International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Longer Fatigue Life for Asphalt Pavement Using (SBS@Clay) Nanocomposite

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Accepted 22 March 2015, Available online 02 April 2015, **Vol.5, No.2 (April 2015)**

Abstract

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. And 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 bitumen used in this research was AC (60/70) penetration grade, modified with 5% styrene–butadiene–styrene as well as nanoclay (nCL) at four different modification levels namely 2%, 4%, 6% and 8% by weight of the bitumen. Morphology and structural of the prepared materials were investigated using spectroscopic techniques such as Transmission electron microscope (TEM) and Scan electron microscope (SEM). Penetration and softening point were used to evaluate the modified bitumen as well indirect tensile strength test and fatigue test were carried out to characterize the properties modified and unmodified asphalt concrete mixtures. Based on the results, it was found that using (SBS@Clay) nanocomposite improves both penetration and softening point of all modified bitumen. Tensile strength for modified mixtures with 5% SBS and 6% nanoclay is higher than unmodified mixtures by nearly three times. Fatigue life of (SBS@Clay) modified mixtures equals to 3.4 times higher than unmodified bitumen.

Keywords: *Modified bitumen, Tensile strength, nano-clay, styrene–butadiene–styrene , fatigue , asphalt concrete mixtures.*

1. Introduction

The question still exists: why do we need to improve the properties of Bitumen? Increased traffic loads and climate change is still a big challenge for researchers in the asphalt road industry. Researches are trying to find a new addition to improve the properties of bitumen and to have a clear impact in the performance of asphalt roads. Physical and mechanical properties of unmodified bitumen make it unable to withstand the loads of traffic as well as climate change, so the researchers tried to search for materials are added to the bitumen to improve these properties. Last decade using polymers to modify bitumen in asphalt concrete pavement applications has been growing rapidly. Many types of polymer are used to improve the properties of the bitumen such as rubber, SBR and SBS. The rheological properties of (SBS) modified bitumen were studied and the result shows that at high temperature real increase in the binder elasticity. On the other hand addition of styrene-butadiene-styrene (SBS) to base bitumen improves the flexibility at low temperatures (Morales, *et al*, 2006), (Xiaohu and Isacsson, 1997), (Bernard, 1996).

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The right material amounts and compatibility for a suitable polymer-bitumen mix depend on several factors, of which the most important are the chemical compositions of the bitumen and polymer, and the manufacturing process. Most likely polymer used to modify bitumen is polyethylene, polypropylene and styrene-butadiene-styrene (SBS). Traditional test is not enough to evaluate the properties of the modified produced bitumen. The engineering properties of modified bitumen are directly affected by the mixing proses polymer into bitumen. During the mixing proses the structural and chemical compositions of both materials are changed. The mixing time affect the compatibility between polymer and bitumen and it should be determine carefully (Pérez-Lepe, *et al*, 2003), (Burak, and Isikyakar, 2008), (Yetkin, 2007), (Ronald, 1998).

Three (SBS) polymer contents was added to base bitumen and the properties of the resulting modified bitumen was evaluated by conventional as well as dynamic shear rheometer (DSR). The resulting modified bitumen is function of different factors bitumen source, bitumen–polymer compatibility and polymer concentration. High aromatic bitumen plus high polymer modification level lead to highly elastic network for the modified bitumen. The highly elastic network increases the viscosity, complex modulus and elastic response of the modified bitumen (Goh, *et al*, 2011), (Ghaffarpour, and Khodaii, 2009), (Gordon, 2003).

On the other hand, scientists found that the addition of polymers to improve the properties of the asphalt is enough to get satisfactory results in terms of the performance of the road. These days, the use of nanoscale materials has become a new addition to the asphalt road industry. Clay can be modified using nanotechnology to produce clay in nano scale which will be compatible with organic monomers and polymers. Using nanoclay as bitumen modifier improve the tensile strength of the resulting modified asphalt concrete mixtures (Jianying,, *et al*, 2007), (Shaopeng,, *et al*, 2009), (Zhanping,, *et al*, 2011).

