International Journal of Materials Chemistry and Physics
Vol. 1, No. 3, 2015, pp. 395-401
http://www.aiscience.org/journal/ijmcp

Influence of Load Repetitions and Heating on Micro Crack Healing of Asphalt Stabilized Subgrade Soil

Saad Issa Sarsam*, Siham Almas Barakhas

Department of Civil Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq

Abstract

The implication of asphaltic materials into the subgrade soil is referred as asphalt stabilization, it usually changes the whole geotechnical properties and behaviour of the soil under repeated loading applied by vehicles through the pavement system. The asphalt material supports the cohesive property and bind the soil particles through the thin film of asphalt, it also introduces some elastic property and introduce the resilience action against deformation under repeated wheel loading. Due to aging and continuous loading, micro cracks will initiate indicating the starting point of distress. This work investigates the possibility of micro crack healing when exposing the cutback asphalt stabilized layer to external heating. Stabilized soil specimens of 100 mm diameter and 200 mm height have been prepared in the laboratory at optimum asphalt content, and at one percent of asphalt above and below the optimum. Specimens were cured for one week at laboratory environment, then the specimens were subjected to repeated compressive stress at 20°C using the Pneumatic repeated load system (PRLS). The test was stopped after a predetermined number of load repetitions, the specimens were released from the testing chamber, and stored in an oven at 60°C for 120 minutes, and then the specimens were cooled to 20°C for 60 minutes, fixed at the testing chamber, and subjected to another cycle of repeated compressive stresses. It was concluded that The resilient modulus was increased by (50, 4, and 17)% due to healing process at asphalt content of (5, 6, and 7)% respectively, while the permanent deformation and initial deformations have decreased due to crack healing by (71, 7, and 56)% and (44, 37, and 42)%, respectively for asphalt content of (5, 6, and 7)%.

Keywords

Crack Healing, Asphalt Stabilization, Cutback, Subgrade, Repeated Compressive Stress

Received: September 5, 2015 / Accepted: November 4, 2015 / Published online: January 8, 2016

1. Introduction

The asphalt cement binder is subjected to continuous degradation due to environmental impact and aging, which results in loss of volatiles and reduction in elastic properties. The binder loses the ability to bind the soil particles together. This results in micro cracks, which allow damaging moisture into the subgrade, and eventual structural failure, [1]. It is generally known that asphalt roads can heal by themselves, but it is a slow process at ambient temperature, and it only works if there is no traffic circulation on the road. It is also well known that the amount of healing increases when the material is subjected to a higher temperature during the rest period, [2]. The ability of the micro cracks to heal can increase the lifetime of asphalt for several years before rehabilitation or reconstruction is required.

As a simplification, bitumen could be considered as a very dense oil; when a crack appears in it, it will close by itself, but it will do much faster if the liquid behaviour of bitumen is increased. That can be done by increasing its ambient temperature. If the temperature of the asphalt is increased too

* Corresponding author
E-mail address: saadisasarsam@coeng.uobaghdad.edu.iq (S. I. Sarsam)

much the asphalt will lose its porosity and with that its functionality, [3] and [4]. Asphalt treated materials are expected to repair themselves during hot summers and (long) rest periods, [5]. The self-healing process of damage in asphalt stabilized materials consists of two main phases, namely the crack closure and the strength gain phase. The driving force can be either thermal (temperature) or mechanical (by confinement, pressure). The self-healing capability is related to the viscosity of the asphalt cement, which increases with increasing healing time, temperature and when the crack size is very small [5]. Healing occurs due to temperature increases while in the micro-cracking range, [6].

The aim of this work is to investigate the impact of external heating and asphalt content on the self-healing of the asphalt stabilized subgrade soil, which is considered as a good method to increase the lifetime of the pavement. In this work, the external temperature process was adopted by storing the asphalt stabilized soil specimens in an oven at 60°C for two hours.

2. Materials and Methods

2.1. Subgrade Soil

The soil used in this research was taken from Al-Taji, 20 km north of Baghdad city from (0.3m-0.75m) depth. This soil represents typical subgrade soil usually used for embankment construction by Mayoralty of Baghdad. Table 1 shows the important physical properties and chemical composition of the soil. Fig. 1. shows the grain size distribution of the subgrade soil.

Table 1. Physical properties and chemical composition of the used soil.

