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# Laboratory evaluation of asphalt concrete mixtures properties modified with nano-Hydrated Lime (nHL)

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***Abstract*— Increasing of traffic volume and tire pressure raise the question, it is still possible to build a pavement structure in heavy traffic area with conventional bitumen. The conventional bitumen has a limited capacity under wide range of loads and temperature which occur over the life of a pavement. Therefore, conventional bitumen needs to be modified to face the heavy loads and weather change. Number of materials used to improve the properties of bitumen and asphalt properties such as polymers and rubber. With the considerable increase demand to get better properties of asphalt concrete mixtures nano scale material ware used as asphalt modifier. One of the most important properties of nano scale material is Surface to volume ratio. The conventional asphalt cement used in this research was AC (60/70) penetration grade, modified with nano-hydrated lime (nHL) at five different modification levels namely 5%, 10%, 15% 20%, and 25% by weight of the bitumen. The physical properties of the modified asphalt cement were evaluated using traditional testes such as penetration test and softening point. On the other hand the properties of the asphalt concrete mixtures were evaluated using Marshall Stiffness, fatigue and flexural bending tests and. Based on the results, it was found that the physical properties of nano-hydrated lime (nHL) modified asphalt was enhanced successfully. For all modified asphalt concrete mixtures the stiffness was improved more than two times but for fatigue life small improvement had been done.**

***Index Terms*— Modified bitumen, Tensile strength, Nano-hydrated lime**

## I. INTRODUCTION

The increase of road traffic during the last two decades in combination with an insufficient degree of maintenance has caused an accelerated, deterioration of road structure; these roads show early signs of distress such as rutting, cracking, low temperature cracking, ageing and stripping. Heavier loads and higher traffic volume demand higher performance of pavement [1, 2]. Excellent performance of pavement requires bitumen that is less susceptible to high temperature, rutting or low temperature cracking. Asphalt cement is visco-elastic materials, where temperature and rate of load application have a great influence on their performance. The viscoelastic behaviour of asphalt leads to pavement distress. At high temperatures under traffic loading asphalt is not able to maintain the original shape of the pavement, which leads to permanent deformation, known as rutting. At low temperatures asphalt gets brittle and tends to crack because the stiffer structure is not able to relax the internal stresses from the traffic load [3-6]. The conventional bitumen lacks the proper of visco-elastic balance with the increase of the traffic volume. Conventional bitumen has a limited capacity under wide range of loads and temperature, which occur over the life of a pavement. Therefore, binders are modified to face the load and weather Challenges. Modified bitumen can bring real advantage to the field of highway construction, by improving pavement performance as well as extent the pavement life [7-8]. Nowadays using nano-materials in the field of highway construction is extremely popular today. Nanotechnology has become the vanguard of the most important and exciting areas in physics, chemistry, biology, engineering and many other fields. The concept of nanotechnology depends on the grounds that the particle size of less than one hundred nanometers (a nanometer is part of one billion of a meter) gives the material within the structure and properties of new behaviors. This is because these particles (which are smaller than the characteristic lengths associated with some of the phenomena) show new physical and chemical concepts [9]. Addition of nanoclay and carbon microfiber would improve a mixture's moisture susceptibility performance or decrease the moisture damage using 5% SBS plus 2% nano-SiO2 powder as asphalt concrete mixtures modifiers can increase the physical and mechanical properties of asphalt binder and mixtures. Small amounts of nano-clay can enhance stiffness and tensile strength, tensile modulus, flexural strength and modulus thermal stability. The elasticity of the nanoclay modified bitumen is much higher than unmodified bitumen [10, 11]. nanoclays may have the potential to reduce rutting and cracking[12].

## II. MATERIALS

### *A. Hydrated lime*

Hydrated lime is a dry, colorless crystalline powder manufactured by treating calcium oxide (quicklime) with water, in a process called "slaking [13]. Nano-size hydrated lime material was prepared by using Los Angeles abrasion test machine for three times in the drum which is rotated for 500 revolutions for one time and at a speed of 30 - 33 revolutions per minute. Morphology and structural of the prepared materials were investigated by transmission electron microscopy (TEM, JEOL JEM-1230 with accelerating voltage of 120 kV) with EDX detector unit attached to the

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system. . Figure (1) presented the particle size of hydrated lime which is in the range of 20-200 nm.

