International Journal of Chemical Engineering and Analytical Science
Vol. 1, No. 1, 2016, pp. 53-59
http://www.aiscience.org/journal/ijceas

Influence of Nano Material Additives on Dissipated Energy Through the Fatigue Process of Asphalt Concrete

Saad Issa Sarsam*

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

Abstract

Dissipated energy is defined as the energy loss per load cycle in any repeated or dynamic test. The use of Nano material additives in pavement construction is known to give the conventional asphalt cement and asphalt concrete mixture better engineering properties, as well as it is helpful to extend the fatigue life of asphalt concrete pavement. Fatigue damage occurs due to load repetitions and aging of asphalt concrete, it could be represented as the amount of energy dissipated in the specimen during testing. Fatigue could be minimized by controlling the dissipated energy; which can be used to explain the decrease in mechanical properties, such as flexural stiffness. In this research, an investigation was made in order to understand the influence of Nano additives on the dissipated energy through the fatigue resistance process in asphalt pavement. Repeated four-point flexure bending beam test in controlled strain mode has been implemented. Asphalt concrete mixtures were prepared using different percentages of asphalt cement and additives (silica fumes, coal fly ash). Asphalt concrete slab samples of (300 x 400 x 60) mm were prepared using roller compaction, beam specimens of (400 x 50 x 60) mm were cut from the slab samples. Beam specimens were for fatigue life using Nottingham four point bending beam device under the influence of three levels of micro-strain (750, 400, 250), at 20°C. During testing, dissipated energy per cycle per volume has been monitored through the changes in mix behavior and damage accumulation. The impact of Nano additives, strain level, and asphalt content on dissipated energy was discussed and compared.

Keywords

Nano Material Additives, Asphalt Concrete, Dissipated Energy, Fatigue Life, Silica Fumes, Coal Fly Ash, Flexure Bending

Received: June 15, 2016 / Accepted: June 27, 2016 / Published online: July 21, 2016

1. Introduction

The fatigue behavior of asphalt pavements has been intensively studied, it was related to stress or strain levels and other material constants, while the fatigue properties of asphalt concrete were expressed by a relationship between repetitive loading applications and the tensile stress or strain repeatedly applied, [1, 2].

Through the approaches in the 1960s and 1970s, [3-6], a large number of laboratory fatigue tests on asphalt mixtures were conducted to characterize asphalt pavement fatigue response. With such approaches, the fatigue life of asphalt concrete mixtures was related to stress or strain levels and other material constants. Attempts have also been made to determine the mode of loading that best simulates actual pavement conditions, [7]. The fatigue properties of asphalt concrete were expressed by a relationship between repetitive loading applications and the tensile stress or strain repeatedly applied, [8].

Early in the 1970s, other two alternative approaches were studied; the dissipated energy approach and the fracture mechanics methods. In the dissipated energy approach, [9], cumulative dissipated energy was recognized as the only

* Corresponding author
E-mail address: saadisasarsam@coeng.uobaghdad.edu.iq

factor used to predict fatigue life, and this energy seemed to be independent of the mix formulation and testing type, which meant that the fatigue life could be predicted if only the dissipated energy was measured. Later, it was suggested by [10, 11] that the relationship between cumulative dissipated energy and the number of cycles is not independent of the mix formulation and other characteristics of the test methods, such as temperature, modes of loading, and frequency. Dissipated energy remains a useful concept in fatigue investigation and is highly correlated with stiffness reduction during fatigue testing and helps to explain the effects of mode of loading on mix behavior, [12-14]. It is well known that the influence of filler particles size on the asphalt binder increases with decreasing size of the filler particles. However, only rough instructions are given on the dosage such as the acceptable content of filler. Nano material could improve long-term performance and functional properties of the asphalt concrete in a significant way without reducing the clear advantages of existing asphalt pavement materials, [15]. The value of Nano materials comes from the properties generated as particle size becomes smaller and the surface area to bulk ratio increases dramatically. Higher surface areas lead to a marked improvement in performance of materials used in various applications. The physical and chemical properties of Nano materials can be tuned to enable specific applications. Nano composites are produced by adding Nanoparticles to a bulk material in order to improve the bulk material properties. Materials reduced to Nano-scale can suddenly show very different properties compared to what they exhibit on a macro-scale, enabling unique applications [16-18]. The impact of three types of Nano materials on stripping potential of asphalt concrete has been investigated by [19], and the stripping of Nano asphalt concrete was modeled. The improvements in Asphalt cement physical properties after it was digested with Nano materials has been investigated by [16]. Nano materials have been reported as beneficial additives to asphalt cement and asphalt concrete mixture, fly ash, silica fumes, and hydrated lime have proved its positive impact on strength and resistance to deformation of asphalt concrete, while it improves the surface free energy of asphalt cement to resist stripping, [20, 21]. The objective of this work is to study the influence of Nano materials on the variations in dissipated Energy through the Fatigue Process of Asphalt Concrete.

