved the fatigue property of the asphalt concrete mixes as determined by flexural test, the k_2 value (inverse slope of fatigue line) for mixes with 2.5 percent hydrated in dry and wet addition methods was more than that of 0 percent hydrated lime by 29 and 31.4 percent, respectively.
- The use of 2.5 percent hydrated lime in wet addition method as replacement for limestone dust mineral filler has shown a significant improvement of asphalt concrete behavior and has added to the local knowledge the possibility of producing more durable mixtures with higher resistance to distresses.

Specimens Nomenclature

The mix designation or nomenclature is the layer and the amount of hydrated lime that were substitute to filler and addition method. The mix nomenclature is the first letter that refers to the layer wearing followed by the actual amount of hydrated lime and the last letter that refers to the method of adding hydrated lime to mix

REFRENCES

- AASHTO, 2004, *Evaluation of Superpave Gyratory Compactors (SGC's*), AASHTO Designation: PP-35, , American Association of State Highways and Transportation Officials, Washington, D.C.
- Albayati A.,H , Alani A,M., 2012 , *Laboratory investigation in the Hydrated Lime effect on asphalt concrete mixture*, preceding of The First National Conference for Engineering Sciences FNCES'12 , Baghdad , Iraq.
- Albayati, A.H., 2006, *Permanent Deformation Prediction of Asphalt Concrete Under Repeated Loading* Ph.D. Thesis, Baghdad University.
- Albayati,A. H., 2012, *Mechanistic Evaluation of Lime-Modified Asphalt Concrete Mixtures*, 7th RILEM International Conference on Cracking in Pavements RILEM Book series, 2012, Volume 4, PP .921-940.
- AlSuhaibani, A. R., Al-Mudaiheem, J., and Al-Fozan ,F. 1992 , *Effect of Filler Type and Content on Properties of Asphalt Concrete Mixes*. In Effects of Aggregates and Mineral Fillers on Asphalt Mixtures Performance, SPT 1147 (R. C. Meininger, ed.), ASTM, Philadelphia, Pa., pp. 107–130.
- Barksdale, R., 1971, *Compressive stress Pulse Times in flexible pavements for use in dynamic Testing*, No.345 , pp 32-44 ,Highway Research Record.
- Button, J.W., and Epps, J.A. 1983. *Evaluation of methods of mixing lime and asphalt paving mixtures*. Texas Hot Asphalt Pavement Association.

- European Lime Association / Asphalt Task Force, 2011, *Hydrated lime a Proven additives for Durable asphalt Pavement.*
- Hicks, R. G. 1991,: *Moisture Damage in Asphalt Concrete*, NCHRP Synthesis of Highway Practice 175,TRB, National Research Council, Washington, D.C.
- Huang ,Y. H., 2004, *Pavement Analysis and Design*, 2nd edition , Pearson Prentice Hall , Pearson Education, Inc . ,Upper Saddle River, NJ 0745 8.
- Huang, S.-C., J. C. Peterson, R. E. Robertson, and J. F. Branthaver. 2002, *Effect of Hydrated Lime on Long-Term Oxidative Aging Characteristics of Asphalt*. In Transportation Research Record: Journal of the Transportation Research Board, No. 1810, Transportation Research Board of the National Academies, Washington, D.C., pp. 17–24.
- Hydrated Lime, 2003, *More Than Just a Fille*r. National Lime Association, www.lime.org/HydratedLime.pdf.
- Kennedy, T. W., and Ping, W. V. 1991, *An Evaluation of Effectiveness of Antistripping Additives in Protecting Asphalt Mixtures from Moisture Damage*, Presented at Annual Meeting of the Association of Asphalt Paving Technologies.
- Little, D, and Epps, J. 2001,." *The Benefits of Hydrated Lime in Hot Mix Asphalt*. National Lime Association,. www.lime.org/ABenefit.pdf.
- Little, D.N. and Petersen, J.C. 2005. *Unique Effects of Hydrated Lime Filler on the Performance- Related Properties of Asphalt Cements: Physical and Chemical Interactions Revisited*. Journal of Materials in Civil Engineering, Volume 17, No. 2, pp.207-218.
- Mohammad, L. N., Abadie, C., Gokmen ,R., and Puppala, A. J., 2000 , *Mechanistic Evaluation of Hydrated Lime in Hot-Mix Asphalt Mixtures*. In Transportation Research Record: Journal of the Transportation Research Board, No. 1723, TRB, National Research Council, Washington, D.C.,pp. 26–36.
- Monismith, C., Ogawa, N. and Freeme, C. 1975. *Permanent Deformation Characteristics of Subgrade Soils due to Repeated Loadings*, TRR 537.
- Plancher, H., S. Dorrence, and J. C. Petersen. 1977. *Identification of Chemical Types in Asphalts Strongly Absorbed at the Asphalt–Aggregate Interface and Their Relative Displacement by Water*. Proc., Association of Asphalt Paving Technologists, Vol. 46, pp. 151–175.
- SCRB/R9 2003. *General Specification for Roads and Bridges*, Section R/9, Hot-Mix Asphalt Concrete Pavement, Revised Edition. State Corporation of Roads and Bridges, Ministry of Housing and Construction, Republic of Iraq.
- Sebaaly, P, E., 2006, *The Benefits of Hydrated Lime in Hot Mix Asphalt*, National Lime Association.

