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Assessment the Impact of Different Hydrated Lime Addition Methods on Fatigue Life Characteristic

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ABSTRACT

The purpose of this study is to evaluate the effect of hydrated lime addition methods as filler replacement on fatigue performance of Hot Mix Asphalt (HMA). Three types of addition methods of hydrated lime were introduced namely dry HL on dry aggregate and saturated surface aggregate above 3% and slurry HL on dry aggregate, ordinary Lime stone powder was reduced by three HL percentage (1.0, 2.0 and 3.0 %). The effect of different methods were investigated on the fatigue properties of HMA using, third-point flexural fatigue bending Test. Pneumatic Repeated Load System (PRLS) was carried out to establish the effect of hydrated lime on the fatigue failure criteria and to select the proper hydrated lime application methods on fatigue behavior of HMA mixtures. The fatigue functions for asphalt mixture with hydrated lime are obtained and compared, and it confirm that the fatigue property of asphalt mixture can be improved using all methods and the addition methods were exhibited different optimality for the result due to its effect . The test results were carried out through the performance analysis using Vesys 5W (2003) to study the long term effectiveness of hydrated lime effect.

Keywords: Hydrated Lime, Flexural Beam, Fatigue Test, Indirect Resilient Modulus, Fatigue, PRLS, and Asphalt.

تقيم طرق الاضافة المختلفة للنورة المطفأ على خصائص الكلل

الخلاصة يهدف هذا البحث الى دراسة التأثيرات الناتجة من استخدام النورة المطفأ كبديل جزئي للمادة المالئة على اداء الكلل في الخلطات الاسفلتية من خلال استخدام ثلاث طرق اضافة مختلفة وذلك باضافة نورة جافة على ركام جاف او رطب السطح بنسبة 3-2% اضافه الى استخدمة كخليط مع الماء و اضافته الى الركام . حيث تم تقليل المادة المالئة الفلر و استبدالها بنورة مطفأ وبمقدار ثلاث نسب وزنية 1,2,3 % من وزن الركام الكلي لدراسة التأثيرات المختلفة لهذه الطرق على خصائص الاداء للكلل باستعمال فحص الانحناء للعتبات الاسفلتية من خلال استخدام جهاز

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الحمل الدوري المتكرر لتقيم اداء الكلل للخلطات الاسفلتية المعدلة بالنورة المطفأ و اختيار الطريقة و النسبة المثلى حيث اظهرت النتائج بأن خصائص الكلل تختلف من طريقة الى اخرى و بتغير نسب الاستبدال و اخيرا تم استخدام هذه النتائج كمدخلات رئيسة لبرنامج Vesys 5W (2003) من اجل دراسة فعالية النورة المستبدلة على اداء الخلطات الاسفلتية للمدى الطويل.

BAKGROUND

Hydrated lime has been acknowledged as a superior additive for asphalt concrete and has extensive track record nationally. The beneficial nature of this material in asphalt concrete is related to both the particular chemistry of the system and the mechanical nature of fine particles in an asphalt binder matrix. Numerous studies over the years detail the benefits of hydrated lime as both (1) a filler and (2) as an agent to reduce moisture-induced stripping (Plancher et al. 1976, Tunnicliff 1977, Welch et al. 1977, Petersen et al. 1987a, b, Collins 1988, Sebaaly et al. 2003,, Little et al. 2005). Presumably, since the use of mineral filler was generally advocated and specified by state of highways department, asphalt contractor chose the less expensive fillers. Also, numerous specialty mineral filler compound were vigorously promoted and largely replaced hydrated lime in spite of their higher cost.

The observed benefits of hydrated lime range from very significant as active filler, to less significant but still useful filler, i.e., similar to more standard inert fillers such as baghouse fines (Little et al. 2005). When lime is added to HMA, it reacts with the aggregates, strengthening the bond between the bitumen and the aggregate. At the same time, the lime treats the aggregate; it reacts with the asphalt itself. Lime reacts with highly polar molecules that can otherwise react in the mix to form water-soluble soaps that promote stripping. When those molecules react with lime, they form insoluble salts that no longer attract water (Petersen et al. 1987a). In addition, the dispersion of hydrated lime throughout the mix makes the mix stiffer and tougher, thereby reducing the possibility that the bond between the asphalt cement and the aggregate will be broken mechanically, even if there is no water effect.

Even though it has been shown repeatedly that the use of hydrated lime in asphalt concrete mixtures is beneficial, confusion still exists as to the best method for adding lime to asphalt mixtures. Selecting the appropriate method for adding the lime is complicated by the lack of consistent results from the literature. Some researchers suggest that the method used for lime addition is not an important factor at all (Gardiner et al. 1987, Collins 1988), whereas others clearly demonstrate that differences in material properties are evident when the lime addition method changes (Button et al. 1983, Kennedy et al. 1983, Sebaaly et al. 2003). The conflicting results from the literature indicate that further study is needed on this topic**.**

SURVEYED LITERATURE ON HYDRATED LIME EFFECTS ON FATIGUE CRACKING

The fatigue resistance of an asphalt mixture refers to its ability to withstand repeated bending without reaching fracture. Fatigue, a common form of distress in asphalt pavements, manifests itself in the form of cracking from repeated traffic loading. It is important to have measurements of the fatigue characteristics of specific mixtures over a range of traffic and environmental conditions, so that fatigue considerations can be incorporated into the process of designing asphalt pavements. The fatigue characteristics of asphalt mixtures are usually expressed as relationships between the initial stress or strain and the number of load repetitions to failure, determined by using repeated flexure, direct tension, or diametral tests performed at several stress or strain levels (Tayebali et al., 1994).

One mechanism that explains hydrated lime's ability to extend fatigue life in pavements while at the same time stiffening them is called "crack pinning". The tiny hydrate particles intercept and deflect micro cracks as they form preventing them from coalescing into macro cracks that can reflect through the pavement layer. Because of lime's chemical activity it adsorbs acid components from the bitumen to its surface, increasing the effective volume of the particles making them more effective than inert fillers at intercepting the micro cracks (Lesueur and Little, 1999). (Sebaaly 2006) has justified the improvement in fatigue performance of asphalt mixtures by the addition of hydrated lime with the following argument: "The greater improvement in fatigue life due to the addition of hydrated lime is a result of the reaction between hydrated lime and the polar molecules in the asphalt cement, which increases the effective volume of the lime particles by surrounding them with large organic chains.

Consequently, the lime particles are better able to intercept and deflect microcracks, preventing them from coalescing into large cracks that can cause pavement failure. (Diab et.al 2013) studied the effect of the addition of hydrated lime on phenomenological fatigue model parameters using controlled stress split tension fatigue with content of 5.5% by dry aggregate weight using slurry method, it was concluded that fatigue parameter (a) increased with the addition of hydrated lime, while fatigue parameter (b) seemed to be insensitive to mixture type (control mixture and hydrated lime modified mixture). This means that hydrated lime modified mixtures last longer under traffic loading than control mixtures; meanwhile, hydrated lime plays an important role in preventing fatigue damage of HMA pavements. Since crack phenomena are governed substantially by properties of the mastic, mixture performance can be improved if the mastic is engineered to resist (Kabir 2008) reported that hydrated lime particles toughen the mastic, making it more resistant to fracture and crack propagation.

