International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Issue: 03 | Mar 2023 www.irjet.net p-ISSN: 2395-0072

Behavior of Hot Asphalt Mixture Modified with Carbon Nanotube and Reclaimed Asphalt Pavement

Hadeer Asem[1], Abdallah Wahdan [2], Sameh Ahmed Galal [3]

[1] Assistant Lecturer, Civil Engineering Department, Higher Future Institute for Engineering, Fayoum, Egypt ,PHD Researcher in Azhar University, Egypt
[2] Professor, Civil Engineering Department, Faculty of Engineering, Al- Azhar University, Cairo, Egypt
[3] Professor, Civil Engineering Department, Faculty of Engineering, Fayoum University, Fayoum, Egypt

---***---

Abstract

Nowadays, nanotechnology is widely applied in pavement engineering to improve the properties of materials and performance. Nanotechnology can be considered as the measurement on nanometer scale that affects the material used in pavement due to its unique characteristics. Therefore, this new technology might indirectly solve the current pavement construction problems.

During the past years' different researchers have studied the causes of failure of flexible pavements and they offered variety of alternatives for solving these failure problems such as rutting, fatigue and low temperature cracking which are sourced from many reasons for example moisture susceptibility and temperature sensitivity of either asphalt, aggregate or the asphalt mixture as a whole. Therefor recycling using the RAP with nano carbon tube is used to improve asphalt properties. Due to economic reasons and the need for environmental conservatism, there has been an increasing shift towards the use of Reclaimed Asphalt Pavement (RAP) materials in the pavement construction industry. The majority of HMA mixtures in Egypt are produced only from virgin materials although there are about 4 million tons per year of reclaimed asphalt materials, because it continuous pavement milling or scraping processes, are not used. The increasing number of roads which are removed (RAP) and decreasing the wastes in a way that will not negatively affect the environment. Reclaimed Asphalt Pavement(RAP) obtained from damaged pavement used in hot asphalt mixtures has evolved into regular practice in many countries around the world. Use of these materials in the past has not only proved to be economical but also environmentally sound. Mixing Rap in virgin materials in the light of the increasing cost of asphalt, shortage of asphalt and pressing need to preserve the environment. In this investigation, it has been attempted to promote technical characteristics of asphalt mixture using carbon nanotubes as an additive material for bitumen with reclaimed asphalt pavement. In this study, marshal test parameters of hot mix asphalt, modified with carbon nano tube with Rap, are investigated and compared to conventional asphalt mix. In this study marshal test parameters of modified asphalt by .5, 1.0, 1.5, 2.0 and 2.5% carbon nanotube and 20%, 30%, 50% and 70% Rap content in bitumen was evaluated considering marshal test, then results were compared to conventional asphalt mix. Obtained results shown, using carbon nanotube with rap improves hot mix asphalt stability and flow.

Keywords

Hot asphalt mix, Carbon nanotubes, Reclaimed Asphalt Pavement, Marshall test

1. Introduction

The use of Reclaimed Asphalt Pavement (RAP) in the construction of roads and resurfacing of existing roads is economically beneficial and environmentally sound. The huge road modernization exposes challenges of various concerns pertaining to depletion of resources like good soil and aggregates, long run to get good quality aggregates and increase in fuel consumption etc. Moreover, the supply of bitumen, whose cost keeps on increasing, is dependent on foreign sources, and energy that is needed for processing new materials is becoming costlier every day. The recycling of existing bituminous mixes are the only alternatives, through the reuse of aggregate and bitumen. Use of the recycled materials in the road construction has been favored over fresh materials in the light of increasing cost of bitumen, rarity of good quality aggregates and the priority towards preservation of the environment. Considering the material and construction cost alone, it is estimated that using recycled materials, saving ranging from 14 to 34% from asphalt layer cost can be achieved. It is universally recognized that an important benefit of asphalt as a pavement construction material is its ability to be recycled. This factor is becoming more relevant as the use of rap in RAP in asphalt mixtures could produce important benefits in terms of performance and economics.

