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Effect of Hydrated Lime on Asphalt Cement and Asphalt Mixtures Properties

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ABSTRACT *In 2014, it was noticed that, asphalt cement obtained from some Egyptian refineries did not meet the specification limits of asphalt cement 60/70 used in Egypt. Using this defective asphalt will produce low stability and high flow asphalt mixtures which leads to the formation of rutting and cracks in the pavement. This study has two objectives. The first objective is to investigate the effect of using hydrated lime on defective asphalt and also on its asphalt mixtures properties. While the second objective is to evaluate the performance of asphalt mix containing hydrated lime. To achieve these study objectives, an experimental program was designed. Selecting and performing qualification tests on aggregates and two specimens of asphalt. Asphalt specimens were defective asphalt and non-defective asphalt. Adding different percentages of hydrated lime to defective asphalt cement and performing some tests to determine the properties of modified asphalt. Then performing Marshall, loss of stability, indirect tensile strength and wheel tracking tests on modified and unmodified asphalt mixtures to evaluate the characteristics and performance of asphalt mix. After analyzing the results, the study reveals that the optimum hydrated lime percent to be used in asphalt mixture is 5 % by weight of asphalt.*

KEY WORDS *Asphalt cement, Viscosity, Penetration, Hydrated lime, Wheel tracking test, Indirect tensile strength, Loss of stability*

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I. Introduction

Cracks and rutting were the most distresses noticed on several highways network. These distresses due to many factors such as heavy traffic load and mixture design. The performance of cracks and rutting has a close relationship with rheological properties of asphalt such as penetration and viscosity [1].

Asphalt cement is a viscoelastic material with rheological and mechanical properties for traditional paving due to its good adhesion properties to aggregates. The chemical composition of the asphalt cement has a great effect on its viscoelastic properties and then on its performance as road paving material [2]. Several additives have been used to improve asphalt cement properties such as polymers, fly ash, hydrated lime….etc. Many studies had been made to investigate the benefits of using hydrated lime in asphalt mixtures. The useful nature of hydrated lime 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. Also, hydrated lime is considered as an agent to reduce stripping [3]. Hydrated lime has a wide range of particle size distribution and proportion. Its large particles can act as a filler to enhance the stiffness of the asphaltic mixture, while the small particles can increase the asphalt cement viscosity to improve its cohesion [4]. Al- Tameemi et al showed that hydrated lime can improve asphalt mix to resist permanent deformation, cracks, and moisture damage [5]. Satyakumar et al concluded that adding 1.5 % of hydrated lime by the total weight of specimens increases the stiffness modulus of asphalt mix up to 55 %. This might be due to that the hydrated lime stiffens the asphalt film coating on the aggregates surface and enhances the bonding between aggregates and asphalt [6]. Al- Suhaibani et al found that the hydrated lime improves the resistance of asphalt mix to permanent deformation [7]. Albayati et al have found that asphalt concrete with added hydrated lime showed a reduction of hardening age, and increasing of flexural stiffness and resilient modulus at moderate and high temperatures. These studies also found that the modified asphalt concrete have improved durability, including the ability to resist permanent deformation, fatigue failure, thermal cracking, as well as moisture increase [8,9]. Using hydrated lime to improve asphalt mix characteristics for practical pavement applications, more information and experimental data are still needed for the sake of the development of design standards. Therefore, there is a bad need for sufficient studies on the combined effects of asphalt mix with different percentages of hydrated lime contents for different applications.

II. Problem Statement

At the beginning of the year 2014, Egyptian government started the national roads project which aimed to construct a new road network with 6000 km. A serious problem was discovered in the properties of asphalt mixtures used in a large number of new constructed highways. Stability values of used asphalt mixtures were less than the specifications limits while air voids and flow values were more than the specifications limits. To explore the possible reasons of this problem, qualification tests were performed on asphalt mixtures components such as asphalt cement, aggregates, and mineral filler. The results of qualification tests showed that the properties of used asphalt cement was the main reason of the asphalt mixture problem because these properties were out of the specification limits of asphalt cement 60/70 used in Egypt. Penetration value of used asphalt cement was higher than the specification limits while viscosity and asphaltene values were lower than the specification limits. This defective asphalt was obtained from some Egyptian refineries. So, using this defective asphalt cement may produce problems in the properties of resulting asphalt mixture and causing rutting and cracks in the pavement. This problem needs to be investigated to obtain possible solutions to avoid the formation of future pavement distresses such as rutting and cracks. Hydrated lime can be used to improve the characteristics of defective asphalt.

III. Study Objectives

The main objectives of this study are:

- To investigate the effect of using hydrated lime on defective asphalt cement and also on its asphalt mix properties.
- To evaluate the performance of asphalt mixes containing the hydrated lime and determine the optimum percentage of used hydrated lime.

IV. Materials and Experimental Testing Program

To achieve the objectives of this study, an experimental program was designed. Fig. (1) shows the steps of this experimental program. The first step is collecting the study materials. These materials are aggregates, asphalt, and hydrated lime. Aggregates consists of coarse aggregates, fine aggregates, and mineral filler. Coarse aggregates was crushed dolomite stone and crushed lime stone obtained from Attaka quarry. The fine aggregates was siliceous and natural sand obtained from Attaka quarry. The mineral filler was cement dust. Two specimen of asphalt was used in this study. The first specimen was defective asphalt cement which did not meet the specification limits of asphalt cement 60/70 which used in Egypt. This defective asphalt was obtained from Alexandria refinery. The second specimen was non-defective asphalt cement which met the specification limits of asphalt cement 60/70 which used in Egypt. Its penetration grade is (60/70) and 1.02 specific gravity. The non-defective asphalt was obtained from Suiz refinery. The non-defective asphalt was used in this study as a guiding level for evaluating the defective asphalt cement properties before and after treatment. After that, qualification tests were conducted on the selected materials. Six percentages of hydrated lime (HL) were added to defective (Alex.) asphalt specimen. These added percentages of hydrated lime are 0%, 5%, 10%, 15%, 20%, and 25%. Then viscosity, penetration, and softening point tests were conducted on all modified asphalt specimens. Asphalt mixes containing different percentages of hydrated lime was prepared. Marshal test were conducted on these asphalt mixes to obtain the optimum asphalt content and other asphalt mix properties. These properties are stability, unit weight, air voids, voids in mineral aggregate and mix flow. As shown in fig. (1), the next step is conducting some special tests on the asphalt mix to evaluate the mix behavior under different loading conditions. These tests include three important tests. The first is the indirect tensile test (ITT) to be used as an indicator of asphalt pavement ability to resist cracking. While the second is the loss of stability test to be used as a measure of the asphalt pavement ability to resist water immersion. The third is the wheel tracking test to be used as an indicator of asphalt pavement ability to resist rutting.