Table 1. Lime addition techniques with major positive and negative (Button and Epps 1983).

Method	Description	Major Positives	Major Negatives
Dry	- Simplest method - Lime and mineral filler introduced immediately after introduction of	- Least expensive method - Direct contact between aggregates and hydrated lime - Lime and mineral filler introduced immediately after introduction of	- Dusting and lime loss - Minimal mixing and coating of aggregates

	asphalt	asphalt	
Wet	- Lime metered into aggregate at a moisture content of 2-3% higher than SSD condition - Mixture processed in pug mill to ensure thorough mixing	- Proper coverage and application - Portion not mixing with aggregate will mix with asphalt, thus still aiding as anti-stripping agent	- Expensive due to extra fuel needed to dry aggregates before mix production
	- Aggregates kept in moist condition and marinated for up to 48 hours	- Moisture content slowly reduces over stockpiling period - Stockpiling can be separated from production, thus providing an economic advantage	- Aggregate handling effort is increased - Storage space needed for aggregate stockpiling - Concerns over carbonation of stockpiles with long stockpiling times
Slurry	-Slurry of lime and water applied to aggregates -Marinating optional	-Improved coverage of aggregates -Reduced dispersion and loss of lime -Improved stripping protection	-Increased water and fuel costs -Expensive, specialized equipment requirements

Table 2. Properties of asphalt cement

Property	ASTM designation	Penetration grade 40-50	
		Test results	SCRB specification
1-Penetration at 25C,100 gm,5 sec. (0.1mm)	D-5	45	40-50
2- Rotational viscosity at 135°C (cP.s)	D4402	523	……
2- Softening Point. (°C)	D-36	49	……
3-Ductility at 25 C, 5cm/min,(cm)	D-113	>100	>100
4-Flash Point, (°C)	D-92	290	Min.232
5-Specific Gravity	D-70	1.041	……
6- Residue from thin film oven test	D-1754		
- Retained penetration,% of original	D-5	59.5	>55
- Ductility at 25 C, 5cm/min,(cm)	D-113	80	>25

Table 3. Physical properties for Alnibaie aggregate

Property	Alnibaie aggregate		
	Coarse Aggregate	Fine Aggregate	SCRB
Bulk Specific gravity (g/cm^3) (ASTMC127 and C128)	2.646	2.63	-----
Apparent Specific gravity (g/cm^3) (ASTM C127 and C128)	2.656	2.667	-----

Percent water absorption (ASTM C127 and C128)	0.14	0.523	-----
Percent wear (Los-Angeles Abrasion) (ASTM C131)	19.69		30 Max
Fractured pieces, %	98		90 Min
Sand Equivalent(ASTM D 2419)		55	45 Min*. Superpave (SP-2),
Soundness loss by sodium sulfate solution,% (C-88)	3.4	-------	12 Max

Table 4. Selected gradation for wearing and binder course

sieve size Inch	mm	Wearing course Selected gradation	Specification limit (SCRB 2003/R9)
3/4	19.0mm	100	100
1/2	12.5mm	95	100-90
3/8	9.5mm	83	76-90
No.4	4.75mm	59	44-74
No.8	2.36mm	37	28-58
No.50	0.3 mm	13	5-21
No.200	0.075mm	7	4-10

Table 5. Physical properties of hydrated lime and limestone

Material property	Hydrated lime	Limestone dust
Specific gravity	2.41	2.78
Specific surface (m^2/Kg) *	398	244
-100 Mesh (150 µm) passing	100	100
-200 Mesh (75 µm) passing	90	85

*Tested by Blaine Air Permeability at material laboratory of civil engineering department according to ASTM C204

Table 6. Chemical composition and physical properties hydrated lime and limestone

Chemical composition	Hydrated lime	Limestone dust
% CaO	56.1	68.3
% SiO2	1.38	2.23
% Al2O3	0.72	-
% Fe2O3	0.12	-
% MgO	0.13	0.32
% SO3	0.21	1.2
% L. O. I.	40.65	27.3

Table 7. Marshall Design properties for wearing using dry and wet hydrated lime addition method

