

PERFORMANCE EVALUATION OF MODIFIED BITUMINOUS MIX USING CARBON NANOTUBES – A REVIEW

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Abstract: The incorporation of modifiers to bitumen binder has been demonstrate the improved performance when compared to base asphalt. Pavements modified with polymers such as SBS, Elvaloy, rubber, polyethylene, nano silica (NS), gilsonite, rock asphalt (RA), ceramic fiber (CF), carbon nanotubes (CNTs), cement additives, recycled plastic waste (RPW) and others provide greater rutting resistance and thermal cracking, and decreased fatigue damage and temperature susceptibility. Carbon nanotubes (CNTs) are cylindrical nanostructures composed of carbon atoms arranged in a hexagonal lattice, similar to graphene. They exhibit unique properties that make them valuable in various fields, including materials science, electronics, and medicine. Modified bituminous mix using CNT provides better resistance against rutting, fatigue and cracks. Also CNT improves the Marshall stability and Indirect Tensile Strength (ITS) values of the modified mix. This study describes the importance of CNT in modification of bituminous mix. This study carried out a structured review of investigative rresearch on modified bituminous mix employing CNT.

Keywords: Carbon nanotubes, Marshall Stability, Rutting, Bitumen, Penetration, Fatigue.

1. INTRODUCTION

Bitumen is one of the most commonly used materials in bituminous mix to construct flexible pavements. Unmodified bituminous mix has various limitations which cannot hold on the increasing traffic loads under wide range of temperature variations. Temperature variations and variable loading intensities of traffic adversely affect the performance of the road. High temperature leads to permanent deformation while at low temperatures bitumen losses its elastic property which leads to cracking due to stiffness in the pavement. So it is necessary to modify bituminous mix using modifiers or polymers to enhance the mechanical properties of bituminous mix [1-4]. The quest for durable and sustainable infrastructure materials has driven extensive research and innovation in civil engineering. Among these innovations, modified bituminous mixes have garnered significant attention due to their potential to enhance the performance and longevity of pavement structures. Polymer-modified binders successfully implemented in diverse locations of high stress, such as intersections of busy streets, airports, vehicle weigh stations, and race tracks [5]. Prudent characteristics of polymer-modified binders include greater elastic recovery, a higher softening point, greater viscosity, greater cohesive strength, and greater ductility [5, 6].

Now a day's various nanomaterials were used for modification of bituminous mix to enhance the mechanical properties [7] such as Carbon nanotubes (CNT), nanoclay [8-10], nanosilica [11, 12], nano zinc oxide, grapheme etc [13-20]. These nanomaterials having size 10^{-9} m improves various properties of bituminous mix when added [21-23]. Carbon Nanotubes (CNTs) is one of the promising additives in this domain. Carbon Nanotubes, renowned for their exceptional mechanical, electrical, and thermal properties, have emerged as a revolutionary material in various industries. In bituminous mix modification, CNTs offer the potential to improve the mechanical properties and durability of bituminous mixes significantly. Their high tensile strength and modulus, along with their ability to improve the viscoelastic properties of bituminous mix, make them a highly effective additive for enhancing the performance of pavement materials.

CNTs are of three types:

1. **Single-Walled Carbon Nanotubes (SWCNTs):** These consist of a single layer of carbon atoms rolled into a tube. They typically have diameters in the range of 0.7 to 2 nanometers.

2. **Multi-Walled Carbon Nanotubes (MWCNTs):** These consist of multiple layers of graphene rolled into concentric tubes. Their diameters range from a few nanometers to several tens of nanometers.
3. **Chirality:** The way the graphene sheet is rolled (chirality) affects the electrical properties of CNTs, making them either metallic or semiconducting.

2. Chemical composition of Carbon Nanotubes (CNTs)

The chemical composition of carbon nanotubes (CNTs) is fundamentally based on carbon atoms arranged in a hexagonal lattice, forming a cylindrical structure. These carbon atoms are bonded via sp² hybridization, creating strong covalent bonds that result in the extraordinary mechanical strength and electrical conductivity of CNTs. Chemical composition of carbon nanotubes is demonstrated in table 1.