The mix gradation (4-C), as specified by the general specifications for Egypt, was selected to be used in this study. The selected mix gradation is shown in table (1).

4.1 Laboratory tests

Three types of laboratory tests were applied. The first type is the qualification tests. It is conducted to identify the different properties of materials used in this study. While the second type is the tests performed on the modified and unmodified asphalt. The third type of laboratory tests is the main tests used to measure the intended properties of the investigated mixtures such as Marshal test, indirect tensile test, loss of stability test, and wheel tracking test.

4.1.1 Qualification tests

The qualification tests performed on aggregates are Los angles test, Water absorption test, fragment, specific gravity test, plastic limit test, liquid limit test, and aggregate gradation test. Tables (1,2,3) show the results of qualification tests on aggregates. These tables show that the properties of aggregates are within the specification limits. Table (4) shows the physical properties of hydrated lime.

The qualification tests performed on asphalt cement were physical properties and chemical composition tests. The physical properties tests include penetration test, softening point test, and kinematic viscosity test. The chemical composition tests include asphaltene and maltene test and HCSNO TEST [10, 11]. The different physical properties and chemical composition of defective (Alex.) and non-defective (Suiz) asphalt cement are shown in table (5). This table shows that the physical and chemical properties of non-defective (Suiz) asphalt are within the specification limits. But some results of the defective (Alex.) asphalt are out of specification limits such as penetration, kinematic viscosity, asphaltene %, maltene %, and oxygen %.

4.1.2 Preparation of modified asphalt sample

Modified hydrated lime asphalt was prepared using wet process technique. The asphalt cement was heated in oven till fluid condition. The hydrated lime percentage (as a percent of asphalt binder weight) was slowly added and temperature was kept between 150 C and 160 C. then mixing by high shear mixer to produce homogenous blend [12].

4.1.3 Laboratory tests on modified asphalt specimens

After adding five percentages of hydrated lime to defective (Alex.) asphalt, some tests were performed on the modified asphalt to measure different properties of modified asphalt. These tests are penetration test at 25 C, Viscosity test at 135 C, and softening point test. Penetration test was performed according to AASHTO Designation T-49. Kinematic viscosity test was performed according to AASHTO Designation T-201. softening point test was performed according to AASHTO Designation T-53.

4.1.4 Laboratory tests on asphalt mixes specimens

Laboratory tests performed on the two asphalt mixes samples are Marshall test, loss of stability test, indirect tensile test, and wheel tracking test.

4.1.4.1 Marshall test

Marshall test was conducted on the used asphalt mix to obtain the optimum asphalt content and the properties of asphalt mix such as stability, flow, air voids, voids in mineral aggregates, and density. The test was performed with 75 blows Marshall compaction according to AASHTO T-245.

4.1.4.2 Loss of stability test

This test was performed to measure mix durability by evaluating the resistance of the asphalt mix to moisture damage. Test was performed according AASHTO T-165. In this test, asphalt mix specimens are placed in water bath with a temperature 60 C and tested in several times (0.5, 24 hours) to measure the loss in mix stability of asphalt mixes containing defective (Alex.) asphalt, non-defective (Suiz) asphalt and modified asphalt.

4.1.4.3 Indirect tensile strength test

This test was used to evaluate the tensile strength of asphalt mix. After determination of optimum asphalt content, the asphalt mix was prepared for indirect tensile strength (ITS) test according to manual of testing procedures, 1968 (Texas highway department). The following equation can be used to calculate the value of indirect tensile strength of the specimen [13]: $\mathbf{St = (2000P) / (\pi\, t\, D)}$

Where:

St = IDT strength, kPa

P = maximum load, N

t = specimen height immediately before test, mm

D = specimen diameter, mm

4.1.4.4 Wheel tracking test

Wheel tracking test (WTT) was used to measure the rut depth of the asphalt mix. Test was performed according to AASHTO T-324. In this test, a loaded wheel is run over an asphalt mix sample (33.5 cm * 44.5 cm * 5 cm) at 60 C. The device applies a (53.5 kg) vertical force through 335 mm wide steel wheel with 5 cm thick rubber contact surface. Rut depth, temperature, and elapsed time during the test were recorded to plot rut depth versus time via displacement instrumentation on each loaded wheel. The rate of loading is 23 cycles per minute, which corresponding to 46 wheel passes per minute. The total test time was 60 minutes. Since the height of test specimens is expected to vary by 5 cm.

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V. Results and Analysis

The effect of adding hydrated lime on the properties of defective (Alex.) asphalt cement and its asphalt mix is discussed in this part.

5.1 Effect of hydrated lime on asphalt cement properties

Table (6) shows the results of tests conducting on non-defective (Suiz), defective (Alex.), and modified asphalt. These tests are penetration, kinematic viscosity, and softening point tests. .

5.1.1 Effect of hydrated lime on the penetration test values of asphalt cement

Fig. (2) shows the effect of adding different percentages of hydrated lime to defective (Alex.) asphalt cement on the penetration test values. From this figure, it is noticed that, increasing the added percentage of hydrated lime decreases the penetration test values (inverse relationship). The value of penetration test of defective (Alex.) and non-defective (Suiz) asphalt cement is 74 and 67 respectively. The specification limits range is from 60 to 70. So, penetration value of defective (Alex.) asphalt is out of the specification limits. Also, value of penetration test of modified asphalt, at each percent of added hydrated lime, is less than the value of penetration test of unmodified asphalt. Penetration value at 25 % of added hydrated lime is out of the specification limits because it is equal to 57. The rate of decreasing of penetration values is high for the range from zero to 5 % added of hydrated lime while the rate of decreasing of penetration values is small for the range from 5% to 25% added of hydrated lime. The reason for this may be due to hydrated lime has higher dry porosity which generates a higher stiffening effect. This stiffening effect is coming from an expected adsorbed layer of bitumen components onto the particles of hydrated lime. At high temperature, bitumen fills the internal porosity of the hydrated lime particles. These filled particles are seen as hard spheres in the bitumen matrix and increasing the volume fraction. The pertinent volume fraction controlling the stiffening is consequently that of the bitumen-filled hydrated lime particles.

5.1.2 Effect of hydrated lime on the kinematic viscosity test values of asphalt cement

The effect of adding different percentages of hydrated lime to defective (Alex.) asphalt cement on viscosity test values is shown in fig. (3). From this figure, it is noticed that, increasing the added percentage of hydrated lime increases the kinematic viscosity test values (direct relationship). The value of kinematic viscosity test of defective (Alex.) and non-defective (Suiz) asphalt cement is 340 and 375 centistoke respectively. Also, value of kinematic viscosity test of modified asphalt, at each percent of added hydrated lime, is more than the value of kinematic viscosity test of unmodified asphalt. All values of kinematic viscosity test of modified and unmodified asphalt are within the specification limits (not less than 320 centistoke). The rate of increasing of kinematic viscosity values is high for the range from zero to 5 % added of hydrated lime while the rate of increasing of kinematic viscosity values is small for the range from 5% to 25% added of hydrated lime. The reason for this may be due to hydrated lime reacts with the acids and anhydrides, absorbs the oils, resins and other components which are typically concentrated in the asphaltenes. This absorption eliminates the bad side effects of defective (Alex.) asphalt and enhances the viscosity of defective asphalt.