Mixture	OAC %	Density gm./cm^3	Stability kN	Flow mm	Air voids %	VMA %	VFA %
SCRB requirement			Min. 8.0 Kn	2-4	3-5	14 Min.	65-75
Control	4.9	2.338	11.67	4	4.018	14.07	70.4
W1H-d	4.9	2.337	12.12	3.75	4.01	13.93	70.2
W1.5H-d	5	2.331	12.47	3.5	4.08	14.08	72.4
W2H-d	5.2	2.328	14.37	3.5	4.14	14.33	72.1

W2.5H-d	5.2	2.316	13.77	3	4.30	14.41	71.1
W3H-d	5.3	2.309	12.01	2.75	4.09	14.57	71.2
W1H-w	4.9	2.328	12	3.75	4.17	14.06	74.6
W1.5H-w	4.9	2.326	13.79	3.75	4.12	14.09	72.4
W2H-w	5	2.317	12.02	4	4.21	14.17	73.5
W2.5H-w	5.2	2.311	11.51	4.25	4.12	14.31	70.6
W3H-w	5.2	2.296	10.22	4.75	4.32	14.34	70.7

Table 8. Effect of dry hydrated lime addition method on Intercept and slope Coefficient of permanent deformation

Mixture	20 C^0		40C^0		60C^0	
	a	b	a	b	a	b
Control	41.659	0.2761	115.3	0.3787	335.1	0.5675
W1H-d	39.717	0.2758	106.9	0.3576	311.6	0.5626
W1.5H-d	38.365	0.2682	98.8	0.3407	276.28	0.5332
W2H-d	34.225	0.2632	80.2	0.3203	240.5	0.5285
W2.5H-d	33.226	0.2628	71.9	0.3127	213.1	0.5225
W3H-d	31.389	0.2619	69.2	0.3005	200.83	0.511

Table 9. Effect of wet hydrated lime addition method on Intercept and slope Coefficient of permanent deformation

Mixture	20 C^0		40C^0		60C^0	
	a	b	a	b	a	b
W1H-w	41.004	0.2722	89.8	0.3551	289.8	0.5505
W1.5H-w	38.226	0.2681	78.9	0.3279	270.0	0.5359
W2H-w	37.412	0.267	61.1	0.3089	211.93	0.5169
W2.5H-w	35.129	0.259	60.0	0.3022	200.5	0.5082
W3H-w	33.356	0.2566	61.1	0.3372	205.48	0.5296

Table 10. Effect of dry and wet hydrated lime addition method on resilient modulus, Psi

Mixture	20C^0	Gains%	40C^0	Gains%	60C^0	Gains%
Control	179076	0	114814	0	79987	0
W1H-d	223220	19.7	127754	10.1	88059	9.16
W1.5H-d	247922	27.7	149119	23.0	93008	13.9
W2H-d	255959	30	157591	27.1	97943	18.3
W2.5H-d	278217	35.6	164636	30.2	100507	20.41
W3H-d	299952	40.2	177258	35.22	102547	21.9
W1H-w	199968	10.4	137754	16.65	85700	6.6
W1.5H-w	213299	16.04	159119	27.84	90126	11.24
W2H-w	234109	23.5	161210	28.77	117772	32.0
W2.5H-w	239962	25.3	164301	30.11	126629	36.8
W3H-w	252591	29.1	163350	29.71	103209	22.49

Mixture	Fatigue Equation	Number of repetition to fracture (N_f) Stress level(N)			
		222	489	311	400
Control	$N_f = 1.32484E\text{-}07\varepsilon t^{-3.03}$	11285	7556	2332	1802
W1H-d	$N_f = 1.08303E\text{-}08\varepsilon t^{-3.44}$	13542	8260	5427	2105
W1.5H-d	$N_f = 1.48877E\text{-}09\varepsilon t^{-3.77}$	14531	9650	6321	3189
W2H-d	$N_f = 2.0395E\text{-}10\varepsilon t^{-4.09}$	15780	13341	7443	4210

W2.5H-d	$N_f = 7.74597E\text{-}11\varepsilon t^{-4.27}$	16780	13123	8502	3277
W3H-d	$N_f = 7.47221E\text{-}10\varepsilon t^{-3.93}$	13140	8420	5434	3780

Table 12. Fatigue life equation- wet hydrated lime.

