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Study the Behavior of Asphalt Cement Modified by Different Types of Nanocarbons

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Abstract

Nanocarbon application as an asphalt cement modifier has revealed improved and satisfactory results in the rheological properties of modified asphalt cement. All previous studies examined the effect of one or more nanocarbons, regardless of the effect of nanosized and nanoparticle shapes on these results. Therefore, this study is meant to contribute to knowledge on the novelty of the effect of nanocarbon particle shapes for the modification of asphalt cement. For this purpose, three distinct nanocarbon forms—nano graphite (NGR) powder, multiwalled carbon nanotubes (MWCNTs), and nano carbon black powder (NCB)—are employed to modify asphalt cement, while restricting their nano dimension to small ranges (20–40 nm), and added with various dosage percentages (1.5%, 3%, 4.5%, and 6% by weight of the binder). They were evaluated utilizing Field Emission Scanning Electron Microscope (FESEM), Fourier transform infrared (FTIR), rotational viscosity (RV), and Dynamic Shear Rheometer (DSR). The results showed that the performance of asphalt cement was enhanced by all varieties of nanocarbons employed in this investigation, and increasing the percentage of nanocarbons utilized to modify the asphalt also had a favorable effect. However, when comparing the performance of utilizing these different types of nanocarbons, MWCNTs performed best in terms of dispersion within the asphalt matrix, decreasing asphalt oxidation, reducing sensitivity to temperature changes, improving rheological properties, and increasing resistance to permanent deformation.

Keywords: Nano Carbon-Modified Asphalt; Nano Graphite; Multiwalled Carbon Nanotubes; Carbon Black Powder; Fourier Transform Infrared; Dynamic Shear Rheometer.

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1. Introduction

The conventional asphalt concrete mixture consists of two major components: aggregates and binder. The aggregate represents the major component in the mix, accounting for approximately 95%, while asphalt cement comprises about 5% of the total mixture weight. Although this amount of binder is small, it has a greater effect on the characteristics of the obtained mixture [1]. Researchers consequently seek novel modifiers to significantly enhance pavement performance. Nanotechnology has become a more advanced method in recent years. Owing to the exceptional success of Nanotechnology in other engineering fields, Researchers are focusing on implementing advanced nanotechnology to enhance pavement performance [2]. Numerous research studies have been carried out in the last decade on the modification of asphalt binder by different nanoparticles like nano silicon dioxide, nano titanium oxide [3, 4], nano zinc oxide [5], nano aluminum oxide [6], nano iron oxide [7], nano calcium carbonate [8], nano copper oxide [9]. As various exciting carbon nanomaterials emerge, including fullerenes, carbon nanoparticles, carbon nanotubes/fibers, graphene,

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and nano-diamonds, they have garnered significant interest from the scientific community and engineering due to their unique mechanical, chemical, optical, thermal, and physical properties [10]. Depending on the structure of the formed bond, nano-carbons can be classified into sp2 and sp3 materials. Typical sp2-carbon nanomaterials include zero-dimensional (0D) fullerene and carbon dots, which are amorphous nanoclusters of carbon with diameters less than 10 nm, one-dimensional (1D) carbon nanotubes/fibers, and two-dimensional (2D) graphene. Sp3-carbon nanomaterials, however, are often nano-diamonds (NDs) with nanoscale crystal sizes [11].

1.1. Carbon Nano Tube (CNT)

Commonly, CNT is a seamless cylindrical structure with a surface composed of sp^2 hybridized graphite sheets, comprising two types: single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) [12]. One of the most widely used nanomaterials is carbon nanotubes (CNTs), which are strong, light, tiny, and have a vast surface area [13]. Compared to conventional reinforcing elements (such as glass fibers or carbon fibers), the high aspect ratio of carbon nanotubes (CNTs) is anticipated to result in bituminous composites that are noticeably stronger and better. The high specific strength, chemical resistance, electrical conductivity, and thermal conductivity of carbon nanotubes (CNTs) make them suitable for use as reinforcement in building superior bituminous composites [14]. According to earlier studies, adding more than 1% (mass fraction) of MWCNTs to asphalt will cause agglomeration and greatly enhance its performance [15]. While Saltan et al. (2018) observed that the addition of multi-walled carbon nanotubes (1%, 3%, and 5%) to modify the asphalt binder, used in the preparation of hot mix asphalt samples, demonstrated greater moisture resistance than standard samples. The results of scanning electron microscopy indicated that a homogenous mixture was produced. The majority of the nanomaterial aggregation in the combinations was determined to be less than 4 µm [16].

