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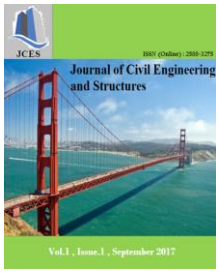

Studying the technical effect of carbon nanotube on asphalt mixture with solid granulation

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Abstract: Asphalt, this wonderful mixture that all of us deal with it every day. Perhaps the engineers in this domain as one of the solution have placed the modification of technical properties of asphalt on top of their activities for improvement of the features of this wonderful mixture. Modifying the technical properties of bitumen and asphalt has created many study opportunities all around the world. Along with it and in this article at first, with adding carbon nanotube with the amounts of 0.25, 0.50, 1 and 1.5 weight percent of base bitumen, the effect of this additive on mechanical properties of asphalt mixture was studied. In the continuation, the asphalt samples amplified with carbon nanotube for doing the Marshall Test were evaluated and tested. The results indicated that this additive causes to change in the Marshall test parameters such as increase of strength and reduction of flow. On the other hand, the special weight of asphalt mixture has faced with increase and the void space percent of aggregates faced with relative reduction. Also the void space percent of asphalt mixture and the percent of void space filled with bitumen were increased relatively. In the economic study of the effect of carbon nanotube on mixture, it was concluded that with gradual increase of carbon nanotube, the economical advantage of the project is reduced. Finally, with regard to the obtained results and analysis of the effect of this material on the bitumen and asphalt properties, it was concluded that this additive can be used in the regions with warm climate with heavy traffic and in the limited regions.

Keywords: Carbon nanotube; Bitumen; Asphalt; Marshall.

1. Introduction

Nano materials have been defined as the materials that at least one of their dimensions (length, width, thickness) is below the nanometer. Nano materials of structural elements and constituent components of bitumen and asphalt are in the micro form in Nano scale. Using of nanotechnology can cause to improve the properties of these materials; the resistance of asphalt against the losses arising from humidity, strength and life span, saving in the cost for maintenance of asphalt or the key properties like pressure strength, tensile strength and durability in enduring the load in high temperature degree can be mentioned as some of these properties (Amiri, 2011). In the study of the effect of nanoscale and fiber materials on asphalt, Zarei et al, Zahedi and Zarei and others have been mentioned [1], [2], [3], [4], [5],[6], [7] and [8].

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In this article, the nanotechnology was used for amplification of asphalt mixture. Also for construction of samples, the asphalt mixture with solid granulation and according to the ATSM standard was used. Also at the end, the economic study of the effect of this additive on asphalt mixture was done.

1.1 The researches background

Lijima (1991) declared that One of the great explorations related to the nanotechnology is carbon nanotube. It has been explored by Lijima in 19991. Nanotubes have an integrated structure with beehive hexahedral networks with a diameter of a few nanometers and a length of a few micrometers [9].

De Heer (2004)declared that nanotubes with superior mechanical properties with regard to the tube radius, the Yung modulus and tensile strength can reach in order up to 1000GPa and 1500GPa [10]

Shirakawa and et al (2012) with preparing some combinations of bitumen emulsions containing carbon nanotube and studying the distribution properties of bitumen concluded that adding the nanotubes to the emulsion combinations is effective on the ability of distribution in the emulsion so that with adding it to the emulsion in one stage, it has less effectiveness on distribution than a state that the same amount of nanotube has been added to the emulsion gradually and after mixing [11].

Akbari Motlagh and et al (2012) in order to promote the technical properties of bitumen and asphalt mixtures, used of the carbon nanotube as an additive to the bitumen.. With regard to the obtained results, whatever the amount of carbon nanotube is increased, the technical properties of asphalt concrete are also increased, so that the sample containing nanotube of 0.001 of the bitumen weight has had the best results. This sample in terms of the Marshal Strength of 62.9 percent has been superior to the witness sample [12].

The study presented by Santagata and et al (2012) has been concentrated on using of carbon nanotube in bitumen and their rheological properties in different oldness conditions have been studied that after doing the tests on combinations, the viscosity amounts with increase of temperature have been reduced and in addition, with increase of carbon nanotube percent in the combination, the viscosity has been increased and increase of viscosity is useful in improvement of resistance against permanent transformation in high temperature degree [13].