Mixture	Fatigue Equation	Number of repetition to fracture (N_f) Stress level(N)			
		222	489	311	400
W1H-w	$N_f = 2.7558E\text{-}08\varepsilon t^{-3.35}$	14537	10921	6258	3865
W1.5H-w	$N_f = 7.7565E\text{-}09\varepsilon t^{-3.58}$	16482	11051	7320	5582
W2H-w	$N_f = 1.759E\text{-}10\varepsilon t^{-4.18}$	22421	15237	11592	8872
W2.5H-w	$N_f = 3.745E\text{-}11\varepsilon t^{-4.42}$	22532	17542	13542	6210
W3H-w	$N_f = 4.3598E\text{-}10\varepsilon t^{-4.06}$	18218	13279	8421	5103

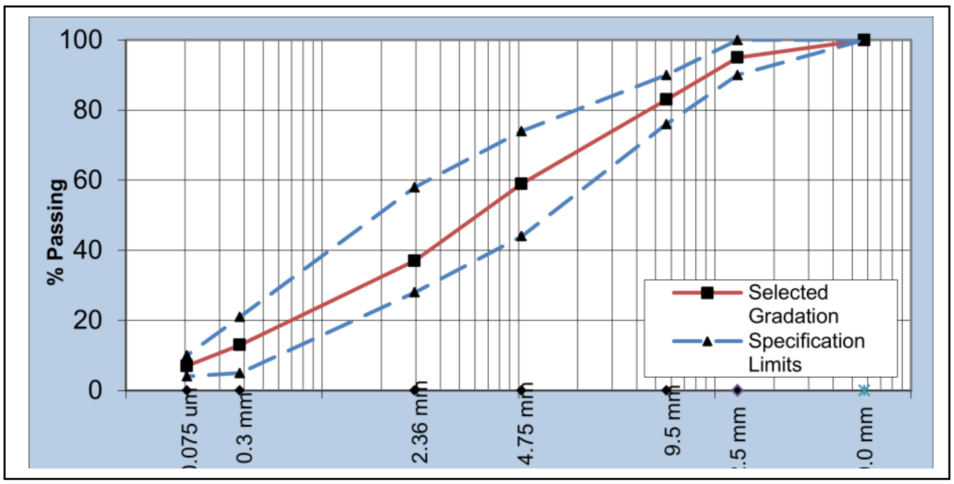

Figure 1. Wearing course gradation (W).

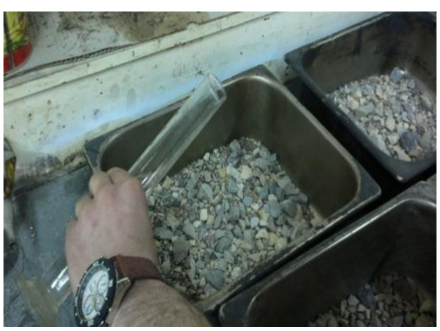

Figure 2. Adding water to the aggregates**.**

Figure 3. Mixing water with the aggregates.

Figure 4. Adding, Mixing hydrated lime to the wet Aggregate**.**

Figure 5. Oven dried Mix**.**

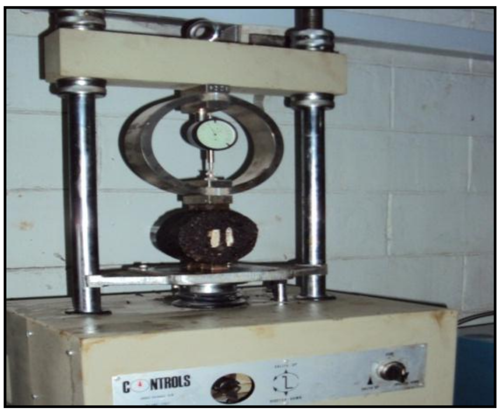

Figure 6. Photograph for ITS test**.**

Figure 7. Photograph for the PRLS**.**

Figure 8. Photograph for Permanent Deformation Specimen .

Figure 9. Photograph for Flexural Beam Specimen.

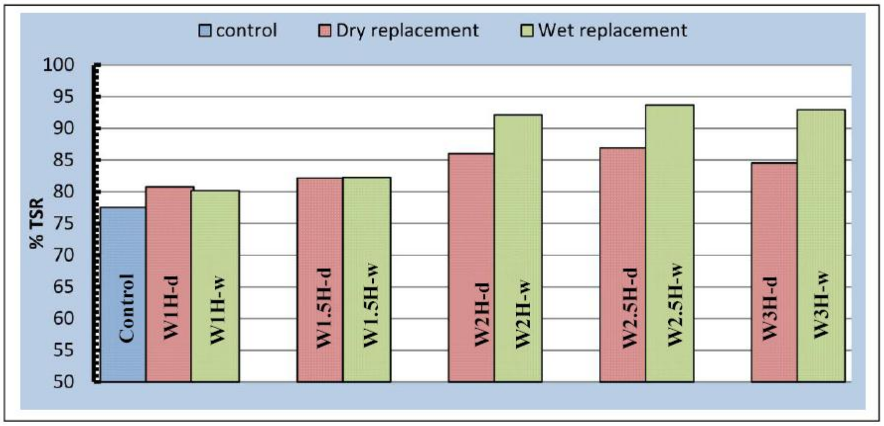

Figure 10. Effect of Dry and Wet hydrated lime addition method on TSR %.

