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Bitumen Modification Using Carbon Nanotubes

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Abstract: In this investigation, it has been attempted to promote technical characteristics of bitumen and asphalt mixtures using carbon nanotubes as an additive matterial for bitumen,. Therefore, in this research, parameters such as bitumen's permeability degree, softening point, flash point, ductility, marshal stability, marshal flow, marshal ratio (stability/flow) and asphalt specific gravity will be investigated. In the samples containing nanotube, nanotube should completely be mixed with the bitumen. In this case with increasing the amount of carbon nanotube, technical characteristics will also be better. But the issue that should be considered is the cost of this plan. Among the made examples, the sample that its bitumen contains carbon nanotube equals to 0.001 of weight bitumen, has the best results; while its initial cost is higher than prototype, it can cause a considerable saving in total cost. But due to its high initial cost, it's better to use this sample in projects in which economic issues are less important and quality is more considered, like airport superstructure. Using these mixtures, in addition to improving asphalt pavement properties, will decrease thickness of under layers and as a result reduce stone materials consumption.

Key words: Nano technology · Carbon nanotubes · Bitumen · Asphalt pavement · Construction cost

INTRODUCTION

Science and nanotechnology (nano science and nanotechnology), is the ability to take control of matter at nanometer scale (molecular) and utilizing the properties and phenomena of this dimension in materials, tools and modern systems. This simple definition has much of its meaning. For instance, nanotechnology with its cross-disciplinary nature will encompass all today's technologies in future and instead of competing with available technologies will take their growth direction in hand and integrate them as " a word of science".

Nanotechnology is mentioned as a "technology renaissance" and "smooth flow of capital". New products based on this technology will cause major mutation in the welfare and quality of life, environmental and defense capabilities and also major economic displacement. Now public and private sectors of different countries like Japan, America, Europe Union and etc. are in intense competition for being the world's leading in at least one area of this technology. Now collectively about 30 countries have a "national program" or developing it in the field of nanotechnology and during the past five years, they have increased the budget of nanotechnology research up to 3.5 times. Japan and the United States have declared the nanotechnology as the first priority in the technology field [1].

In nanometer dimensions, there are several important parameters such as size, shape, atomic bonds between them, etc. that influence the properties of the materials. In the case of carbon nanotubes, physical and chemical properties include some parameters such as length, diameter, number of walls, structural defects and functional groups on nanotubes. A nanotube is a hollow cylinder with a diameter in nanometers as its name suggests. Nanotube length can be several nanometers to several micrometers [2].

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Special and unique properties of carbon nanotubes including high Young's modulus, good tensile stability, high thermal conductivity, high surface density and carbon nature of nanotubes (carbon material, which is due to the low weight, extremely stable and easy to process and cheaper to produce than metal) led to be used as an additive and asphalt modifier.

MATERIALS AND METHODS

Carbon Nanotube: One of the major discoveries related to Nanotechnology, is discovery of Nanotube (Figure 1). Nanotubes are pages of carbon atoms that move inside roller part and are similar to wire net. In fact, Carbon Nanotube, is a hollow carbon tube (Figure 2) [3].

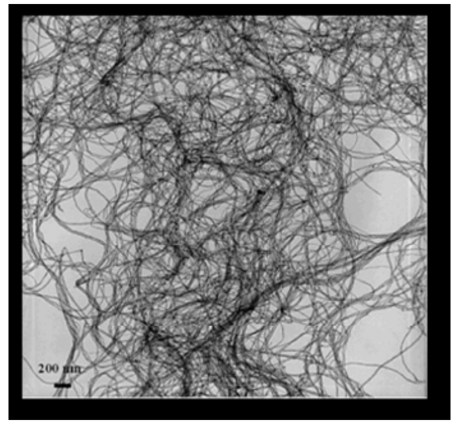

Fig. 1: Carbon Nanotube [3]

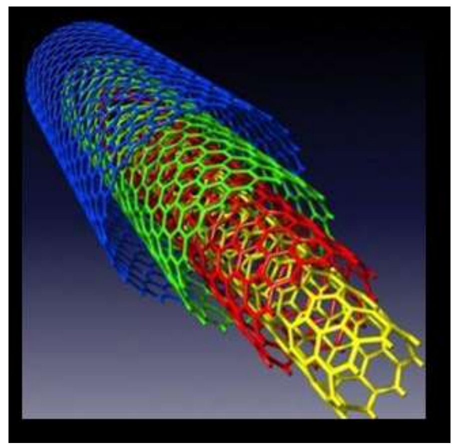

Fig. 2: hollow carbon tube [3]