Faramarzi et al. (2015) found that adding CNTs to asphalt binder can lower binder penetration. In contrast, tests for softening point, dynamic shear rheometer, and viscosity showed better results with modified asphalt [15, 17]. Ziari et al. (2014) employed CNTs as a modifier for asphalt cement with four bitumen weight percentages (0.3, 0.6, 0.9, and 1.2%). This addition improved bitumen's performance features (phase angle, complex modulus, fatigue, and rutting parameters) as well as its traditional properties (penetration and softening point) [18-20]. Similarly, when bitumen was modified with varying amounts of carbon nanotubes by Galooyak et al. (2015), it was found that adding 1.2% of carbon nanotubes to bitumen greatly improves its rheological characteristics at both high and low temperatures. Additionally, the base bitumen's stiffness and phase angle were decreased with the addition of the nanotube [21]. This is consistent with Amin et al. (2016), who also concluded that the addition of MWCNTs to bitumen enhanced its performance at both high and low temperatures [22]. The impact of CNTs on the fatigue and fracture performance of asphalt was examined by Ameri et al. (2016). Applying increasing percentages of CNT resulted in a noticeable improvement in fracture resistance [23]. Another study concluded that the addition of 2% MWCNTs to the asphalt binder increases the material's resistance against permanent deformation and fatigue failure [24]. The research by Gong et al. (2018) shows that asphalt treated with carbon nanotubes (CNTs) has superior anti-aging properties and a smaller rise in the sulfoxide index as it ages. The mechanism of CNT modification is described in detail by AFM characterization [25]. While Ismael et al. (2021) found that the addition of carbon nanotubes (CNT) to the binder under aged and unaged conditions resulted in a considerable increase in rotational viscosity and the $G^*/\sin\delta$ value, which can be utilized as a measure of rutting resistance [26].

1.2. Nano Graphite (NGR)

Graphene (Gr), graphene oxide (GO), and graphene nanosheets (GNPs) exhibit exceptional thermal and electrical conductivity, which can reduce the electrical resistivity of asphalt and asphalt mixtures while enhancing thermal conductivity. At the same time, it can enhance the aging resistance, moisture damage resistance, high-temperature rutting resistance, and fatigue life [27]. Moretti et al. [28] and Wu & Tahri [29] concluded that graphene nanoplates' large surface area strengthens the pavement's bonding and stiffens the asphalt binder, therefore improving the mechanical performance of the modified asphalt mixture and its durability. Hafeez et al. (2019) found that the modifying effect of 4% graphene nanoplatelets (GNPs) is more noticeable than that of 2% GNPs, where GNPs provide the pavement with a nanotexture that improves its resistance to skids [30]. The effect of graphite and mineral powders on the asphalt cement softening point has been investigated by Liu et al. (2008) and proved to increase the bituminous softening point from 45°C to 70°C when 9% graphite is used in the bitumen modification, and the rutting parameter increases from 1.555 kPa to 3.745 kPa at 40°C [31]. Likewise, Lawal et al. (2024) observed that adding graphite to bitumen improved the physical properties (penetration, softening point, ductility, flash, and fire points) of asphalt cement. Thus, the graphite-modified asphalt concrete exhibited higher Marshall stability and flow, with optimum values of 18.09 kN and 3.80 mm, respectively, at 8% graphite content. The optimum indirect tensile strength of 986.20 kPa also occurred at 6% graphite content [32]. Whereas a study by Le et al. (2020) assessed the potential of employing GNPs to enhance the performance of asphalt mixtures. The addition of GNPs at a weight percentage of 2–6% has been found to improve the bitumen's low-temperature performance and elastic characteristics, as well as resistance to permanent deformation, moisture susceptibility, and skid resistance [33]. Likewise, graphite raised the rutting parameter and caused the viscosity values to rise. Without affecting the phase angle values, the rutting parameter rose by 21% when 16% graphite was employed instead of pure binder. These findings demonstrated that the high-temperature performance was modified by the graphite used to enhance the thermal characteristics [34]. Additionally, graphite-modified asphalt concrete exhibited improved permanent deformation and fatigue resistance compared to typical asphalt concrete, but exhibits poorer moisture stability [35]. Graphite and carbon fiber were used as fillers in another study by Liu & Wu [36] which significantly improved the asphalt mixture's mechanical and electrical properties and raised Marshall stability, residual stability, and rutting dynamic stability. Also, graphite-modified asphalt binders exhibited improved storage stability compared to the conventional sample, enhancing the anti-aging qualities of asphalt binders, as demonstrated by the differences in the rheological and physical characteristics of the aged samples and the unaged asphalt binders [37].

1.3. Nano Carbon Black (NCB)

Carbon black that has been reduced in size to the nanoscale is known as nanocarbon black. It can be used to reinforce road materials due to its exceptional mechanical, electrical, and thermal properties. Concrete and asphalt become more durable, strong, and rigid when nanocarbon black is added [38]. Saritha & Kiran Kumar (2015) conducted experiments using varying percentages of Carbon Black (CB) (0–2% with increment 0.25), and they observed an insignificant difference in the ductility, penetration, and softening point values [39]. The effects of several types of carbon black on the performance of SBS-modified asphalt were investigated by researchers. They found that carbon black enhances the asphalt's thermal and electrical conductivity characteristics, thereby increasing its resistance to aging and high temperatures. Additionally, adding carbon black particles to asphalt can make it less flexible and more viscous, and it may also have an adsorption impact on some of its lighter components [40, 41]. Whereas Mohammadi et al. (2025) examined the rheological characteristics of the e-waste-modified asphalt, recycling ABS plastics with a blending content of 5% along with 5% carbon black can improve the asphalt's resistance to cracking in cold weather and its ability to resist rutting at high temperatures [42].