Physical properties	Specification	Test results
Liquid limit%		35.75
Plastic Limit %	(ASTM D-4318)	23.1
Plasticity Index %		12.6
Maximum dry density	(ASTM D690-00a)	17.7 kN/m^3
Optimum water content%	Standard proctor	15%
Unified classification system		CL
AASHTO classification system		A-6(12)
ASTM classification system		7% sand, 63% silt, 30% clay
% Total soluble salt (T.S.S)		6.02
% Organic content		0.945
% Total (CaCo3)		33.50

2.2. Cutback Asphalt

Medium curing cut-back (MC-30) manufactured at AL-Dora refinery was implemented in this investigation, the properties as supplied by the refinery are listed in the Table 2.

2.3. Determination of Optimum Asphalt Content

The optimum cutback asphalt content and fluid content that were suitable for all geotechnical properties of the soil such as direct shear test, one-dimensional compression test and unconfined compression test were determined, it was found as (6%) and 15% by weight of dry soil respectively, the details of testing were published elsewhere, [7].

Table 2. Properties of Cut-back Asphalt (as per Dora refinery).

Grade	MC-30
Viscosity(CSt)@60°C	30-60
Flash point (C.O.C)°C (min)	38
Water% V(max)	0.2
Residue from distillation to 360°C% V(min)	50
Test on Residue from Distillation	
Penetration @25°C (100g, 5sec, 0.1 mm)	120-250
Ductillity@25°C (cm)(min)	100
Solubility in Tri-chloro ethylene % wt. (min)	99.0

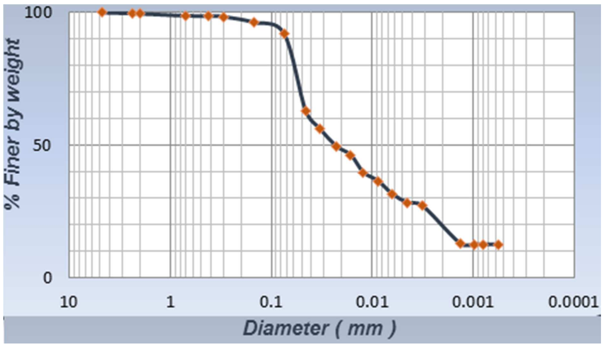

Fig. 1. Grain size distribution.

2.4. Preparation of Specimen

The pulverized and homogenous soil passing No.10 sieve was oven dried at temperature of (100°C) to constant weight. The optimum fluid content (6% cutback asphalt +9% water) and the target maximum dry unite weight of soil (17.7 kN/m^3) that was found through standard compaction test were selected for preparation of specimens. The water was added and mixed thoroughly by hand for three minutes until the water dispersed through mixture, thereafter cutback asphalt was added to mixture and mixed by rubbing the mixture between palms for five minutes, so that the mixture had homogenous character and proper coating of soil particles with asphalt occurred. The mixture was allowed to aeration for two hours at room temperature (20±5°C) as recommended by [8]. The compaction mold used in this test is 10 cm in diameter and 20 cm in height, filter paper was placed at the bottom of the mold, the mixture was placed into the mold and compacted statically, after that, the specimen was extracted from the mold and allowed to curing for (7) days before test as per the procedure by [9]. The procedure of the static compaction is shown in Fig. 2, while Fig. 3. Shows the aeration process. On the other hand, Fig. 4 shows the prepared specimens.

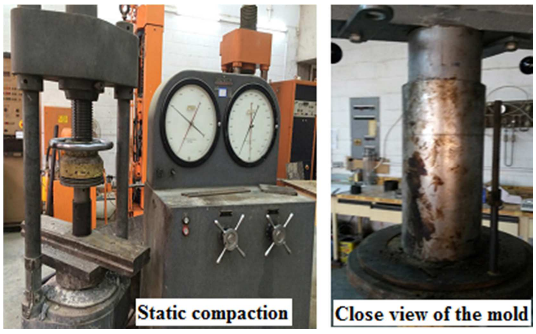

Fig. 2. Static Compaction of the mixture.

Fig. 3. Aeration process of mixture.

Fig. 4. Prepared asphalt stabilized specimens.