Carbon nanotubes are made of carbon sources such as graphite or hydrocarbon gases by some methods such as electrical discharge. Because of these properties such as high specific surface area (700-1000 m^2/g), high stability and unique electrical and electronic properties, they are used for many applications such as a base of catalyst, mechanical reinforcement of polymers and composite and electronic parts. They are 10 times stronger than steel while their weight is one sixth of steel weight. This point has caused them to be the first choice for building bridges, airplanes or even spaceships. The only problem is that the biggest nanotube made in the laboratory is only a few millimeters. But this problem causes that carbon nanotube to be ideal in small cars. One of the problems which negatively affected on the quality of tools is abrasion of very little parts that happens thousands of times per second. The bearings are made of nanotubes, there is almost no friction and the major advantage is that the nanotubes are in both conductive and non-conductive state and this feature causes them to be used in various electrical devices. There are two types of nanotubes: single wall and double wall nanotubes, which were discovered in 1991 and 1993, respectively. Double wall nanotubes are made of graphite while, single wall nanotubes are composed of fullerene fibers. Since their discovery, several applications of these materials have been proposed among which we can mention the use of single wall type in electronic devices or as a suitable medium for hydrogen storage [4].

Fig. 3: Mechanical Stirrer [5]

In this plan, nanotubes should be mixed with bitumen uniformly. The ultrasonic mixer should be used for this work; however, considering the possibility of damage caused by the use of bitumen and the high cost of equipment, this risk cannot be done. So here, Mechanical Stirrer (Figure 3) was used for the mixing bitumen and carbon nanotubes [5].

Table 1: Control Sample (7)

Sieve size	25	19	12.5	9	4.75	2.36	1.18	0.5	0.3	0.15	0.075	Filler
Sieve No.	1	3.4	1.2	3.8	4	8	16	30	50	100	200	--
Percent on the sieve	--	0	5	--	36	16	--	--	30	--	7	6
The weight on the sieve per 1200 grams specimens	--	0	60	--	432	192	--	--	360	--	84	72

To do this, we should pour some bitumen and the desired amount of carbon nanotubes in a beaker and place it on the device. Because it should be somehow fllow so that it can be easily mixed, the heater should also be on. If the bitumen is heated up to its softness degree or slightly higher, it would reach the extent of flow required for this experiment. When building other samples, just for an hour, bitumen is heated at 120°C and then for one minute is heated up to about 130°C and immediately mixed with the used materials.

Therefore, to prevent excessive heating of the bitumen, when using the Mechanical Stirrer, the device is set at approximately 120°C and allowed to do mixing for an hour. Then when building the sample, only about one minute bitumen is heated at 130°C and immediately mixed with the aggregates. In this case, bitumen and carbon nanotubes are mixed well and bitumen is not too much heated [5].

Bitumen And Aggregates: Bitumen used in the experiments for all mixtures, should be similar and materials should also be equal. Here, for all mixtures, bitumen 70/60 and a similar optimum percentage of bitumen was used. All mixtures were built according to Issue No. 234 (Table 1) [7].

Tests

Marshal Test: Marshal test is performed on cylindrical samples with a diameter of 4 inches (10 centimeters) and height of 2.5 inches (6.25 cm). The compression of asphalt was done with the 10 pounds hammer (4.5 kg) from 45 cm height of hammer falling. After the samples were cooled at room temperature for one day, put in water bath at 60±1°C for 30 to 40 minutes and then are loaded. The experimental results are obtained from the mean of 3 samples. Number of kicks are different according to the traffic level of the desired direction. This test is described in detail in ASTM D1559 standard. Marshal resistance is the maximum load (in kilograms) that asphalt sample, without a break, will bear. Flowing is the deformation seen (in terms of millimeters) in the maximum load and failure. The Marshal Ratio is the ratio of resistance to fluidity that is an indicator for asphalt mixtures stability [6].

In this study, the mechanical characteristics of the control samples and built samples should be compared. So that finally the effect of type and quantity of materials and value of obtained changes are specified.

RESULTS

Bitumen Optimum Percentage: In this study, the bitumen optimum percentage of control mixture must be used for built samples too. According to the Marshal tests done on built samples with the desired grain size and with different percentages of bitumen (3, 3.5, 4, 4.5, 5, 5.5, 6 and 6.5), finally the 4.4% bitumen was selected as the optimum percentage. For 1200 g marshal samples, bitumen optimum percentage is equal to:

$$[X/(X+1200)]\times 100=4.4$$
$$100X = 4.4 \times 1200 + 4.4X$$
$$X = 55.2 \text{ g}$$

The results for control sample (built sample with the optimum percentage of bitumen) are showed in Table 2:

Penetration Degree Test: The first experiment performed on the bitumen, is penetration degree test. In this study, penetration degree test was done for Control sample and samples containing different percentages of carbon nanotubes. Figure 4 shows a graph of the penetration degree changes.