On the other hand, Zhong et al. (2021) mixed asphalt with three various sizes of CB at concentrations of 2%, 4%, and 6%. The medium-temperature fatigue performance and rutting resistance of virgin asphalt binders have been found to be improved by the addition of CB. The CB particle size is 2.6μm, and a level of 2% was recommended [43]. While the study by Geckil et al. (2018) examined the impact of carbon black (CB) as an addition on bitumen's resistance to delaying or avoiding rutting. Concluded that adding an ideal amount of 10% carbon black to bitumen enhances the rutting and fatigue resistance and effectively reduces the temperature susceptibility of binders [44]. Similarly, a study conducted by Rafi et al. (2018) showed that 10% of the bitumen's weight was the ideal dosage of CB in asphalt. The homogeneous and non-agglomeration of CB in the asphalt binder was confirmed by the results of storage stability tests and scanning electron microscopy [45]. Also, Zarroodi et al. (2023) examined the effect of the carbon black additive on resistance to moisture damage in the asphalt samples that had been modified with four different carbon black contents. Results showed that adding 8% carbon black to the asphalt mixture improved moisture sensitivity [46]. The cost study conducted by Zahedi et al. (2020) demonstrated that the asphalt mixture with 5% nano-carbon black and 0.4% polyester fiber was a good option from an economic and mechanical perspective. These types of asphalt mixtures can be employed in regions with moderate temperatures and a climate with a high level of smooth traffic [47].

2. Experimental Program

2.1. Materials Characterization

2.2.1 Asphalt Cement

The asphalt cement with a penetration grade of (40-50) was utilized in this study, brought from the Phonex oil refinery in Sulaymaniyah city, northern Iraq. The physical properties of the asphalt cement are listed in Table 1.

Table 1. Physical Properties of Asphalt Cement

Properties	Unit	ASTM	Test Results
Penetration at (25°C, 100 g, 5 s)	0.1 mm	D5	41.66
Rotational Viscosity @135 °C	mPa.S	D4402	554
Softening Point (Ring and Ball)	°C	D36	51.16
Ductility (25°C, 5 cm/min)	cm	D113	132
Flash point	°C	D92	>232
Fire point	°C	D92	>250

2.2.2. Nano Carbon

This study employed three different types of nanocarbons, which were manufactured in China by Jiangsu Xfnano Materials Tech Co. Ltd. The application of each type of nanocarbon as follows:

- Industrial Grade Multiwalled Carbon Nanotubes MWCNTs: Commonly utilized for reinforcement of composites, improving strength, elasticity, fatigue resistance, isotropy, lithium-battery anodes, energy conversion, hydrogen storage, supercapacitors, electromagnetic wave absorption and shielding, catalysts, sensors, etc. Table 2 summarizes the physical characteristics of the multiwalled carbon nanotube MWCNT powder

Table 2. PHYSICAL Properties of Multiwalled Carbon Nanotubes MWCNTs

Properties	Multiwalled Carbon Nanotubes
Appearance	Black Powder
Specific Surface Area	>80 m^2/gm
Outer diameter	20-40 nm
Inner diameter	5-10 nm
Tube length	10-30 µm
Apparent density	0.17 g/cm^3
Tap density	~2.1g/cm^3
Purity	95%

- Nano Graphite Powder: High lubrication, high adsorption, catalytic performance, and high conductivity, steel lubrication, chemical industry, lubricants, and other fields. Table 3 summarizes the physical characteristics of the nano graphite powder.

Table 3. Physical Properties of Nano Graphite Powder

Properties	Nano Graphite
Appearance	Black Powder
Thickness	< 40nm
Diameter	3-6 µm
Purity	99.9%

- High Conductivity Nano Carbon Black Powder: Conductive carbon black with low resistivity is suitable for modifying rubbers, plastics, and other materials, as well as the raw materials of dry cells. Table 4 summarizes the physical properties of the nano carbon black powder.

Table 4. Physical Properties of Nano Carbon Black Powder

Properties	Carbon Black Powder
Appearance	Black Powder
Specific Surface Area	120-130 m^2/gm
Particle Diameter	30-45 nm
Purity	99.0 %
Compacted Density	280-300 g/L

2.2. Sample Preparation

To produce the modified asphalt cement, the asphalt binder was heated to 160°C. Four distinct concentrations of each type of nanocarbons-nano graphite (NGR) powder, multiwalled carbon nanotubes (MWCNTs), and nano carbon black powder (NCB)-were added directly to asphalt at weight percentages of 1.5%, 3%, 4.5%, and 6%, manually blending for 10 minutes until be ensure all nanoparticles were coated with asphalt cement. Then, the sample was placed in an oil bath, which was heated to 160°C to maintain a consistent temperature during the mechanical mixing process. This was achieved by employing a high shear mixer at a mixing speed of 4000 rpm for 30 minutes, resulting in a homogeneous material.