2. Materials and Methods

2.1. Asphalt Cement

Asphalt cement of (40-50) penetration grade was implemented in this study. It was obtained from AL-Nasiriya Refinery, south of Iraq. Tests conducted on asphalt cement confirmed that its properties complied with the specifications of State commission for Roads and Bridges (SCRB 2003) [22], the physical properties of asphalt cement are shown in Table 1.

Table 1. Physical Properties of Asphalt Cement.

Property	Test Conditions	ASTM Designation No.	Value	SCRB Specifications
Penetration	25°C, 100gm 5 sec	D5-06	42	40-50
Softening Point	(ring &ball)	D36-895	49	-
Ductility	25°C, 5cm/mi	D113-99	136	>100
Specific Gravity	25°C	D70	1.04	-
Flash Point	Cleave land open cup	D92-05	256	>232
After thin film oven test properties D1754-97				
Penetration	25°C, 100gm, 5 sec	D5-06	33	
Ductility of Residue	25°C,5cm/mi	D113-99	83	
Loss on Weight	163°C, 50g, 5 hr.'s		0.35	-

2.2. Coarse and Fine Aggregates

Crushed coarse aggregate (retained on sieve No.4) with a nominal size of 19 mm was obtained from AL-Ukhaydir-Karbala quarry. Crushed sand and natural sand were used as Fine aggregate (passing sieve No.4 and retained on sieve No.200), and were obtained from the same source. The aggregates were air dried and separated into different sizes. Their physical properties are listed in Table 2.

Table 2. Physical Properties of Coarse and Fine Aggregate.

Property	Value	ASTM Designation No.
Coarse Aggregate		
Bulk specific gravity	2.542	C127-01
Apparent specific gravity	2.554	C127-01
Water absorption %	1.076%	C127-01
Wear %(lose Angeles abrasion)	18%	C131-03
Fine Aggregate		
Bulk specific gravity	2.558	C128-01
Apparent specific gravity	2.563	C128-01
Water absorption %	1.83%	C128-01

2.3. Mineral Filler

The mineral filler passes sieve No.200 (0.075mm). The filler used in this work is limestone dust, and was obtained from Karbala governorate. The physical properties of the filler are presented in Table 3.

Table 3. Physical Properties of Filler (Lime stone dust).

Property	Value
Bulk specific gravity	2.617
% Passing Sieve No.200	94

2.4. Coal Fly Ash

Coal Fly ash is the finely divided residue that results from the combustion of ground or powdered coal, it was obtained from local market, it was sieved, and the portion passing sieve No.200, (75 micron) was implemented in this investigation as Nano material for partial substitution of filler. Table 4. Shows its physical properties. The chemical composition is illustrated in Table 5.

Table 4. Physical properties of Coal fly ash.

Property	Specific gravity	Specific surface area (m^2/ kg)
100% passing sieve size (75) micron	2.645	650

Table 5. Chemical composition of coal fly ash class F.

Chemical composition	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	Loss on ignition
%	61.9	2.6	28.8	0.8	0.3	0.26	0.8

2.5. Silica Fumes

It was manufactured by Wacker Silicon Company in Germany as fluffy powder, and obtained from local market; silica fumes were added as Nano material to the asphalt cement directly with continuous heating and stirring. Table 6 shows its physical properties, while Table 7 presents the chemical composition of the Silica fumes.

Table 6. Physical properties of Silica fumes.

Maximum sieve size	PH value	Density (kg/m^3)	Specific surface area (m^2/ kg)
Passing 0.075	4.5	2.6455	200000

Table 7. Chemical components of Silica fume as supplied by the manufacturer.

Chemical Composition	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	SO_3	Loss on ignition
%	99.1	35.0 P.P.M	<0.035	<0.006	0.03	52.0 P.P.M	<0.07	0.7

2.6. Selection of Aggregate Gradation

The selected gradation in this study follows the SCRB Specification [22] for dense graded wearing course, with 12.5 (mm) nominal maximum size of aggregates. Fig. 1 show the selected aggregate gradation.