A major study by with dry method was done by(Albayati 2012), the author conclude that the use of hydrated lime as a filler substitute within a range of 1.5-3 percent has improved the fatigue property of the asphalt concrete mixes as determined by flexural test. The K2 value (inverse slope of fatigue line) for mixes with 2 and 3 percent hydrated lime was more than that of 0 percent hydrated lime by 53.6 and 24.4 percent, respectively. Historically, there are five methods for introducing hydrated lime into HMA. These are: (1) lime slurry to dry or wet aggregate, (2) dry lime to wet aggregate, (3) dry lime to dry aggregate (4) dry lime to bitumen, and (5) quicklime slurry to dry or wet aggregate. Dry hydrated lime to wet aggregate is one of the most commonly used addition methods. In this method, dry hydrated lime is either added to wet aggregate (containing 3–5 percent water) or added to dry aggregate and then sprayed with water. The addition of lime to wet aggregate is generally the better method and enables good mixing, coating and treatment especially with poor aggregates.

Moreover, it is the most suitable method for application in laboratory conditions based on that the primary objective of this research is to study the effect of hydrated lime effect on fatigue life characteristic and detail a comparison between various lime addition methods (dry, wet and slurry)to lime content (1.0, 2.0 and 3.0%) as limestone mineral filler replacement.

Laboratory Experiment

The laboratory experiment plan are listed in Table (1), the asphalt mixture performance tests were conducted on prismatic rectangular beam (381x75x75 mm) for flexural fatigue and resilient modulus (75x150mm) using three kind of lime application method at varying content 1, 2 and 3% and this percentage were selected based on past studies that have shown the effect of hydrated lime with attention to particular properties have been recuperated volumetric properties of asphalt mixtures as a limestone replacement for instance (Albayati 2012 , Diab et.al .2013 , Al-Suhaibani and Al-Mudaiheem 1992 ,Arabani 2009 ,Aragão2007)

Materials Selection

To accomplish more realistic simulation of (HMA) mixtures paved in Iraq, the most widely used local paving materials (aggregates and asphalt binder) were selected for fabricating laboratory samples. Hydrated lime, which has been produced in Karbala, Alnibaie aggregate and Aldurah asphalt cement were selected and evaluated in this study. The aggregate used in this study brought from Alnibaie Quarry in north of Baghdad. Physical properties are listed in Table (2). Alnibaie aggregate mainly consists of angular particles with brownish in color. In order to produce a controlled gradation, aggregate were separated in different sieves sizes and recombined to get the required gradation wearing course was selected according to Iraqi standard Specification for Road and Bridge (SCRB/R9 2003 Revision). The gradations are shown in Table (3) and Figure (1).

Asphalt cement (40/50) penetration grade is used in this study, it produced in Aldurah refinery. The main reason for using this grade of asphalt cement because it is the only one available in Baghdad province. A series of ASTM tests were conducted for identification of basic physical properties of asphalt cement used in this study are listed in Table (4) present fundamental properties of asphalt used in this study, It meets the required (SCRB/R9 2003 Revision) specification.

Hydrated lime has been recommended by SRCB about 1.5% by weight of aggregates, approved as a chemical admixture may be used as an anti-stripping additive where HMA pavements are susceptible to moisture-related stripping.

Hydrated lime was obtained from lime factory in Karbala governorate, south east of Baghdad, while Limestone dust ($CaCo_3$) are locally produced and brought form AL Ramadi district. Tables (5 and 6) illustrate chemical and physical properties of hydrated lime and limestone dust, respectively.

Mixture Design

The preparation of the samples involves batching of the aggregate fractions and placing them along with asphalt in the oven at mixing temperature to obtain the desired optimum asphalt content (OAC) based on Marshall Mix design method. Table (7) detailed desirable properties for control and lime modified mixes at their OAC.

Three lime contents as a mineral filler replacement were deployed 1.0, 2.0 and 3.0% by weight of aggregates. Each mix was designed with the same blend of aggregates to avoid variability due to physical and mineralogical characteristics of the aggregates. The only variable to differentiate mixes is the lime percentage remark (X) as shown in Flow chart (1). For the modified mixes one dry method and two wet methods (not marinated for 48hours) were performed in terms of introducing lime into aggregate prior to asphalt mixing. For the first method, termed Dry method (D) hydrated lime was substituted for a portion of limestone dust following the normal procedure for preparing the general mix. The second method wet method (W) introduces the hydrated lime to wet aggregate at a moisture content of 2%–3% over saturated-surface dry conditions. The final modified mix design slurry method (S) prepared with same intention to match the same amount of hydrated lime and water was used diluted in 6, 12, and 18% water, representing a lime/water ratio of 0.16, and then mixed with dry aggregates to produce well-distributed lime-water films on the aggregate surface. Based on Marshall mix design method, OAC was obtained and specified at higher stability as well as density and targeted air voids range, hence 4.9% for control mix and 5.2% for all lime treated mixture was chosen to avoid the variability in the design mixtures for compacted beams , since the increase in lime content increase the need of mix to more asphalt to warp the large surface area of hydrated lime as indicated by other researcher (Albayati and Alani 2012 , Albayati 2012 , Al-Suhaibani and Al-Mudaiheem 1992) .

Specimen Preparation

A rectangular beam specimens with dimension 381x75x75 mm (15×3×3 in) needed approximately 5420 grams of mixture each hydrated lime content in order to fabricate one specimen that according to mix design formula. A number of four specimens were tested for each hydrated lime content Therefore, a total of 60 beam specimens were used in this experiment with a range of 4 stress levels. A steel iron molds Plot (1) with 25.4 mm (1in) thickness were manufactured to employ the sample fabrication by static compaction, by using a "double plunger" arrangement, using compressive machine device in the laboratory of material at Civil Engineering Department as shown in Plot (2) . The mold was able to carrying heavy load up to 160,000lbs. Four trial mixes were

Compacted with load (49900, 54431, 58967, 63502 kg), to accomplish the desired density required, the 63502 kg was selected which gave density above 2.3 gm. /cm3.

The mix design method uses volumetric optimum asphalt content for each hydrated lime content. After mixing, the mixture poured into preheated steel mold and pressed in compressive machine under the gradual application of a static load for 2 minutes according to (ASTM-D1074-96). The compaction temperature is typically selected 170 oC, 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 shown in Plots (3, 4, 5, 6, 7). The resilient modulus of a mixture is a relative measure of mixture stiffness. In accordance with the test method, a cylindrical compacted sample was prepared by using superpave gyratory compactor. A number of three replicate per each lime and control mix were prepared to a thickness of 75±2 mm for a 150±2mm diameter specimen.