Table 1: Chemical composition of CNT

Property	Carbon Nanotubes (CNTs)
Primary Element	Carbon (C)
Carbon Content	> 99%
Hydrogen Content	Negligible
Oxygen Content	Negligible
Sulfur Content	Negligible
Nitrogen Content	Negligible
Other Elements	Possible trace metals or catalysts (e.g., Fe, Ni, Co)
Structure	Cylindrical nanostructures
Molecular Weight	Varies (depends on length and diameter)
Purity	Typically high (depends on synthesis method)
Functionality	High aspect ratio, conductive, high strength

3. Molecular composition of carbon nanotubes (CNTs)

Carbon nanotubes (CNTs) are cylindrical nanostructures composed entirely of carbon atoms arranged in a hexagonal lattice. The carbon-carbon bonds in CNTs are sp² hybridized, giving them remarkable strength and electrical conductivity due to the delocalized π -electrons. Table 2 illustrates the molecular composition of carbon nanotubes.

Table 2: Molecular Composition of Carbon nanotubes (CNTs)

Aspect	Carbon Nanotubes (CNTs)
Basic Structure	Cylindrical nanostructures made of rolled-up sheets of graphene
Molecular Arrangement	Hexagonal lattice of carbon atoms forming a tube
Bonding	Covalent bonds in a continuous network

Aspect	Carbon Nanotubes (CNTs)
Crystallinity	Highly crystalline
Dimensionality	One-dimensional (1D) nanostructures

4. Literature Review

Haq, Muhammad Faizan ul et al. (2018) [24]

The work in this paper focuses on the study of the dispersion of carbon nanotubes (CNT) in bituminous mix using dry and wet mixing methods. SEM test was used to check the dispersion and homogeneous mixing of CNTs in bituminous mix and on the other hand, FTIR analysis was performed for the assurance of the removal of solvents used for the wet mixing process. Conventional bitumen tests such as penetration test, softening point test, ductility test, DSR test, rolling bottle test, and bitumen bond strength test were also performed to evaluate the rheological and adhesion properties of bitumen. Also wheel tracker test was performed to check the enhancement in permanent deformation resistance of bituminous mix modified with CNTs.

The research methodology used for this research paper was the CNTs of various dosages of .5%, 1%, 1.5%, and 3% of the bitumen binder were added to the base binder. CNTs were added to the methanol. Then the mix was stirred up in a shear mixer for 180 min. with a speed of 550 rpm. This was done for the proper dispersion and homogeneous mixing of CNTs in the solvent. After homogeneous dispersion and mixing of CNTs in methanol, the solution was mixed in bitumen binder and the mixture was heated up further up to 158 °C for the next 45 min. at a stirring speed of 3000 rpm to obtain a homogenous mixture. The results obtained through this research article showed that the wet mixing techniques were better for homogeneous dispersion of CNTs in bitumen rather than dry mixing. The penetration and ductility values were decreased while the softening value was increased due to the usage of CNTs as modifiers in bitumen which results in the increment in the stiffness of the bitumen binder when modified by using CNTs. Also, it was found that the bitumen bond strength was increased in both dry and moist conditions by adding CNTs to the bituminous mix. Through various tests performed it was concluded that 3% CNT dosage was the optimum dose.

The limitation or research gap in this research manuscript is that the comparison of CNTs modified bituminous mix with base bituminous mix was based on limited CNT dosage. The dataset of this manuscript is small and it can be escalated. Involvement of further experimental stakeholders in the following opportunities for future research about binary blended additives or modifiers (Gilsonite and CNT).

Faramarzi, M., et al. (2015) [25]

The work in this paper focuses on the study of the dispersion of carbon nanotubes (CNTs) in bituminous mix using dry and wet mixing methods. Conventional tests such as penetration test, softening point test, ductility test, DSR test, and RV test were also performed to check the rheological properties of modified and base bituminous mix for comparison.

The research methodology used for this research paper was the CNTs of various dosages of 0.1%, 0.5%, and 1% of the bitumen binder were added to the base binder. For the dry process, the mix was stirred up in a shear mixer for 40 min. with a speed of 1550 rpm at a constant temperature of 160 °C by applying oil bath heating. For the wet process firstly the CNTs-Kerosene mixture was prepared by sonication. This was done for the proper mixing and dispersion of CNTs in the solvent. After homogeneous dispersion and mixing of CNTs in kerosene then the solution of dispersed CNTs was mixed in bitumen and the mixture

was heated up further up to 158 °C for the next 45 min. at a stirring speed of 2500 rpm to obtain a homogenous mixture.