According to Figure 4, it is seen that 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 be further reduced. Finally the produced bitumen can be used in warmer climates or areas with more traffic.

Softening Point Test: Figure 5 shows a graph of the softening point changes.

When using carbon nanotubes, softening point increases, because the Young's modulus and high stability carbon nanotube causes the bitumen to show

Table 2: Marshal test results for control samples

	Weight (g)	Volume (cm^3)	Specific Gravity (g/cm^3)	Marshal stability (Kg)	Marshal flow (mm)
Control sample	1251.7	535.4	2.338	1496.34	3.25

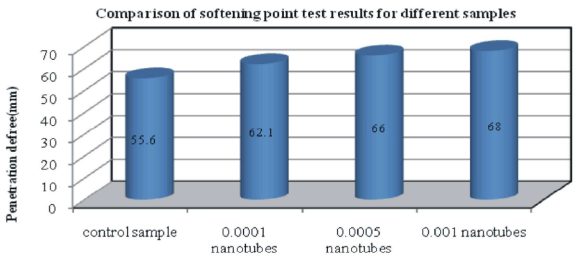

Fig. 4: Comparison of penetration degree test results for different samples

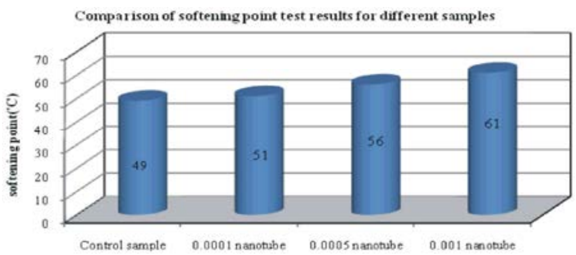

Fig. 5: Comparison of softening point test results for different samples

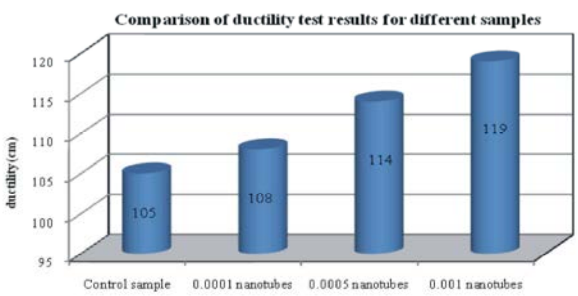

Fig. 6: Comparison of ductility test results for different samples

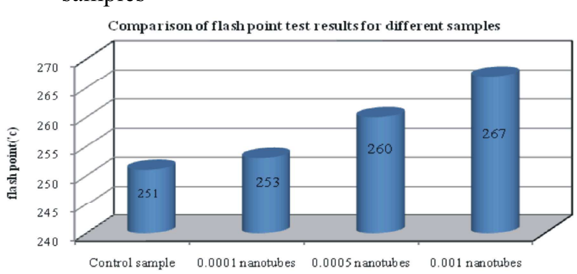

Fig. 7: Comparison of flash point test results for different samples

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.