5.1.3 Effect of hydrated lime on the softening point test values of asphalt cement

Fig. (4) shows the effect of adding different percentages of hydrated lime to defective (Alex.) asphalt cement on softening point test values. From this figure, it is noticed that, the value of softening point test of pure defective (Alex.) and non-defective (Suiz) asphalt cement is 48 and 53 respectively. Also, increasing the added percentage of hydrated lime increases the softening point test values (direct relationship). At each percent of added hydrated lime, the value of softening point test is greater than the value of softening point test of unmodified asphalt. Also, the rate of increasing of softening point test values is nearly constant of modified asphalt. This increase in the value of softening point means that the modified asphalt cement with hydrated lime will have good adhesive properties and then good performance in service.

5.2 Effect of hydrated lime on Marshall test results

After adding different percentages of hydrated lime (5 %, 10 %, 15 %, 20 %,and 25 % by weight of asphalt) to defective (Alex.) asphalt cement, asphalt mixtures specimens with different asphalt content (4.5 %, 5 %, 5.5 %, 6 %, and 6.5 %) were prepared to perform Marshall test. Table (7) shows the summary of results of performing of Marshall test on these prepared asphalt mixtures at optimum asphalt content. The results and analysis of Marshall test parameters are discussed in the following part. These parameters include stability, flow, density, air voids %, and voids in mineral aggregates. Also, rigidity is discussed in this part.

5.2.1 Analysis of optimum asphalt content and mix stability results

Fig. (5) shows the effect of using different percentages of hydrated lime on the stability values of asphalt mixtures at different percentages of asphalt content. The value of stability of asphalt mixtures at optimum asphalt content for each percent of added hydrated lime is shown in fig. (6). Fig. (7) shows the values of optimum asphalt content of asphalt mixtures at each percent of added hydrated lime. From these figures, it can be seen that the value of the maximum stability of defective (Alex.) asphalt mix is 1060 kg. at 5.58 % optimum asphalt content while the value of the maximum stability of non-defective (Suiz) asphalt mix is 1530 kg. at 5.33 % optimum asphalt content. At optimum asphalt content, the values of stability of modified asphalt are within the specification limits. But the value of the stability, at the optimum asphalt content, of defective (Alex.) asphalt is out of the specification limits. A specification limit of the stability value is not less than 1200 kg. So, the percent of increasing in the stability value, at optimum asphalt content, are 41.5%, 36.79%, 31.13%, 35.85%, and 32.08% with respect to the maximum stability of defective (Alex.) asphalt mix, for 5%, 10%, 15%, 20%, and 25% of added hydrated lime respectively. So, the maximum percent of increasing of stability occurs at 5 % added hydrated lime then the percent of increasing of the stability value decreases with the increasing of adding percentage of hydrated lime. Also, the value of maximum stability of modified asphalt, at each percent of added hydrated lime, is greater than the maximum stability value of defective (Alex.) asphalt. The reason for this may be due to the increase in the viscosity of the modified asphalt mixtures which leads to the formation of more thick mixture film of asphalt. Also, it is noticed that, as the percent of added hydrated lime increases the stability values decreases (inverse relationship). The reason for this may be due to when the percent of hydrated lime increases the air voids increase, this leads to the decrease of the stability value. Also, it is noticed that as the percent of added hydrated lime increases the value of optimum asphalt content increases. The reason for this may be due to the relatively high specific surface area of hydrated lime particles which attract more particles of asphalt cement to achieve a more thorough hydration process.

5.2.2 Analysis of mix flow results

The effect of using different percentages of hydrated lime on the flow values of asphalt mixtures at different percentages of asphalt content is shown in fig. (8). Fig. (9) shows the value of flow of asphalt mixtures, at optimum asphalt content for each percent of added hydrated lime. From these figures, it can be noticed that, at optimum asphalt content for each percent of added hydrated lime, the flow value increases with the increasing of added percentage of hydrated lime (direct relationship). The reason for this may be due to the decrease of stability with the increasing of the added percent of hydrated lime. Flow value of modified asphalt mixes at 5 % of added hydrated lime is within the specification limits. While the flow values of modified asphalt mixes at %10, 15 %, 20 %, and 25 % of added hydrated lime are higher than the specification limits. The specification limits of flow are from 2 to 4 mm. At optimum asphalt content, the value of flow of defective (Alex.) and non-defective (Suiz) asphalt mix is 3.7 and 3.5 mm. respectively. Also, values of flow of modified asphalt mixes are higher than the value of defective (Alex.) asphalt mix. The reason for this may be due to hydrated lime affects the internal friction of asphalt mixture in negative manner.

5.2.3 Analysis of mix density results

Fig. (10) shows the effect of using different percentages of hydrated lime on the density values of asphalt mixtures at different percentages of asphalt content. Fig. (11) shows the value of density of asphalt mixtures, at optimum asphalt content for each percent of added hydrated lime. From these figures, it can be seen that, at a specific percent of asphalt content, the value of density decreases with the increasing of the percent of added hydrated lime. Also, at the optimum asphalt content as the percent of added hydrated lime increases the value of density of modified asphalt mix decreases (inverse relationship). At optimum asphalt content, the value of density of defective (Alex.) and non-defective (Suiz) asphalt mix is 2.355 and 2.405 gm./cm^3 respectively. Also, at the optimum asphalt content for each percent of added hydrated lime of modified asphalt mixes, the density value is less than the density value of unmodified and non-defective (Suiz) asphalt mixes. The reason for this may be due to two reasons. The first reason is the low density and high porosity of hydrated lime. The second reason is related to the increasing of air voids. In general, the addition of hydrated lime tends to increase the viscosity and makes the asphalt mixture too stiff. Therefore, the degree of compaction may decrease with the increasing of hydrated lime content.

5.2.4 Analysis of air voids results

The effect of using different percentages of hydrated lime on the air voids % values of asphalt mixtures at different percentages of asphalt content is shown in fig. (12). Fig. (13) shows the value of air voids % of asphalt mixtures, at optimum asphalt content for each percent of added hydrated lime. From these figures, it can be noticed that, at a specific percent of asphalt content, the value of air voids % increases with the increasing of the percent of added hydrated lime. Also, at optimum asphalt content, the air voids % value increases with the increasing of added percentage of hydrated lime (direct relationship). At optimum asphalt content, value of air voids % for defective (Alex.) and non-defective (Suiz) asphalt mix is 4.4 % and 3.3% respectively. Also, at optimum asphalt content, air voids value % of unmodified asphalt mix is greater than the values of air voids % of modified asphalt mixes at 5 % and 10 % added of hydrated lime and vice versa for the rest percentages of the added hydrated lime. The reason for this may be due to the high dry porosity of hydrated lime. The specification limits of air voids are from 3 % to 5 %. So, at optimum asphalt content for 5 %, 10 %, and 15 % added of hydrated lime, the values of air voids are within the specification limits and vice versa for the rest percentages of the added hydrated lime. Also, the values of air voids of defective (Alex.) and non-defective (Suiz) asphalt mix are within the specification limits.