2.3. Objectives and Scope of the Study

In this study, three different types of nanocarbons-nano graphite (NGR) powder, multiwalled carbon nanotubes (MWCNTs), and nano carbon black powder (NCB)-were utilized to modify the asphalt cement. To achieve a satisfactory dispersion of the nanocarbons, a high-shear mixer operating at 4000 rpm was used to mix asphalt cement with various nanocarbon contents of 1.5%, 3%, 4.5%, and 6% for 30 minutes at a mixing temperature of 160°C. To determine the content of nanocarbon materials that will be used in this study to modify asphalt cement, the literature has been reviewed. According to Rasheed et al. (2025), increasing the percentage of carbon nanomaterials to more than 6% leads to the formation of aggregates in the asphalt material [48]. However, the maximum content of carbon nanotubes utilized was 5% by Saltan et al. (2018) [16]. While the graphite content used to modify asphalt cement reached high levels, 9.0% by Liu et al. (2008) [31] and 16% by Erkuş et al. (2017) [34]. Moreover, Geckil et al. (2018) [44] and Rafi et al. (2018) [45] utilized nanocarbon black at a content of up to 10% to improve the performance of the asphalt binder.

The main objectives of this research can be summarized as follows:

- Utilizing the Field Emission Scanning Electron Microscope (FESEM) test to investigate the dispersion of the various types of nanocarbons used to modify asphalt cement.
- Employing the Fourier Transform Infrared Spectroscopy (FTIR) test, which refers to the chemical functional change due to the modification of asphalt cement by a different type of nanocarbons.
- Evaluating the effect of different types of nanocarbons on the rotational viscosity (RV) of the asphalt cement, which predicts the rutting resistance of the mixture later.
- Utilizing the Dynamic Shear Rheometer (DSR) test to evaluate the high-temperature properties of asphalt cement with and without nanocarbon modifier. To compare the effects of various nanocarbon types when mixed with asphalt cement by observing changes in the asphalt cement's G*, δ, and G*/sinδ values.

The research methodology of the current study is presented stepwise in the form of a flowchart in Figure 1.

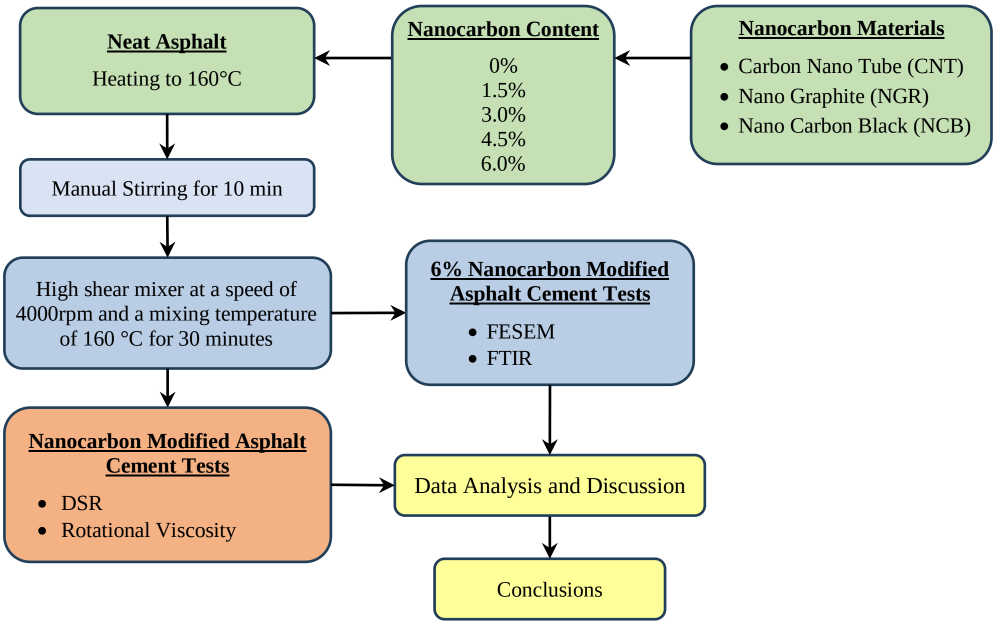

Figure 1. The flow chart of the study

3. Results and Discussion

The effect of different nanocarbon types and concentrations on the conventional properties of asphalt cement samples was investigated in this study.

3.1. Field Emission Scanning Electron Microscope (FESEM) Analysis

A field-emission scanning electron microscope (FESEM) was employed to create ultra-high-resolution images of the nanocarbon-modified asphalt cement sample's surface using a focused electron beam, revealing the specific topography, morphology, and elemental composition of the various nanocarbon shapes within the sample. Although all the modified asphalt cements were prepared with the same nanocarbon content of 6% by weight and the same mixing condition (4000 rpm for 30 minutes), a comparative FESEM study showed that the surface roughness and dispersion behavior of the different nanocarbon materials varied significantly. In Figure 2-a, the nano carbon black modified asphalt cement sample exhibits a homogeneous, smooth, and continuous surface morphology with no discernible agglomerates, indicating great compatibility and excellent dispersion between the modifier and the base material. The multiwalled carbon nanotube-modified asphalt cement sample in Figure 2-b has a microstructure that is comparatively uniform and shows no significant phase separation, indicating good dispersion, whereas the discrete areas of denser particle accumulation point to partial microscale agglomeration. On the other hand, the nano-graphite-modified asphalt cement sample shown in Figure 2-c exhibits a highly heterogeneous morphology with distinct agglomerated domains and prominent flake-like clusters, which are indicative of the modifier's poor dispersion and uneven distribution within the matrix. This kind of agglomeration was a sign of either high particle–particle interactions or inadequate particle breakdown, which could harm material homogeneity.