Also, Yung and Thai (2013) declared that Carbon nanotube increases the potential of thermal rutting and cracking strengths in the asphalt concrete and also it reduces the oldness ability of bitumen oxidation which is effective on long-term performance of asphalt mixtures [14].

2. Consumed materials properties

2.1 Aggregates and granulation

Aggregates used in construction of laboratory samples have been prepared from the Ghazanchi asphalt factory in Kermanshah and they are fixed in all stages of test. The mixtures ratios of asphalt mixture aggregates for Topeka layer are determined according to the table 1.

Table 1. The mixture ratios of asphalt mixture aggregates

Aggregates properties	Middle gravel	Fine gravel	Sand
The size of particles	4.75-25mm	0-19mm	0-6mm
The mixture percent of aggregates	10%	42%	48%

The curve of granulation obtained from mixture of needed weight percent in comparison with granulation applied in preparing the samples has been drawn in the Fig 1.

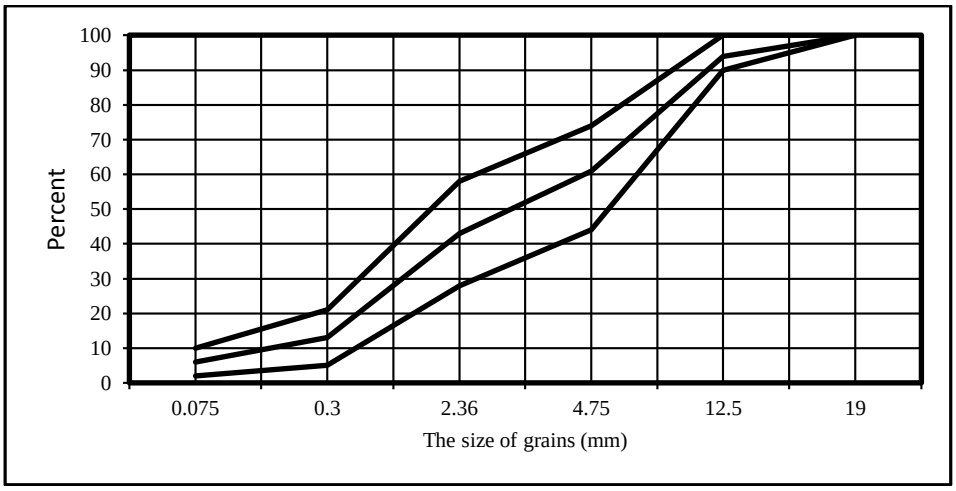

Figure 1. Diagram of granulation of aggregates mixture of asphalt mixture of Topeka layer

2.2 Consumed bitumen

For the bitumen applied from Isfahan refinery in the mixture design, the needed tests have been done on it that the related results have been inserted in the table No.2.

Table 2. The results of customary tests on consumed bitumen in the research

Property	Standard	Results
	ASTM	
The special weight in 25°c	D70	1.015
Penetration degree in 25°c (100gr-5 seconds), in 0.1mm	D5	64
The softness point (loop and ball), in centigrade	D36	49
The tension amount in 25°c, in centimeter	D113	More than 100
Inflammation degree (opencast-Cleveland), in centigrade degree	D92	289
The tension amount in 25°c, in centimeter	--	More than 100

2.3 Carbon nanotube

Carbon nanotube used in this research is multi-walled carbon nanotube with the properties of table 3.

Table 3. The properties of multi-walled carbon nanotube (MWCNTs)

Purity	External diameter	Internal diameter	Length	Specific Surface Area (SSA)	Real density	Production method
>95%	5-15nm (nanometer)	3-5nm (nanometer)	50Mm (Micrometer)	>233 m^2/g	2.6 g/cm^3	Chemical Vapor Deposition (CVD)

This additive and modifier material of bitumen according to the accomplished studies is combined with bitumen in four weight percent amounts of bitumen namely 0.5, 1, 1.5 and 2 percent. For doing this

work by using of a mechanical mixer, we should pour some bitumen with intended amount of carbon nanotube in the laboratory dish and since the bitumen should become fluid to an extent that enables us to do the mix action easily, we use of a heater for exerting heat. Therefore, for prevention from excessive exertion of heat on bitumen, we regulate the temperature of device almost on 120°c and we do the mix action for one hour [9].