2.5. Testing of Specimen

Pneumatic repeated load system (PRLS) shown in Fig. 5 was implemented. Specimens were stored in the chamber of the testing machine at room temperature (20±1°C). The Specimen was fixed inside the (PRLS) chamber, a piece of Rubber sheet of 1.5 mm thickness was attached under & above the specimen to reduce the impact of excessive load on the Specimen since the system was originally designed for Asphalt Concrete testing. Also the rubber sheet may represent the flexible asphalt pavement which absorb and distribute the wheel loading and simulate the actual field condition. The Door was closed to maintain the temperature. The test was conducted according to AASHTO, [10]. Uniaxial compressive repeated loading was applied on the specimen which was centred on the specimen as shown in Fig.6, the repeated load was applied in the form of rectangular wave with constant loading frequency of (56) load cycles per minutes. A heavier sine pulse of (0.1) sec load duration and (0.9) sec rest period is applied over test duration. Dial gage of the deformation reading was set to zero before test start and the pressure actuator was adjusted to the specific constant stress level equal to (56 kPa) which was used in the test. The temperature of the tests was (20 ± 1°C) since the micro cracking occurs at temperature around (20°C) [11]. The deformation due to the number of load Repetitions for each percentage of asphalt was captured by fixing a digital video Camera. Three Specimens were prepared of each percentage of asphalt. The test began with rate of (56 Rep. / min.) until (30 minutes) of loading completed. Such loading period was recommended by [12] and [4] as the initiation of micro cracking starts. Digital Camera was fixed on the surface of the (PRLS) to capture the number of the load Repetitions and deformation as shown in Fig. 7 upon completion of test, the recording was terminated and the specimen was removed from the test chamber. The Specimens were removed outside the (PRLS) and stored in Oven at (60°C) for two hours, Cooled to (20°C), then tested again in the same Apparatus by the same conditions to detect the possible healing of micro cracks, then the deformation of the Specimen due to load increments after possible healing was detected and the results were compared with the test before healing. The impact of load repetitions on the accumulated permanent deformation and resilient modulus were assessed. The average of three sample of each percentage of cutback asphalt was calculated and considered for analysis. Total of 9 specimens were prepared and tested.

Fig. 5. Pneumatic repeated load system.

Fig. 6. Testing of Specimen.

Fig. 7. The Digital camera.

3. Results and Discussion

3.1. Crack Healing of Asphalt Stabilized Specimens Using Repeated Compressive Strength Test

Crack healing rate was determined in terms of the changes in resilient modulus and rate of deformation of asphalt soil mixture specimens. It was observed that crack healing rate varied according to the percentage of asphalt. Healing occurred in the soil mixture specimens due to the internal structure change, this change was occurred due to the several mechanisms such as closure of micro cracks and macro cracks, coalescence of air voids, which increase the compression strength of mixture, similar findings were reported by [4]. Fig. 8 shows the effect of possible crack healing on the values of % ϵ. It was observed that % ϵ was lower for each Percentage of Asphalt content after healing due to the stiffness gained after heating of Asphalt stabilized soil specimens. The heating works in two stages, the first stage was the reduction of percent of volatiles in the specimen and the second stage is the expansion of the volume of asphalt which will heal the cracks by the adhesion and binding the cracked particles surface together and fill more voids. Such stages could increase the stiffness of the mix. The deformation was reduced by (71% at 5% Asphalt, 9% at 6% Asphalt and 55% at 7% Asphalt) because the macro-cracks that occurred during repetitive loading were healed after heating, and retained the stiffness of the mixture. Fig. 9 shows the relationship between the deformation % ϵ and % Cutback Asphalt content before and after Healing Potential.

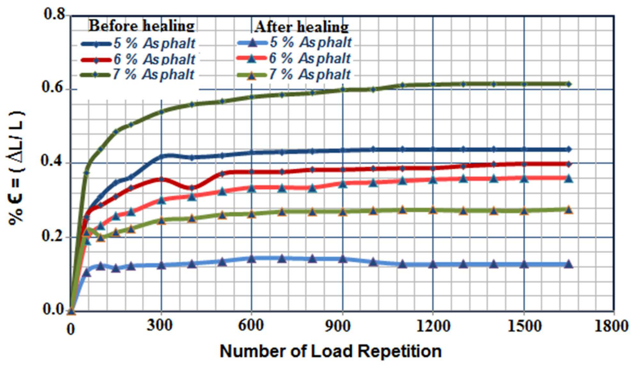

Fig. 8. The deformation before & after Healing.