Clay/styrene–butadiene–styrene (SBS) modified bitumen composites have higher higher complex modulus, lower phase angle than unmodified bitumen (Mikula,, *et al*, 2003), (Shell Bitumen, 1991), (Khodary, 2010). Nanoclay modified bitumen show better rheological properties compared to unmodified bitumen. The addition of 2% nanoclay to the unmodified bitumen increase the dynamic shear complex modulus (G*) value by 66%. CaO/Bitumen and Ca(OH)2 Nanopaticles was found that can improve stiffness properties of bitumen and asphalt concrete mixtures (Mahdi,, *et al*, 2009), (Khodary,, *et al*, 2014),

Pavement distress is considered complex topics as several factors contribute to the pavement failure. At high temperatures under traffic loading the asphalt is not able to maintain the original shape of the pavement, which leads to permanent deformation, known as rutting at low temperatures the asphalt, gets brittle and tends to crack because the stiffer structure is unable to relax the internal stresses (Finn,, *et al*, 1997), (Yi-Chang,, *et al*, 2009).In this work 5% (SBS) modified bitumen was mixed with 4 modification level of Nanoclay namely 2%, 4%, 6% and 8%. The rheological and mechanical properties of the resulting blend were evaluated in terms of penetration, softening point, static creep test and fatigue test.

2. Materials

Different types of materials were used in this work to design asphalt concrete mixtures aggregate, bitumen, styrene–butadiene–styrene and Nano- clay. The mixture proportions determined in accordance with the design limitation of the Egyptian specifications.

2.1 Aggregate

Aggregate generally accounts for 92 to 95 percent of asphalt concrete mixtures. Aggregates are divided into two types; coarse and fine aggregates. Coarse aggregates are portions that are retrained on a sieve of 2.36 mm while aggregates that are retrained on between 2.36mm and 75μm are considered as fine aggregates. Crashed lime stone aggregate were used in this study and the lime is used as filler. The properties of the used aggregates are shown in Table (1).

Table 1 Aggregate properties

Test	AASHTO Designation No.	Results	Spec. Limits
Specific Gravity	T-85	2.75	2.5 : 2.8
Water absorption (%)	T-85	2.39	≤ 5
Los Angeles Abrasion (%)	T-96	27	≤ 40

2.2 Bitumen

A petroleum substance that has a high viscosity is extracted by crude oil distillation process under pressure and high temperatures up to 300 degrees Celsius. It has many types differ by liquidity and concentration as well as the different degree of melting and freezing temperatures. Bitumen type affects the properties of the produced asphalt concrete mixtures In this work bitumen (60/70) penetration grade was used. The physical properties of the used bitumen are presented in table (2).

Table 2 Bitumen properties

Test	Result	Specification limit
Penetration (at 25ºC), 0.1 mm	67	60 - 70
Softening Point, ºC	51	45-55
Specific Gravity	1.04	1-1.1
Flash Point,	260	≥250

2.3 Styrene butadiene styrene (SBS)

Styrene butadiene styrene (SBS) is assumed to be one of the most important asphalt additives. SBS polymer gives the modified binder the desired properties such as elasticity, plasticity and elongation. Therefore using SBS-modified asphalt improves the adhesive property of the mixtures, fatigue resistance and rutting resistance. The physical properties of styrene butadiene styrene (SBS) are presented in table (3).

Table 3 Physical properties of styrene butadiene styrene (SBS)

Physical properties of SBS	Unit
Denestiy	1240 kg/m³
Young's modulus (E)	2.800-3100 MPa
Tensile strength (σt)	30-50 MPa
Elongatian at break	10-200%
Melting point	180 °C

2.4 Clay Nanoparticles

The X-ray fluorescence (XRF) technique is a proven technique for material analysis in a broad range of industries. In this work XRF is used to determine chemical composition of the used nano-caly. Using this techniques help to understand the chemical reaction between the materials used in this study. Clay consists of Al2O3, SiO2, CaO, TiO2 and Fe2O3 in different proportions. SiO2 represents the highest chemical composition of clay. Table (4) and Figure (1) presented the chemical composition of nano-caly.