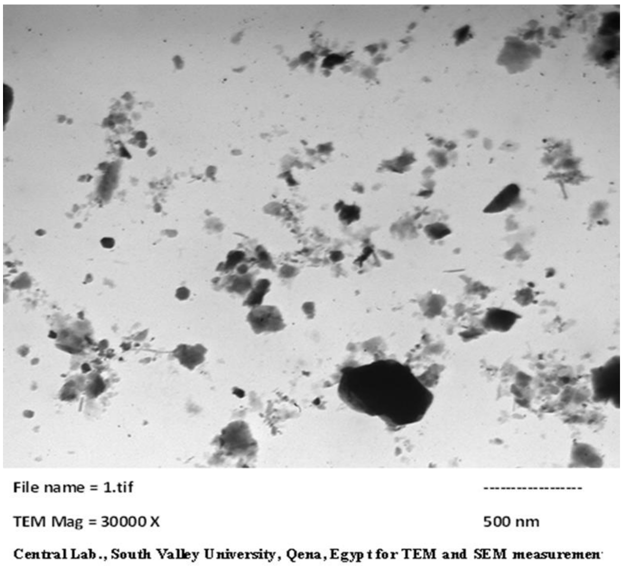


Figure (1): particle size of hydrated lime

The Hydrated lime in nano size was added to asphalt cement with different percentages namely, 5%, 10%, 15% 20%, and 25% by weight asphalt cement. The mixing temperature of bitumen with cement bypass was adjusted between 130 0C and 160 0C. Low shear mixer was used to prepare homogenize mixtures.

*B. Asphalt cement*

Asphalt cement of 60/70 penetration grade was used in this study. This asphalt was obtained from Suez refinery. The physical properties of this bitumen are given in Table (1) including penetration, softening point and specific gravity.

Table (1) physical properties of asphalt cement

| Property | Value | Specifications |
|---|---|---|
| Penetration | 65 | 60-70 |
| softening point | 52.2 | 45-55 |
| Specific gravity | 1.02 | 1-1.1 |

*C. Conventional Tests for Asphalt cement*

Penetration test result measuring the consistency of a bituminous material at a given temperature and softening point helps to know the temperature up to which a bituminous binder should be heated for various road use applications [14, 15]. The result of pentation test was presented in table (1). The pentraion grade decrease with increase of nano-hydrated lime (nHL) percentage. Modified bitumen with 15% Nano-hydrated lime (nHL) shows higher improvement for both penetration and softening point. Using Nano-hydrated lime (nHL) as asphalt modifier produce a hard bitumen which, is useful to resist rutting. Higher softening point indicates lower temperature susceptibility and is preferred in hot climates. The result till 15% of nano-hydrated lime (nHL) is acceptable for asphalt concrete pavement construction. Using Nano-hydrated lime (nHL) as asphalt modifier produce a hard bitumen which, is useful to resist rutting. Greater value of penetration indicates softer consistency. Higher softening point indicates lower temperature susceptibility and is preferred in hot climates area. But using more the 15% of nano-hydrated lime (nHL) the bitumen start to be very hard which is not valid for asphalt pavement construction. Table No. (2) shows the test result for both Penetration and softening point.

Table (2) penetration test and softening test result

| Bitumen Type / Test | Penetration @ 25 ° C | Softening Point ° C |
|---|---|---|
| Unmodified bitumen | 70 | 45 |
| Modified (AC) with 5% Nano-hydrated lime (nHL) | 66 | 48 |
| Modified (AC) with 10% Nano-hydrated lime (nHL) | 60 | 59 |
| Modified (AC) with 15% Nano-hydrated lime (nHL) | 47 | 71 |
| Modified (AC) with 20% Nano-hydrated lime (nHL) | 33 | 80 |
| Modified (AC) with 250% Nano-hydrated lime (nHL) | 29 | 93 |

*D. Aggregates*

Siev analysis was performed on crushed limestone aggregates on accordance to Egyptian highway standard specifications. Gradation of aggregates obtained from sieve analysis is presented in table (3) to achieve the required gradations 23 % of coarse aggregate (a) was blended with 36 % of coarse aggregate (b) and 36 % of sand these were blended together. The selected gradations of aggregate used in all asphalt concrete mixtures meet the Egyptian highway standard specifications.