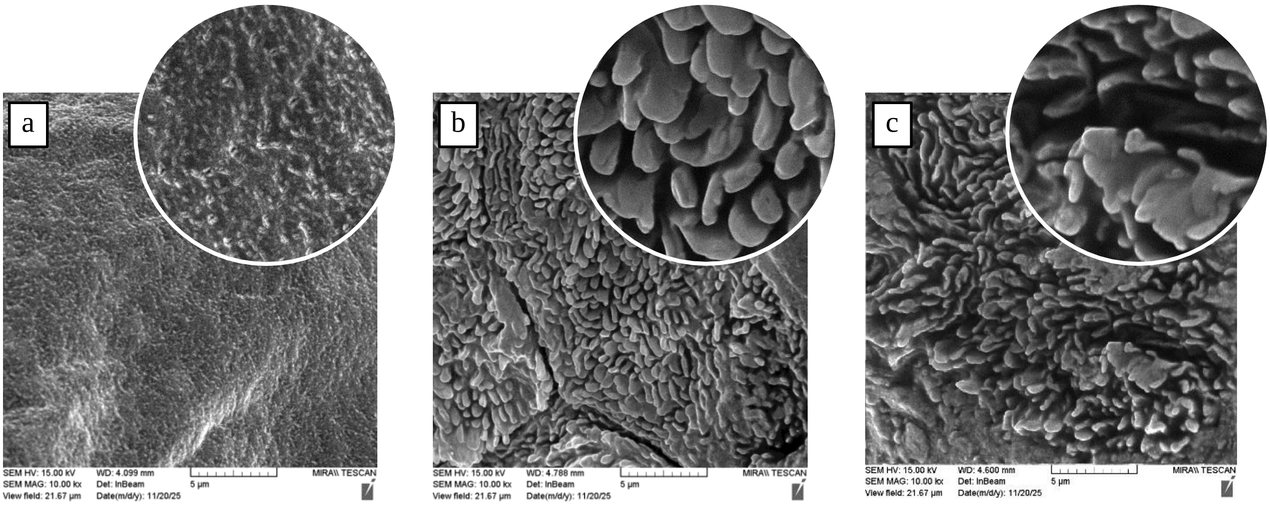

Figure 2. (a) SEM images-5µm Nano carbon black powder modified asphalt cement; (b) SEM images-5µm Multiwalled carbon nanotubes modified asphalt cement; (c) SEM images-5µm Nano graphite modified asphalt cement

3.2. Fourier Transform Infrared Spectroscopy Analysis

A Fourier Transform Infrared (FTIR) Spectrophotometer with a 4,000–400 cm^{-1} spectral range was employed. To clarify the modification in the functional groups, Figure 3 illustrates the transmittance spectra of neat asphalt, asphalt cement modified by NGR, MWCNTs, and NCB materials as a function of wavenumber. In the neat asphalt, the adsorption peak at around 3445 cm^{-1} is attributed to phenols, H-bonded alcohols, and O–H stretch. The adsorption maxima at around 2922 cm^{-1} and 2851 cm^{-1} are attributed to C-H symmetric stretching (aliphatic) and C-H aliphatic hydrogen, respectively. C=C stretch vibrations in aromatics are responsible for the peak at approximately 1615 cm^{-1}. Additionally, at 1452 cm−1 and 1376 cm^{-1}, respectively, C–H bend alkanes and C–H symmetric bending of CH$_3$ from asphalt were produced. Meanwhile, the added nanocarbons caused these peaks to become sharper, especially MWCNTs and NGR, which can be attributed to improvement in the chains ordering, also generating new peaks of C-H stretch at 700-900 cm^{-1} in the nanocarbons modified asphalt cement curves. Whereas the O-H stretching peak at ~3435 for a neat asphalt showed a wide hump, but the broadening was reduced slightly for nanocarbon-modified asphalt, due to the ability of the nanocarbons' surface to adsorb, particularly the MWCNTs. Furthermore, the addition of any type of nanocarbon will result in a lower intensity for the C=O peak at ~1730 cm-1, which refers to reducing the oxidation of asphalt cement.