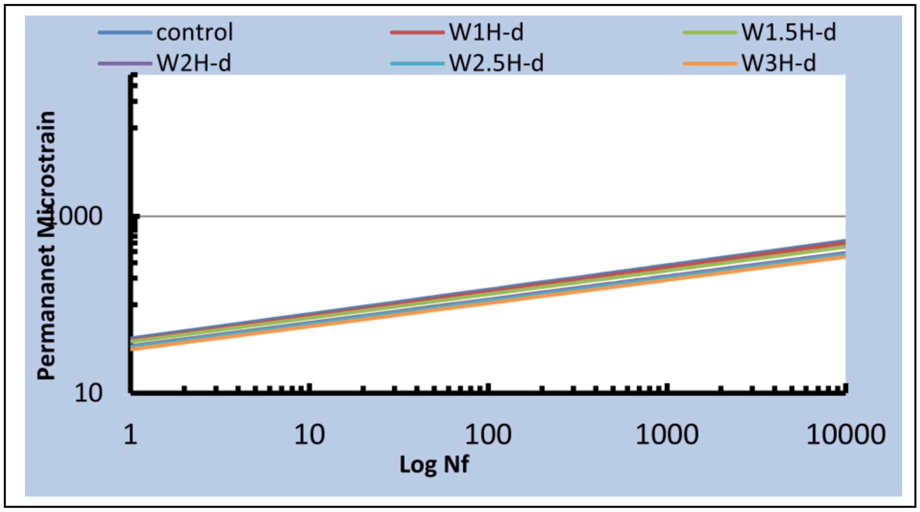

Figure 11. Effect of dry hydrated lime method on permanent deformation at 20^{o}C .

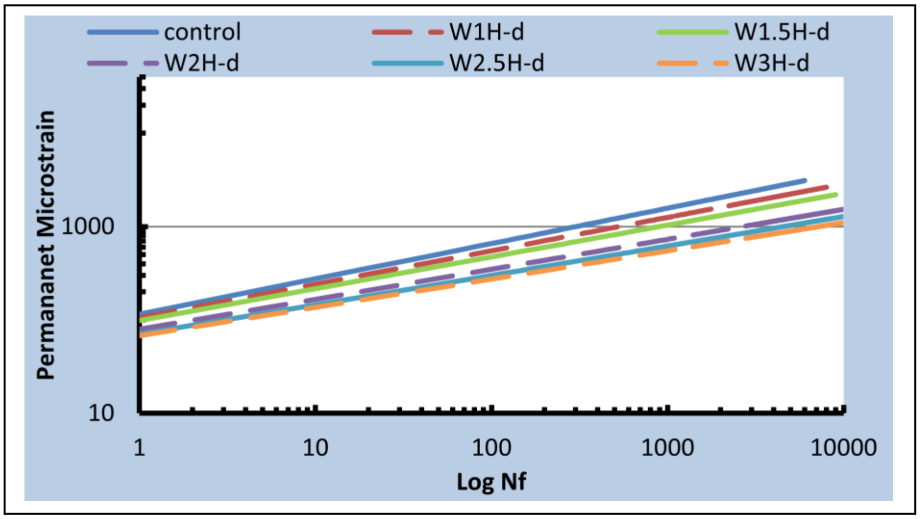

Figure 12. Effect of dry hydrated lime method on permanent deformation at 40^{o}C.

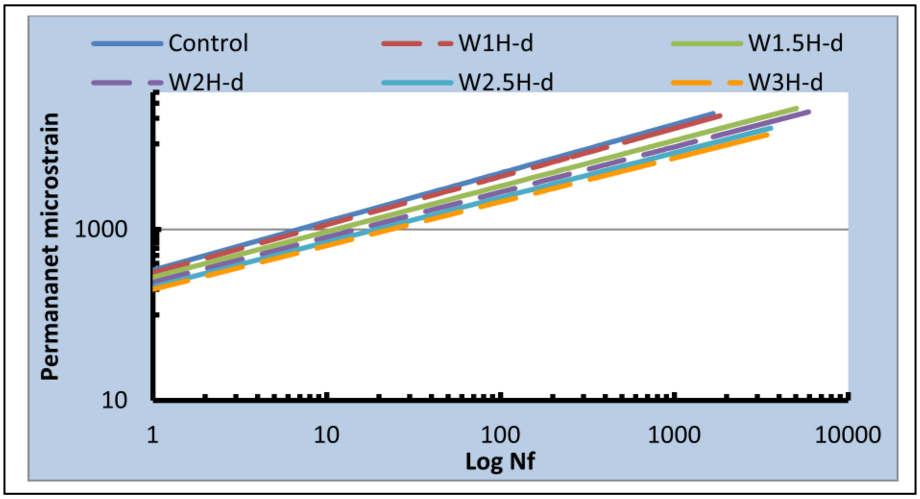

Figure 13. Effect of dry hydrated lime method on permanent deformation at 60^{o}C.