5.2.5 Analysis of voids in mineral aggregates results

Fig. (14) shows the effect of using different percentages of hydrated lime on the voids in mineral aggregates percentage (VMA %) values of asphalt mixtures at different percentages of asphalt content. Fig. (15) shows the value of VMA % of asphalt mixtures, at optimum asphalt content for each percent of added hydrated lime. From these figures, it can be seen that, at a specific percent of asphalt content, the value VMA% increases with the increasing percentages of added hydrated lime. Also, at optimum asphalt content the VMA% value increases with the increasing of added percentage of hydrated lime (direct relationship). At optimum asphalt content, the value of VMA % of defective (Alex.) and non-defective (Suiz) asphalt mix is 16.6% and 15.1% respectively. In general, at optimum asphalt content for each percent of added hydrated lime, the value of VMA % of modified asphalt is greater than the value of VMA % of unmodified asphalt. The reason for this may be due to the high dry porosity of hydrated lime and this is expected as the mixtures with the hydrated lime has higher voids in the total asphalt mixture. Also, the value of VMA % of modified and unmodified asphalt mixes are within the specification limits (≥ 15 %).

5.3 Analysis of loss of stability test results

The loss of stability test was performed on asphalt mixture samples prepared at optimum asphalt content obtained from Marshall test. Loss of stability test is considered an important measure of mix durability by evaluating the resistance of the investigated asphalt mixes to moisture damage. Fig. (16) and table (8) show the effect of using different percentages of hydrated lime on the loss of stability values of asphalt mixtures at optimum asphalt content. From the figure and table, it can be seen that, the loss of stability percentage value decreases with the increasing of the percent of added hydrated lime (inverse relationship). At optimum asphalt content, the value of loss of stability % of defective (Alex.) and non-defective (Suiz) asphalt mix is 22% and 12.4% respectively. It is clear that all % values of the loss of stability of modified and unmodified asphalt are within the specification limits (loss of stability ≤ 25 %). Also, the % value of loss of stability of modified and non-defective (Suiz) asphalt mixtures is less than the value of loss of stability of defective (Alex.) asphalt mixture. The difference of loss of stability values of defective (Alex.) asphalt mix and modified asphalt mix at 5 % added percentage of hydrated lime is 4.6 % which equal to 20.9 % of its original value (defective (Alex.) asphalt). The difference between loss of stability value of defective (Alex.) asphalt and loss of stability of 10 %, 15 %, 20 %, and 25 % added hydrated lime are 5.5 %, 6.8 %, 8.8 %, and 8.2 % respectively. The percent of improvement of loss of stability are 25 %, 30.9 %, 40 %, and 37.27 % for 10 %, 15 %, 20 %, and 25 % added hydrated lime respectively. In general, the rate of percent of improvement of loss of stability value is high between defective (Alex.) asphalt and 5 % added hydrated lime. After that the rate of percent of improvement of loss of stability between 5 % and the subsequent percentages values of added hydrated lime is small. Therefore, it is recommended that the optimum percent of hydrated lime to be used in asphalt mixes is 5 % by weight of asphalt.

5.4 Analysis of indirect tensile test results

Indirect tensile strength test (ITS) was performed on asphalt mix samples prepared at the optimum asphalt content obtained from Marshall test. ITS test is considered an important measure for the ability of the asphalt mix to resist cracking. In this study, the ITS test was performed on asphalt mixes containing 0 %, 5 %, 10 %, and 15 % added percentages of hydrated lime. The results of ITS test are shown in fig. (17) and table (9). From the figure and the table, it is clear that, as the percentage of added hydrated lime increases the value of ITS increases (direct relationship). The value of ITS of defective (Alex.) asphalt mix, at optimum asphalt content, is 1122 kpa. Also, at each percent of added hydrated lime, the values of ITS of modified asphalt mixes is greater than the value of ITS of unmodified asphalt. The percent of improvement in ITS values between defective (Alex.) asphalt and 5 % added percent of hydrated lime 2.67 % with respect to the ITS value of defective (Alex.) asphalt. While, the percent improvement in ITS values between defective (Alex.) asphalt and 10 %, 15 % added percent of hydrated lime are 3.03 %, and 3.29 % respectively. So, the rate of improvement in ITS values is high for the range from zero to 5 % added percentages of hydrated lime, after that, for the range from 5% to 15 % of added hydrated lime, the rate of improvement in ITS values becomes small. The reason for this may be due to that, at high percentages of added hydrated lime asphalt mixes become too stiff, making these asphalt mixes prone to cracking. Therefore, it is recommended that the optimum percent of hydrated lime to be used in asphalt mixes is 5 % by weight of asphalt.

5.5 Analysis of wheel tracking test results

Wheel tracking test (WTT) was performed on asphalt mix samples prepared at the optimum asphalt content obtained from Marshall test. WTT test is considered an important measure for the ability of the asphalt mix to resist rutting. In this study, the WTT test was performed on asphalt mixes containing 0 %, 5 %, 10 %, and 15 % added percentages of hydrated lime. The results of WTT test are shown in fig. (18, 19) and table (10). From these figures and table, it is clear that, for each percentage of added hydrated lime, rut depth increases with the increasing of time (direct relationship). The rut depth values, at the end of the test, of modified asphalt mixes are 2.032, 2.88, and 5.9 mm. for 5 %, 10 %, and 15 % of added hydrated lime respectively. The value of rut depth, at the end of the test, of defective (Alex.) and non-defective (Suiz) asphalt mix, at optimum asphalt content, is 8.3and 5.1 mm. respectively. Also, at a specific time, the value of rut depth increases with the increasing of the added percentages of hydrated lime. So, the least values of rut depth occur at 5 % added of hydrated lime, then at 10 % and 15 % added of hydrated lime, respectively. In general, the values of rut depth of modified asphalt are less than the values of rut depth of unmodified asphalt, at any specific time of test. The reason for this might be due to the increasing of added percentage of hydrated lime increasing air voids which caused increasing in rut depth. Also, for modified and unmodified asphalt, the rate of increasing of rut depth is high through the first ten minutes, then this increasing rate becomes small through the rest time of the test. Therefore, it is recommended that the optimum percent of hydrated lime to be used in asphalt mixes is 5 % by weight of asphalt.