Two CNT-asphalt cement mixing procedures including simple and wet processes were investigated. Viscoelastic properties of modified AC incorporated with 0.1, 0.5, and 1 (%w/w) CNT were evaluate, adding carbon nano tubes (CNTs) provides an enhancement of rutting resistance potential along with the resistance to thermal cracking (2). The need to replace outdated pavement materials with new ones that are of higher quality, comply with current safety regulations, and are more dependable as well as ecologically friendly has arisen in recent decades as a result of a sharp increase in traffic loads (4). Three different percentages of carbon nanotubes (CNTs) (0.1%, 0.5%, and 1% by mass of asphalt cement) were used to modify conventional asphalt cement (60/70) adding CNTs into asphalt cement enhances the performance of asphalt concrete pavement in both hot and cold weather, which in turn prolongs the pavement's service life and saves maintenance expenses (1). Instead of using materials in large scale, we can use nanomaterials which are defined as restructuring of matter in the order of nanometers (i.e., less than 100nm) to create materials with fundamentally new properties and functions. Nanotechnologies are the design, characterization, production and application of structure devices and systems by controlling shape and size at nanometer scale. In last years, many researchers try to use organic and nonorganic additives such as polymers, fibers, nanoclay and carbon nanotube to improve mechanical properties of asphalt (11), (8) ,(7), (6), (5),(3). Due to their outstanding qualities, carbon-based nanoparticules and platelets have also attracted a lot of attention recently among the diverse nanomaterials. CNTs in particular the most promising addition to improve the performance of building and structural materials (9) ,(10). It is widely seen as having huge potential to bring benefits in diverse areas such as production of stronger and lighter materials (13). In recent years, numerous researchers have experimented with the use of organic and inorganic additives to enhance various physical and rheological properties of asphalt binder and asphalt mixture. These additives include polymers, nanoclay, nanofillers, crumb rubber, fibres, and bio-rejuvenators (18). 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 (11),(12).One of the most desired properties of nanomaterials in the construction is their ability to mix with bituminous- based on structural materials. Carbon nanotubes (CNTS) were discovered by Iijima in 1991 as the fourth form of carbon (14). 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. (15). 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 (16). 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 reinforcement materials (e.g. glass fibers or carbon fibers).In fact, because of their size (ranging from 10nm to 20nm) and aspect ratios, CNTs can be distributed in a much finer scale than common fibers, Laser ablation (12). Carbon nanotubes used in this investigation were produced by chemical vapor deposition technique with diameters from 10 up to 20 nm and different length. Asphalt recycling has many benefits like preservation of the environment and reduction land filling, energy conservation and improved pavement smoothness, cost saving over traditional rehabilitation method and improved pavement physical properties modification of existing aggregate gradation and asphalt binder properties.

2. Research Methodology

The mechanical behavior of bituminous depends on the structural elements and phenomena that occur in a micro and nano scale. As a result, nanotechnology can modify the molecular structure of asphalt, which leads to improvement in the material's properties. Nanotechnology can also improve the mechanical performance, durability, and sustainability of asphalt mixture. 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{1} . While a large amount of research studies has been carried out in the last decade on modification of asphalt binder by different nano particles like nano clay{2} , nano zinc oxide {3}, nano silicon dioxide{4} , nano titanium oxide {4}, carbon nano fibers (CNFs) {5}. Few studies have been conducted in the area of carbon nano tubes (CNT)- with RAP[modified binders and mixtures. In this paper carbon nano tube is mixed with asphalt mixture to study enhancement the properties of asphalt with carbon and the changes that occur in the properties of mixtures. The Marshal test was used to evaluate physical and mechanical properties of HAM.

3. Materials

3.1 Reclaimed Asphalt Pavement (RAP)

Reclaimed asphalt pavement (RAP) is the term given to removed and (or) reprocessed pavement materials containing asphalt and aggregates. These materials are generated when properly crushed and screened, RAP consists of high- quality well-graded aggregates coated by asphalt.

3.2Carbon Nanotube

Since CNTs exhibit great mechanical properties {6} {7}along with extremely high aspect ratios (length- to- diameter ratio) ranging from 30 to more than several thousand {8}, they are expected to produce significantly stronger and more improved bituminous composites than traditional reinforcing materials (e.g., glass fibers or carbon fibers). The high specific strength, the chemical resistance, the electrical conductivity, and the thermal conductivity of carbon nanotubes (CNTs) make them attractive for use as reinforcement to develop superior bituminous composites {9}, {10}. Some researches have been performed on mixing process of CNFs in asphalt mixtures but not for CNTs which are about 100 times smaller than CNFs and harder to disperse and figure 1 show Carbon Nanotube under microscope. Dispersion of CNTs has been one of the largest challenges due to the aggregation of the nanotubes {11}.