Table (3) asphalt concrete mixtures gradation.

| Sieve size | Aggr. (2) | | Aggr (1) | | Sand | | Mineral fill | | Design limits | Spe.,limits (4-c) |
|---|---|---|---|---|---|---|---|---|---|---|
| | % P | 23% | % P | 36% | % P | 30% | %P | 36% | | |
| 1 in | 100 | 23 | 100 | 36 | 100 | 36 | 100 | 5 | 100.00 | 100 |
| ¾ in | 91 | 20.93 | 100 | 36 | 100 | 36 | 100 | 5 | 97.93 | 80-100 |
| ½ in | 34 | 7.82 | 100 | 36 | 100 | 36 | 100 | 5 | 84.82 | 70-90 |
| 3/8 in | 3 | 0.69 | 83 | 29 | 100 | 36 | 100 | 5 | 71.57 | 60-80 |
| No, 4 | | | 27 | 9.72 | 100 | 36 | 100 | 5 | 50.72 | 48-65 |
| No, 8 | | | 3 | 1.08 | 91 | 32.8 | 100 | 5 | 38.84 | 35-50 |
| No, 30 | | | 0.5 | 0.18 | 55 | 19.8 | 100 | 5 | 24.98 | 19-30 |
| No, 50 | | | | | 35 | 12.6 | 100 | 5 | 17.60 | 13-23 |
| No, 100 | | | | | 11 | 3.96 | 97 | 4.85 | 8.81 | 7-15 |
| No, 200 | | | | | 4 | 1.44 | 68 | 3.4 | 4.84 | 3-8 |

## III. Asphalt Concrete Mixture Design Results

Marshall Stability and flow tests were carried out on compacted specimens at various bitumen contents according to ASTM D1559. The Marshall test is an empirical test in which cylindrical compacted specimens, 100 mm diameter by approximately 63.5 mm high are immersed in water at 60ºC for 30– 40 min and then loaded to failure using curved steel loading plates along diameter at a constant rate of compression of 51 mm/min. The Marshall stability value (in KN) is the maximum force recorded during compression whilst the flow (in mm) is the deformation recorded at maximum force. Stability is measured as the maximum load sustained by the sample before failure. Flow is the deformation at the maximum load. From the asphalt cement traditional test result 15% was selected to be added to bitumen and the Marshall specimens were designed. The result of Marshall tests for each of the mixtures is showing in Table (4).five separate smooth curve are drawn Marshall stability, flow, Density, air voids (Vv) and voids filled with bitumen (VFB). Optimum bitumen content is selected as the average bitumen content for maximum density, maximum stability and 4% air voids in the total mix .The optimum content was found to be approximately of 5%. All results at optimum content satisfy the Egyptian highway specification

Table (4) Marshall Mix Design Results

| | Asphalt Content | | | | |
|---|---|---|---|---|---|
| | 4% | 4.5% | 5% | 5.5% | 6% |
| Density(t/m3) | 2.26 | 2.38 | 2.46 | 2.45 | 2.44 |
| %Vv | 10.4 | 7.2 | 4.00 | 1.9 | 1.42 |
| %VFB | 45.6 | 56.2 | 78.4 | 85.2 | 90.5 |
| Stability (Kg) | 7.2 | 8.3 | 11 | 9 | 7.3 |
| Flow | 2.20 | 4.35 | 5.20 | 5.35 | 5.5 |

## IV. Results and Discussion

### A. *Marshall Stiffness test result*

Figure (2) presents the mean values of Marshall Stiffness for control mixture and Modified Asphalt Concrete Mixtures [16]. The results were calculated using the following equation

$$MS = \frac{S}{F * T} \qquad \text{Equation (1)}$$

Where:

MS = Marshall Stiffness,
S = Marshall Stability,
F = Marshall Flow, and
T = specimen's thickness.

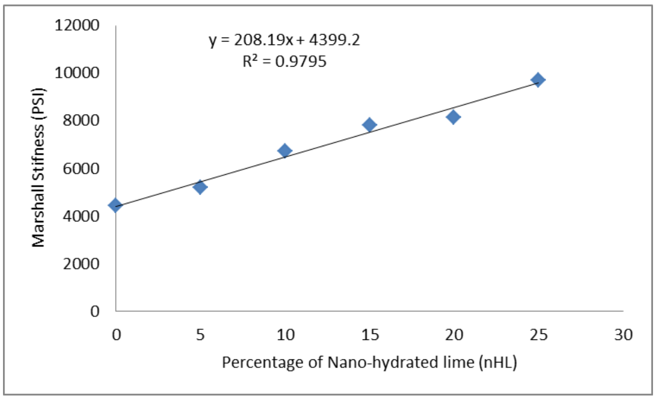


Figure (2) Marshall Stiffness test results

It can be noticed that, the addition of Nano-hydrated lime (nHL) generally enhanced the results of Marshall stiffness for all modified mixtures as compared to the control mixtures. Adding 15% of Nano-hydrated lime (nHL) improve the Marshall stiffness nearly two time than the unmodified asphalt concrete mixtures.