Test procedure

All tests were performed in a controlled- stress in room chamber at 20oC. The numbers of cycles (fatigue life) that cause completely failure of the beam commonly consider as indicator of fatigue cracking potential. The details of the factorial variables which used in the experimental design of the flexural beam fatigue test are:

• Stress Levels: Four levels of stress, 222, 311, 400& 489 N are selected as targets, control stress, time loading 0.1sec and rest period 0.4.sec A range of stress selected so that the specimens will fail within a range from 100 to 100,000 repetitions.

• Test Temperature: one level of the test temperature 20 ± 1°C is used because the fatigue cracking occurs at an intermediate temperature of around 20°C.

Pneumatic repeated load device (PRLS) (Albayati 2006) and control stress have been used as illustrated in Plot (8). Digital cameras have been used for recording the deflection at mid span of the beam until failure. The vertical deflection during the test of the beam at the mid span was measured with LVDT, which in turn is connected to data acquisition system were the deflection at various time intervals stored and analyzed for finding strain at any number of cyclic desired for every test. The general equations for analysis of a simply supported beam are as follows (Huang 2004):

$$\sigma = \text{—} \quad \ldots (1)$$

$$E_s = \frac{Pa(3 \quad\quad ^2)}{^3\Delta} \quad \ldots (2)$$

$$e_t = \frac{s}{E} \; \frac{d\Delta}{\quad} \quad \ldots (3)$$

Where:

σt = extreme fiber stress in N/mm2, a = distance between the load and the nearest support in mm, P = total repeated load with P/2 applied at each third point in N, b = specimen width in mm, d = specimen depth in mm, Es = stiffness modulus bas on center deflection in N/mm2, L = span length between support in mm, and ε_t = extreme fiber tensile strain in mm/mm. Δ = dynamic deflection Fatigue life relationship established by using at least four stresses level (222, 311, 400, 489 N) and constant temperature (20^oC). Fatigue life relationship result in log strain applied (Ɛ) versus log NF relationship. This result in a relationship for fatigue tests of the form (Monismith et al. 1971):

$$NF = K1\ \varepsilon t^{-K2} \quad \ldots (4)$$

In the case of resilient modulus that is generally defined as the ratio between the maximum stress and the maximum strain. Is calculated by the following equation (BS DD 213)

$$Mr = [L (\nu + 0.27)] / D\ t \qquad \ldots (5)$$

Where L is the peak value of the applied vertical load (N), D is the mean amplitude of the horizontal deformation obtained from 200 applications of the load pulse (assumed to be 0.35 from vertical deflection), t is the mean thickness of the test specimen (mm), and μ is the Poisson's ratio (a value of 0.35 is normally used). The magnitude of the applied force conditioning pulses such that the specified target transient diametral deformation was achieved by 20Psi.

TEST RESULTS

Effect of Hydrated lime on Initial tensile strain-fracture life relationship

The most important variables from the fatigue test are the intercept and the slope of the fatigue curve, K1 and K2 respectively. The fatigue parameters K1 and K2 vary from one model to another, usually, K2 values vary in a range between 3 and 6 while K1 may vary by several magnitudes (Ghuzlan and Carpenter 2003). The fatigue parameters K1 and K2 are shown in Table (8) values of K1 and K2 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 K2 If two materials have the same K1 value, then a large value of K2 indicates a potential for longer fatigue life. On the other hand, a lower K1 value represents a shorter fatigue life when the fatigue curves are parallel, that is, K2is constant. K2 value for mixes partially replaced with hydrated have shown a great increase in their value. Figures (2, 3 and 4) show the effect of hydrated lime content and addition method on fatigue life. Higher K2 values were observed for the lime modified mixes, for dry method K2 value gained an increasing in their value about 10% for D1 mixture, this increasing followed by drastic reduction with increasing in lime content from 2 to 3% for D2 and D3, Since stiffer mixtures are generally more susceptible to cracking such as fatigue damage This view was shared by many researchers including (Mohammad et.al 2000), which indicated that stiffer asphalt mixtures crack more; otherwise, the addition of hydrated lime improves fatigue characteristics and reduces cracking.

It was observed that the better performance observed in the case of hydrated-lime-mixed HMA was interpreted to be an indicator that a mechanism, the physicochemical interaction between the binder and hydrated lime, beyond the volume-filling effect occurred. The opposite trend was observed with wet and slurry hydrated lime addition method as shown in Figure (4) mixture W2 with 2% hydrated lime replace with wet method exhibited gains in K2 value up to 30% , However, for more than 2.0% additional hydrated lime with wet method , no additional improvement in performance was observed. Similarly, from the test result it can be inferred that wet the fatigue life increase as more hydrated lime was increase in the mix in term of K2 value with slurry method.

Hence, S1, S2 and S3 show an improvement gains in their K2 by approximately 7.5%, 20.9% and 29.6% respectively and that was a clear indication of the positive effects of hydrated lime on fatigue damage resistance by its toughening mechanisms related to physicochemical interactions with binder and mineral aggregates. However, the toughening can be impeded by adding a critical amount of hydrated lime which produces mixtures that are prone to cracking due to material brittleness. In the light of finding, hydrated lime could be considered effective filler in increasing the resistance to fatigue cracking at 1.0% content for dry method and 2.0 to 3.0 for wet and slurry methods , these scattered resulted could be possible due to the physical and chemical interaction of hydrated lime with mixture . Also wet and slurry method seems to be more effective in increasing the fatigue strain - fracture than dry method that increase mixture stuffiness makes it prone to cracking.

Effect of lime additive on Average Fatigue Life

Another important factor may be studied in this research that the effect of hydrated lime on increasing the endurance of fatigue repetition to fracture for the specimens. However, as clearly illustrated in Figure (5), the contribution of hydrated lime on fatigue damage resistance depended on the amount of hydrated lime and the method of addition. Figure (5) show the effect of hydrated lime on average fatigue lives for the lime addition method. From figure illustrated it can be inferred that hydrated lime increase the number of repetition to fracture for all method , despite with dry method, thus could be happened due to extra stiffness acquired .

Asphalt modified mixes with wet and slurry show better properties as compared to mixture modified with dry or no lime could be attributed to the best coverage of aggregate surfaces. On the other hand lime slurries show increase in number of repetition to fracture by 36, 52 and 61 % for S1, S2 and S3 respectively while the same increase could be observed with wet method that reach its maximum value to 2.0% and increase by 35, 60 and 48% for W1, W2 and W3 respectively due to the control mix. once can be drawn conclusion that wet hydrated lime method offered and increase in average fatigue life as represented by number of cycles to fracture best values with W2 then slurry with S3 and finally with dry method with D1 indicating that wet method seems to be more effective in increasing the endurance of fatigue life due to the superior coverage and depression of tiny particles. However, it can be seen that fatigue life values for hydrated lime replaced mixture with various application method approximately was found to be sensitive to the addition method to these mixes.

Effect of Hydrated Lime on Stiffness Modulus (Es)

The deflection – based stiffness modulus decreased during the controlled stress flexural fatigue test under the repeated load of PRLS. The initial stiffness modulus at 200^{th} load repetition decreased as stress level increased for all mixes. However, Es stress dependency varied for different treated mixes and method of lime adding. Such behavior, are shown in Figure (6) which shows the initial Es for all lime replacement methods. It is apparent from this Figure that the Es increase as lime percentage increases in the mix and this clearly at 3% replacement. This behavior is much more for dry hydrated lime replacement method than that for wet lime replacement when comparing the effect of two methods.