VI. Conclusions

Based on the analysis and discussion of this study results, the following conclusions may be obtained:
1 – Increasing the percent of added hydrated lime increases the values of kinematic viscosity, softening point, flow, optimum asphalt content, air voids, VMA, ITS and rut depth (direct relationship) and also decreases the values of penetration, stability, density, and loss of stability (inverse relationship).
2 - For modified asphalt, the values of kinematic viscosity, softening point, stability, optimum asphalt content, flow, VMA, and ITS are greater than those values of unmodified asphalt. Also, for modified asphalt, the values of penetration, density, loss of stability, and rut depth are smaller than those values of unmodified asphalt. Values of air voids % at 5 and 10% added of hydrated lime are less than those values of unmodified asphalt and vice versa for the rest percentages of added hydrated lime.
3 - In general, the rate of percent of improvement of all studied parameters values between zero and 5 % added hydrated lime is high. After that the rate of percent of improvement of all studied parameters values between 5 % and the subsequent percentages values of added hydrated lime is small.
4 – Only 5 % added of hydrated lime, to asphalt cement and asphalt mix, satisfies the requirements of specification limits for all parameters of asphalt cement and asphalt mix such as penetration, kinematic viscosity, softening point, stability, flow, air voids %, VMA %, and loss of stability. So, the optimum hydrated lime percent to be added to asphalt mix and used in pavement is 5 % by weight of asphalt.

VII. Recommendations

In view of the previous conclusions the following recommendations can be considered:
1 – The optimum hydrated lime percent to be added to asphalt mix and used in pavement is 5 % by weight of asphalt.
2 – Conducting of field testing of asphalt mix containing 5 % added hydrated lime is highly recommended in the future to reflect the actual performance under different traffic loads and environmental conditions experience.
3 – Conducting an economic analysis study for using 5 % added hydrated lime in asphalt mix.
4 – Conducting a large scale study is recommended taking into considerations several factors to investigate the behavior of the asphalt mix containing 5 % added hydrated lime. These factors include using several types of aggregates such as lime stone and basalt with different gradations.
5 – Conducting a future study of using hydrated lime in which determination of chemical properties of defective asphalt should be made before and after adding different percentages of hydrated lime.

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Table (1): Aggregate gradation

Type / Sieve size	Coarse aggregate (pin 2)	Coarse aggregate (pin 1)	Natural sand	Siliceous sand	Mineral filler	Design gradation mix	Specification limits
	% Passing						
1	100	100	100	100	100	100	100
3/4	67	100	100	100	100	93.4	80 - 100
1/2	10	97	100	100	100	80.8	-------------
3/8	4	72	100	100	100	69.9	60 – 80
No. 4	1	20	97	100	100	48.5	48 – 65
No. 8	0	11.8	93	82	100	40.7	35 – 50
No. 16	0	9.3	82	58	100	33	--------------
No. 30	0	7.7	57	43	100	24.9	19 – 30
No. 50	0	6.1	17	43	100	14.6	13 – 23
No. 100	0	3.5	4.2	24.6	98	10	7 – 15
No. 200	0	2.2	3	18	91	7.7	3 - 8

Table (2): Properties of coarse aggregate

Test No.	Test	Type of Aggregate	AASHTO Designation No.	Results	Specifications Limit
1	Abrasion value after 100 revolution	Pin 2	AASHTO T 96-02	5%	$\leq$ 10 %
		Pin1		5%	
2	Abrasion value after 500 revolution after washing	Pin 2		23%	$\leq$ 40 %
		Pin1		23%	
3	Water absorption values	Pin 2	AASHTO T (85-10)	2%	$\leq$ 5 %
		Pin1		2.80%	
4	Fragmentation	Pin 2	AASHTO T (112-00)	0.20%	————
		Pin1		0.40%	——
5	Specific gravity Bulk	Pin 2	AASHTO T (85-10)	2.602	
	Saturated			2.654	
	Apparent			2.745	
	Bulk	Pin 1		2.583	
	Saturated			2.656	
	Apparent			2.785	
6	plastic limit & liquid limit	Pin2&Pin 1	AASHTO T (90-00)& (89-10)	No-plasticity	

Table (3): Properties of fine aggregate

Test No.	Test	Type of Aggregate	AASHTO Designation No.	Results	Specifications Limit
1	Water absorption values	siliceous sand	AASHTO T (85-10)	2.80%	$\leq$ 5 %
2	Specific gravity	siliceous sand			
	Bulk			2.602	
	Saturated			2.675	
	Apparent			2.807	

Table (4): Physical properties of hydrated Lime

Specific gravity(gm./cm3)	2.43
No 100	100
No 200	99

Table (5): Physical properties and chemical composition of defective (Alex.) and non-defective (Suiz) asphalt cement specimens

Test No.	Test		AASHTO designation No.	Non-defective (Suiz) asphalt	Defective (Alex.) asphalt	Specification limits
1	Penetration 0.1 mm.		AASHTO T 49	67	74	60 – 70
2	Kinematic viscosity		AASHTO T 201	375	300	≥ 320
3	Softening point		AASHTO T 53	53	48	45 – 55
4	Flash point		AASHTO T 48	275	265	≥ 250
5	Asphaltene and maltene test	Asphaltene %	According to John, H. 1995 and Noureldin, S. 1982 [11 & 12]	20.18	8.66	25± 5
		Maltene %		79.82	91.43	75± 5
6	HCNSO test	Carbon %		82.59	82.95	82 – 88 %
		Nitrogen %		1.09	0.95	0 -1 %
		Hydrogen %		9.61	9.74	8 – 11 %
		Sulphur %		4.54	4.75	0 – 6 %
		Oxygen %		2.17	1.61	0 – 1.5 %

Table (6): Penetration, kinematic viscosity and softening point test results for modified and non-modified asphalt cement

Hydrated lime %	Penetration(1/10 mm)	Kinematic Viscosity ,cst	Softening point
Non-defective (Suiz) asphalt	67	375	53
Defective (Alex.) asphalt	74 *	340	48.0
5.0	65.000	410	49.0
10.0	65.000	438	50.0
15.0	61.000	442	51.0
20.0	62.000	444	53.0
25.0	57.000	527	54.0

Note: * the value does not meet the specifications limits.

Table (7): Values of Marshall parameters for different % of hydrated lime at OAC.

Marshall properties	Hydrated lime %							
	Non-defective (Suiz) asphalt	Defective (Alex.) asphalt	5%	10%	15%	20%	25%	Specification limits
O.A.C	5.33	5.58	5.78	5.82	5.82	5.83	6	
Stability (kg)	1530	1060*	1500	1450	1390	1440	1400	≥1200
Density (gm/cm3)	2.405	2.355	2.354	2.353	2.341	2.328	2.313	
Air voids %	3.3	4.4	4.1	4.3	4.7	5.4*	5.6*	3 : 5
Flow (mm)	3.5	3.7	3.8	4.1*	4.25*	4.35*	4.9 *	2 : 4
V.M.A %	15.1	16.6	16.75	16.85	17.25	17.75	18.5	≥15

Note: * the value does not meet the specifications limits.