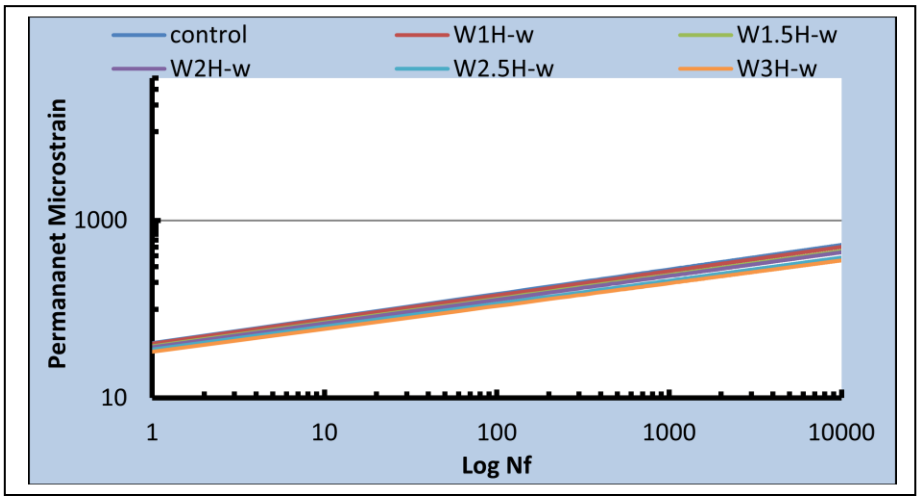

Figure 14. Effect of wet hydrated lime method on permanent deformation at 20^{o}C .

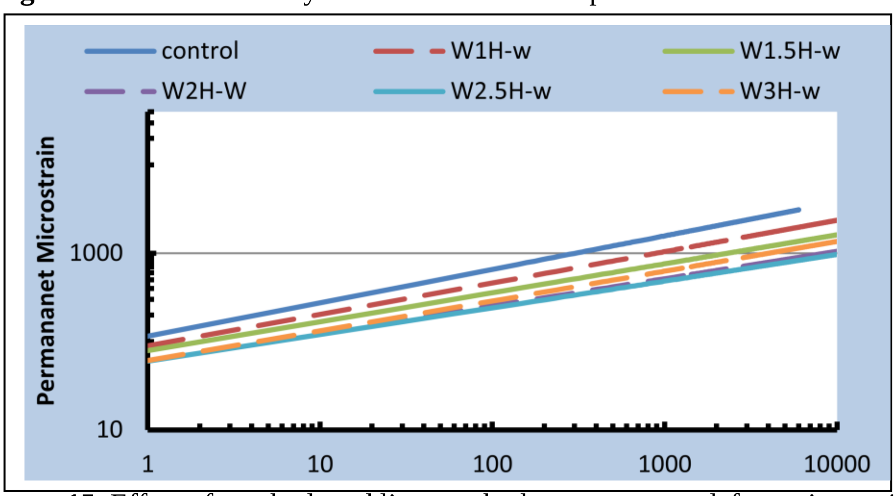

Figure 15. Effect of wet hydrated lime method on permanent deformation at 40^{o}C.

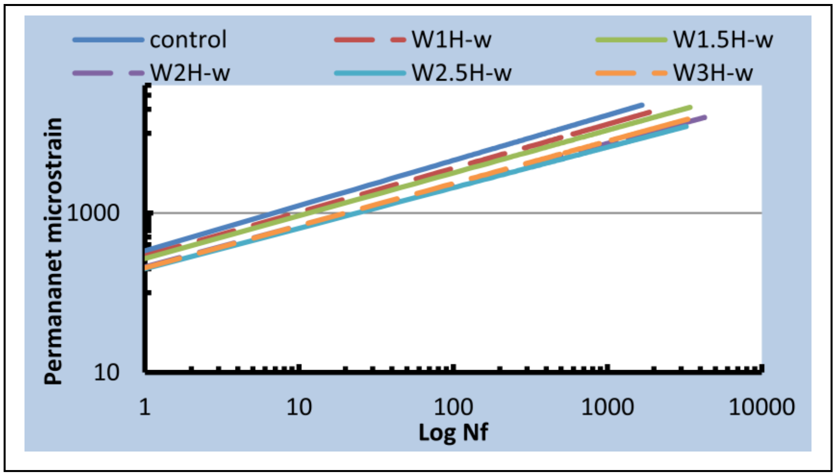

Figure 16. Effect of wet hydrated lime method on permanent deformation at 60°C.