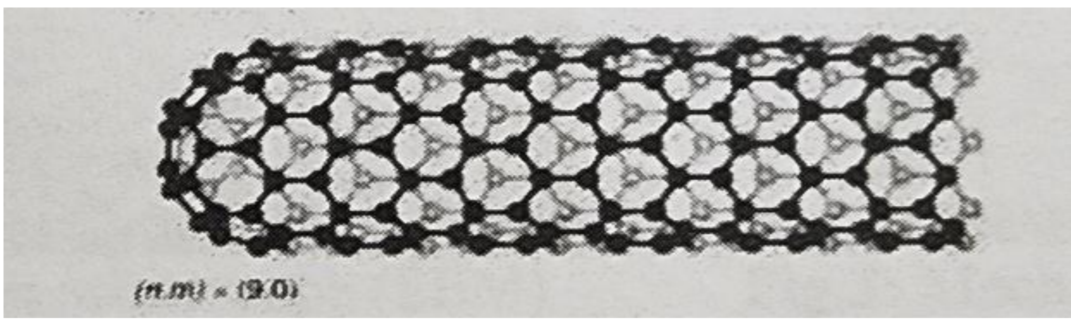

Figure 1 Carbon Nanotubes (CNTs)

3.3 Bitumen Material and Aggregates

Materials used in the experimental investigation included neat bitumen 60/70-penetration grade which was obtained from Suez Nasr Petroleum Company (NCP). The percentages of asphalt used to preparemixturesarefrom4% to 6% increasing about .5%. Laboratory tests were carried out on asphalt and its specification of asphalt are presented in table 1 through table 3. The aggregates used was brought from the quarry from the western Assiut road. The aggregate was a combination of coarse aggregate with specific gravity 2.573, the fine aggregate with specific gravity 2.508 and mineral filler and were graded with AASHTO 1993 which is presented in table 4 and virgin aggregates without Rap shows in figure 2.

Table 1. Test Procedures at Standard Specification of Asphalt

Test	Designation Number		Function
	AASHTO	ASTM	
I- Asphalt Cement			Measurements of Consistency
1- Penetration at 25 C, 100 gm, 5 sec (0.1 cm)	T49	D5	
2- Softening point (Ring and Ball) C	T52	D36	
3- Kinematics Viscosity (C.S.T.,135 C)	T201	D4402	
II- Asphalt Concrete Mixes			Design of Asphalt Mix
Marshall Test	-----	D1559	

Table 2. Results of Absolute Viscosity tests

Temp., C	Viscosity	Log (log(Visc))	Log(Temp)
135	406	0.416395175	2.86611
150	232	0.373920746	2.881784
165	150	0.337677104	2.8969118

Table 3. ASTM and Egyptian Standard Specification for 60/70 Penetration Grade of Asphalt Pavement

Test	Penetration Code		Binder Results
	60/70		60/70
	Min	Max	
1- Penetration at 25C, 100 gm, 5 sec (1cm)	60	70	64
2- Softening Point (Ring and Ball) C	45	55	48
3- Kinematic Viscosity (C.S.T, 135C)	320		406

Table 4. Gradation of used aggregates

Sieving size(mm)	25	19	12.5	9.5	4.75	2.36	.3	.075
p.p%	-	100	95	-	59	43	13	6

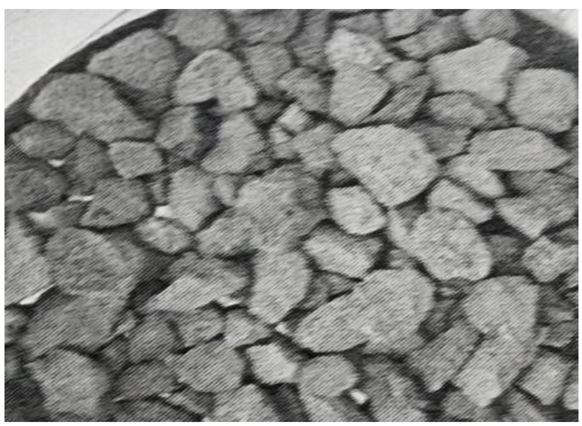

Figure 2 Virgin aggregates without Rap

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 summarized at the table 5. The content RAP in the mixture was 20%, 30%, 50%, and 70%, by mass.