The results obtained through this research article showed that the wet mixing techniques were better for homogeneous dispersion of CNTs in bituminous mix rather than dry mixing which was analyzed by SEM test. The penetration performance and ductility values were decreased while the softening value was increased due to the usage of CNTs in bituminous mix which results in the increment in the stiffness of the bitumen binder when modified by using CNTs. Also, it was found that the bitumen bond strength was increased in both dry and moist conditions by adding CNTs to the bituminous mix. Also, permanent deformation resistance was increased as the dosage of CNTs was increased.

The limitations or research gap in this research manuscript which were suggested by the author were that other specific aspects of the bitumen binder behavior should be evaluated using the cost-benefit analysis to increase the usage of this modified bituminous mix at the industrial level. Also, the author suggested more efforts were needed to generalize the results and understand the process by which modifying effects are obtained. The comparison of CNTs modified bituminous mix with base bituminous mix was based on limited CNT dosage. The dataset of this manuscript is small and it can be escalated.

Eisa, Mohamed Samir, et al. (2022) [26]

The work in this paper focuses on the study of the evaluation of mechanical properties of CNTs modified asphalt mix. Conventional tests like penetration grade, kinematic viscosity, softening point, and DSR tests were performed to evaluate the physical properties of the modified asphalt mix and compare it with the base asphalt mix.

The research methodology used for this research paper was the CNTs of various dosages of 0.1%, 0.5%, and 1% of the asphalt binder were added to the base binder. First, the base asphalt was liquefied by heating it to 150.C. Then CNTs were added to the asphalt. For homogeneous dispersion of CNTs, the mixture was heated up further up to 150 °C for the next 60 min. at a stirring speed of 2500 rpm to obtain a homogenous mixture. Two controlled samples were prepared for the measurement of the effect of mixing conditions on the asphalt; both are at 0% of CNT content.

The results obtained through this research article showed that the physical properties of base asphalt were enhanced by adding CNTs as a modifier. Modified asphalt mix provides low penetration but a high softening point and viscosity. In addition to 1% of CNTs, there was a decrement of 16% in penetration grade, and the increment of 6.8% in softening point and 17% in kinematic viscosity was noted. The rutting parameter was increased of CNTs modified asphalt mix. Also, better indirect tensile strength values were noted when the base asphalt was modified by using CNTs. Modified asphalt mix showed better resistance to rutting, fatigue, and crack propagation as compared to base asphalt mix.

The limitations or research gap in this research manuscript which were suggested by the author were that further measurements are needed to assess the rutting resistance of asphalt mix at various contents of CNTs. Also, the author suggested that potential and timely research in this area is recommended. Some research gaps which were suggested by the author in this area are:

1. Study the synergy between nanofillers i.e. CNTs and traditional modifiers.
2. Investigating chemical properties and modification of nanofillers i.e. CNTs before adding into asphalt.
3. Studying other functional parameters which include self-healing, thermal and electrical conductivity, and wear resistance of CNTs modified asphalt mix. Also, the comparison of CNTs modified asphalt with base asphalt was based on limited CNT dosage. The dataset of this manuscript is small and it can be escalated.

Motlagh, A. Akbari, et al. (2012) [27]

The work in this paper focuses on the study of the evaluation of technical characteristics of CNTs modified asphalt mix and base asphalt. The parameters like permeability degree, flash point, softening point, ductility, marshal stability, marshal flow, marshal ratio, and specific gravity were evaluated by performing various tests.

The results obtained through this research article showed that the marshal stability, softening point, ductility, and flash point of the modified samples were increased on increasing the content of CNTs but the penetration degree was reduced on increasing the CNTs content of the asphalt.

The limitations or research gap in this research manuscript is that limited tests were performed on limited samples. The rheological properties are also examined by conducting various tests on CNTs modified asphalt. Also, the comparison of CNTs modified asphalt with base asphalt was based on limited CNT dosage. The dataset of this manuscript is small and it can be escalated. Involvement of further experimental stakeholders in the following opportunities for future research about binary blended additives or modifiers (Gilsonite and CNT).

Ismael, Mohammed Q. et al. (2021) [28]

The work in this paper focuses on the study of the evaluation of the worthiness of the use of CNTs as a strengthening modifier. For this four different contents of CNTs of upper limit 2% were blended in two grades of asphalt (40/50 and 60/70). Several tests like penetration test, softening point test, viscosity test, and rheological properties were conducted to check the worthiness of the modified asphalt mix. A Marshal test was also performed for underwent volumetric and stability analysis and a wheel tracking test was performed to examine the rutting resistance.