Hence mixture with D3, W3 and S3 show the higher Es with respect to all other mixes and increased by 39.84%, 30.40%, 10.8% and 10.45% respectively due to control mixture. And this due to increase in air-void content at higher level of lime replacement results in a decrease in laboratory fatigue life. According to these preliminary results, higher loading frequency results in higher material stiffness and, therefore, in higher stress levels and shorter fatigue lives under the stress-controlled test.

Another consideration should be mentioned that hydrated has the ability to increase the demand for asphalt in the mix and that reflect on reducing the thickness of films between aggregate which result in higher stress leading to increasing in stress and shorter fatigue life at higher percentage replacement for all methods and especially when using dry method. For dry method with increasing in lime content from 2 to3 % modules increase by 10.7 and 32.4%for D2 and D3 respectively.

In the case of wet and slurry, both method exhibited a trend of decrease as more lime content increase in the mix as shown from Figure (6) and the lower stiffness value could be observed with W1 and S1.According to these preliminary results, the higher loading frequency results in higher material stiffness and, therefore, in higher stress levels and shorter fatigue lives under the stress-controlled test. Another consideration should mentioned hydrated lime has the ability to increase asphalt in the mix and that reflect on reducing the thickness of films between aggregate which result in higher stress in this leading to increasing in stress and shorter fatigue life at higher percentage replacement for both methods and especially when using dry method.

Hence, the effect of all methods summarize in brief of test result as:

•Comparing the effect of three methods on overall result for fatigue test, it can be notice that wet and slurry method extend the fatigue life more than dry method.

•Stiffness modulus decrease with increase in stress level at constant temperature of 20oC, in this study the result indicated that the average stiffness modulus increase as the amount of lime increase in the mix, the increasing could in stiffness modulus clearly apparent when using dry method replacement.

•At higher lime replacement for both method 2.0 to 3 % the mixture with dry method show lower fatigue resistance while the opposite trend observed with dry and slurry method ,this behavior could be correlate optimum asphalt content and air voids . Since, higher lime content decreases the thickness of the binder film between aggregates, which results in higher stress in the binder film, while higher air void content creates a no homogeneous aggregate asphalt structure, smaller, and did not better-distributed voids, resulting in more stress concentration at large voids according to study carried by (Harvey and Tsai 2007).

•Wet and slurry of hydrated lime replacement seems to be effective in increasing the fatigue life than dry replacement as well as number of fracture to failure. 2.0% to 3.0% seems to be the best amount of lime replacement using both methods. The increasing beyond this value had slight effect in reducing and deteriorating the fatigue resistance as mentioned before.

•In the light of finding, although the increase in stiffness of the lime mixture indicates a better resistance to rutting, a stiffer mixture is also more likely to fail faster in fatigue. Therefore, the additional stiffness of the Lime mixture does not contribute to premature fatigue cracking. This finding is consistent and agreement with previous studies of other researcher that have shown lime to be able to stiffen asphalt mixtures while actually reducing micro-crack growth potential (Lesueur and Little,1999 , Little and Petersen 2005) and increasing micro-crack healing potential (Little and Petersen 2005).

Effect on Resilient Modulus

Results of resilient modulus test at 25°C along with hydrated lime different content and method of adding for the twelve mixtures are Presented in Table 9 and Figure (7) the data presented are the mean value of three tested specimens for each method of hydrated lime. It was observed that the resilient modulus values of paving mixtures increased when lime content increase up to 3.0%.

It was also found that as lime content increase the resilient modulus increase at higher value obtained with dry, wet and slurry all methods show better response than control mix , this easy explained to the mixture become stiffer at lower temperature hence the dry method exhibited superior stiffness than other combinations and among the other methods. All resilient data were imported for further study using performance analysis with Vesys 5W (2003).

Pavement performance predictions through VESYS 5W (2003)

The objective of this section is to present a step-by-step procedure for performance analysis for typical pavement sections by implementing A computer program for analyzing a multi-layer viscoelastic pavement system using (VESYS 5W 2003).the basic parameter inputs for this program were specified as

•Selection of initial thickness: this section specifies the thickness design procedure used in the analysis, AASHTO design method is followed in the design of pavement structure with 5 layers. The geometry of the pavement structure is shown in Figure (8). It is necessary to quantify the material stiffness as defined by the resilient modulus and Poisson's ratio when the pavement structure is treated as multi-layer elastic system. These properties are needed for the calculation of the stresses, strains and deflections response in the pavement system under the application of traffic loading and this Cleary shown in the Figure below.

•Material Properties: to obtain the input parameters required for the VESYS 5W (2003) software, the total permanent strain versus incremental repeated loading is calculated from the repeated load test that performed on asphalt mixture are used as input into the VESYS 5W (2003) software to estimate the rut depth of a selected pavement structure using properties of different asphalt mixtures. Resilient modulus values, Alpha (α) and Mu (μ) parameters for base, sub- base and subgrade courses are taken as a default values (Fujie and Tom 2002). Resilient modulus values of various control and lime modified asphalt mixtures which were obtained by conducting cylindrical specimens for different asphalt mixes at repeated load with 0.1S and 0.9S load and rest period at 50 to 100th, while, flexural beam test result also obtained by taking in consideration the K1 and K2 values form fatigue life relationship for wearing coarse only, hence taking the depth for determination of fatigue cracking index for first layer. Since the laboratory test was placed at constant temperatures of 20 oC with four different stresses at 0.1S and 0.4S for load and rest period. Also, the variability coefficients of the course properties were taken as 0.15, 0.15, 0.15, 0.2 and 0.25 for the surface, binder, base, sub-base and subgrade courses respectively.

•Traffic Loading: Initially an equivalent 80 KN (18 Kip) single axle load (ESAL) with dual tires was adopted. Traffic loading is assumed to be 6,000,000 ESAL at end of pavement service life. The dual tires are spaced 13.57 inch (34.5 cm) apart with tire pressure of 87 psi (552 Kpa) and radius contact area of 4.25 inch (10.8 cm).Tire contact area depends on contact pressure .Thus , the contact pressure was assumed equal to the tire pressure (no effect of tire wall) .

•Environmental Conditions: Environment input data include to selecting temperature intervals into which the yearly pavement temperature history is divided. The vector of mean pavement is assumed at 20oC, which temperatures expected to occur in the middle of the asphalt concrete pavement layer during the winter seasons in Iraq. The design needs to be justified by either change the structural design or mix design and re-analyze the pavement until the VESYS predicts satisfactory performance at the end of design life for 15 years of analysis.