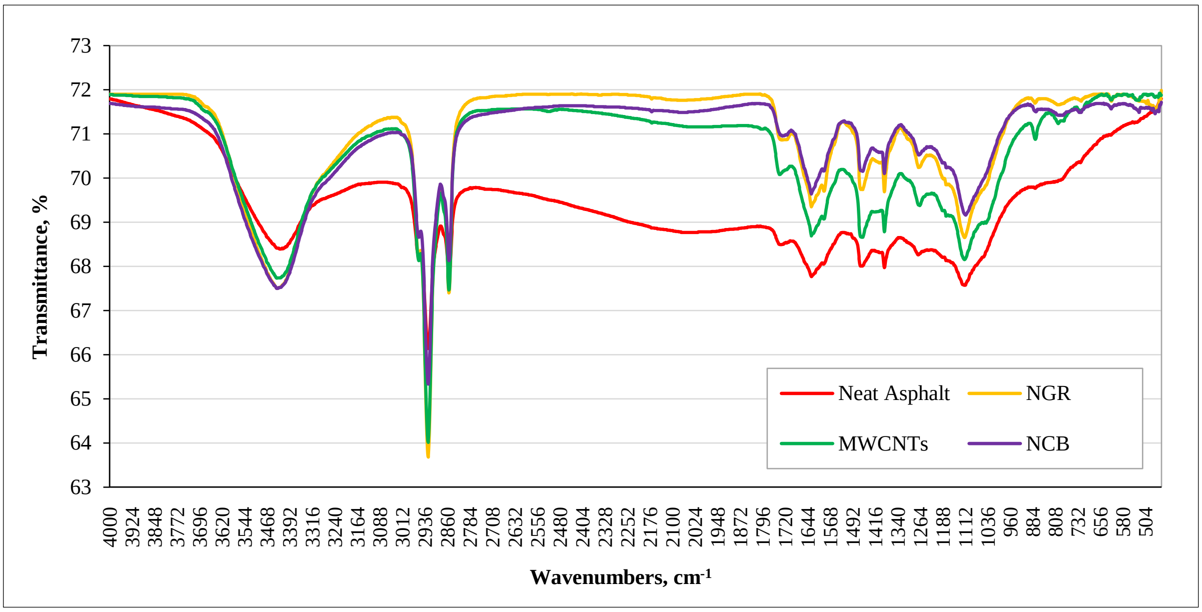

Figure 3. FTIR spectra of the neat asphalt and modified asphalt cement using three different types of nanocarbon

3.3. Dynamic Shear Rheometer Test

A dynamic shear rheometer test was performed to check the rheological properties of the asphalt cement at high temperatures. Figure 4 shows the relationship between a Complex Shear Modulus (G*) and temperature for the neat, NGR-modified, MWCNTs-modified, and the NCB-modified asphalt cement. It was observed that the failure temperature of neat asphalt was about 68 °C, so the upper performance grade of the neat asphalt binder was 64°C. Meanwhile, adding the different contents and types of nanocarbons increased the failure temperature of samples to 70°C, except for the MWCNTs-modified asphalt with 4.5% and 6% samples which the failure temperature increased to 76°C and 82°C, respectively. This indicates the reduction in temperature susceptibility of the nanocarbon-modified asphalt cement. Whereas, the phase angle (δ) decreases for nanocarbons modified asphalt cement, as shown in Figure 5. Hence, the Rutting parameter (G*/Sinδ) values increased for nanocarbons modified asphalt cement compared with neat asphalt, as shown in Figure 6. Where the failure temperature was determined as per the Superpave method for unaged asphalt cement on G*/Sinδ value becoming less than 1 kPa. Finally, Figure 7 summarizes the pass/fail temperature of various nanocarbon concentrations and types.

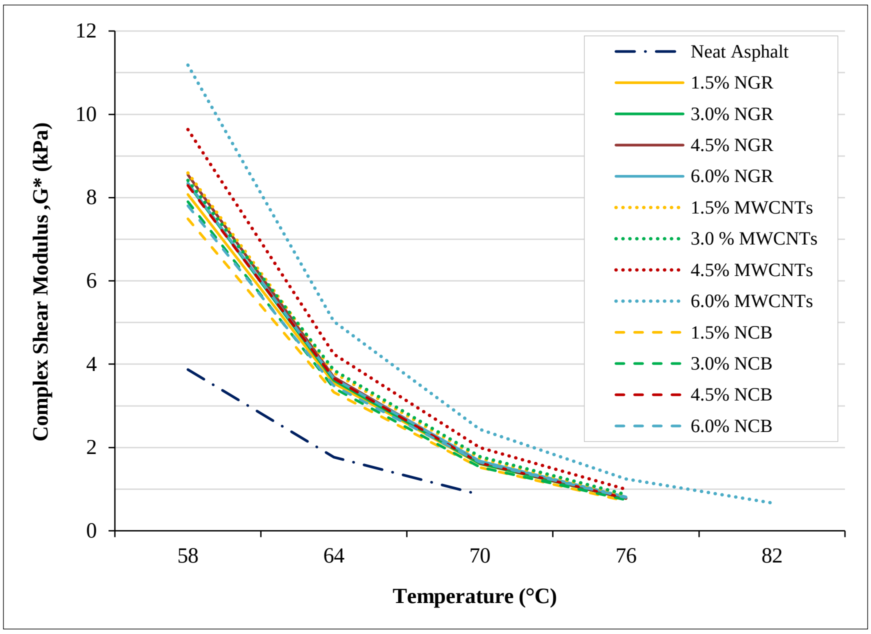

Figure 4. . Relationship between the complex shear modulus (G*) versus temperature for unmodified and nanocarbons-modified asphalt cement

