A Study on the Effects of CNT's on Hot Mix Asphalt Marshal-Parameters

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Abstract

Asphalt pavement is considered as the national capital and every year, much of the country's development budget is spent on road maintenance and improvement of the engineering characteristics of pavements. Therefore, new plans must be used to improve quality and to increase productivity and durability of conventional asphalt pavements. In this investigation, it has been attempted to promote technical characteristics of asphalt mixture using carbon nanotubes as an additive material for bitumen. So far, there has been little discussion about carbon fibber modified asphalt concrete but dimension of discussed fibbers have been in range of micro not nano. In this article, marshal test parameters of hot mix asphalt, modified with carbon nanotubes, are investigated and compared to conventional asphalt mix. Wet and dry process methods are most practical ways of mixing CNF in AC. It was decided that the best method to adopt for this investigation was dry process. In this study marshal test parameters of modified asphalt by 0.1, 0.5, and 1% carbon nanotube content in bitumen was evaluated considering marshal test, then results were compared to conventional asphalt mix. Obtained results shown, using carbon nanotube improves hot mix asphalt marshal stability and decreases marshal flow.

Key words: hot mix asphalt, carbon nanotubes, additive, marshal test

1. Introduction

Instead of using materials in large scale, we can use nanomaterials which are defined as restructuring of matter on the order of nanometers (i.e., less than 100 nm) to create materials with fundamentally new properties and functions. Nanotechnologies are the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometer scale. It is widely seen as having huge potential to bring benefits in diverse areas such as production of stronger and lighter materials [Bergman and Jung de Andrade, 2011]. In the field of civil engineering, while a large amount of research has been carried out in the last decade on carbon nano-modification of cement-based materials [Oncel and Yurum, 2006] and polymer composites [Chong and Garboczi, 2002; Makar and Beaudoin, 2003], very few studies have been conducted in the area of bituminous binders and mixtures. The mechanical behavior of bituminous mixtures depends on structural elements and phenomena that occur in a micro and a nano scale. As a result, nanotechnology can modify the molecular structure of asphalt, which leads to improvement in the material's bulk properties. Nanotechnology can also improve the mechanical performance, durability, and sustainability of asphalt concrete. The revolutionary effects accompanying nanotechnology allows the development of cost-effective, high-performance, and long-lasting products of bitumen and asphalt concrete which can lead to unprecedented uses of such materials. One of the most desired properties of nanomaterials in the construction sector is their capability to confer a mechanical reinforcement to bituminous-based structural materials. Carbon nanotubes (CNTs) were discovered by Iijima in 1991 as the fourth form of carbon [Zhang, 2007]. CNT can now be considered as the "king" of nanomaterials as it is being used in many applications i.e medicine, electronics, energy and environment, etc [Wilson et al., 2008]. Because of the carbon-carbon sp^2 bonding, carbon nanotubes (CNTs) have high stiffness and axial strength. Carbon Nanotubes (CNTs) have a Young's modulus of 1 TPa, five times larger than the best steel and also five times larger than high-quality carbon fibers [Taha, 2009].

Carbon nanotubes (CNTs) are hollow tubular channels, formed either by one single walls carbon nanotube (SWCNTs) or malty walls carbon nanotube (MWCNTs) of rolled graphene sheets [Grobert, 2007; Lau and Hui, 2002]. They have received an increasing scientific and industrial interest due to their physical and chemical properties that is suitable for different potential applications ranging from living matter structure to nanometer-sized computer circuits and composites [Dai, 2002; Popov, 2004].

Since CNTs exhibit great mechanical properties along with extremely high aspect ratios (length-to-diameter ratio) ranging from 30 to more than many thousands, they are expected to produce significantly stronger and more ductile bituminous composites than traditional reinforcing materials (e.g. glass fibers or carbon fibers). In fact, because of their size (ranging from 10 nm to 20 nm) and aspect ratios, CNTs can be distributed in a much finer scale than common fibers, giving as a result a more efficient crack bridging at the very preliminary stage of crack propagation within composites. However, properties and dimensions of CNTs are strongly depend on the deposition parameters and the nature of the synthesis method, i.e., arc discharge [Ando, 1994], laser ablation [Maskar et al., 2002], or chemical vapor deposition (CVD) [Maskar et al., 2002; Oncel and Yurum, 2006]. Carbon nanotubes used in this investigation were produced by chemical vapor deposition technique with diameters from 10 up to 20 nm and different length (fig.2). The high specific strength, chemical resistance, electrical conductivity and thermal conductivity of carbon nanotubes (CNTs) make them attractive for use as reinforcement to develop superior bituminous composites [Chong and Garboczi, 2002; Makar and Beaudoin, 2003].