Table (8): Effect of different hydrated lime percentage on loss of stability values

Hydrated lime %	Stability 0.5 hour	Stability 24 hour	Loss of stability	Specifications limits
Non-defective (Suiz) asphalt	1550	1357.8	12.4%	≤25
Defective (Alex.) asphalt	1080	842.4	22.0%	
5% hydrated lime	1500	1239	17.4%	
10% hydrated lime	1400	1169	16.5%	
15% hydrated lime	1370	1161.76	15.2%	
20% hydrated lime	1410	1225.29	13.1%	
25% hydrated lime	1400	1206.8	13.8%	

Table (9): Effect of different hydrated lime percentage on I.T.S values

Hydrated lime %	I .T.S(Kpa)
Defective (Alex.) asphalt	1122
5% hydrated lime	1152
10% hydrated lime	1156
15% hydrated lime	1159

Table (10): Effect of different hydrated lime percentages on WTT values

Hydrated lime %	W.T.T(mm)
Non-defective (Suiz) asphalt	5.1
Defective (Alex.) asphalt	8.38
5% hydrated lime	2.032
10% hydrated lime	2.88
15% hydrated lime	5.9

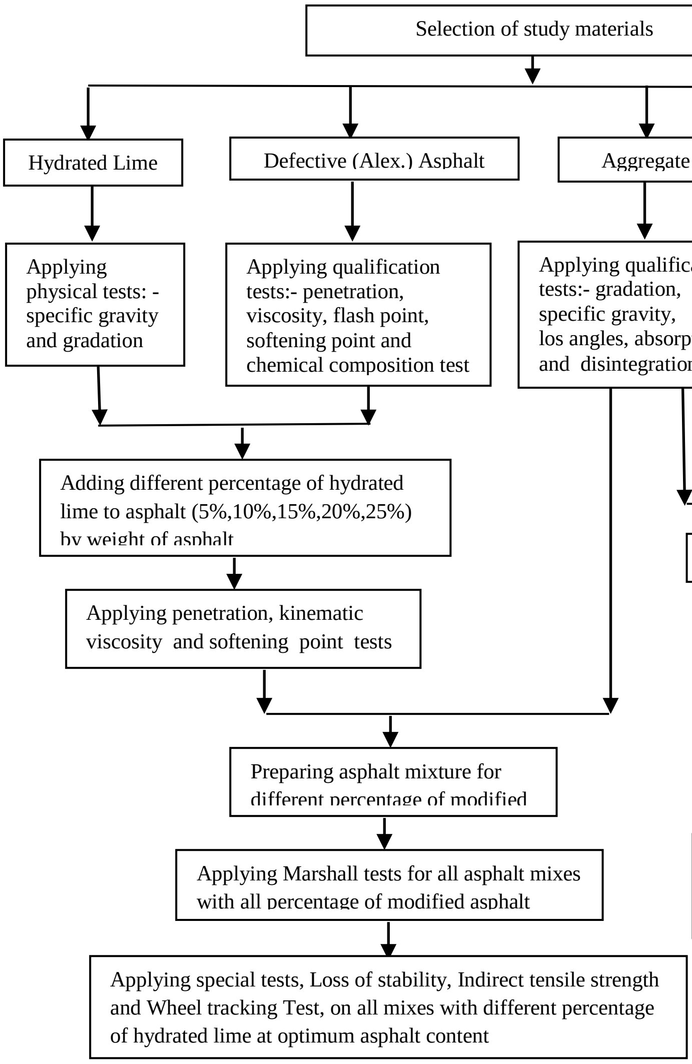

Figure (1): experimental program

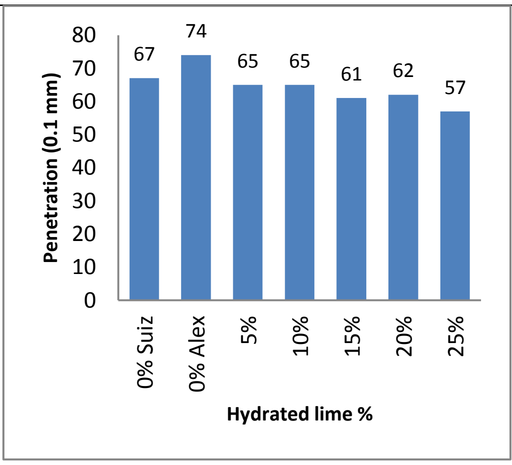

Figure (2): effect of adding different % of hydrated lime on the penetration test values of asphalt cement

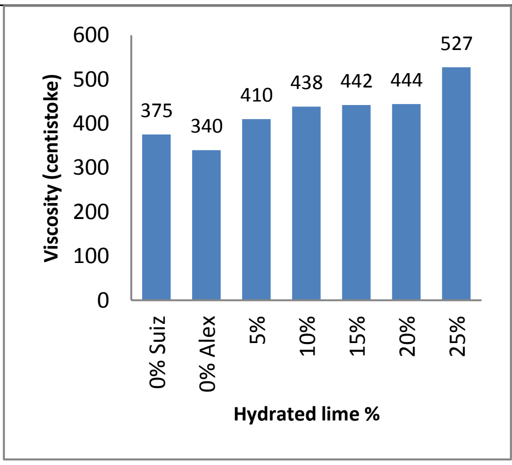

Figure (3): effect of adding different % of hydrated lime on the kinematic viscosity test values of asphalt cement

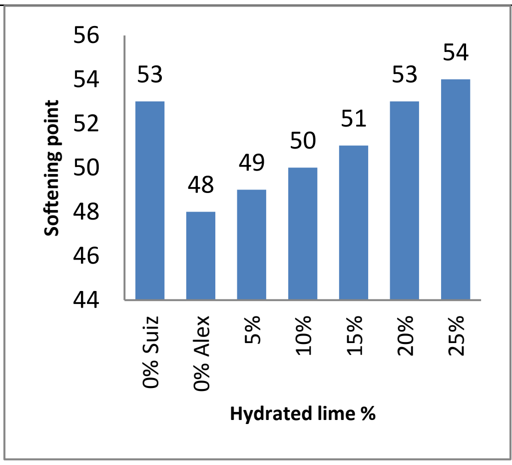

Figure (4): effect of adding different % of hydrated lime on softening point test values of asphalt cement