### B. *Flexural bending test result*

The Flexural Strength test is performed to determine the flexural properties of asphalt concrete mixtures. It is used to determine the modulus of rupture for the tested specimen. The flexural strength of the asphalt concreter mixtures can be obtained through applying two concentrated loads in the middle third of the asphalt concert beam (four-point bending test) with free rotation and horizontal translation [17, 18].

The flexural strength can be calculated using the following equation;

$$\sigma = \frac{2PL}{bh^2} \qquad \text{……………….. Equation (2)}$$

Where:

σ= Flexural stress,
P= Peak load,
L= Total span of the tested beam,
b= Breadth of cross section for the tested beam, and
h= Height of cross section for the tested beam.

Figure (3) presented the four-point bending test system for flexural strength test and figure (4) present the test result for all modified and unmodified asphalt concrete mixtures. Adding Nano-hydrated lime (nHL) enhance the Flexural strength for all modified asphalt concrete mixtures

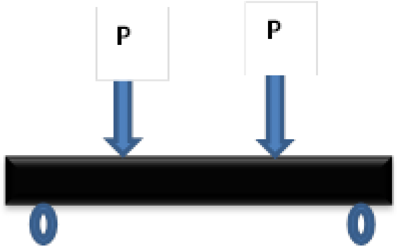


Figure (3) four-point bending test

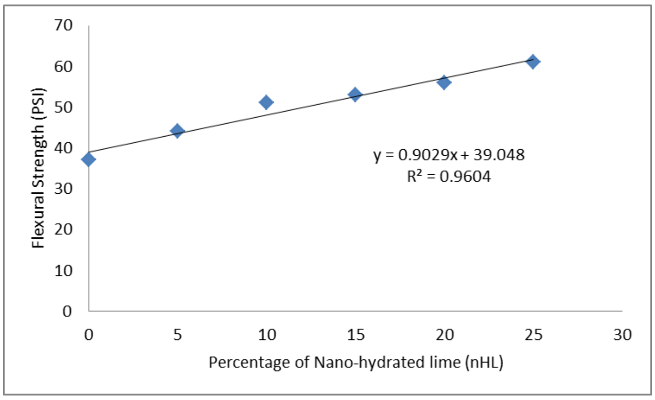


Figure (4) Flexural strength test results

### C. *Fatigue test result*

Number of cycles at fracture of each studied mixture was recorded using the computer control electro-hydraulic servo universal testing machine. The maximum number of cycles was recorded when the peak tensile stress drops sharply. Figure (5) shows the number of cycles to failure for the fatigue test in controlled-stress mode for modified and unmodified asphalt concrete mixtures. The results show that, fatigue life for all modified mixtures with Nano-hydrated lime (nHL) was higher than that for control mixture. The percentage of improvement in fatigue life is very small as compare to other type of additives [19]

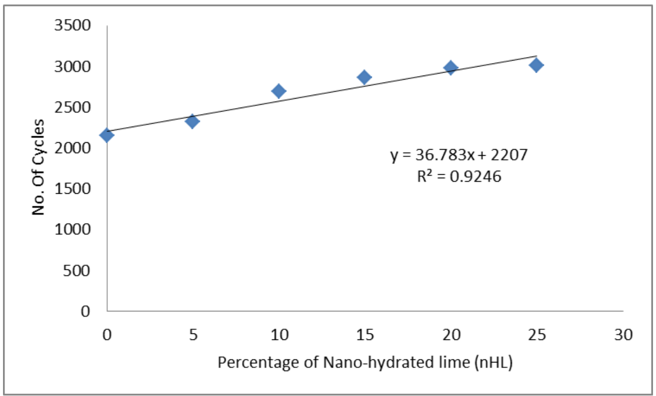


Figure (5) Fatigue test results

## V. CONCLUSIONS AND RECOMMENDATIONS

Based on the analysis of the results obtained in this research, following can be summarized as:-.

1. Using Nano-hydrated lime (nHL) in asphalt mixtures gives good indicator that this materials can enhance the physical properties of the used asphalt cement.
2. Using Nano-hydrated lime (nHL) produce harder asphalt cement that can used for high climate area.
3. The mechanical properties of modified asphalt concrete mixtures were improved in the terms of Marshall stiffness and flexure strength.
4. The fatigue life for modified asphalt concrete mixtures with Nano-hydrated lime (nHL) was improved.
5. The improvement in fatigue life for modified asphalt concrete mixtures with Nano-hydrated lime (nHL) is not high as compared to other types of additives.
6. Trail section is needed to evaluate the pavement performance for asphalt concrete mixtures modified with 15% Nano-hydrated lime (nHL) under natural field condition.


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