In the study presented in this paper process of making bitumen modified by carbon nano tubes was explained and marshal stability, specific gravity and flow of asphalt specimens containing various percentages of CNTs were evaluated. Also penetration and softening point which are two classic test on bitumen were done to evaluate modified bitumen properties. Based on the obtained experimental results, the effects of CNTs on material properties were analyzed and discussed.

2. Materials and methods

2.1. Material

Materials used in the experimental investigation included a neat bitumen 60/70-penetration grade from Tehran mineral oil refinery with the physical properties listed in Table 1. The aggregates used in this study were graded using the continuous type IV scale of the AASHTO standard [AASHTO, 1993] which is presented in table 2.

Purity grade	Deflagration	Softening point	Penetration Grade	Density
	^{o}c	^{o}c	mm/10	25^{o}c
99	262	49	53	1.03

Table 1. Properties of used bitumen

Sieving Size (mm)	25	19	12.5	9.5	4.75	2.36	0.3	0.075
Topka's P.P (%)	-	100	95	-	59	43	13	6

Table 2. Gradation of used aggregate

A commercially available multiwall CNTs with purity up to 95%, was used in this research. All mixtures were built according to ASTM D1559 [ASTM, 2002]. The image of Carbon nanotubes was presented in figure 1. Also the Characterization of Carbon nanotubes (CNTs) is showed at the Table 3.

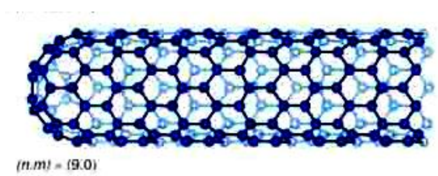

Fig.1: Carbon nanotubes (CNTs) image

Properties	Unit	Value	Method of Measurement
Average Length	µm	10-30	TEM
Carbon Purity	%	95	TGA
Amorphous Carbon	-	*	HRTEM
Density	g/cm^3	2.1	-

Table.3 Carbon nanotubes (CNTs) Properties

2.2. Experimental Procedure

Three different percentages of CNT were chosen to produce bitumen-CNT blends (0.1%, 0.5% and 1.0% by weight of the base binder). A simple shear mixing technique was employed to incorporate CNTs into the base bitumen not only because it is very convenient in laboratory operations, but also because it has the potential of being easily transferred to the industrial scale in hot mix asphalt plants. Following preliminary attempts in which different mixing times and temperatures were considered. The final mixing protocol adopted in the study consisted of two subsequent phases. the first phase in which CNTs were added and manually blended to the bitumen, and the second phase in which the bitumen-CNT blends were mixed with a mechanical stirrer operating at a speed of 1,550 rpm for a total time of 40 minutes in order to obtain satisfactory homogeneity. Scanning electron microscope (SEM) image of Carbon nanotubes (CNTs) are shown in figure 2. Also the image of mechanical stirrer is presented in figure 3. During both phases of mixing, temperature was set at 160°C and kept constant by means of an oil bath, which was heated by a hot plate.

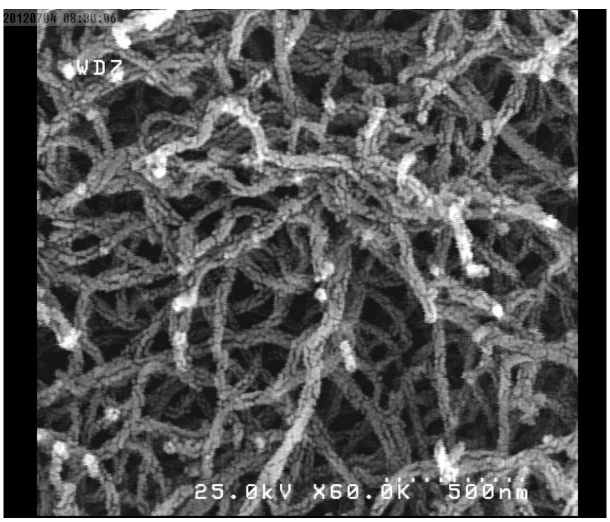

Fig. 2: Scanning electron microscope (SEM) image of Carbon nanotubes (CNTs)