3. The methods related to the construction of samples

The sample of normal asphalt mixture in the tests of this research has been a cylinder with a diameter of 4 inch (101.6mm) and a height about 2.5 inch (63.5mm) [15] that after weighting different components of aggregates, we pour the mixture which is inside the tank in the Marshall frame and by using of Marshall hammer with exertion of 75 taps on each side (for simulation of heavy traffic), the samples are compressed. The samples are taken out from inside the frame by special jacks 24 hours after compression and they are prepared for doing the tests [16].

4. The optimum percent of bitumen and Marshall Parameters of normal sample

According to the results of Marshall test of mixture design used, the percent of optimum bitumen of normal asphalt samples for Topeka layer has formed 5.2 weight percent of a sample with 1200gr weight namely 62.4 gr of the sample weight that as the result of doing the Marshall tests on the samples with different percent amounts of bitumen and obtained curves, the parameters obtained from Marshall test for the sample constructed with the optimum bitumen percent (witness sample) are according to the table 4.

Table 4. The results of Marshall test for the witness sample

Parameter	Strength (kg)	Flow (mm)	Special weight (gr/cm^3)	Void space of aggregates (percent)	Void space of asphalt mixture (percent)	Void space filled with bitumen (percent)
Amounts	1005	3.1	2.290	14.8%	3.5%	72%

5. The results of tests and discussions

By doing the Marshall tests on the asphalt concrete samples constructed from glass powder and carbon nanotube simultaneously, the physical properties and volume parameters of asphalt mixture such as Marshall strength, Marshall flow, special weight, percent of void space of aggregates mixture, percent of void space of compressed asphalt mixture and percent of void space of aggregates filled with bitumen are determined and studied.

5.1 Explanation and analysis of Marshall Strength test of asphalt mixture samples constructed with carbon nanotube

Figure 2 indicates the results of test for determining the Marshall strength of combinations containing different amounts of carbon nanotube. With regard to the obtained results, adding nanotube to the bitumen in asphalt concretes causes to increase the Marshall strength and its diagram has had an ascending procedure so that the least amount of strength for combination with 0.25 percent of nanotube and for a sample that Nano material has been used for its bitumen as much as 1.5 weight percent of bitumen. The

cause of this affair in fact refers to the special properties of carbon nanotube that high superficial density and its high tensile strength can be mentioned as some of these properties.

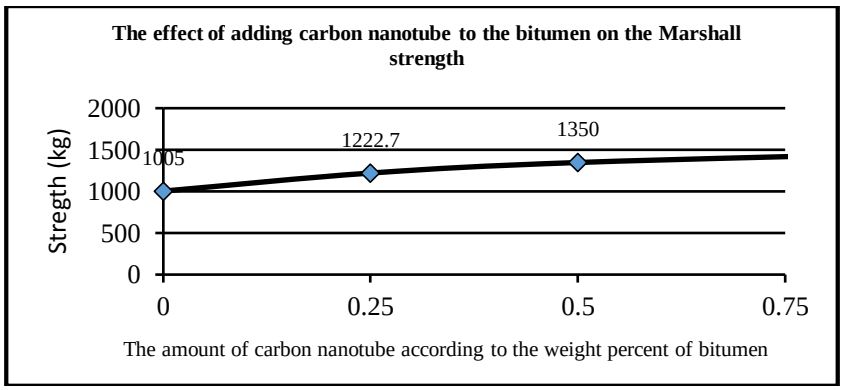

Figure 2. The changes of Marshall Strength in the state of adding the carbon nanotube to the bitumen

5.2 Explanation and analysis of Marshall flow test of asphalt mixture samples constructed by carbon nanotube

As it is observed in the diagram of the Fig 3, adding the carbon nanotube to the bitumen causes to reduce the flow of asphalt concrete. In this form that at first for the sample with 0.25% of nanotube, the flow has been reduced equal to 22.58% and after it for combination of 0.50%, the flow amount has been increased and it has become equal to 3mm that the most important cause of it is the Yung modulus of upper carbon nanotube and after it, the flow amount has had a descending procedure, because the nanotube properties like high tensile strength has surmounted on the Yung modulus.