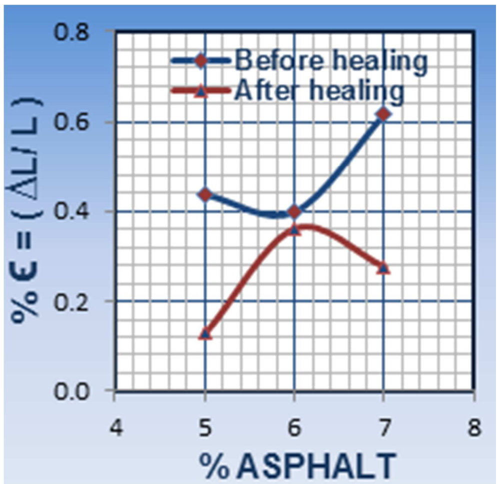

Fig. 9. Impact of asphalt content on healing.

3.2. Impact of Crack Healing on Resilient Modules (Mr)

The Resilient Modulus (Mr) is the ratio of the applied stress to the recoverable strain that takes place after removing the applied stress, throughout the test the resilient deformation was measured at the load Repetition of 1650 (the end of the test), then the resilient strain (εr) and (Mr) were calculated as recommended by [13] using (Eq. 1 and 2). Fig. 10 shows the Liner log-log relationship of the number of load Repetitions with the Permanent deformation (ϵ_p) before crack healing which was calculated using (Eq.3 and 4). From the Power equation, the (ϵ_p) and the Plastic Parameters (a & b) of each percentage of Asphalt content were obtained [15]. Fig. 11 shows the Liner log-log Curve of number of load Repetitions with the Permanent deformation (ϵ_p) in Micro strain after healing.

$$\varepsilon_r = \frac{rd}{h} \tag{1}$$

$$Mr = \frac{\sigma}{\varepsilon_r} \tag{2}$$

$$\varepsilon p = a\ N^{\ b} \tag{3}$$

Where

εr = axial resilient Strain in (mm / mm).

rd = axial resilient deflection in (mm).

h = Specimen's height in (mm).

Mr = Resilient modulus in (MPa).

σ = repeated axial Stress (kPa).

ϵ_p = Permanent deformation in Micro strain.

a = Intercept (initial deformation after seating load) in Micro strain.

N = No. of Repetitions at the end of the test = 1650 repetitions.

b = Slope of the deformation line.

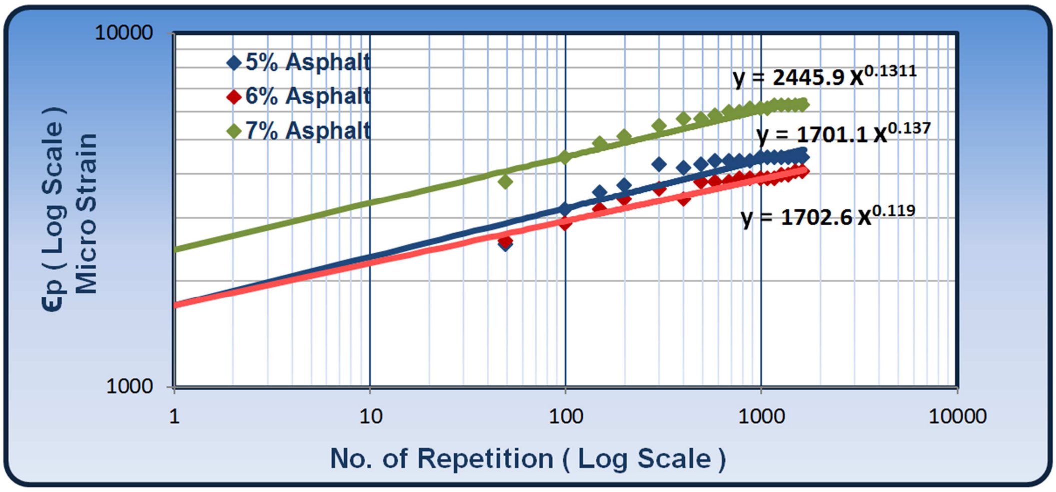

Fig. 10. Number of Repetitions - (ϵ_p) relationship before crack healing.