Fig.3: Mechanical stirrer used in this research

2.3. Laboratory Tests

2.3.1. Rheological Tests on Bitumen

To determine the optimum content of carbon nanotubes (CNTs), empirical rheological tests carried out on conventional and modified bitumen with different CNTs content. In this study, the penetration degree test was done for Control sample and samples containing different percentages of carbon nanotubes. The empirical tests were performed according to the standard test procedures. The penetration test is an empirical test which measures the consistency (hardness) of asphalt at a specified test condition according to ASTM-D5 standard. Also for determination the softening point of bitumen, the ASTM-D36 was used.

2.3.2. Marshall Test

Marshall experiment is one of the most important tests used in this regard. This experiment is described in detail in the ASTM D1559 standard. Marshall stability is the maximum load (in kilograms) that asphalt sample can support without breaking when loaded and Marshall flow is the deformation read (in millimeters) during the maximum load and failure. Marshall Quotient (stability/flow) is an indicator for the strength of asphalt mixtures. In this study, mechanical properties of the samples are compared with each other and finally, amount of materials and the resulting changes will be determined.

3. Results and Analysis

3.1. Penetration Degree Test

Figure 5 shows a graph of the penetration degree changes. According to Figure 5, at first, it can be seen that there is no change in graph between control sample and 0.1% modified bitumen. It is because of the negative effect of aging, which happens during mixing process in high temperatures. With the addition of carbon nanotubes to bitumen, penetration degree of bitumen reduces. This reduction is due to the high surface density and high stability and tensile stability of carbon nanotubes. It is obvious that with increasing the amount of nanotubes, penetration degree will further be reduced. Finally, the produced bitumen can be used in warmer climates or areas with more traffic.

3.2. Softening Point Test

Figure 6 shows a graph of the softening point changes. As the result of aging during the mixing process and its effect on the bitumen thermal sensitivity a decrease is seen in the softening point at low levels of carbon nanotubes usage, but the higher levels of carbon nanotubes resulted in an increase, because the Young's modulus and high stability carbon nanotube causes the bitumen to show more stability against the flowing and thus increases the softening point. This bitumen can be used in areas with high average annual temperature or areas with more and heavier traffic.

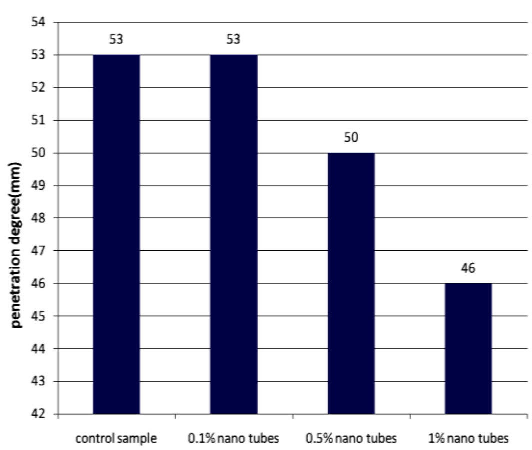

Fig.5: Comparison of penetration degree test for different samples

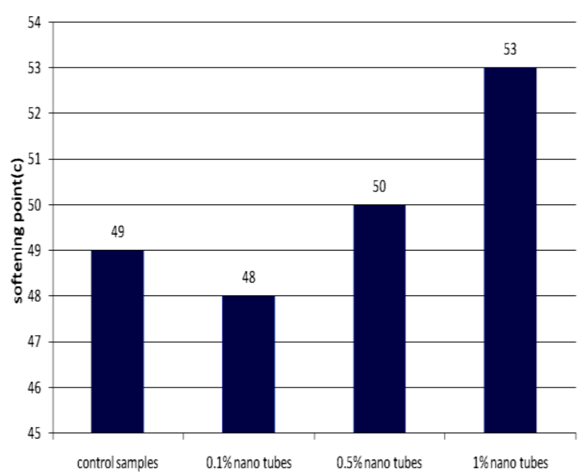

Fig.6: Comparison of softening point test results for different samples

3.3. Marshal Test

As mentioned in the first stage with Mechanical Stirrer and 160°C and for 40 minutes, carbon nanotubes were uniformly mixed with the bitumen. Then using this product, samples of asphalt concrete Marshal Test was made. Given the high cost and lack of easy access to the carbon nanotubes, at this stage of the process economic aspects should be considered more than before. Therefore, it was just contended to make samples containing 0.001, 0.005 and 0.01 carbon nanotubes by weight of bitumen. Based on the results, the graphs of different characteristics of asphalt concrete samples for various percentages of nanotubes are listed below: The Figure 7 shows that the use of carbon nanotubes increases the Marshal stability of asphalt concrete. According to Figure 8, it can be seen that carbon nanotubes cause decreasing in specific gravity to 0.68% less than the control sample.