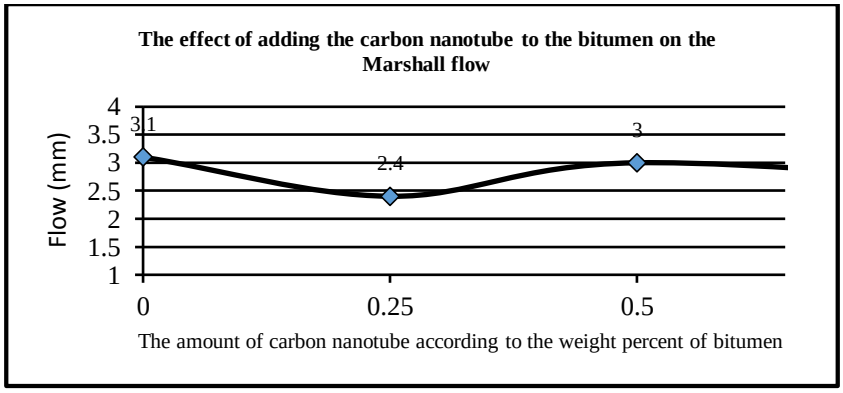

Figure 3. The changes of Marshall flow in the state of adding carbon nanotube to the bitumen

5.3 Explanation and analysis of testing the real special weight of asphalt mixture samples constructed with carbon nanotube

With regard to the obtained results, the special weight of all mixtures with nanotube is more than the control sample so that the most special weight is related to the sample containing 1% of nanotube with 1% increase in comparison with the sample without additive. Among the samples containing nanotube, the least amount of special weight related to the asphalt mixture containing 0.5 weight percent of bitumen is nanotube which is equal to 2.304 gr/cm^3 and it has had 0.61% increase in comparison with witness sample. Reduction of special weight for this sample is arising from high superficial density of nanotube; but in the continuation, high tensile strength has dominated on superficial density and it causes to increase the special weight (Fig 4).

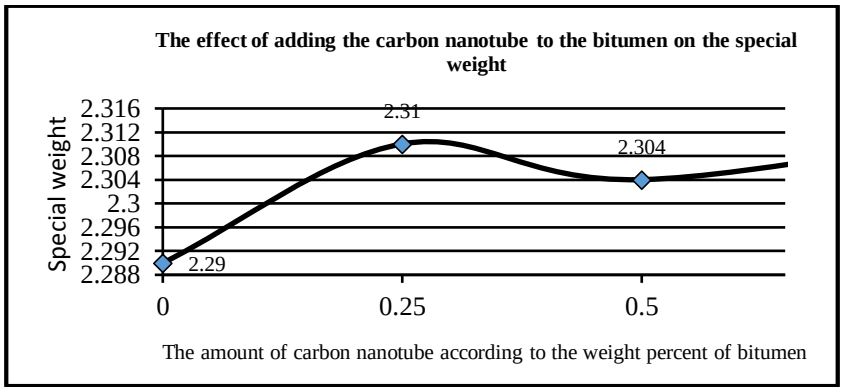

Figure 4. The changes of special weight in the state of adding carbon nanotube to the bitumen

5.4 Explanation and analysis of the results related to the void space of aggregates (VMNA) of asphalt mixture samples constructed with carbon nanotube

The results presented for the percent of void space of aggregates in the Fig 5 indicate that for all mixtures containing nanotube additive with different percent amounts, the least amount is related to the mixture of 0.25% with an amount of 14.46 and the most amount is related to the mixture of 0.50% with an amount of 14.68 that for these two combinations, it is in order 2.3 and 0.8 percent less than the witness sample. Therefore, all amounts obtained for the percent of void space of aggregates are less than the amount obtained for the witness sample.