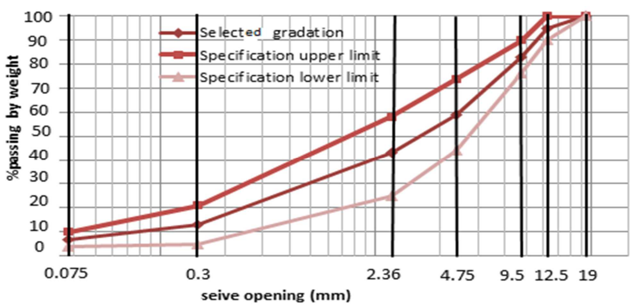

Fig. 1. Selected Aggregate Gradation and Specification Limits.

2.7. Preparation of Asphalt Cement – Nano Material Mixture

Modified Asphalt cement with Nano material was prepared by using the wet process. In the wet process, asphalt cement was heated to a 150°C and then blended with a Silica Fumes with different percentages (1%, 2% and 3% by weight of asphalt cement) using a blending speed of about 1300 rpm and blending temperature of 170°C for 20 minutes to promote the chemical and physical bonding of the components as shown in Fig. 2. During the blending process, the asphalt cement swells, which is an indication of possible reaction with Silica fumes. 3% of silica fumes was selected for this investigation. Details of blending and testing are presented in [20, 21].

2.8. Preparation of Asphalt Concrete – Nano Material Mixture

Modified asphalt concrete mixture was prepared by using the dry process. In the dry Process, coal Fly Ash was added to the mixture as partial replacement of filler. Various percentages of coal Fly Ash (2%, 4% and 6% by weight of aggregates) have been tried. 4% of coal fly ash was selected for this investigation. Details of the mixing and testing are presented in [16, 17].

2.9. Preparation of Asphalt Concrete Mixture

Coarse and fine aggregates were combined with mineral filler to meet the specified gradation as per SCRB, [22]. The combined aggregate was then heated to a temperature of (160°C) before mixing with asphalt cement. The asphalt cement was heated to a temperature of (150°C) to produce a kinematic viscosity of (170±20) centistokes. Then, asphalt cement was added to the heated aggregate to achieve the desired amount, and mixed thoroughly by hand using a spatula for two minutes until all aggregate particles were coated with asphalt cement. The mixture was then subjected to 4 hours of short term aging process at 135°C according to AASHTO procedure as cited by [1] before compaction. The asphalt concrete mix was casted in a slab mold. Mixes were prepared at optimum asphalt content and at an asphalt contents of 0.5 percent above, and 0.5 percent below the optimum. Slab Specimens were prepared using Roller Compactor Device according to, EN12697-33 procedure as cited by [1, 8]. A slabs specimen of 400 mm in length, 300 mm in width, and of 60 mm thickness was prepared using the hot aged loose mix. A static load of (5 kN) and number of variable passes depended on the asphalt content and the target bulk density of 2.2826 Kg/cm^3 in mix have been implemented, 20 passes for 5.4% asphalt content, 30 passes for 4.9% asphalt content (optimum), and 60 passes for 4.4%asphalt content. Then the compacted slab were cut by the Diamond saw into beams 63±6 mm wide and 400 mm (15.75 in) long. Details of slab and beam preparation are fond in [1, 8, 23].

2.10. Testing of Beams for Repeated Flexural Fatigue

The four point flexure fatigue procedure as per (AASHTO T 321) [24], was implemented to determining the Fatigue Life of Compacted Hot-Mix Asphalt, and to monitor the dissipated energy variation under Repeated Flexural Bending. The flexural fatigue test was performed by placing the asphalt concrete beam in repetitive four points loading at a specified strain level. During the test, the beam is held in place by four clamps and a repeated haversine (sinusoidal) load is applied to the two inner clamps with the outer clamps providing a reaction load as shown in Fig. 3. This setup produces a constant bending moment over the center portion of the beam (between the two inside clamps). The deflection caused by the loading is measured at the center of the beam. The number of loading cycles to failure can then give an estimate of mixture's fatigue life. Another important value that can be obtained from the beam fatigue test is the dissipated energy of the specimen. The testing is performed at intermediate temperatures of 20°C.

Fig. 2. Blending of modified asphalt cement.

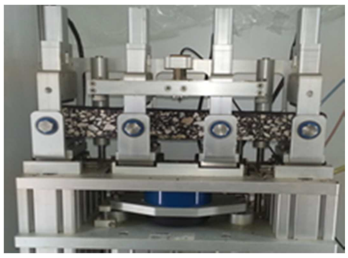

Fig. 3. Repetitive four points loading.