The performance analysis was done and the result fatigue lives were measured in criteria of Fatigue Area (m2/1000m). the result show the superior performance were obtained with W3 and S3 that exhibited fatigue area of less than control mixture by approximately by 65% and 67% , while D1 show decreased in their fatigue area by nearly 25.% as shown in Figures 9 , 10 , 11. Finally, a conclusion can be made When the laboratory fatigue characteristics and resilient modulus of the mixtures were incorporated into the performance analysis, the following observations were obtained: it can be noticed that, Fatigue area for mixtures modified with hydrated lime added is higher than that for control mixtures, this was an expected phenomenon since the addition of hydrated lime resulted in stiffer mixtures.

Beside, slurry method of addition had the highest value as compared to other modified mixtures. It can also be seen that, the fatigue area for mixtures modified with hydrated lime using wet method are lower than that for mixtures modified with hydrated lime using dry method and all the test result come in accordance with performance analysis software.

CONCLUSIONS

On the basis of the analysis of the presented data obtained from controlled –stress fatigue test, in can be observed that,

- •Replacement of hydrated lime with ordinary limestone filler generally improved the fatigue life characteristic that could be regardless the method of lime application. The test results seem to be sensitive to method of adding lime.

- Incorporating hydrated lime in the form of wet and slurry due to dry method provide suitable procedure intended to design pavement that can withstand fatigue distress mode. This is a clear indication of the positive effects of hydrated lime on fatigue damage Resistance by its toughening mechanisms related to physicochemical interactions with Binder and mineral aggregates. However, the toughening can be impeded by adding a critical amount of hydrated lime which produces mixtures that are prone to cracking due to material brittleness.
- Finally the result of performance analysis come in accordance with the laboratory fatigue test and mixture with W3 and S3 show the best performance by extending the fatigue through decreasing the fatigue area.

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Table (1) List of test.

Aggregate	Asphalt	Hydrated lime addition method	Performance Test	
			Flexural Fatigue Beam 25^0C	Resilient Modulus 20^oC
Alnibaie	Aldura 40-50	Dry HL method	18	3
		Wet HL method	18	3
		Slurry HL method	18	3
		Control Mixture	6	3

Table (2) Physical properties of aggregate.

Property	Alnibaie aggregate		
	Coarse Aggregate	Fine Aggregate	SCRB
Bulk Specific gravity (g/cm3) (ASTMC127 and C128)	2.646	2.63	-----
Apparent Specific gravity (g/cm3) (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 Mix Design
Soundness loss by sodium sulfate solution,% (C-88)	3.4		10 Max

Table (3) Aggregate gradation.

		wearing coarse	SCRB- specification limit
sieve size		**selected gradation**	**specification**
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 µm	13	5-21
No.200	0.075µm	7	4-10

Table (4) Asphalt physical properties.

Tests	units	40/50 AC specification	SCRB Specification
Penetration at 25C, 100gm,5 sec (ASTM-D5)	0.1 mm	45	40-50
Softening point R&B (ASTM-D36)	^{o}C	48	-------
Specific gravity at 25 C (ASTM-D70)	----	1.04	----
Flash point (ASTM-D92)	^{o}C	290	Min.232
Ductility (ASTM -D113)	cm	132	Min100
Residue from thin film oven test D-1754			
Retained penetration,% of original D-5	0.1mm	59.5	Min 55
Ductility at 25 C, 5cm/min,(cm) D-113	cm	90	Min 25

Table (5) Chemical properties of mineral filler

Chemical composition	Hydrated lime	Chemical composition	limestone
% Ca(OH)2	92	% CaO	56.1
% Mgo	0.3	% SiO2	01.38
% R2O3	0.6	% Al2O3	0.72
% CaCo3	2.3	% Fe2O3	0.12
% Al2O3+ % Fe2O3	0.5	% MgO	0.13
% SiO2	0.9	% SO3	0.21
%Insoluble in acid	1.0	% L. O. I.	40.65

Table (6) Physical properties of mineral filler.

Material property	Hydrated lime	Limestone dust(filler)
Specific gravity(gm./cm^3)	2.41	2.78
Specific surface (m^2/Kg)	398	244
-100 Mesh (150 μm)	100	100
-200 Mesh (75 μm)	90	85

Table (7) volumetric properties.

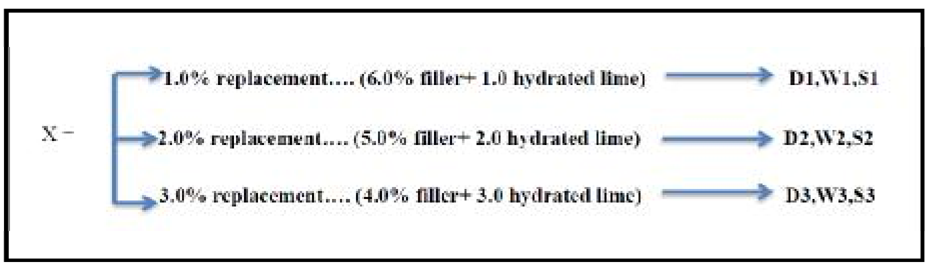
Mixture		Volumetric proprties (Marshall Mix Design method) ASTM- D6927-2010b At their optimum asphalt content			
	Density Gmb, gm/ cm^3	Air Voids % 3-5	VMA% 14 Min	VFA% 65-75%	Asphalt Content%
Control Mix	2.338746	4.018537	14.07	70.47	4.9
D1	2.337177	4.013748	13.938	68.93	4.9
D2	2.328469	4.148308	14.336	68.51	5.2
D3	2.309692	4.098285	14.57	67.06	5.3
W1	2.328884	4.178721	14.069	68.08	4.9
W2	2.317215	4.210588	14.17	65.66	5.0
W3	2.296358	4.326851	14.347	62.37	5.2
S1	2.296359	4.091245	13.42	69.52	5.0
S2	2.275692	4.331009	13.55	67.22	5.1
S3	2.266211	4.443979	14.08	65.31	5.2

Table8 Fatigue life equation

Mixture	Fatigue Equation	Number of repetition to fracture (N_f)			
Control	$N_f = 1.32484E\text{-}07\varepsilon t^{-3.0303}$	11285	7556	2332	1802
D1	$N_f = 2.02224E\text{-}08\varepsilon t^{-3.3670}$	13542	8260	5427	2105
D2	$N_f = 3.08988E\text{-}07\varepsilon t^{-2.8818}$	7692	5254	3472	2101
D3	$N_f = 1.36583E\text{-}06\varepsilon t^{-2.5575}$	5928	3631	1931	1317
W1	$N_f = 2.75581E\text{-}08\varepsilon t^{-3.355}$	14537	10921	6258	3865
W2	$N_f = 3.16575E\text{-}11\varepsilon t^{-4.329}$	22421	15237	11592	8872
W3	$N_f = 1.16382E\text{-}09\varepsilon t^{-3.861}$	18218	13279	8421	5103
S1	$N_f = 3.4642E\text{-}08\varepsilon t^{-3.27869}$	11336	8524	5872	2327
S2	$N_f = 1.1675E\text{-}09\varepsilon t^{-3.83141}$	16213	12406	7781	4270
S3	$N_f = 6.88037E\text{-}11\varepsilon t^{-4.3103}$	22002	14541	9214	6671

Table (9) Resilient modulus value.