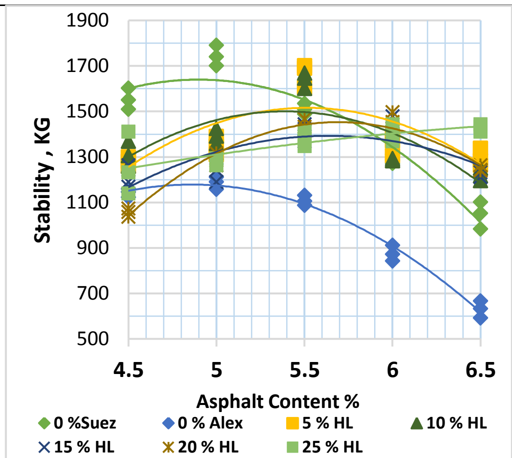

Figure (5): effect of adding different % of hydrated lime on stability values of asphalt mix at different % of asphalt content

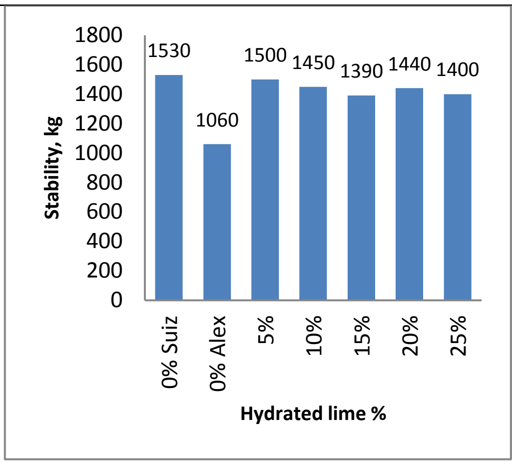

Figure (6): effect of adding different % of hydrated lime on stability values of asphalt mix at OAC

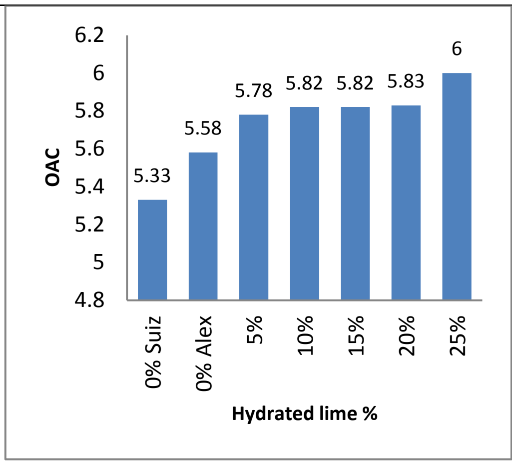

Figure (7): effect of adding different % of hydrated lime on OAC values of asphalt mix

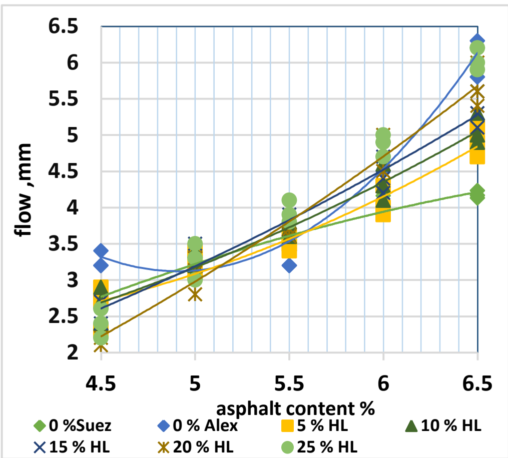

Figure (8): effect of adding different % of hydrated lime on flow values of asphalt mix at different % of asphalt content

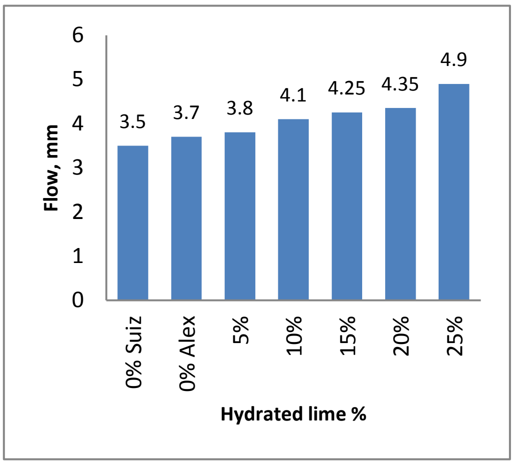

Figure (9): effect of adding different % of hydrated lime on flow values of asphalt mix at OAC

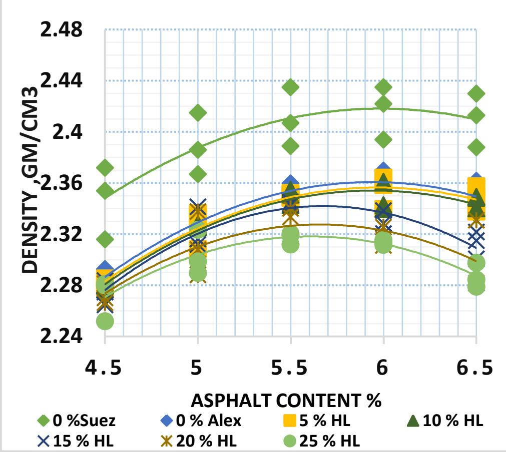

Figure (10): effect of adding different % of hydrated lime on density values of asphalt mix at different % of asphalt content

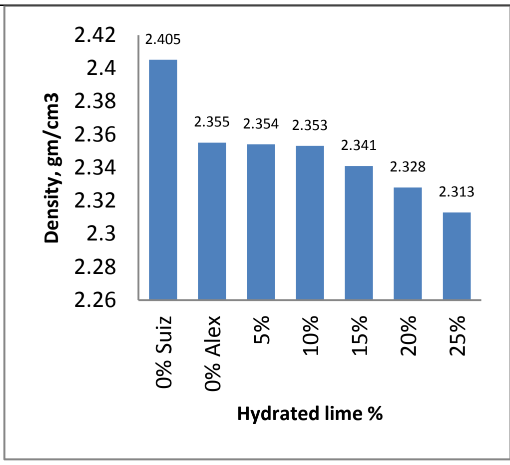

Figure (11): effect of adding different % of hydrated lime on flow values of asphalt mix at OAC

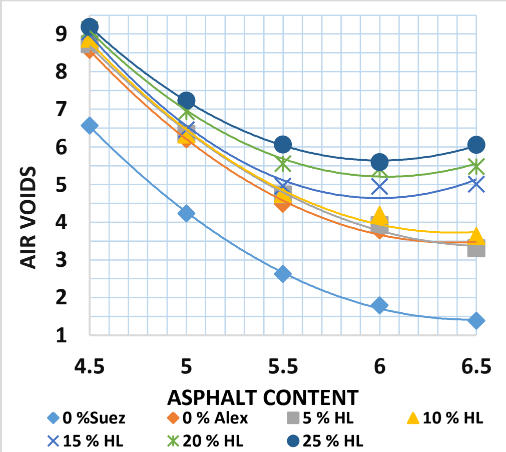

Figure (12): effect of adding different % of hydrated lime on air voids % values of asphalt mix at different % of asphalt content