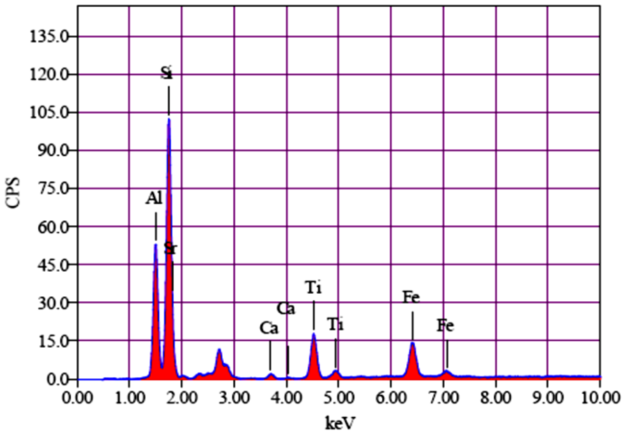

Fig.1 Results of X-ray fluorescence test on used nanocaly

Table 4 Chemical composition of nanoclay

Element	Wieght %	Element	Wieght %
Al	36.2315	Al2O3	28.0483
Si	58.4555	SiO2	67.9236
Ca	0.6107	CaO	0.5453
Ti	3.1178	TiO2	2.7018
Fe	1.1655	Fe2O3	0.4694

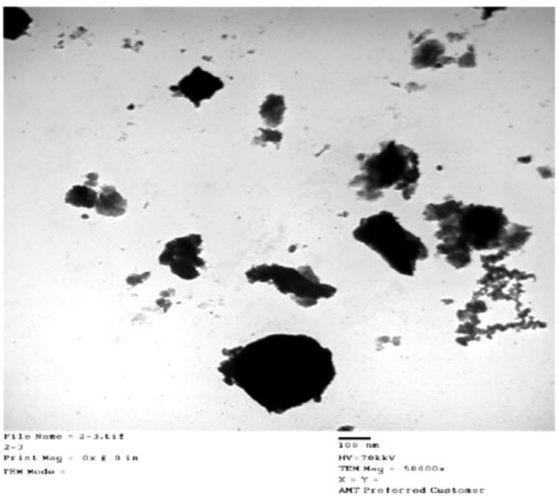

Fig.2 Morphology and structural of the nanocaly

Morphology and structural of the nanocaly materials were investigated by transmission electron microscopy (TEM, JEOL JEM-1230 with accelerating voltage of 120 kV) with EDX detector unit attached to the system. From figure (2) it is appear that the dimension of nanoclay ranges between 1 nm and 200 nm. Smaller particle of nanoclay decrease the void ratio in asphalt concrete mixtures which directly increase the resistance to permanent deformation.

3. Preparation of modified sample and asphalt mixtures

To prepare the modified bitumen, firstly the bitumen is heated alone to a 175°C. 5% of styrene butadiene styrene (SBS) (by weight of the total bitumen content in asphalt concrete mixtures) is added to the heated bitumen to produce the required modified blend. The modified blend is thoroughly mixed at 170 °C for 25 minute with a low shear mixer at a blending speed of 700 rpm.

Four modification level of nanoclay is added after heating the bitumen with (SBS). The percentages of nanoclay added to the modified bitumen are 2%, 4%, 6, and 8% by weight of the total bitumen content in asphalt concrete mixtures). After this step the modified bitumen with (SBS@Clay) is ready to use in asphalt mixtures.

The aggregates were placed in an oven at 175 °C for 1 hour. After mixing aggregate and binder the mixture was placed in the heated mold and the mixture was compacted with standard Marshall compaction hammer on each side. Marshall-sized specimen of (2.5 in. height by 4 in. diameter) is fabricated. Marshall specimen used for indirect tensile strength test as well as fatigue test. The percentage of each asphalt concrete mixtures component was present in table (5) according to the Egyptian specification (4c).