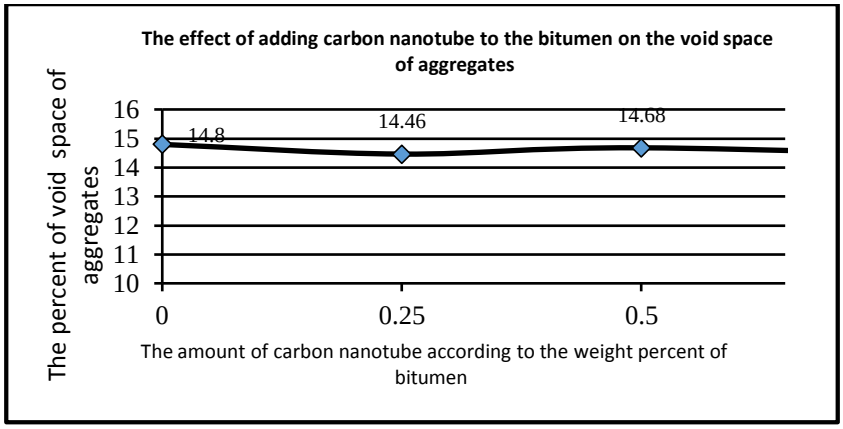

Figure 5. The changes of void space of aggregates in the state of adding carbon nanotube to the bitumen

5.5 Explanation and analysis of the results related to the void space of asphalt concrete (VTM) of the samples constructed with carbon nanotube

With regard to the diagram of the Fig 6, it is seen that increase of carbon nanotube at first causes to increase the void space of asphalt mixture up to 4.57% more than the control sample and this ascending procedure has been continued up to the sample with 0.50 weight percent of nanotube bitumen. Then the diagram has traversed the descending procedure to reach to its least amount namely 3.53% among the mixtures modified with Nano material. We should explain that the percent of void space of asphalt mixture of all samples with nanotube is more than the normal laboratory sample and these amounts are in the permitted range of regulation.

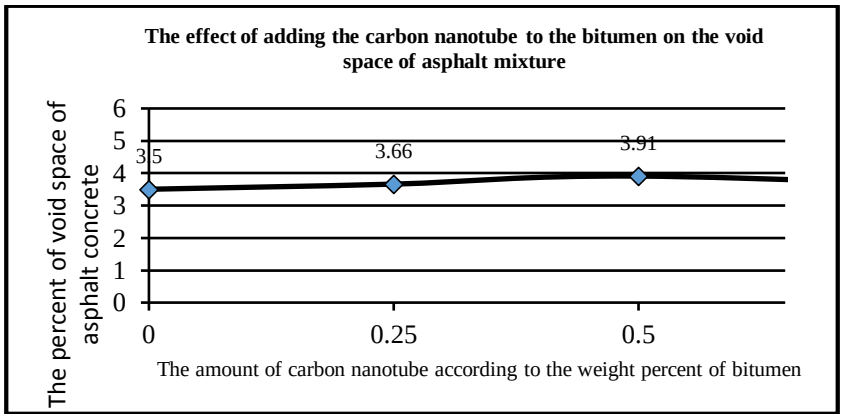

Figure 6. The changes of void space of asphalt mixture in the state of adding the carbon nanotube to the bitumen

5.6 Explanation and analysis of the results related to the void space filled with bitumen (VFA) of the asphalt mixture samples constructed with carbon nanotube

With regard to the results obtained from the Fig 7, it is observed that the volume of the void space filled with bitumen of the mixtures modified with nanotube is more than the normal sample and at first, it has an increase equal to 3.75% for the combination of 0.25%. Also the least amount of increase is related to the mixture with 0.50% of nanotube which is 1.91% more than the witness sample. The amount of space filled for a sample that its bitumen contains 1% of nanotube is equal to 75.37% that is more than other samples and it is a simple sample; while the maximum permitted amount for the heavy traffic is 75%. Therefore, it doesn't satisfy the regulation necessities about this feature.