Dry			Wet			Slurry		
D1	D2	D3	W1	W2	W3	S1	S2	S3
223220	255959	299952	199968	234109	262591	188752	220489	247864



Flow chart (1) Detail for each mixture.

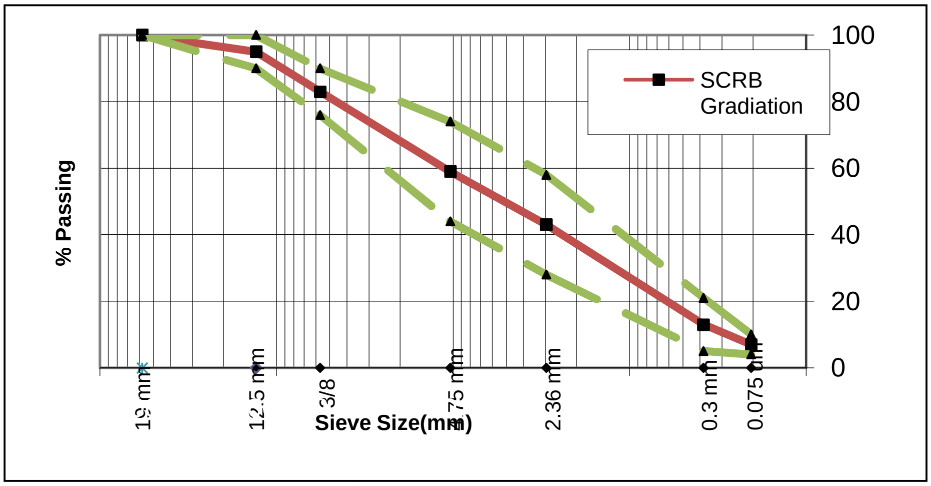


Figure (1) Gradation used in this study (wearing).

Plot (1) Fabricated Mold.

Plot (2) Beam compaction.

Plot (3) Beam setup.

Plot (4) Beam specimen .

Plot (5) Beam failure .

Plot (6) resilient modules specimen.

Plo(7) Resilient modules setup test.

Plot (8) PRLS photograph .

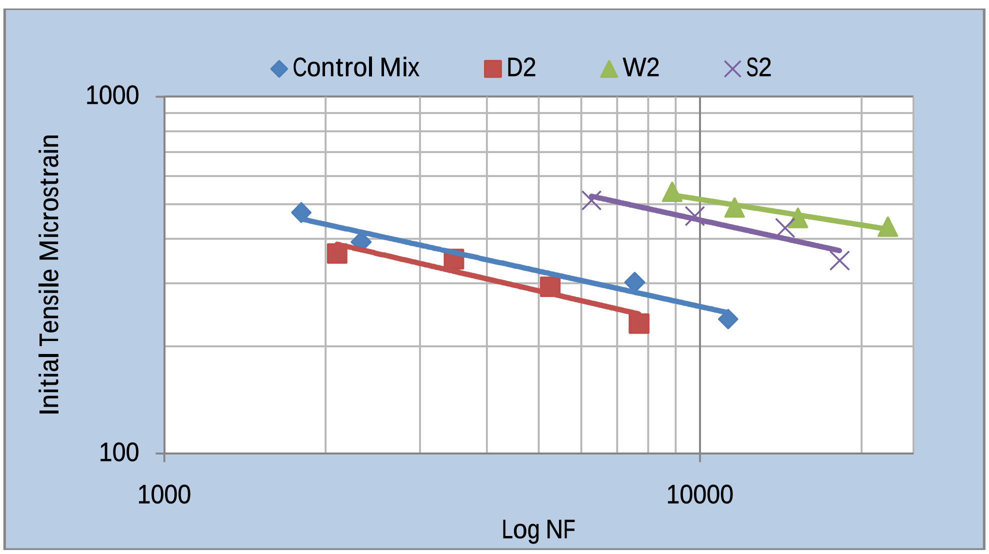


Figure (2) Effect of 1.0% hydrated lime replacement on fatigue life relationship.

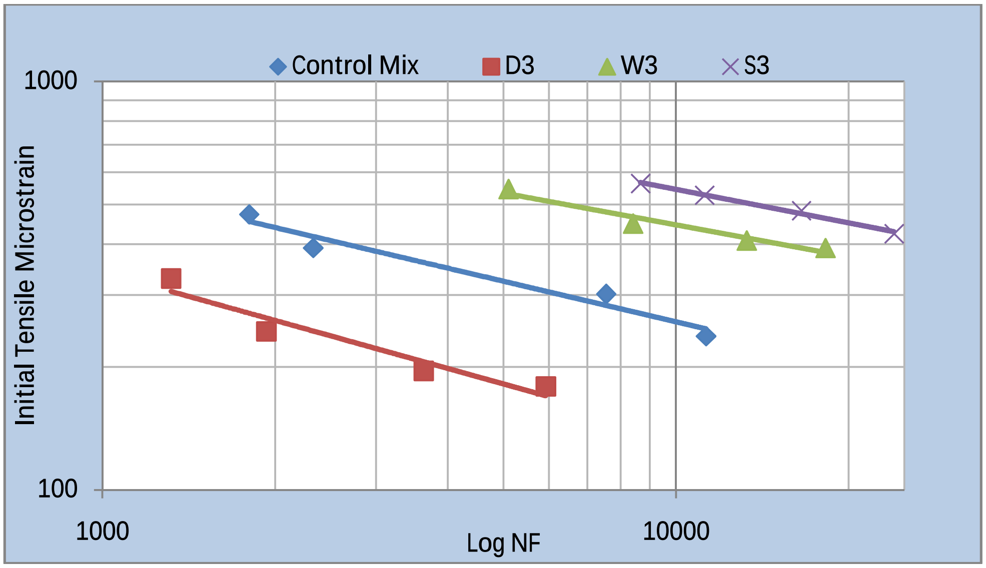


Figure (3) Effect of 2.0% hydrated lime replacement on fatigue life relationship.