Table.5 Carbon nanotubes (CNTs) Properties

Properties	Unit	Value	Method of Measurments
Average Length	Mm	10-30	TEM
Carbon Purity	%	95	TGA
Amorphous Carbon	-	*	HRTEM
Density	g/cm3	2.1	-

4. Experimental Procedure

In this study, various percentages of RAP are used with virgin aggregates and different percent of Carbon Nanotubes to evaluate the properties of HMA. The percentages of Rap are 20%, 30%, 50%, and 70% by mass. Figure 3 shows the mix of aggregates with RAP. Five different percentages of CNT were chosen to produce bitumen- CNT blends (.5%, 1%, 1.5%, 2% and 2.5% by weight of the base binder). Scanning electron microscope (SEM) image of Carbon nanotubes (CNTs) are shown in figure 4. Five different percentages of RAP were chosen to mix with virgin mix and with CNTs (20%, 30%, 50%, and 70%). There are four phases of mixtures virgin mix, CNTs with bitumen, RAP with bitumen and CNTs with RAP and bitumen.

Figure 3 Virgin aggregates with Rap

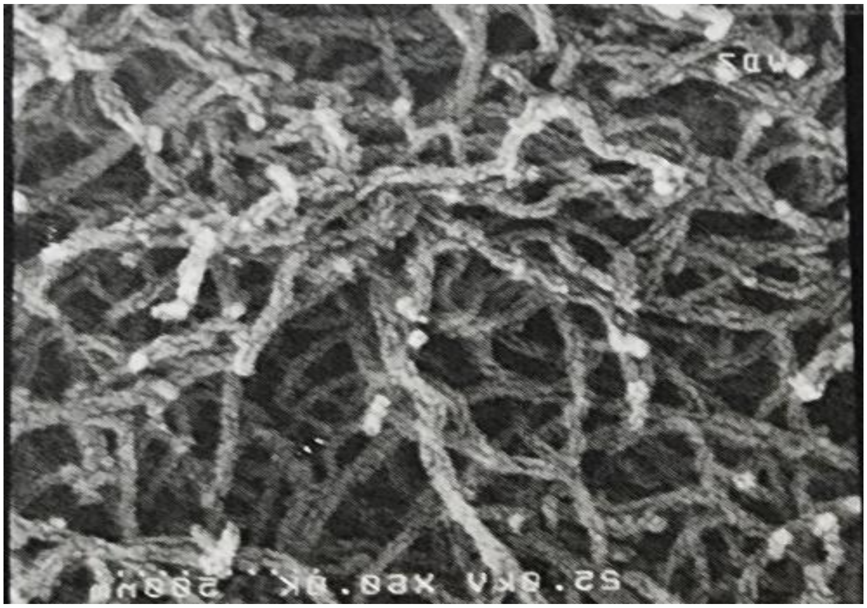

Figure 4 Scanning electron microscope (SEM) image of CNTs

4.1Marshall Test

The Marshall method of asphalt mix design is widely practiced in construction materials laboratories to select and proportion aggregate and asphalt materials for pavement construction. The focus is on determining an optimum asphalt content that will provide maximum power to the mix with minimum deformation from axle loads. Marshall stability and flow test values, density, and air voids in the mix and test was carried out to evaluate the physical and chemical properties of the asphalt mixture, without additives or with RAP and CNT. Marshall stability is the maximum load (in kilograms) the asphalt sample can support without breaking when loaded and Marshall flow is the deformation read (in millimeters) during the maximum load and failure. 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. Figure 5 shows marshall test according to ASTM D6927.

Figure 5 Marshall Test

5. Analysis and Results

The Marshall test was carried out on different asphalt ratios to determine the optimal ratio, and 5.5% achieved the best ratio. The test was carried out repeatedly on different rap ratios, measuring the different stability and flow ratios, then re-testing with different ratios of rap with different percent of carbon nanotubes. Combination of Rap and different percent of CNT had been done with the following percentages (.5%, 1%, 1.5%, 2% and 2.5%) and mixing virgin aggregate with Rap 20%, 30%, 50%, and70% by weight of the base binder. In addition, Rap and CNTs were mixed with virgin aggregates in their different percentages. Table 6 summarized stability of asphalt mixtures with RAP and CNTs, while table 7 summarized flow of asphalt mixture with RAP and CNTs.