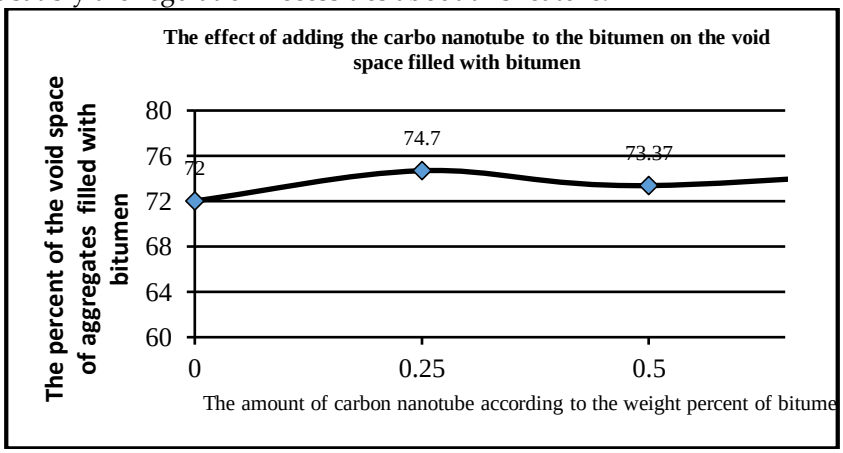

Figure 7. The changes of the void space filled with bitumen in the state of adding the carbon nanotube to the bitumen

5.7 The summary of Marshall results

In the table 5, the summary of results has been mentioned.

Table 5. The summary of Marshall Test of the samples constructed with carbon nanotube

The name of the combination	Strength (kg)	Flow (mm)	Special weight (kg/cm^3)	The percent of void space of aggregates (VMA)	The percent of the void space of the whole of mixture (VTM)	The percent of the void space filled with bitumen (VFA)
Witness	1005	3.1	2.29	14.8%	3.5%	72%
C0.25	1222.7	2.4	2.31	14.46%	3.66%	74.70%
C0.50	1350	3	2.304	14.68%	3.91%	73.37%

6. The economic analysis of using of carbon nanotube

Due to the high cost of using of carbon nanotube in the asphalt mixtures, the amount of using of this material in the bitumen should be determined with the condition of its economical justification. The cost of each gram multi-walled carbon nanotube used in this research is 4.3 dollars that for the asphalt sample with the highest percent of using of this material in the bitumen which is 1.5% of the bitumen weight namely 0.936 gram, the cost arising from carbon nanotube is equal to 4 dollars that for each one of the percent amounts of nanotube used in a sample, it is calculated according to the following relations:

a) 0.5%×62.4= 0.312 gram

b) 0.936×4.3=134.16 dollars

Namely this amount is spent for each Marshall sample and it will not be economical in the large works and this percent amount of nanotube can not be used in the normal works. But with regard to the very high strength which is obtained as the result of using of this material with different percent amounts in the asphalt concrete and studying the volume and kind of work, a specified amount of nanotube can be used in the asphalt mixtures. On the other hand, due to the increase of the asphalt strength with nanotube, the thickness of pavement layers can be considered less than the control sample and consequently some costs of the carbon nanotube are compensated. In this research, with regard to the amounts obtained for the Marshall parameters of samples especially the amount of Marshall strength and with estimation of a cost which has been indicated in the diagram of the Fig 8, using of the samples with 0.25 and 0.50 percent of nanotube and with technical specifications superior to the normal asphalt, it can be a method for improvement of the mechanical properties of the asphalt mixtures.

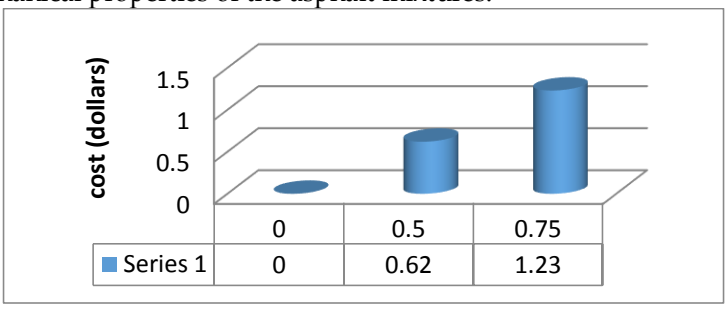

Figure 8. The comparison of the amount of the surplus cost imposed on each sample for different percent amounts of carbon nanotube

7. Conclusion

The main purpose in this research is to present a solution for achieving the pavement with better performance and strength properties than the normal pavements and since the asphalt pavements are accounted as the national capital and every year a large amount of the construction budget of the country is spent for the roads pavement, the maintenance and improvement of mechanical properties of asphalt with keeping the economical aspect are considered with regard to the results and discussions, this additive combination can be utilized for using in the asphalt of the warm regions due to the reduction of flow and with heavy traffic due to the increase of strength and also the limited regions due to the economical load.

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