The research methodology used for this research paper was the CNTs of various dosages ranging from 0.0 to 2% with a uniform differential increase of 0.5% of the asphalt binder was added to the base binder and a comparison of modified asphalt with base asphalt was studied. Two steps were followed to achieve homogeneity of the binder-CNT blend. First, the base asphalt was manually mixed with CNTs. Then for homogeneous dispersion of CNTs, the mixture was heated up further up to 163 °C for the next 45 min. at a stirring speed of 1500 rpm to obtain a homogenous mixture. During this mixing process, it was important to take care that there was no discontinuity in the modified asphalt binder molding process.

The results obtained through this research article showed significant rutting resistance improvement while using 1.5% CNT content as a modifier i.e. 61% resistance ability for 40/50 grade asphalt and 57% resistance ability for 60/70 grade asphalt. Also, the Marshall Stability value for 40/50 grade had a growth factor of 35% for 1.5% content of CNTs. The author also analyzes the cost by using the CBR method which showed less economic benefits. By performing and analyzing various tests it was recommended by the author that 40/50 grade asphalt modified with 1.5% of CNT content improves the rutting resistance.

The limitation or research gap in this research manuscript is that the comparison of CNTs modified asphalt with base asphalt was based on limited CNT dosages. The dataset of this manuscript is small and it can be escalated. Also, limited tests of modified asphalt mix were performed on limited samples. The comparison of CNTs modified asphalt with base asphalt was based on limited laboratory tests.

Zahedi, Mohsen et al. (2017) [29]

The work in this paper focuses on the study of rheological specification, physical characteristics, and bulk parameters of the surface layer of bituminous mix when modified by using CNTs. The technical characteristics of modified bituminous mix were evaluated by conducting some tests like penetration test, softening point test, viscosity test, and thermal sensitivity test by mixing the CNTs in various contents (0.25, 0.50, 1 & 1.5% by weight of bitumen). The Marshall Test was also performed to evaluate the stability of the sample.

The results obtained through this research article showed a significant increase in softening point, viscosity, stability, and specific gravity on adding CNTs as a modifier in the base bituminous mix but thermal sensitivity and penetration degree decreased. The author also analyzes the cost which showed less economic benefits. The author strongly suggests the use of CNTs as a modifier based on various tests performed.

The limitation or research gap in this research manuscript is that the comparison of CNTs modified bituminous mix with base bituminous mix was based on limited CNT dosages. The dataset of this manuscript is small and it can be escalated. Involvement of further experimental stakeholders in the

following opportunities for future research about binary blended additives or modifiers (Gilsonite and CNT).

Santagata, Ezio, et al. (2012) [30]

The work in this paper focuses on the study of analyzing the rheological characteristics in different aging conditions. For this three different contents of CNTs (0.1%, 0.5%, and 1%) were blended with base bituminous mix. Several tests like viscosity and oscillatory loading tests using BRV and DSR were conducted to understand the rheological characteristics of the modified bituminous mix. RTFO and PAV were used for short-term and long-term aging analysis. Master curves were used to analyze the complex modulus, Phase angle, and rut factor.

The research methodology used for this research paper was the CNTs of various dosages ranging from 0.1, 0.5, and 1% were added to the base binder and a comparison of modified bituminous mix with base bituminous mix was studied. Some initial attempts were made considering different mixing times and temperatures, then the final mixing protocol was adopted which consists of two phases. First, the base bituminous mix was manually mixed with CNTs. Then for homogeneous dispersion of CNTs, the mixture was heated up further up to 160 °C for the next 40 min. at a stirring speed of 1550 rpm for obtaining a homogenous mixture. During this mixing process, it was important to take care that there was no discontinuity in the modified bitumen binder molding process.

The results obtained through this research article showed significant enhancement of rheological characteristics of modified bituminous mix than base bituminous mix. By analyzing the master curves and CAM model parameters which were derived from the FS test it was found that there is a significant improvement in stiffness and elasticity at low frequencies and high temperatures when a high content of CNTs i.e. 0.5% was added to the base bituminous mix. Due to these enhanced properties of modified bituminous mix, the rutting resistance was increased by a significant amount. The dataset which was prepared by conducting various experiments showed a good reduction of susceptibility to oxidative aging.

The limitations or research gap in this research manuscript which was suggested by the author of this article is that more research and testing are needed to generalize the findings and understand the mechanism of modification of base bituminous mix by using CNTs. Also, he suggested analyzing the cost benefits of this modification to apply it at the industrial scale. Also, CNTs modified asphalt with base asphalt was based on limited CNT dosages. The dataset of this manuscript is small and it can be escalated.