Test results were recorded at each load cycle intervals and the test was terminated when the beam has reached a 50 percent reduction in stiffness. Test results were completed in a Microsoft Access database application.

3. Results and Discussion

Dissipated energy was measured at strain level of 750µƐ, 400µƐ, and 250µƐ, frequency level of 5Hz, and Test temperature of 20°C. Results for Dissipated energy were obtained from the software of flexural fatigue test.

3.1. Impact of Nano Material Type and Micro Strain Levels on Dissipated Energy

Fig. 4 shows the impact of Nano materials on dissipated energy at 4.4% asphalt content, it demonstrates that as the micro strain level increases, the fatigue life decreases. The fatigue life of asphalt concrete modified with coal fly ash decreased by 50% when the micro strain level increases from 250 to 400, while it decreases by 90% as the micro strain level increases from 400 to 750. Such finding correlates well with [23] work.

It can be observed that the dissipated energy increased sharply at the early loading cycles up to 15 cycles, then the rate of increment was gentle for further loading. The trend of the relationship was parallel at different micro strain levels and is concave down. At failure (50% of the stiffness retained), higher dissipated energy could be observed at lower micro strain level, 20% reduction in dissipated energy could be detected when micro strain level was increased from 250 to 400. On the other hand, 85% reduction in dissipated energy was noticed when the micro strain level increases from 400 to 750.

When silica fumes were implemented as Nano material additive, Fig. 5 demonstrates that the dissipated energy was low up to 200 loading cycles for various micro strain levels, then the dissipated energy increases sharply and exhibits lower fatigue life when compared to coal fly ash case. The trend of the relationship was concave up, and the variation in fatigue life with the change in micro strain level was high. The fatigue life decreases by 80% when the micro strain level increases from 250 to 400, while the fatigue life decreases by 60% when the micro strain level increases from 400 to 750. It could be concluded that silica fumes exhibits minor influence on the loss of energy during fatigue as compared to coal fly ash, while it shows lower fatigue life.

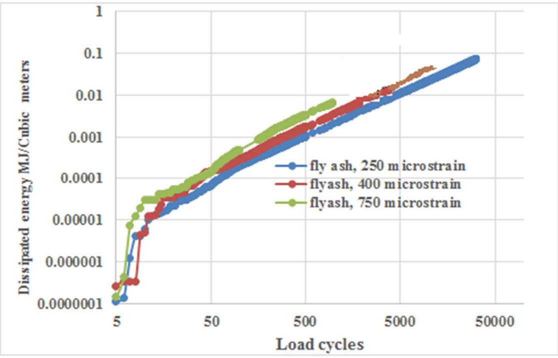

Fig. 4. Impact of coal fly ash at various micro strain levels.

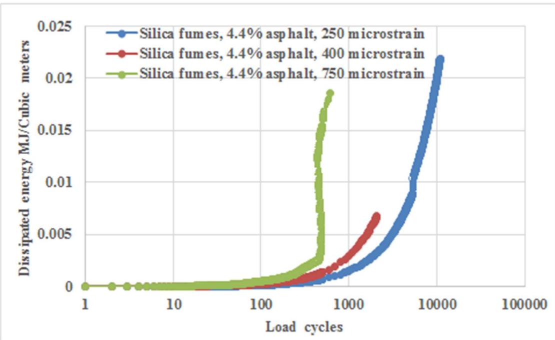

Fig. 5. Impact of silica fumes at various micro strain levels.

3.2. Impact of Asphalt Content on Dissipated Energy

Fig. 6 show that the dissipated energy per cycle increases as the number of load repetitions increases at optimum asphalt content and high micro strain level of 750. Coal fly ash exhibit longer fatigue life of 50 and 40% when compared to both silica fumes and reference mixes respectively. On the other hand, low level of dissipated energy at failure could be observed for all mixes at optimum asphalt content when compared to those of lower percentage of asphalt content presented in Fig. 5 at the same micro strain level.

Fig. 7 shows that at higher asphalt content of 5.4% and low micro strain level, the impact of Nano material additives was not significant in terms of dissipated energy. Coal fly ash exhibit the longest fatigue life of 48000 load cycles as compared to that of silica fumes and reference mixes with 45000 and 30000 load cycles respectively.