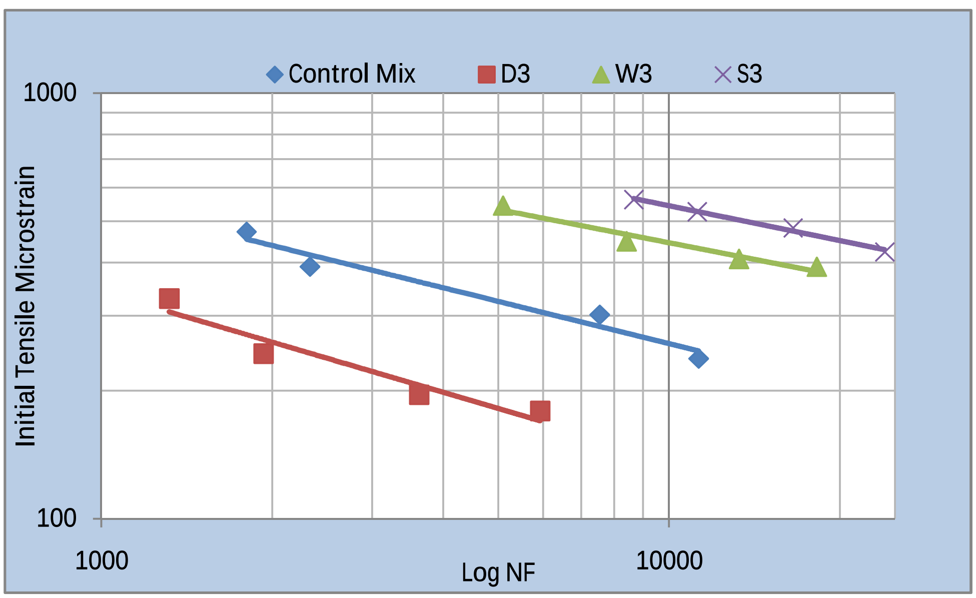


Figure (4) Effect of 3.0% hydrated lime replacement on fatigue life relationship.

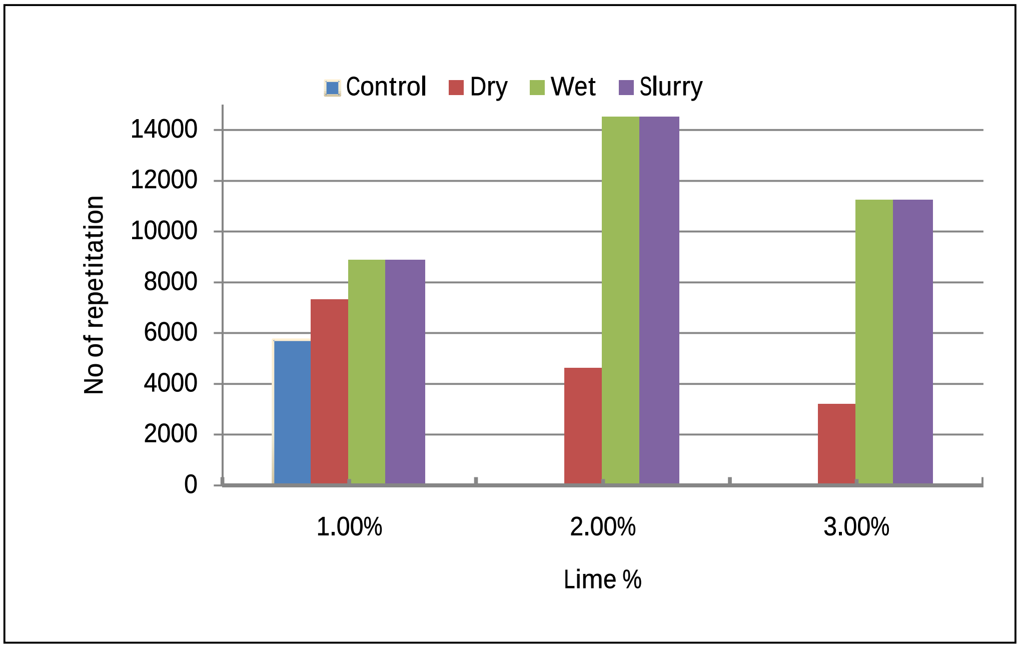


Figure (5) Effect of hydrated lime average fatigue Life.

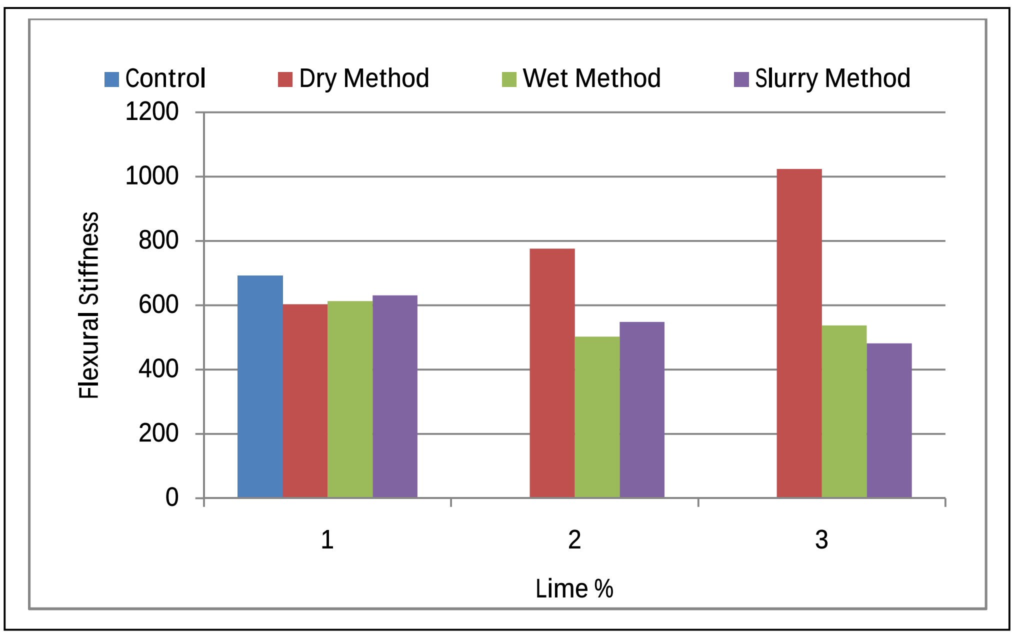


Figure (6) Effect of Hydrated Lime on Stiffness Modulus

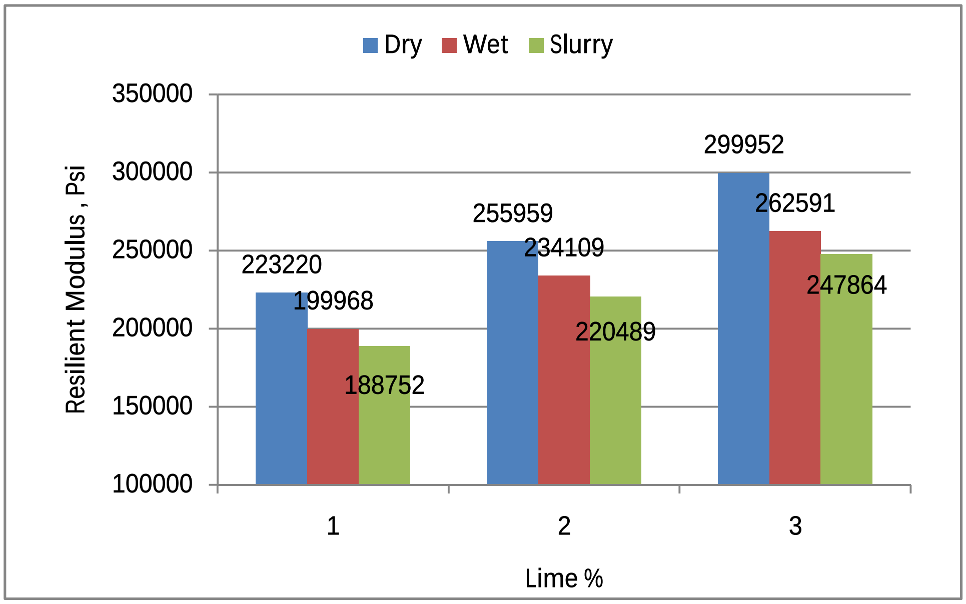


Figure (7) Effect of hydrated lime on resilient modulus.