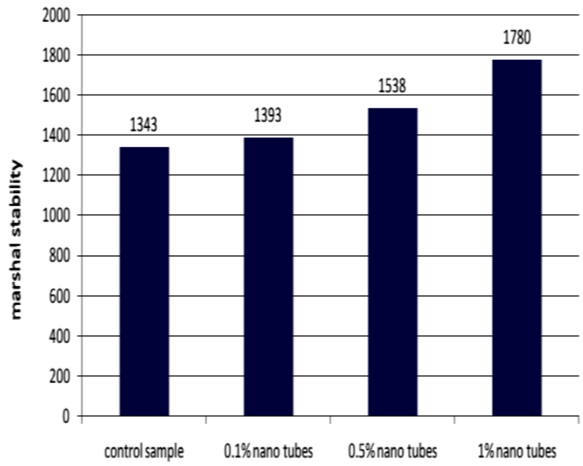

Fig.7: Marshal stability changes in adding to bitumen

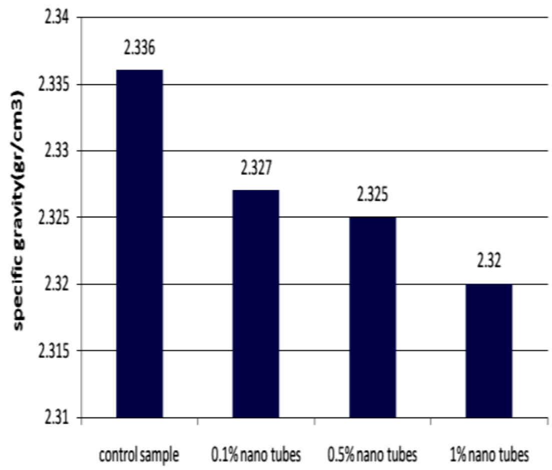

Fig. 8: Specific gravity changes in adding to bitumen

Decreasing in specific gravity is due to the high surface density of the carbon nano tubes. The reason is actually the special properties of carbon nanotubes, but the most important are surface density, high stability and high tensile stability. As shown in the Figure 9, it is observed that increasing carbon nanotubes causes decrease in flow of asphalt concrete. The reason of decreasing of flow is high Young's modulus of carbon nanotubes. According to the changes of resistance and flow and their relationship with Marshal Ratio, the Figure 10 is quite reasonable. For example, sample containing 0.01 Carbon nanotubes has highest stability and lowest flow and thus has the highest Marshal ratio.

3.4. Best Selections

According to the results, charts, diagrams, and based on criteria such as stability, flow, marshal ratio and specific gravity, the best example of this mode is selected. In this case, the more carbon nanotubes increase, the better asphalt concrete specifications will be. Thus sample containing 0.01 carbon nanotubes by weight of bitumen, has the best results. This sample regarding Marshal Stability 32.53 percent and Marshal Ratio 44.71 percent is higher than the control sample. Also Marshal flow 8.4 percent and specific gravity 0.68 percent is lower than control sample. It should be noted that despite the decrease in flow, it is still within the permitted regulation.