Table 5 Gradation of aggregates and Filler for asphalt concrete mixtures

Sieve size (mm)	aggregate (A)		aggregate (B)		sand		Filler		Total Mix.	Specification (4C)	
	%P	30%	%P	30%	%P	35%	%P	5%		lower	Upper
25	100	30	100	30	100	35	100	5	100	100	100
19	85	25.5	100	30	100	35	100	5	95.5	80	100
12.50	33	9.9	100	30	100	35	100	5	79.9	70	90
9.50	4	1.2	87	26.1	100	35	100	5	67.3	60	80
4.75			30	9	100	35	100	5	49	48	65
2.36			5	1.5	89	31.15	100	5	37.65	35	50
0.60			1	0.3	50	17.5	100	5	22.8	19	30
0.30					31	10.85	100	5	15.85	13	23
0.15					9	3.15	94	4.7	7.85	7	15
0.075					5	1.75	46	2.3	4.05	3	8

4. Characterization of Bitumen and Asphalt Concrete Mixtures

Different laboratory tests were conducted in this research including Penetration Test, Softening Point, indirect tensile test, fatigue test

4.1 Penetration test

Penetration that measure the strength of asphalt expressed in the distance that standard needle pierced vertically in the sample under certain conditions of loading, time and temperature (100 gram load time is 5 seconds and 25 ° C) to be unity (0.01 cm).

The sample is heated to become liquid and then placed in a template (template penetration) and then the sample placed in a water bath to completely submerge the sample 25 degree Celsius The dish is placed on the base device penetration is then adjust the needle and above fixed weight on the surface of the sample Is accessing the necessary adjustment congruent needle penetration with image on the surface of the asphalt material, the spectrum using flashlight Damocles of convenient place The index is set to zero Launches the needle to penetrate the asphalt material is measured by the distance penetrated the needle in the specified time (Akbar, 2003).

4.2 Softening point test

The softening point is useful in the classification of bitumens and is indicative of the tendency of the material to flow at elevated temperatures. usually soften of the Bitumen at not occur at any time or in any temperature, if the higher temperature state of matter asphalt changed gradually from a solid to a softer and less viscous and most case smoother, and it must make a softening test by way termed Set which can be compared to the results of the asphalt materials among them (ASTM, 1998).

4.3 Indirect tensile test

Indirect tensile test is used to evaluate tensile strength of asphalt concrete mixtures. It is known that indirect tensile test is one of the most popular tests used to evaluate the tensile resistance of asphalt concrete mixtures. The test performed by applying compressive load on Marshall specimen acting parallel to and along the vertical diametric (Kennedy, 1977), (Christensen and Bonaquist, 2004) This loading configuration developed a relatively uniform tensile stress perpendicular to the direction of the applied load and along the vertical diametral plane. The horizontal tensile stress at the center of the test specimen was calculated from Equation (1).

$$\sigma_t = \frac{2P_{max}}{\pi D H} \tag{1}$$

Where

σt = Indirect Tensile Strength
Pmax = Maximum Load
H = Thickness of Specimen
D = Diameter of Specimen

4.4 Fatigue test

A cylindrical specimen is subjected to a constant repetitive compressive load which acts parallel to and along the vertical diametric plane. Damage occurs in a specimen from dynamic repetitive loading that leads to fatigue failure of the specimen. The phenomenological approach was used to calculate fatigue life.

The fatigue life of a specimen is defined as the number of load repetitions at which specimen fracture occurs. Controlled stress at stress level of 50% of the static indirect tensile strength and at a frequency of 10 HZ. Number of load cycles to the specimen failure is defined as fatigue life of asphalt concrete mixtures (Richard,, *et al*, 1997), (Tayebali,, *et al*, 1992),(Zhiming and Lytton, 2002).

$$N_f = a\left(\frac{1}{\sigma t}\right)^b \tag{2}$$

Nf = Fatigue life (number of cycles to failure),
σ_t = initial stress
a , b = Material coefficients, derived of fitting the data.