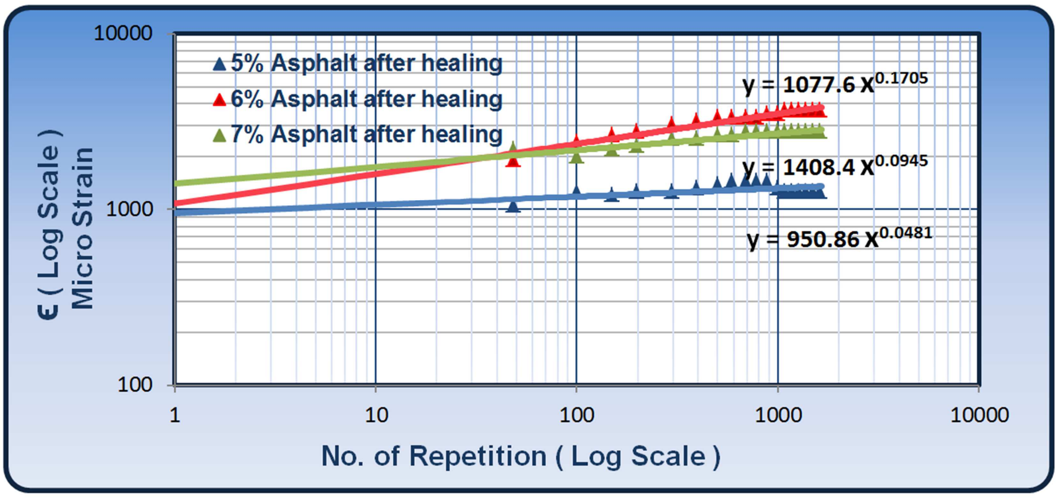

Fig. 11. Number of Repetitions - (ϵ_p) relationship after crack healing.

The results of Fig.10 (before healing) shows that the values of (a) increased as the asphalt content changes from 6 to 7%, and it shows similar values for 5% asphalt content, while the values of (b) is almost the same. On the other hand, Fig. 11 exhibit the results in the case after healing. It shows that the initial strain (a) increases as asphalt content increases. The slope (b) increases as asphalt content changes from 5 to 6% then decreases. The slope presents good indication of crack healing. The intercept (a) represents the permanent strain at N=1 (N is the number of load cycles), the higher the value of (a), the larger is the strain and the potential of permanent deformation. The slope represents the rate of change in the permanent strain as a function of the change in loading cycles (N) in the log-log scale. High slope of the mix indicates an increase in material deformation rate, hence, less resistance against rutting. A mixture with low slope is preferable as it prevents the occurrence of rutting. Table 3 demonstrates the changes in the plastic parameters due to healing phenomena. The values of (Mr) before micro crack healing increased up to 6% of Asphalt content due to increasing the cementing material and Asphalt film thickness between Soil′s particles which led to decreasing the deformation, then decreased at 7% because of sliding of Soil′s particles on each other and reduction of the bonding action of Soil′s particles as the asphalt is in excess, which led to increasing the deformation, higher values of (Mr) indicates greater resistance to deformation. Similar behavior could be detected for specimens after crack healing.

Table 3. Values of Plastic Parameters & Resilient Modules.

Asphalt %	Before Healing				After Healing			
	a (µƐ)	Slop (b)	ϵp (µƐ)	Mr (MPa)	a (µƐ)	Slop (b)	ϵp (µƐ)	Mr (MPa)
5	1701.1	0.1370	4694	5.66	950.9	0.0481	1358	8.47
6	1702.6	0.1190	4111	6.25	1077.6	0.1705	3811	7.48
7	2445.9	0.1311	6460	6.18	1408.4	0.0945	2836	7.26

The values of (a) which represent the initial strain increased as asphalt content increases for both testing conditions (before and after healing). After healing, the values of (b) which represent the slope and the permanent deformation increases up to 6% of Asphalt content then decreased at 7% of Asphalt content. Table 4 presents the changes in the plastic properties due to crack healing, the initial deformation decreases by (44, 37, and 42)%, while the permanent deformation decreased due to crack healing by (71, 7, and 56)% for asphalt content of (5, 6, and 7)% respectively. On the other hand, the resilient modulus was increased by (50, 4, and 17)% due to healing process at asphalt content of (5, 6, and 7)% respectively.

Table 4. Percent change of (a, b, ϵ_p, Mr) after Healing.