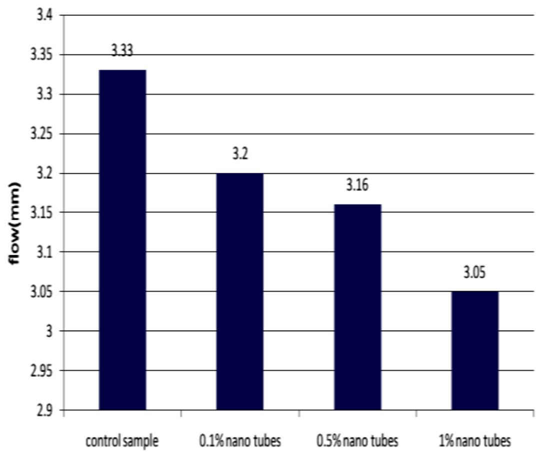

Fig.9: Marshal flow changes in adding to bitumen

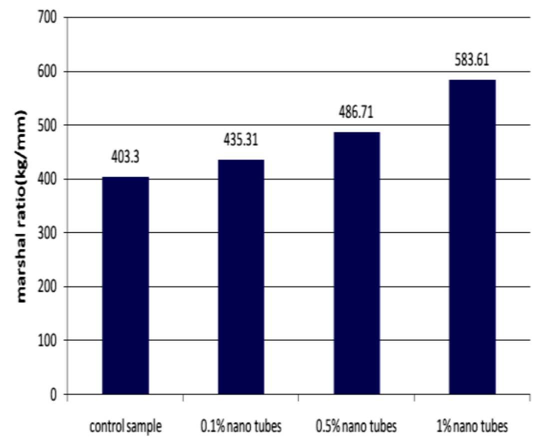

Fig.10: Marshal ratio changes in adding to bitumen

4. Conclusions

Due to the increasing development of nanotechnology and special features of carbon nanotubes, you can use them as the ideal choice in asphalt mixtures. The aim of this study was experimental investigation on the effects of using carbon nano tubes on hot mix asphalt marshal parameters. Based on the laboratory test results, the following conclusions were obtained:

- Two samples, respectively, had the best results:

"A sample is containing 0.0005 carbon nanotubes by weight of bitumen."
"A sample is containing 0.001 carbon nanotubes by weight of bitumen."

- The initial cost of both samples is higher than the control sample but for total cost, the amount and type of work should be investigated.
- When using modified mix, due to its high stability, the lower layer thickness will be less than the control mix and then the amount of total costs will decrease.
- A mixture with minimal mechanical changes in the characteristics of asphalt mixtures is obtained that in comparison with conventional asphalt mixtures, not only in terms of physical properties is not much different, but also improves the quality of its chemical properties.

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References

AASHTO, (1993), Guide for design of pavement structures.

Ando, Y., (1994),The preparation of carbon nanotubes. Fuel Sci Technol; 2(2):173–80.

ASTM D 1559, (2002), Standard Test Method for Marshal Test, Annual Book of ASTM Standards, American Society for Testing and Materials, West Conshohocken.

Bergman, C.P., & Jung de Andrade, M., (2011), Nanostructured materials for engineering applications, Springer.

Chong KP, Garboczi EJ., (2002), Smart and designer structural material systems, Prog Struct Mater Eng; 4: 417–30.

Dai, H., (2002), Carbon nanotubes: opportunities and challenges, Surf Sci; 500: 218–41.

Grobert N., (2007), Carbon nanotubes becoming clean. Mater Today;10 (1–2): 28–35.

Guoping Zhang., (2007), Soil nanoparticles and their influence on engineering properties of soils, Geo-Institute.

James. K. Mitchell, Kenichi. Soga., (2005), Fundamentals of soil behavior, John Wiley & Sons, 3d edition.

Lau KT, Hui D., (2002), The revolutionary creation of new advanced materials – carbon nanotube composites. Composites: Part B; 33: 263–77.

Makar JM, Beaudoin JJ., (2003), Carbon nanotubes and their applications in the construction industry. In: Proceedings of the first international symposium on nanotechnology in construction, Paisley, Scotland; 331–41.

Maser WK, Benito AM, Martinez MT.,(2002), Production of carbon nanotubes the light approach. Carbon;40(10): 1685–95.

Michael A. Wilson, Nguyen H. Tran, Adrian S. Milev, G.S. Kamali Kannangara, Herbert Volk, G.Q. Max Lu., (2008), Nanomaterials in soils, Geoderma journal.

Oncel C, Yurum Y.,(2006), Carbon nanotube synthesis via the catalytic CVD method, a review on the effect of reaction parameters. Fullerene, Nanotubes, Carbon Nanostruct;14: 17-37.

Popov, VN.,(2004),Carbon nanotubes: properties and application. Mater Sci Eng R;43(3): 61-102.

Taha, M.R., (2009), Geotechnical properties of soil-ball milled soil mixtures, Proc. of the 3rd International Symposium on Nanotechnology in Construction, Prague, Czech Republic, 377-382.