5. Test result

5.1 Penetration test result

Penetration test results illustrate the impact of using (SBS@Clay) nanocomposite of the bituminous resistance to penetration. The results show that adding (SBS@Clay) nanocomposite clearly influences penetration of the modified bitumen. By increasing the penetration of modifier the resistance to penetration increased. The decrease in the value of the penetration assumed to be clear evidence of asphalt concrete pavement resistance to traffic loads as well as the permanent deformation. Improvement in penetration properties improve the directly the pavement performance and this is one on the main goals of this research looking for stronger asphalt concrete pavement. Good correlation was found between penetration test rest and modification level. This result is promising result that can to be used in the future for finding the optimum modifier content at the needed penetration. Table (6) and Figure (3) present the result of penetration test.

Table 6 Penetration test results

Bitumen Type / Test	Penetration @ 25 ° C	Softening Point ° C
Control 0% SBS + 0% Nanoclay	70	43
Modified bitumen with 5% SBS + 2% Nanoclay	66	47
Modified bitumen with 5% SBS + 4% Nanoclay	60	55
Modified bitumen with 5% SBS + 6% Nanoclay	56	60
Modified bitumen with 5% SBS + 8% Nanoclay	55	62

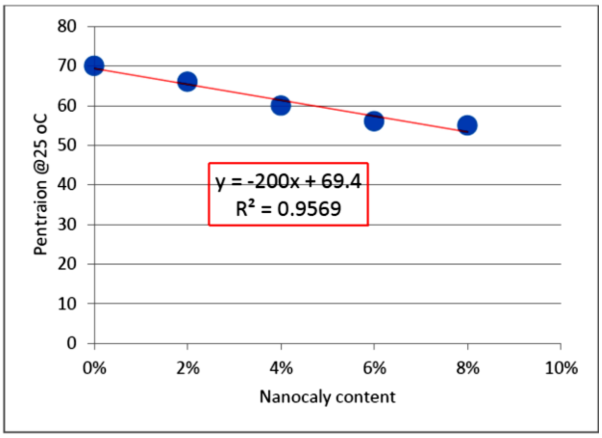

Fig.3 Penetration test results

5.2 Softening Point

Figure (2) present the result of Softening Point. Improvement in the temperature required to soften the modified bitumen is a clear proof of how the modified asphalt concrete pavement can resist climate change. This is a positive impact on the behavior of asphalt roads, especially at high temperature.

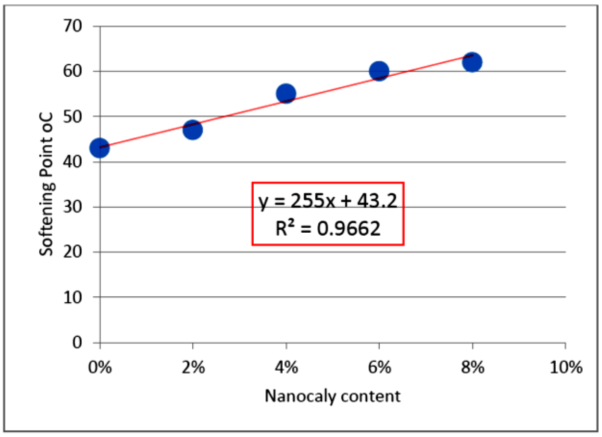

Fig.4 Softening point test results

5.3 indirect tensile test results

The use of (SBS@Clay) nanocomposite leads to a significant improvement in tensile resistance of asphalt mixtures. Improved tensile strength has direct effects on resistance of asphalt pavement to cracks. With the increase in resistance to cracks roads that means longer life of the pavement. One of the most important goals of the research to obtain improved asphalt mixes using nanotechnology and has a high tensile strength. It is clear from the results that this goal has been achieved. Figure (5) presents the indirect tensile test results.