% Asphalt	% Change of (a)	% Change of (b)	% Change of (ϵp)	% Change of Mr
5	- 44	- 65	- 71	50
6	- 37	43	- 7	4
7	- 42	- 28	- 56	17

4. Conclusions

Based on the testing program, the following conclusion could be drawn:

1. For specimens of (soil+6% cutback asphalt+9%water) using repeated compressive strength test, the Resilient Modules (Mr) increased with the increase of the Asphalt content from 5% up to the optimum (6%) then decreased at 7% before crack Healing process, while it decreased up to the optimum (6%) then increased after Healing. Generally, the Resilient Modules was higher for each Percentage of Asphalt content after healing.

2. The resilient modulus was increased by (50, 4, and 17)% due to healing process at asphalt content of (5, 6, and 7)% respectively.

3. The deformation (% ϵ) under repeated compressive stress loading decreased with the increase of Asphalt content from 5% up to the optimum (6%) then increased at 7% when tested before Healing, while it increased up to the optimum (6%) then decreased after Healing. Generally, the deformation was lower for each Percentage of Asphalt content after healing.

4. The permanent deformation (ϵp) decreased due to crack healing by (71, 7, and 56)% for asphalt content of (5, 6, and 7)% respectively.

5. The initial deformation decreased by (44, 37, and 42)%, after crack healing for asphalt content of (5, 6, and 7)% respectively.

References

[1] Garcia A., (2010), “Temperature influence on the healing rates of asphalt concrete”, 2nd International Symposium Service Life Design for Infrastructure, Delft, The Netherlands.

[2] Garcia Hernandez, A, Schlangen, E & Ven, MFC van de (2011) “Asphalt mastic self-healing”, Proceeding of the 3rd international conference self-healing materials (pp. 299-300). Bath, UK.

[3] Garcia, A., Schlangen, E., Ven, M.V.D., Bochove, G.V. (2012) “Optimization of composition and mixing process of a self-healing porous asphalt” Construction and Building Materials, 30, pp. 59-65.

[4] Sarsam, S.I., (2015), "Crack Healing Potential of Asphalt Concert Pavement", International Journal of Scientific Research in Knowledge, 3 (1), pp. 001-012.

[5] Qiu J (2012). "Self-Healing of Asphalt Mixtures: Towards a Better Understanding of the Mechanism", PhD. Dissertation, Delft University of Technology (TU delft).

[6] Sarsam S, Rahem F (2009). "Cracking and crack healing in Asphalt concrete pavement". Graduation Project report, Department of Civil Engineering, University of Baghdad.

[7] Barakhas S. A. (2015) "Verification of the structural capacity of asphalt stabilized embankment", MSc. Thesis, College of Engineering, University of Baghdad, Iraq.

[8] Sarsam S. I., Alsaidi A. A. and Alzobaie O. M. (2014) 'Impact of Asphalt Stabilization on Deformation Behaviour of Reinforced Soil Embankment Model under Cyclic Loading", Journal of Engineering Geology and Hydrogeology JEGH, 2(4):46-53. Sciknow publication Ltd. USA.

[9] Prakash, S. and Sarsam, S., (1981), "Effect of Curing Time on Soil Cutback Mix for Faloga Soil" IRC, Indian Highways, Vol. 9, No. 10.

[10] AASHTO, (2013). "Standard Specification for Transportation Materials and Methods of Sampling and Testing", American Association of State Highway and Transportation Officials, 14th Edition, Part II, Washington, D.C.

[11] Sarsam S. I. and AL-Zubaidi I. (2014) 'Assessing Tensile and Shear Properties of Aged and Recycled Sustainable Pavement", International Journal of Scientific Research in Knowledge, (IJSRK) 2(9), pp. 444-452, 2014.

[12] Sarsam S. I., Al-Delfi K. H. (2014) "Initial Cracking Potential of Asphalt Concrete', International Journal of Scientific Research in Knowledge, IJSRK, 2(12), pp. 538-548.

[13] Yoder E. J. and Witczak M. W. (1975) "Principles of pavement design", 2nd edition, John Wiley and sons Inc.

[14] Sarsam S. I. and Husain A. (2015) "Impact of Nano Materials on the Durability of Asphalt Stabilized Soil", American institute of science, Journal of Nano science and Nano engineering Vol. 1, No. 2, pp. 23-37.