Li, Yongyi, et al. (2022) [31]

The work in this paper focuses on the study of analyzing the rheological response behavior and phase structure of MWCNTs modified asphalt. For this five different contents of CNTs (0.5%, 1%, 1.5%, 2%, and 2.5%) were blended with base asphalt. Several tests like viscosity and oscillatory loading tests by using Brookfield rotational viscometer (BRV) and DSR were conducted to understand the rheological characteristics of the modified asphalt mix. Molecular simulation and phase structure modeling were also derived by MS, Accelrys commercial software to understand the main components of both base asphalt and MWCNTs modified asphalt mix. Electrostatic potential surface analysis was also performed to study the polarity (π - π interaction force) of both base and modified asphalt.

The research methodology used for this research paper contains five key steps or tasks:

1. Sourcing and acquiring the required materials used for this research.
2. Preparation of the asphalt binder samples.
3. Molecular simulation and phase structure modeling.
4. Lab experiments and testing of both base and modified asphalt mix for comparison.
5. Analyzing the dataset obtained by performing several operations and tests and synthesizing them.

The MWCNTs of various dosages ranging from 0.5, 1, 1.5, 2, and 2.5% were added to the base binder and a comparison of modified asphalt with base asphalt was studied. For this first, the base asphalt was

manually mixed with CNTs. Then for homogeneous dispersion of CNTs, the mixture was heated up further up to 155 °C for the next 30 min. at a stirring speed of 5000 rpm to obtain a homogenous mixture. The results obtained through this research article showed significant improvement in polarity (π - π interaction force). It was found that MWCNTs modified asphalt had higher viscosity and complex modulus than the base asphalt. Also, the modified asphalt mix had reduced sensitivity and susceptibility to temperature variations. Finally, it was concluded on behalf of the results that the MWCNTs significantly enhance the rheological properties of the asphalt mix and the high-temperature performance of the asphalt binder.

The limitations or research gap in this research manuscript which was suggested by the author of this article is that future research based on MWCNTs modification should include a wide array of materials, simulation models, and lab testing methods including moisture and crack susceptibility analysis. The dataset of this manuscript is small and it can be escalated.

Faramarzi, M., et al. (2013) [32]

The work in this paper focuses on the study of technical characteristics like ductility, stability penetration degree, etc. of hot mix CNTs modified asphalt mix. Conventional tests like penetration grade, softening point, and marshal stability tests were performed to evaluate the technical properties of the modified asphalt mix and compare it with the base asphalt mix. A scanning electron microscope test was also performed to evaluate the dispersion of CNTs with asphalt.

The research methodology used for this research paper was the CNTs of various dosages of .1%, 0.5%, and 1% of the asphalt binder were added to the base binder. Some initial attempts were made considering different mixing times and temperatures, then the final mixing protocol was adopted which consists of two phases. First, the base asphalt was manually mixed with CNTs. Then for homogeneous dispersion of CNTs, the mixture was heated up further up to 160 °C for the next 40 min. at a stirring speed of 1550 rpm for obtaining a homogenous mixture.

The results obtained through this research article showed that the technical properties of base asphalt were enhanced by adding CNTs as a modifier. Modified asphalt mix provides low penetration but a high softening point and viscosity. In addition to 1% of CNTs, the sample had marshal stability of 32.53% and a marshal ratio of 44.71% which is higher than the base asphalt. Also, marshal flow was 8.4% and specific gravity was 0.68% was low as compared to base asphalt. But despite the low marshal flow the modified asphalt was within permissible limits.

The limitation or research gap in this research manuscript is that the conclusion of this research was based on limited laboratory tests. More testing should be done to generalize the results. Also, the comparison of CNTs modified asphalt with base asphalt was based on limited CNT dosage. The dataset of this manuscript is small and it can be escalated.

Gong, M., et al. (2018) [33]

The work in this paper focuses on the experimental study of carbon nanotube (CNT) modified asphalt binder's performance, and chemical and microstructure properties to achieve the goal of designing long-life asphalt pavements.

The objectives of this research were to analyze the mixing time and properties effect of asphalt binder modified with carbon nanotubes. Further, this research paper aims to analyze the anti-rutting and anti-cracking abilities of asphalt binder which is modified with CNT.