Table 6 Stability of Asphalt Mixtures with RAP and CNTs

%Rap	%CNT	Stability	%Rap	%CNT	Stability
0.0	0.0	1800			
0.0	1.0	1464.00	30	1.0	1685.00
	1.5	1682.00		1.5	1763.00
	2.0	1829.00		2.0	1710.00
	2.5	1777.00		2.5	2267.00
20	1.0	1540.00	50	1.0	2475.00
	1.5	1433.00		1.5	2489.00
	2.0	1655.00		2.0	2520.00
	2.5	1469.00		2.5	2557.00
70	1.0	1980.00			
	1.5	1818.00			
	2.0	1809.00			
	2.5	1760.00			

Table 7 Flow of Asphalt Mixtures with RAP and CNTs

%Rap	%CNT	Flow	%Rap	%CNT	Flow
0.0	0.0	5.5			
0.0	1.0	5.00	30	1.0	3.41
	1.5	4.76		1.5	3.44
	2.0	4.95		2.0	3.33
	2.5	2.95		2.5	4.00
20	1.0	3.00	50	1.0	3.41
	1.5	3.12		1.5	6.97
	2.0	3.21		2.0	7.20
	2.5	4.10		2.5	8.50
70	1.0	7.43			
	1.5	6.50			
	2.0	6.33			
	2.5	6.30			

And making a comparison among values of stability and flow as shown in figure 6 and figure 7.