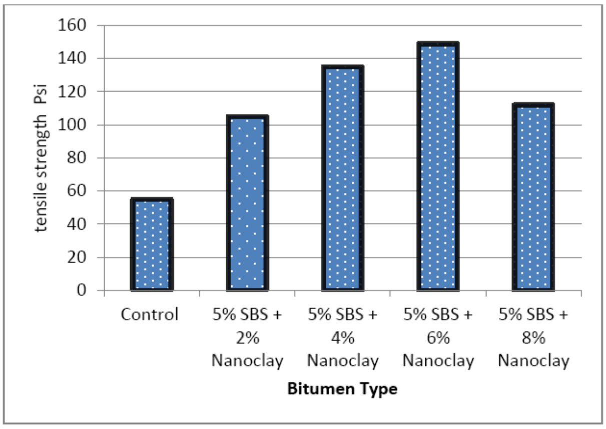

Fig.5 Indirect tensile test results

5.4 Fatigue test

Promising results have emerged after a fatigue test. Using polymer with nano materialos improve extent fatigue life of all modified mixtures. But the modified mixtures with 5% SBS and 6% nanoclay have the highest fatigue life. This result indirect tensile test coincided together with fatigue test results. The interpretation of these results is the ability of polymer materials to form strong network between aggregate and bitumen. The polymer is characterized by its ability to form with Bitumen high elastic materials which can resist tension in asphalt concrete pavement. If the produced mixtures can resist tension that means this mixtures can resist cracks.

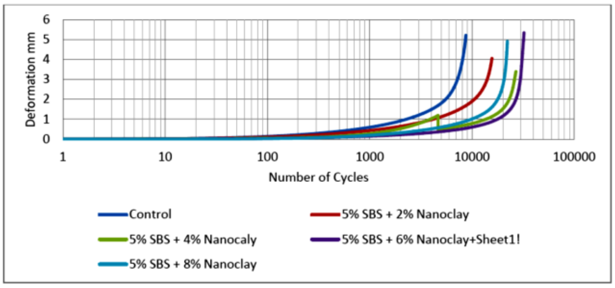

Fig.6 Deformation and number of cycles

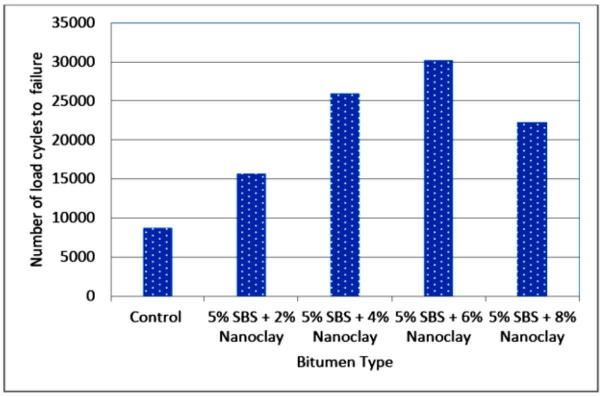

Fig.6 Fatigue life for modified and unmodified asphalt concrete mixtures

Conclusion

In this paper different tests were present to evaluate the properties of (SBS@Clay) Nanocomposite modified bitumen and mixtures. From the test results and discussions the following conclusions are presented:

1) (SBS@Clay) Nanocomposite is effective as asphalt concrete mixtures modifiers.
2) Using (SBS@Clay) Nanocomposite improves both penetration and softening point.
3) Tensile strength of with 5% SBS and 6% nanoclay is higher than unmodified mixtures by nearly three times
4) Fatigue life of (SBS@Clay) modified mixtures equals to 3.4 times higher than unmodified bitumen
5) Stronger and longer fatigue life can be achieved by using (SBS@Clay) Nanocomposite for asphalt concrete pavement.

Acknowledgment

The writer gratefully acknowledges the support offered by South Valley University in providing the facilities for the experimental work in this paper.

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