Fig. 8 presents a summary of dissipated energy test results for various asphalt percentages, micro strain levels, and type of Nano material additive. The positive impact of Nano material additives on lowering the dissipated energy level could be detected at various micro strain levels. Coal fly ash exhibit better performance in retaining the quality of asphalt concrete by increasing its fatigue life and reducing the level of dissipated energy as compared to the performance of silica fumes and reference mixes. Such behavior of coal fly ash agrees well with [1 and 8] findings.

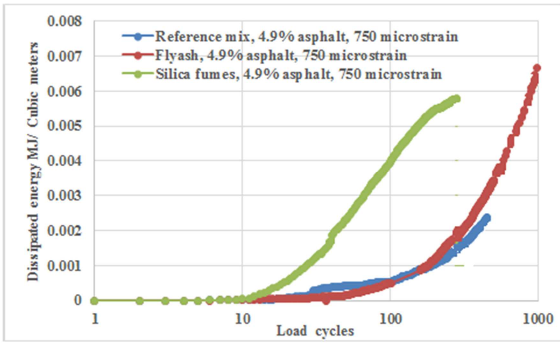

Fig. 6. Impact of Nano additives type at high micro strain level.

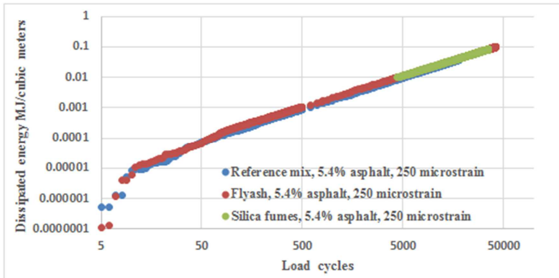

Fig. 7. Impact of Nano additives type at low micro strain level.

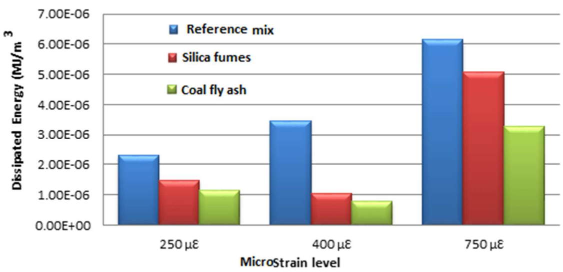

Fig. 8. Summary of Nano materials impact on dissipated energy at optimum asphalt content.

4. Conclusions

Based on the limited testing program, the following conclusions may be drawn:

1. Positive impact of Nano material additives on lowering the dissipated energy level could be detected at various micro strain levels. In general, the increase in micro strain level leads into a remarkable decrease in the fatigue life of asphalt concrete, while, at the same time, it leads into an increase in the dissipated energy value.

2. The fatigue life of asphalt concrete modified with coal fly ash decreased by 50% when the micro strain level increases from 250 to 400, while it decreases by 90% as the micro strain level increases from 400 to 750.

3. The fatigue life of asphalt concrete modified with silica fumes decreases by 80% when the micro strain level increases from 250 to 400, while the fatigue life decreases by 60% when the micro strain level increases from 400 to 750.

4. Silica fumes exhibits minor influence on the loss of energy during fatigue as compared to coal fly ash, while it shows lower fatigue life.

5. At high asphalt content of 5.4% and low micro strain level, the impact of Nano material additives was not significant in terms of dissipated energy.

6. Coal fly ash exhibit better performance in retaining the quality of asphalt concrete by increasing its fatigue life and reducing the level of dissipated energy as compared to the performance of silica fumes and reference mixes.

References

[1] Sarsam S. I. and AL-Lamy A. K. (2016) “Fatigue Behavior of Modified Asphalt Concrete Pavement” Journal of Engineering, Vol. 22 No. 2, February.

[2] Epps, J. and C. L. Monismith (1972) "Fatigue of asphalt concrete mixtures- A summary of existing information." Fatigue of Compacted Bituminous Aggregate Mixtures, Special Technical Publications 508, American Society for Testing and Materials, pp.19-45.

[3] Monismith, C. L. and Deacon, J. A. (1969) "Fatigue of asphalt paving mixtures." Transportation Engineering Journal. ASCE 95(2), pp.317-346.

[4] Deacon, J., Tayebali, A. M., Geoffrey. Monismith, C., (1995) "Validation of SHRP A-003A Flexural Beam Fatigue Test." Book Engineering Properties of Asphalt Mixtures and the Relationship to their Performance, ASTM, STP 1265.

[5] Van Dijk, W. (1975). “Practical Fatigue Characterization of Bituminous Mixes.” Journal of the Association of Asphalt Paving Technologists, Vol. 44, pp. 38.