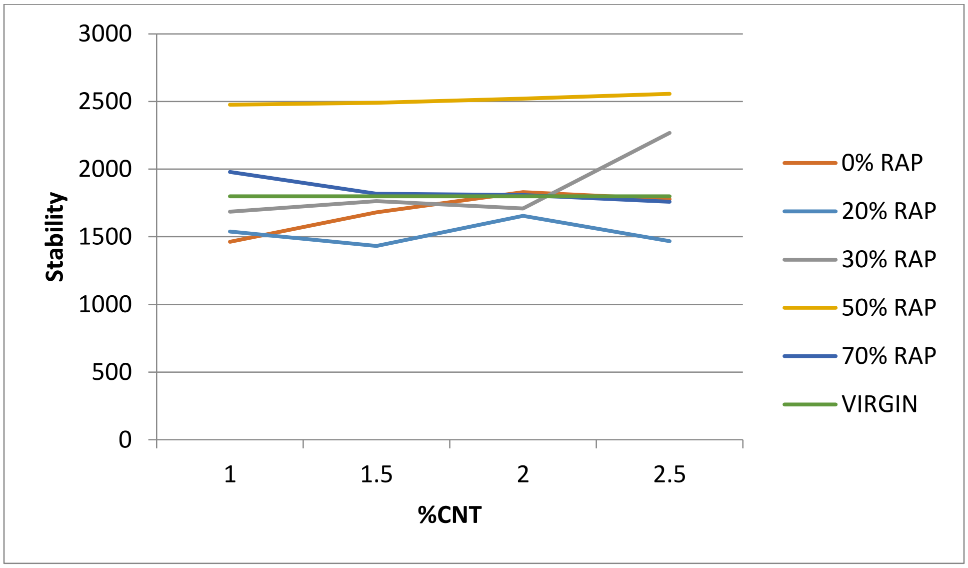

Figure 6 Marshal Stability changes in adding to bitumen

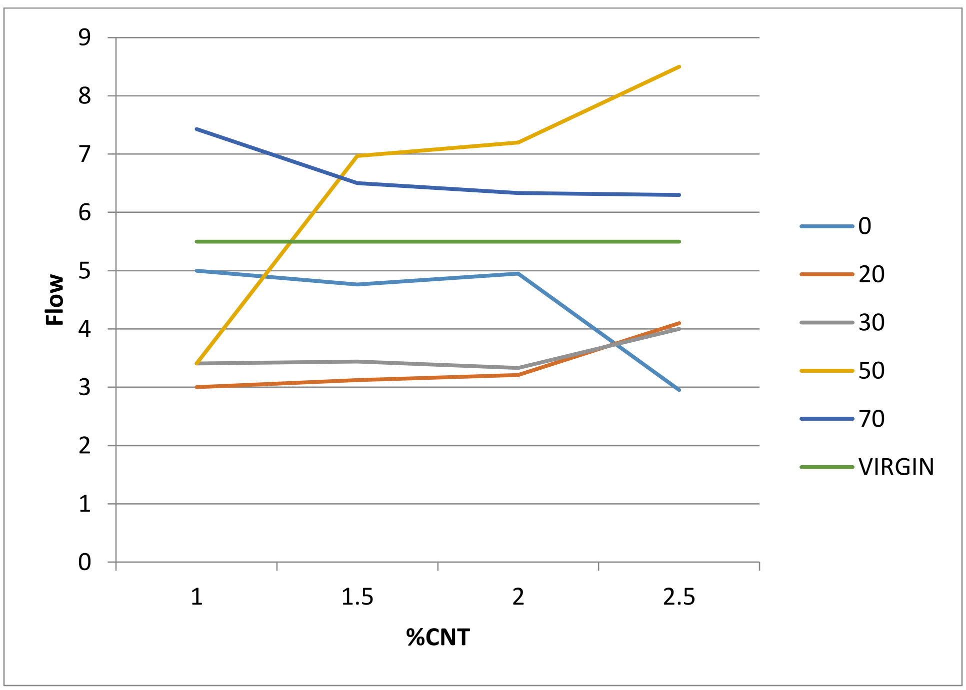

Figure 7 Marshal Flow changes in adding to bitumen

From table 6 and figure 5 it can be concluded that using C.N.T with RAP increase the stability of Hot Asphalt Mixture, 50% of RAP with different percent of carbon nanotubes achieved best results of stability for example at 50% RAP and 2.5% C.N.T stability increase 14% in comparison with virgin mixture By comparing the ratios of RAP alone without additives, which achieved the worst results due to the high percentage of bitumen present in the asphalt mixture, which facilitated the fracture process.. 50%Rap with different percent of C.N.T achieved the highest stability specially at 2.5%CNT. At 50% RAP and 2.5% C.N.T flow increase 15.5% in comparison with virgin mixture

6. Conclusions

Due to the increasing development of nanotechnology and special features of carbon nanotubes and to reduce the huge amount of Rap to save the environment and money, 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 nanotubes and Rap on hot mix asphalt marshal parameters. Based on the laboratory test results, the following conclusions were obtained:

- 50% Rap with different percent of CNTS achieved best results comparison between different mix.
- Adding Rap only to virgin aggregates is the worst solutions.
- A sample containing 2.5%CNT and 50%Rap achieved high stability and flow
- The addition of the rap alone achieved less stability.
- The best ratios in comparison are mixing %50 Rap and all different percent of CNTs.

7. REFERANCES

1- Mohamed Samir Eisa, Ahmed Mohamady, Mohamed E. Basiouny, Ayman Abdulhamid, Jong R. Kim, (2022). Mechanical Properties of Asphalt Concrete Modified with Carbon Nanotubes.

2- Faramarzi, M., Arabani, M., Haghi, A.K., Mottaaghitalab,V. (2015). Carbon nanotubes Modified Asphalt Binder Preparation and Characterization.

3- Zadshir, M., et al., 2018. Investigating bio-rejuvenation mechanisms in asphalt binder via laboratory experiments and molecular dynamics simulation.

4- Ehdi Zadshir, Fangliang Chen, Xiaokong Yu, Xin He, Irene Nigro, Maddalena, (2022). Mixing Cabon Nanotubes with Asphalt Binder througha foaming Process toward high- performance Warm Mix Asphalt.

5- Ziari, H., and Moniri, A., (2019). Laboratory evaluation of the effect of synthetic polyolefin-glass fibers on performance properties of hot mix asphalt.

6- Tahami, S.A., et al., (2019). The use of high content of fine crumb rubber in asphalt mixes using dry process. Construction and Building Materials

7- Vol,H.V.,etal., (2017). Evaluation of asphalt mixture modified with graphite and carbon fibers for winter adaptation: thermal conductivity improvement.

8- Tyson, B.M., et al., (2011). Carbon nanotubes and carbon nanofibers for enhancing the mechanical properties of nanocomposite cementitious materials.

9- Treacy, M.M.J, Ebbesen, T.W, and Gibson, J.M. (1996). Exceptionally High Young's Modulus Observed for Individual Carbon Nanotubes.

10- De Heer, W.A. (2004). Nanotubes and the pursuit of applications.

11- Bai, J.B. and Allaoui, A. (2003). Effect of the Length and the Aggregate Size on the Improvement Efficiency of the Expermental Investigation.

12- Chong, K.P. and Garboczi, E.J. (2002). Smart and Designer Structural Maerial Systems.

13- Makar,J.M. and Beaudoin, J.J. (2003). Carbon Nanotubes and their Applications in the Construction Industry.

14- Bergman, C.P., and Jung de Andrade, M ,(2011). Nanostructured Materials for Engineering Applications.

15- Guoping Zhang., (2007). Soil Nanoparticles and their Influence on Engineering Properties of Soils.

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

17- Grobert N., (2007). Carbon Nanotubes Becoming Clean.

18- Cong, P., Xu, P., and Chen, S., 2014. Effects of carbon black on the anti-aging, rheological and conductive properties of SBS/asphalt/carbon black composites.