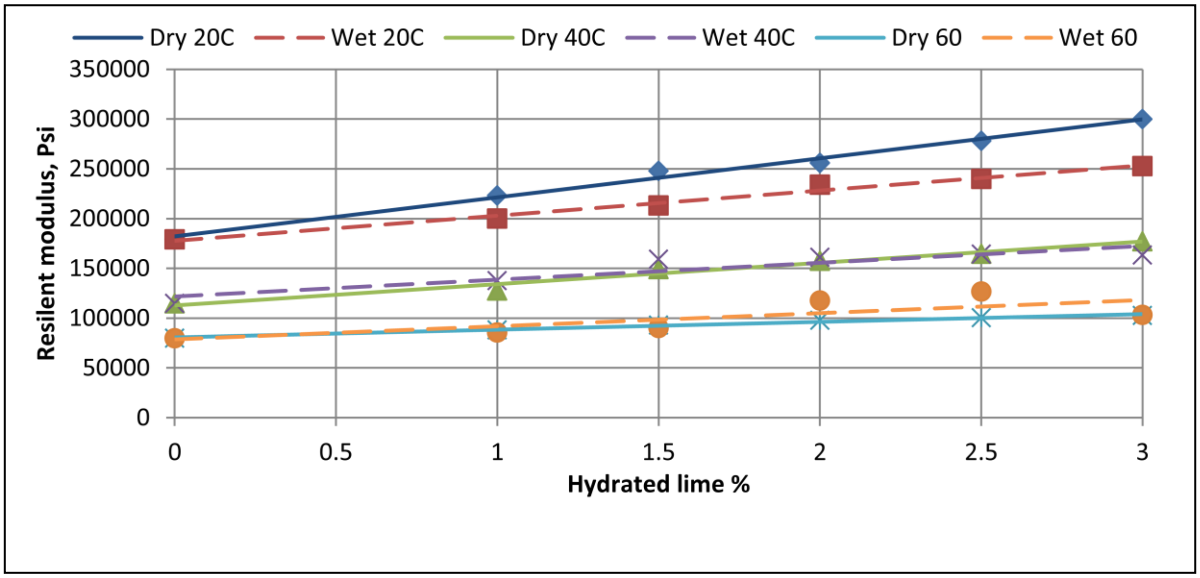

Figure 17. Effect of dry and wet hydrated lime addition method on Resilient Modulus.

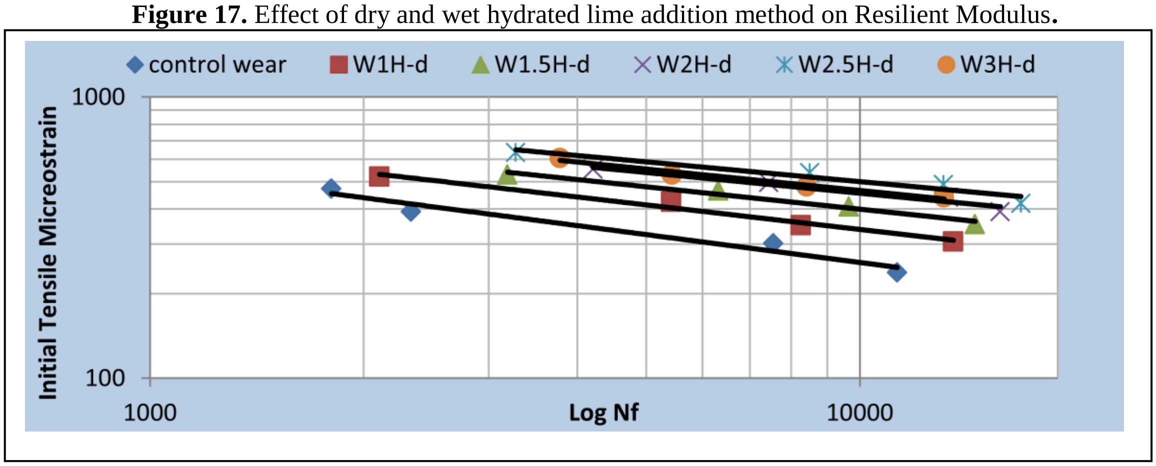

Figure 18. Effect of dry hydrated lime on fatigue cracking relationship.