[6] Adhikari, Zhanping (2010), "Fatigue Evaluation of Asphalt Pavement using Beam Fatigue Apparatus". The Technology Interface Journal/Spring. Volume 10 No. 3.

[7] SHRP-A-404 Report. (1994), "Fatigue Response of Asphalt-Aggregate Mixes", Strategic Highway Research Program, National Research Council, Washington, D. C., USA.

[8] Saad Sarsam and Ali Hussein Alwan (2014) “Assessing Fatigue Life of Super pave Asphalt Concrete” American Journal of Civil and Structural Engineering AJCSE, 1(4): 88-95.

[9] Van Dijk, W. and W. Vesser (1977) “The Energy Approach to Fatigue for Pavement Design.” Journal of the Association of Asphalt Paving Technologists, Vol. 46.

[10] Pronk, A. C., Hopman, P. C., (1990) "Energy dissipation: the leading factor of fatigue. In Highway Research: Sharing the Benefits." Proceedings of the Conference of the United States Strategic Highway Research Program, London, UK.

[11] Ghuzlan, K. A., Carpenter, S. H. (2000) “Energy-Derived, Damage-Based Failure Criterion for Fatigue Testing.” Transportation Research Record, TRB, 1723, 141-149. National Research Council, Washington, D.C, pp. 141-149.

[12] Hamed, F. K., (2010), "Evaluation of Fatigue Resistance for Modified Asphalt Concrete Mixtures Based on Dissipated Energy Concept," Ph.D. Thesis, Department of Civil Engineering and Geodesy Technische Universität Darmstadt.

[13] Maggiorel C., Airey G., Marsac P., (2014) “A dissipated energy comparison to evaluate fatigue resistance using 2-point bending” Journal of Traffic and Transportation Engineering (English Edition), 1(1): 49-54.

[14] Shen S., Carpenter S., (2007) “An energy approach for airport pavement low damage fatigue behavior” FAA worldwide airport technology transfer conference, Atlantic City, New Jersey, USA.

[15] Arabania, M., Haghib, A. K., Tanzadehc, R., (2012) "Laboratory Study on the Effect of Nano-SiO2 on Improvement Fatigue Performance of Aged Asphalt Pavement." Proceedings of the 4th International Conference on Nanostructures (ICNS4)12-14 March, Kish Island, I.R. Iran.

[16] Sarsam S. I. (2013) “Improving Asphalt Cement Properties by Digestion with Nano Materials” Research and Application of Material RAM. Sciknow Publications Ltd. USA, 1(6): 61-64.

[17] Sarsam S. I. (2015) “Impact of Nano Materials on Rheological and Physical Properties of Asphalt Cement” American institute of science, International Journal of Advanced Materials Research, public science framework, Vol. 1, No. 1, pp. 8-14.

[18] Sarsam S. I. (2016) “Influence of Nano Materials Addition as Partial Replacement of Cement in the Properties of Concrete Pavement” Journal of Nano science and Nano engineering, Public science framework, American institute of science, Vol. 2, No. 1, pp. 1-5.

[19] Saad Sarsam and Esra AL-Azzawi (2013) “Effect of Nano materials on surface free energy of asphalt cement” Proceedings, 2nd Engineering scientific conference, college of engineering, Mosul University, 19-21 November, Mosul, Iraq.

[20] Sarsam S. (2015) “Effect of Nano Materials (Silica Fumes And Hydrated Lime) on Rheological and Physical Properties of Asphalt Cement” Proceedings, Third International Scientific Conference, ME3-CM01, University of Babylon-Hilla- IRAQ, May 20-21.

[21] Sarsam, S. I., (2013) "Effect of Nano Materials on Asphalt Cement Properties," International Journal of Scientific Research in Knowledge (IJSRK), 1(10), pp. 422-426, 2013.

[22] SCRB, (2003) “Standard Specification for Roads and Bridges” Section R/9, Revised Edition. State Commotion of Roads and Bridges, Ministry of Housing and Construction, Republic of Iraq.

[23] Sarsam S. and Shujairy A. (2015) “Assessing Fatigue Life of Reclaimed Asphalt Concrete Recycled with Nanomaterial Additives” International Journal of Advanced Materials Research, Public science framework, American institute of science, Vol. 1, No. 1, pp. 1-7 USA.

[24] AASHTO T-321. (2010), "Method for Determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to Repeated Flexural Bending," AASHTO Provisional Standards.