The research methodology followed for this research paper is:

- i) Study of mixing combination which includes shearing time and shearing rate.
- ii) Different CNT content (0.5, 1, 1.5, 2, 2.5, and 3%) modified asphalt binder were analyzed by conducting several tests such as penetration, softening point, ductility, separation TFOT, RV, DSR, and BBR. All tests analyze certain properties of different percentages CNT modified asphalt binders.
- iii) Further two tests were also performed to characterize the functional groups and microstructures of base and modified asphalt before and after aging which are FTIR and AFM.

The results of this study show that a mixture is suitable for modifying asphalt binder with CNT which has a combination of 5000 rpm mixing and 30 min mixing time. With the increase in the percentage of CNT content in the asphalt mix, the penetration value decreases but the softening point increases.

The limitation or research gap in this research manuscript is that only one type of carbon nanotube was used, so it is recommended by the author of this manuscript that other types of CNT be used as modifiers for asphalt binder. Also, recent testing methods could be used in the future like Raman spectroscopy to analyze the modified asphalt binder.

Galooyak, Saeed Sadeghpour, et al. (2015) [34]

In this study, different contents of carbon nanotubes are used to modify the conventional bituminous mix. For the samples prepared using an ultrasonic mixer, it was observed that the CNTs were peeled off and uniformly mixed in bitumen. Then experiments of asphalt, XRD analysis, and rheological tests using DSR, were conducted on the modified bituminous mix.

The results of this research show that the addition of 1.2 wt% of carbon nanotubes to the bitumen has enhanced the rheological properties of bitumen at high and low-temperature service, significantly. Also, the addition of CNTs increases the stiffness and reduces the phase angle of base bituminous mix.

The limitation or research gap in this research manuscript is that the comparison of CNT-modified bituminous mix with base bituminous mix was based on limited laboratory tests. The dataset of this manuscript is small and it can be escalated. Also involvement of further experimental stakeholders in the following opportunities for future research about binary blended additives or modifiers (Gilsonite and CNT).

5. CNT dispersion in bitumen

The most difficult part of modification of bituminous mix using CNT is the proper mixing of CNT to the bitumen. This is due to agglomeration of CNT and high viscosity of bitumen. So it is important that a homogenous dispersion should occur for satisfactory performance and results [34].

There are two mixing methods are used [25]:

- Dry Mixing method
- Wet mixing method

Dry mixing method is very simple. In this method CNT is directly added into the bitumen and stirred until the homogenous mix achieved. But in wet mixing method [24] CNTs were added to the methanol. Then the mix was stirred up in a shear mixer for 180 min. with a speed of 550 rpm. This was done for the proper dispersion and homogeneous mixing of CNTs in the solvent. After homogeneous dispersion and mixing of CNTs in methanol, the solution was mixed in bitumen binder and the mixture was heated up further up to 158 °C for the next 45 min. at a stirring speed of 3000 rpm to obtain a homogenous mixture. Table 3 shows the mixing conditions of various past researches.

Table 3: Summary of mixing conditions of various researches

Authors	Haq et al.[24]	Faramarzi, M., et al.[25]	Faramarzi, M., et al.[25]	Eisa et al.[26]	Ismael et al.[28]	Santagata et al.[30]	Li et al.[31]	Faramarzi, M., et al.[32]
Mixing method	Wet	Dry	Wet	Dry	Dry	Dry	Dry	Dry
Solvent used	Methanol	-----	Kerosene	-----	-----	-----	-----	-----
Mixing time (minutes)	45	40	45	60	45	40	30	40
Mixing	158	160	158	150	163	160	155	160

temp. (°C)								
Frequency (rpm)	3000	1550	2500	2500	1500	1550	5000	1550

6. Conclusions:

The following conclusions are made from the literature review:

1. This study shows that the wet mixing technique is better for homogeneous dispersion of CNTs in bitumen rather than dry mixing.
2. The penetration performance and ductility values are decreased while the softening value is increased due to the usage of CNTs in bituminous mix which results in the increment in the stiffness of the bitumen binder when modified by using CNTs.
3. Also, better indirect tensile strength values are noted when the base bituminous mix is modified by using CNTs.
4. The marshal stability and flash point of the modified samples are increased on increasing the content of CNTs.
5. Modified bituminous mix using MWCNTs shows significant improvement in polarity (π - π interaction force). It is found that MWCNTs modified bituminous mix has higher viscosity and complex modulus than the base bituminous mix.

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