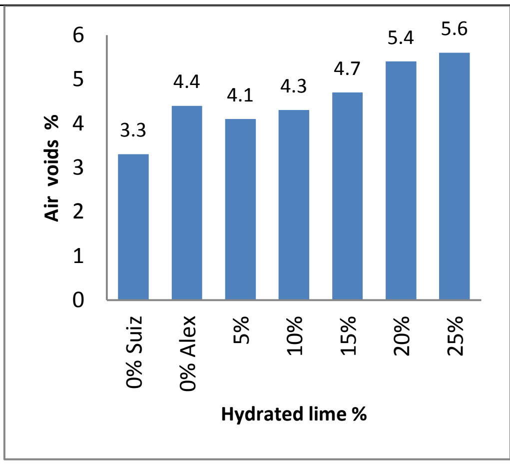

Figure (13): effect of adding different % of hydrated lime on air voids % values of asphalt mix at OAC

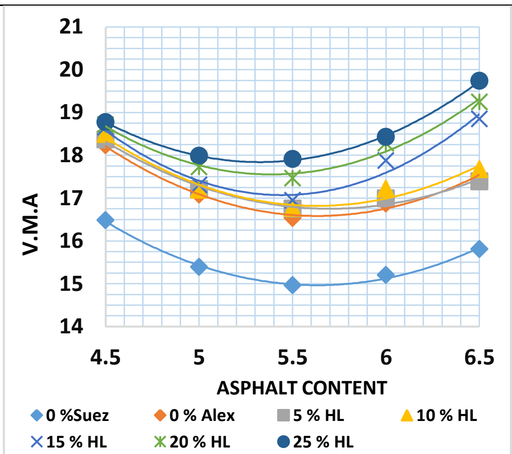

Figure (14): effect of adding different % of hydrated lime on VMA % values of asphalt mix at different % of asphalt content

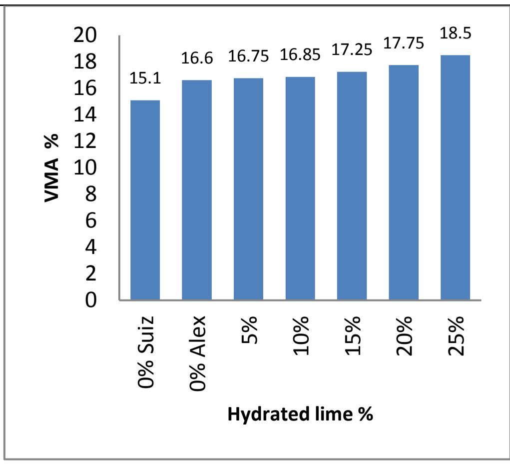

Figure (15): effect of adding different % of hydrated lime on VMA % values of asphalt mix at OAC

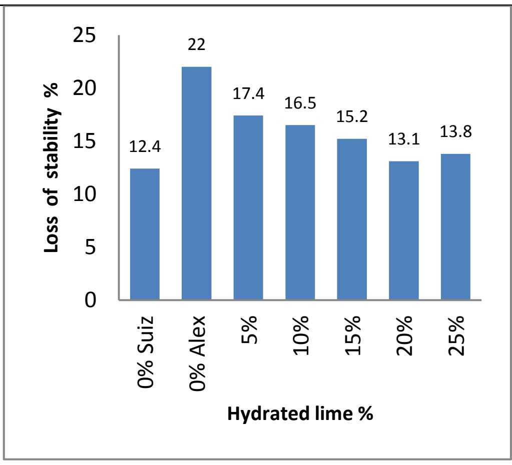

Figure (16): effect of adding different % of hydrated lime on loss of stability % values of asphalt mix at OAC

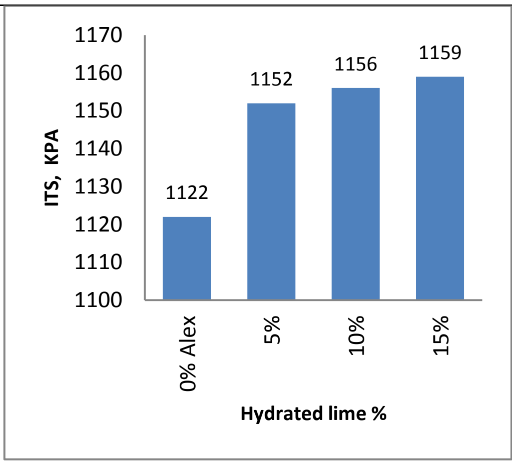

Figure (17): effect of adding different % of hydrated lime on ITS (Indirect Tensile strength) values of asphalt mix at OAC

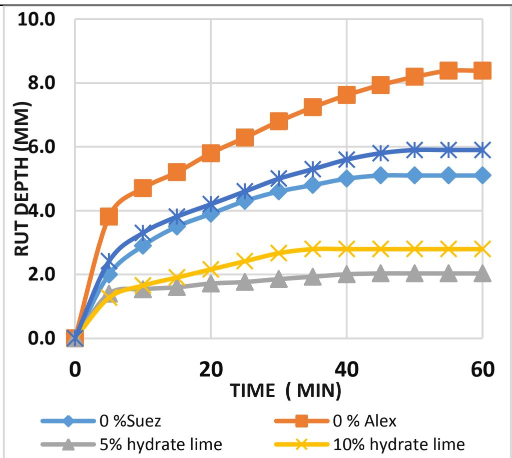

Figure (18): effect of adding different % of hydrated lime on rut depth values of asphalt mix at OAC during WTT (Wheel Tracking Test)

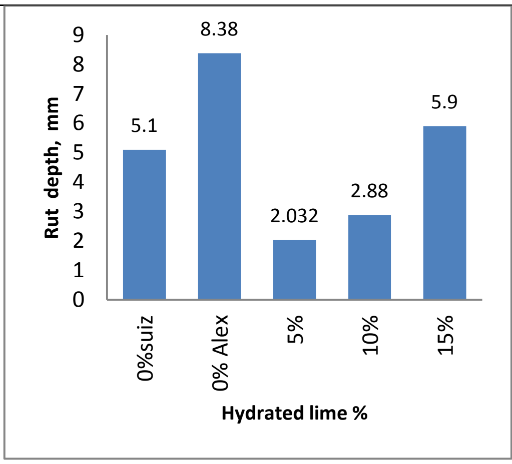

Figure (19): effect of adding different % of hydrated lime on rut depth values of asphalt mix at OAC at the end of WTT (Wheel Tracking Test)

Mahmoud Fathy Abdel-maksoud Khamis. "Effect of Hydrated Lime on Asphalt Cement and Asphalt Mixtures Properties" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Vol. 16, No. 1, 2019, pp. 47-59