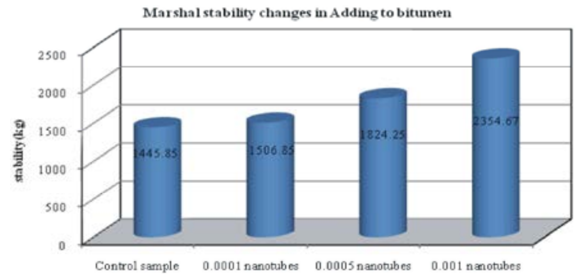

Fig. 8: Marshal stability changes in Adding to bitumen

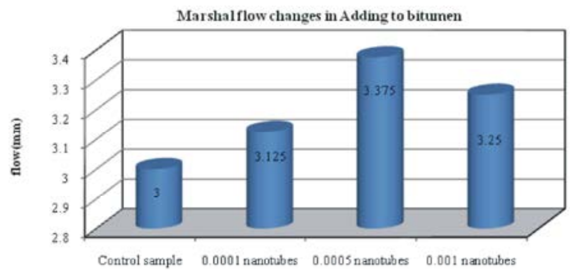

Fig. 9: Marshal flow changes in Adding to bitumen

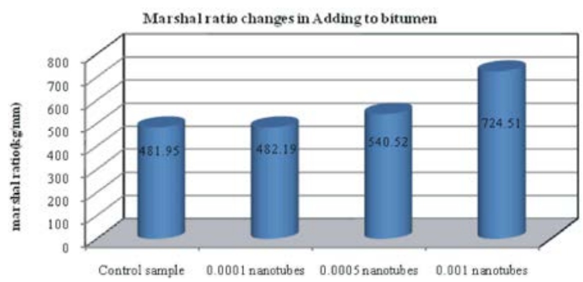

Fig. 10: Marshal ratio changes in Adding to bitumen

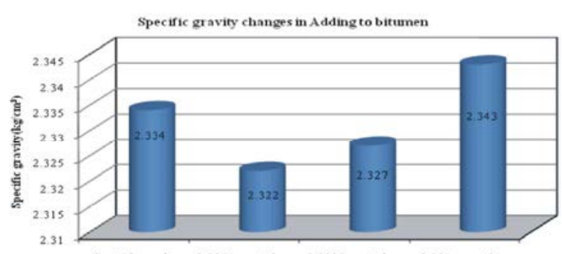

Fig. 11: Specific gravity changes in Adding to bitumen

Ductility Test: In this study, ductility test according to the Standard Methods (IP. 32/55) was done and the sample at 25°C and with a speed of 5 cm/min is drawn. Figure 6 shows a graph of the ductility changes.

In this case, with increasing carbon nanotubes, ductility properties will increase much more. The high tensile stability of Carbon nanotubes causes the greater adhesion of the bitumen and then ductility increases.

Thus, samples made are more adhesive than control sample and have more ability to stick aggregate together and can coat aggregate well.

Flash Point Test: Here to determine the flash point of bitumen, an open cup flash point tester was used. Figure 7 shows a graph of the flash point for control and other samples.

When using carbon nanotubes, with increasing carbon nanotubes, flash point will increase, because the very small size (diameter less than 0.4 nm) and high thermal conductivity of carbon nanotubes cause that bitumen absorbs heat less and reaches flash mode much later and the risk of fire will be less. Therefore flash point of built samples was higher than control sample and thus they can bear higher temperatures without flare and they have less risk of fire.

Marshal Test: As mentioned in the first stage with Mechanical Stirrer and 120°C and for anhour, carbon nanotubes are uniformly mixed with the bitumen. Then using this product, samples of asphalt concrete Marshal Test is made. Given the high cost and lack of easy access to the carbon nanotube, at this stage of the process economic aspects should be considered more than before. So it was just contended to make samples containing 0.0001, 0.0005 and 0.001 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 8 is shown that the use of carbon nanotubes increases the Marshal stability of asphalt concrete.

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 increase in flow of asphalt concrete. The increasing trend up to 0.0005 to continue and then it started to decrease. The reason of primary increasing of flow is high Young's modulus of carbon nanotubes. But the other properties of carbon nanotubes such as high tensile stability conquests Young's modulus later and thus flow reduces.

According to the changes of resistance and flow and their relationship with Marshal ratio, the Figure 10 is quite reasonable. For example, sample containing 0.001 Carbon nanotubes has highest stability and lowest flow and thus has the lowest Marshal ratio.

According to Figure 11, it can be seen that carbon nanotubes cause decreasing in specific gravity to 0.5% less than the control sample. Then graph has trend over the 0.4 percent higher than the control sample. The initial decrease in specific gravity is due to the high surface density of the carbon nanotube; although the high tensile stability overcomes surface density and specific gravity increases.

Best Selections: According to the results, charts and 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 increases, the better asphalt concrete specifications will be. Thus sample containing 0.001 carbon nanotubes by weight of bitumen, has the best results. This sample regarding Marshal stability 62.9 percent, Marshal flow 8.3 percent, Marshal ratio 50.3 percent and specific gravity 0.4 percent is higher than the control sample. It should be noted that despite the increase in flow, it is still within the permitted regulation.

Economic Estimation: When Carbon nanotubes are used, due to the high cost of materials, provisions should be made. Price per gram of single-walled nanotubes carbon with fees for blending with bitumen, almost all will be 16 $. Thus economic aspects should be given, to determine the amount of carbon nanotubes.

In the case of sample containing 0.001 carbon nanotube, the cost to build this sample should also be considered. The cost of carbon nanotubes in this sample is: 0.001 * 55.2 = 0.0552 gr 0.0552 * 16 = 0.8832 $

As it can be seen, the additional costs imposed to Marshal sample, is 8.5 $, this means that for every 55.2 gr of bitumen, the cost should be 8.5 $, that in small projects, would not be affordable.

CONCLUSION

The road pavement problems in the country, especially in the field of quality and durability of pavement, new plans must be used to improve quality and increase productivity and durability. Due to the increasing development of nanotechnology and special features of carbon nanotubes, you can use them as the ideal choice in asphalt mixtures. But because asphalt pavement is considered as the national capital and every year, much of the country's development budget is spent on road pavement, maintenance and improvement of the mechanical characteristics of pavement is the priority.

The following two examples, 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 much higher than the control sample but for total cost, the amount and type of work should be investigated. When using these samples, due to its high stability, the lower layer thickness was less than the control sample and then the amount of total costs will decrease.

Finally, 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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