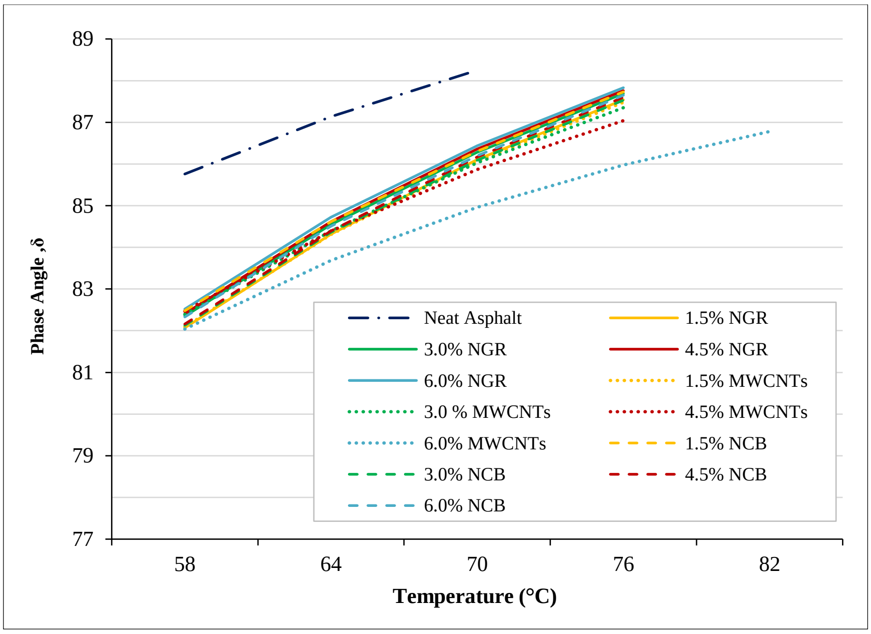

Figure 5. Relationship between the phase angle (δ) versus temperature for unmodified and nanocarbons-modified asphalt cement

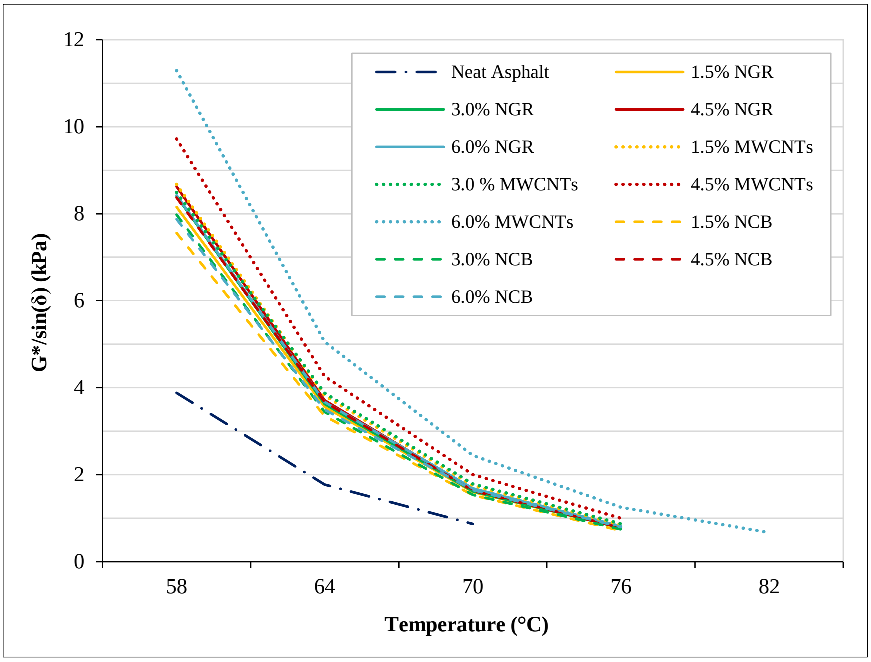

Figure 6. Relationship between the rutting parameter (G*/Sinδ) versus temperature for unmodified and nanocarbons-modified asphalt cement

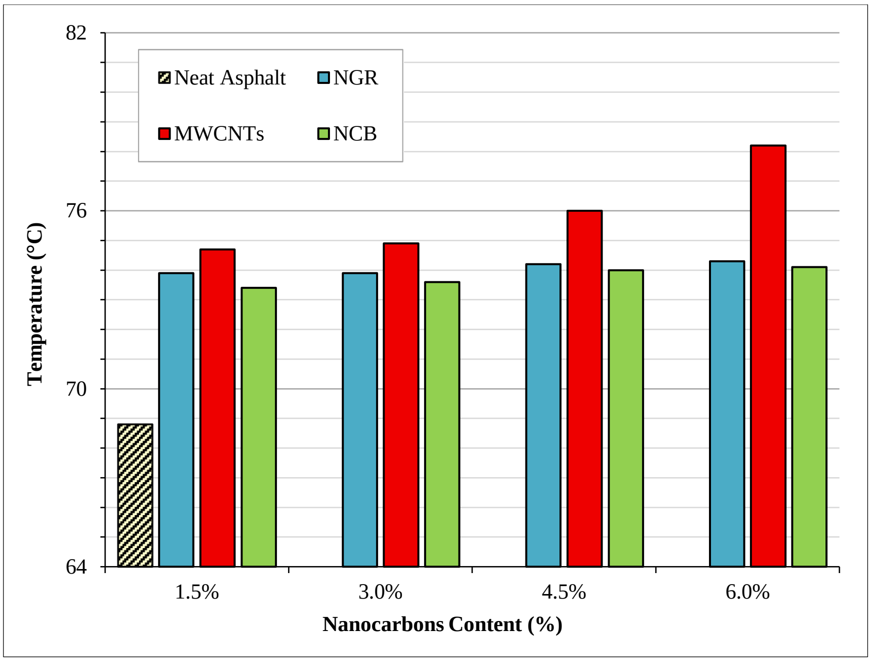

Figure 7. Relationship between the pass/fail temperature and contents of the various types of nanocarbons