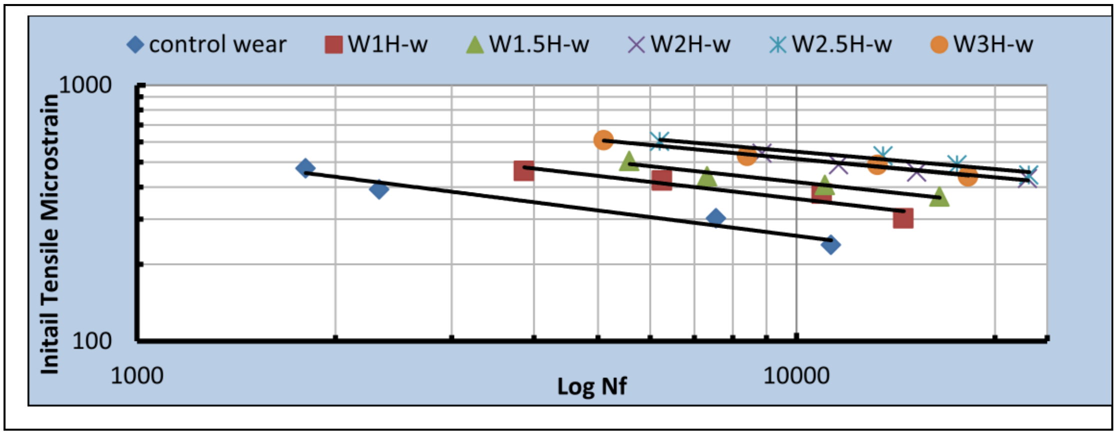

Figure 20. Effect of wet hydrated lime on fatigue cracking relationship **.**

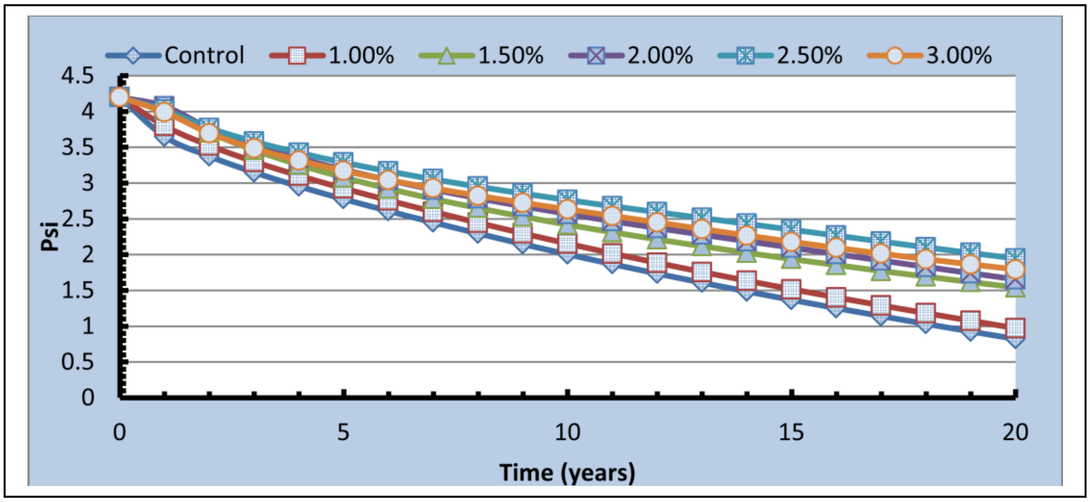

Figure 20. PSI- Time Relationship for control and mixes with dry hydrated lime**.**

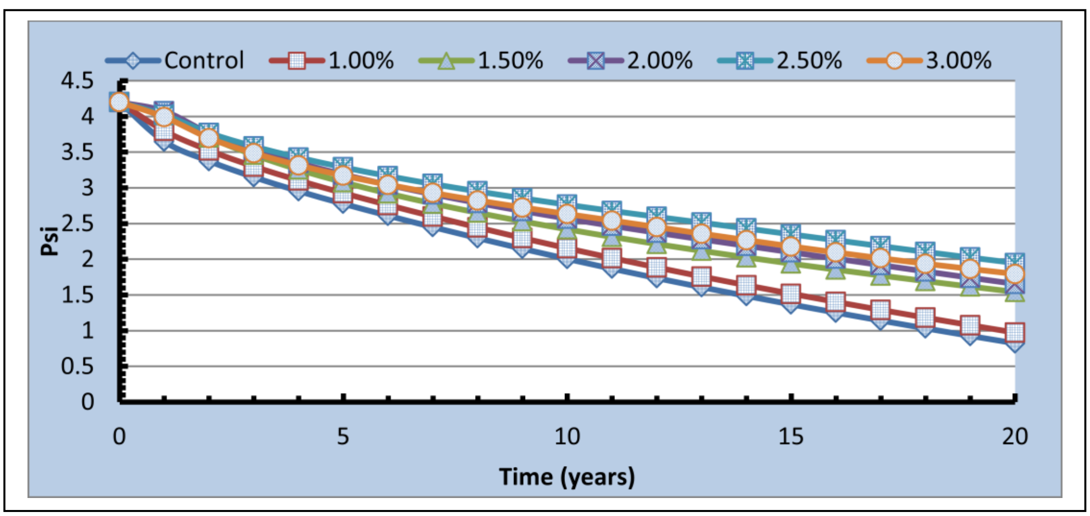

Figure 21 PSI- Time Relationship for control and mixes with wet hydrated lime.