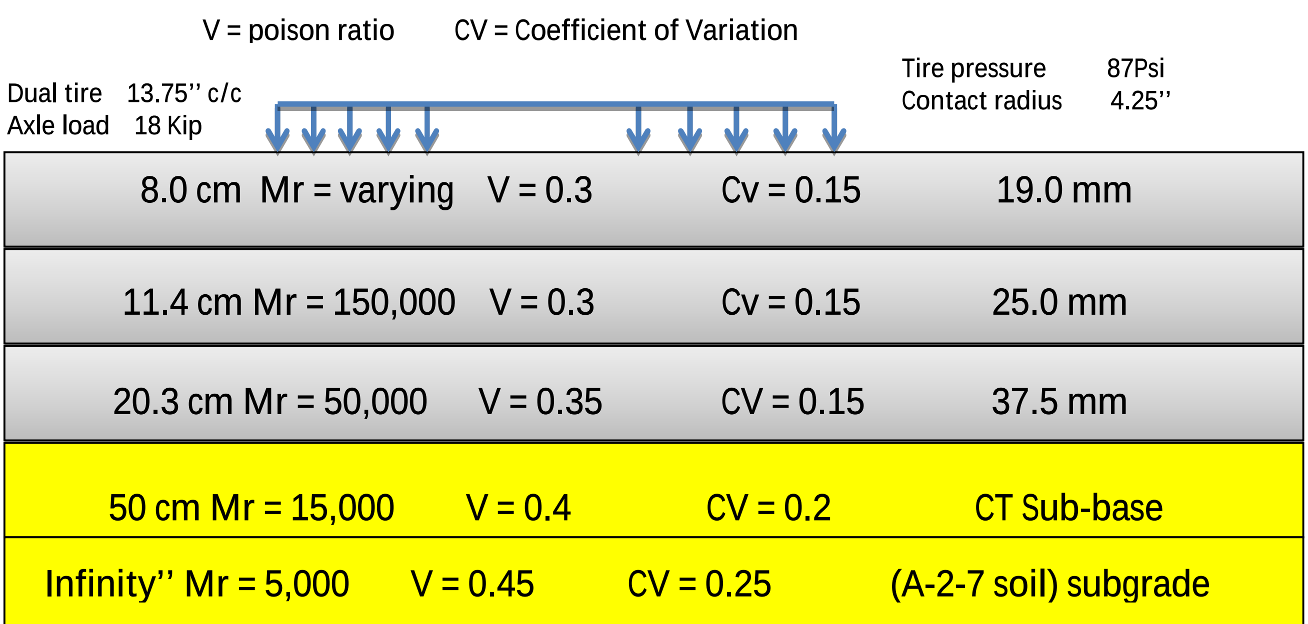


Figure (8) Typical pavement section with selected input

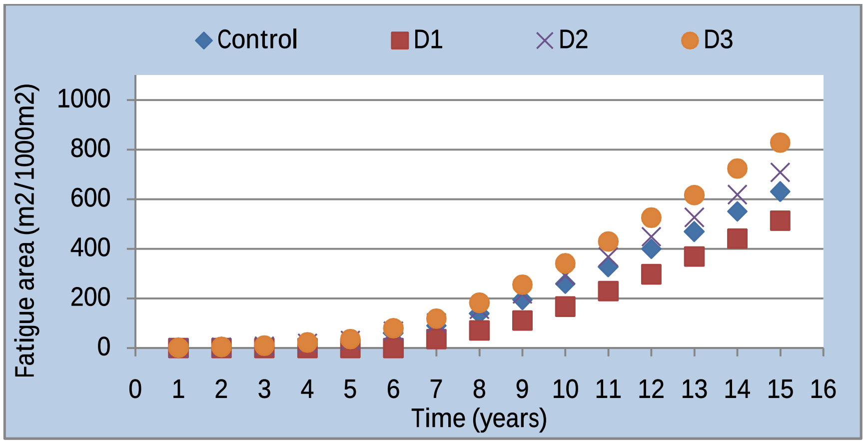


Figure (9) Fatigue area output for hydrated lime Mixes - dry method.

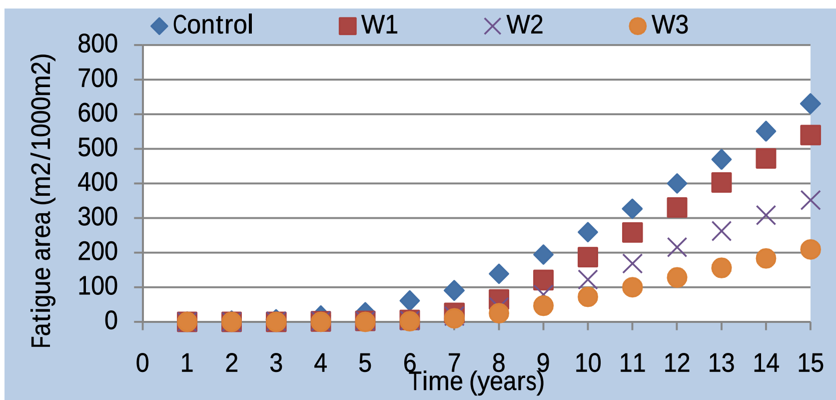


Figure (10) Fatigue area output for hydrated lime Mixes - wet method.

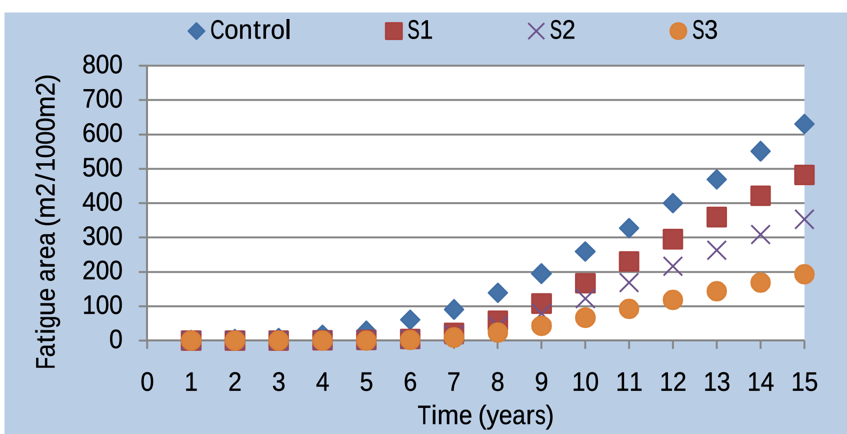


Figure (11) Fatigue area output for hydrated lime Mixes - slurry method.