3.4. Rotational Viscosity Test

The results showed that the rotational viscosity values of nano-graphite-modified asphalt cement increased slightly with an increase in the percentage of added nano-graphite. In contrast, the addition of black carbon resulted in an insignificant change in rotational viscosity values. Meanwhile, the MWCNT modifier had the most significant impact, as the increase in the percentage of added MWCNTs to the asphalt cement caused a sharp increase in the rotational viscosity values. In contrast, 6% MWCNTs had the highest rotational viscosity. According to this, MWCNTs exhibit superior resistance to the rutting parameter. The highest temperatures for mixing and compaction are associated with the highest rotational viscosity, whereas the lowest value is associated with the lowest temperatures. Figure 8 illustrates that all rotational viscosity results for both neat asphalt cement and asphalt cement treated with nanocarbons were less than 3000 mPa·s, which is still within the Superpave Standard's specified limit at 135°C.

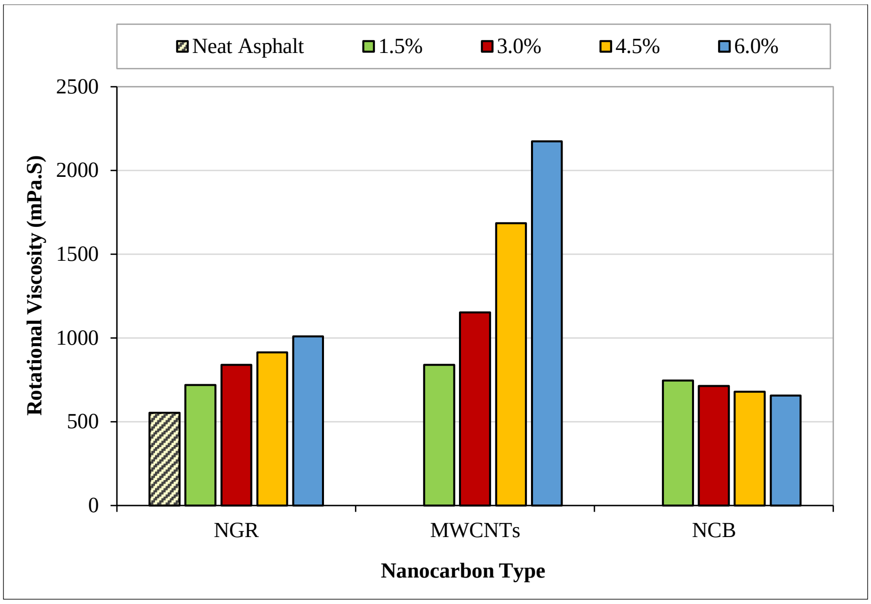

Figure 8. Effect of nanocarbon contents and types on rotational viscosity of asphalt cement

4. Conclusions

In this study, the different types of nanocarbon (NGR, MWCNTs, and NCB) were added to modify the asphalt cement. Based on the SEM, FTIR, RV, and DSR tests, the following conclusions can be made:

- SEM results revealed that MWCNTs and CNB particles are uniformly dispersed in the asphalt matrix with slight agglomeration at nano carbon black (NCB). That could support the improvement in the stiffness of asphalt cement modified by MWCNTs and CNB.
- The FTIR detected new chemical group interactions that appear with added nanocarbons, it is clearly shown by an increase in the number of peaks from 9 in the neat asphalt cement sample to ~15. It was recognized that new C-H and C=O stretching peaks were generated in the nanocarbon-modified asphalt cement curves, which refers to a reduction in the oxidation of the asphalt cement. Meanwhile, the addition of nanocarbons caused the width of O-H stretching peaks to become narrower, which was attributed to the ability of the nanocarbons' surface to adsorb, particularly the MWCNTs.
- It was observed that the addition of all types of nanocarbons to asphalt cement increased the rotational viscosity, but to varying degrees, where the addition of 6% nanocarbons increased the rotational viscosity of neat asphalt by 18% for NCB-modified, 82% for NGR-modified, and 290% for MWCNT-modified asphalt cement. Hence, the sensitivity of modified asphalt to temperature changes will be reduced.
- From the DSR results, all varieties of nanocarbons increase the complex shear modulus (G) and decrease the phase angle (δ), which results in larger values for the parameter G/sin d, which is related to the permanent deformation in terms of rheometry at high temperatures. In particular, the rheological behavior and resistance to permanent deformation are significantly improved when 6% MWCNTs are added to asphalt cement.

5. Declarations

5.1. Author Contributions

Conceptualization, S.A. and H.M.; methodology, S.A.; formal analysis, S.A.; investigation, S.A.; data curation, S.A.; writing—original draft preparation, S.A.; writing—review and editing, H.M.; supervision, H.M. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

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