A SYSTEMATIC REVIEW ON HIGH AND LOW-TEMPERATURE PERFORMANCE OF NANOMODIFIED ASPHALT BINDER CONSIDERING SHORT AND LONG-TERM AGING

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ABSTRACT

The asphalt binder has a high degree of sensitivity to both elevated and reduced temperatures. The existence of temperature variations has a significant impact on the durability of asphalt pavements, leading to numerous performance issues throughout their lifespan. A range of modifiers have been utilized as binders in asphalt to enhance the properties of the asphalt mixture, specifically in terms of its durability against aging, fatigue-induced cracks, temperature conditions, moisture-related deterioration, and permanent deformation. Previous investigations have revealed that polymeric nanocomposites possess distinct properties that make them highly effective. Prior research on three nanomodified asphalt binders known as carbon nanotubes, Al2O3, and nano TiO2 was reviewed for this study. Investigators prioritized the most recent findings on nanomodified asphalt binders from 2014 to 2023. The study's evaluating criteria are the Rolling Thin Film Oven Test (RTFOT), Pressure Aging Vessel (PAV) Test, Dynamic Shear Rheometer (DSR) Test, Phase Angle, and Complex Modulus. This study assembles findings on the effectiveness of nanoparticles as asphalt modifiers at both high and low temperatures. The findings point to the nano modifier type, nano modifier dosage, and nanoparticle size as the primary determinants of asphalt binder performance throughout a range of conditions, including high and low temperatures, and both short and long-term aging. The findings from this investigation will aid future investigations that compare the performance of virgin asphalt with a nanomodified asphalt binder mixture.

Keywords: *Asphalt, binder, nano-particle, high and low temperature, aging.*

1. INTRODUCTION

In modern highway traffic, rutting and cracking are ascribed as major problems confronting asphalt pavement due to the constantly increasing heavy flow of traffic and heavy loads, particularly in climate conditions like; summer heat and winter cold (Riyad et al., 2021)(Saboo & Sukhija, 2020). Temperature plays a significant role on asphalt pavements, sometimes this causes failure to the pavement structures. High and low temperature causes long and short-term aging. Pavements developed with ordinary, unmodified asphalt binders may not maintain adverse traffic and environmental conditions (Ezzat et al., 2020). With these problems, the pavement wouldn't work well and the structure wouldn't last so long. In this manner, researchers and construction agencies are presently centering on modified asphalt binders (mixing asphalt binder with nano silica, fly ash, Ground Granulated Blast-furnace Slag (GGBS), and crushed bone) ((Adiba et al., 2020)& (Zubaer & Riyad, 2023)) to improve pavement deformations.

Modifiers are used to enhance the pavement quality. Certain published studies have proven that nano modifiers can play a noteworthy part in upgrading the performance of asphalt binders and can address major problems with asphalt pavement. Nano-materials in asphalt binders have anti-aging properties and they can withstand fatigue cracking, rutting, and other deformations of asphalt pavements. Various types of asphalt binder modifiers have been widely used in the pavement industry. For instance, rubbers, sulfur, polymers, resins, fiber, nano TiO2, carbon nanotubes, SiO2, Al2O3, and different chemical agents increase the asphalt binder quality (Raufi et al., 2020). In the past few years, the uses of nanomaterials in asphalt binders have increased significantly. Research has shown that the incorporation of nanomaterials enhances a number of the properties of asphalt binders. According to certain research, the hardness and viscosity of asphalt binder were increased by adding nano Titanium dioxide (Debbarma et al., 2022). Compared to regular Titanium Dioxide nanoparticles have a larger surface area and exhibit non-uniform size and arrangements (Shafabakhsh et al., 2014). Some research proved that nano-TiO2-modified asphalt improves the rutting and fatigue behavior of mixtures and is capable of resisting photo-oxidation aging and it has a greater stiffness and elastic behavior (Zhang et al., 2016). In some other studies, Al2O3 is used as a nano-modifier and it provides a good performance to improve oxidation, durability, temperature susceptibility, adhesion, and aging resistance. In addition, nano-ZnO has become increasingly popular in the modification of asphalt to enhance its rheological properties (Bhat & Mir, 2021)& (Zubaer & Riyad, 2023). Asphalt binders which are modified with carbon nanotubes (CNT) have the potential to increase their rutting ability and thus improve their performance at high temperatures. CNT-modified asphalt binder is said to be stable during high temperatures. Furthermore, asphalt binders modified with CNTs performed better under fatigue (Ashish & Singh, 2018).

To identify the results of various researchers using multiple nanomaterials collective, the current study aims to summarize the performance of nanomodified asphalt binders on low and high temperatures considering long and short-term aging. The main topic of this review paper is to look at the findings regarding the modification using Titanium dioxide, Aluminum oxide, and carbon nanotubes in asphalt binders. In actuality, the type of asphalt binder and nanomodifier, the amount of nanomodifier, the size of the nanoparticles, and the method of preparation all have a significant impact on the high and low temperatures of nanomodified asphalt (Li et al., 2021). Consequently, based on earlier studies, it is essential to methodically examine the high and low-temperature performance of asphalt binder modified with a nanomaterial to optimize the use of nano modifiers to control rutting and cracking of asphalt pavement along with their functions in resistance to aging (Picado-santos & Neves, 2019).

2. RESEARCH METHODOLOGY

The intent of this study is to conduct a thorough review of the high and low-temperature performance of nanomodified asphalt binders while taking into account their short and long-term aging. The study is carried out by reviewing prior studies, which mostly focused on three nanomodified asphalt binders known as carbon nanotubes, Al2O3, and nano TiO2. From 2014 to 2023, investigators prioritized the most recent findings on nanomodified asphalt binders. Rolling Thin Film Oven Test (RTFOT), Pressure Aging Vessel (PAV) Test, Dynamic Shear Rheometer (DSR) Test, Phase Angle, and Complex Modulus are the study's assessing criteria.

3. LITERATURE REVIEW

Nanomodification of asphalt binders involves incorporating nanoparticles into the asphalt matrix to enhance its properties. This modification aims to improve the high and low-temperature performance of asphalt binders, addressing issues such as rutting at high temperatures and cracking at low temperatures. High temperature performance involves improved rutting resistance, enhanced aging resistance, reduced softening point and so on. On the other hand, low temperature performance includes improved crack resistance, lower ductility and so on. In this article, the rheological properties of nano-modified asphalt binder are also discussed in a broad manner. The change of the condition of the rheological properties of the asphalt binder can be found from the elaborative analysis of complex modulus and phase angle of different modifiers in asphalt binder.

3.1 Complex Modulus

An indicator of a material's stiffness and resistance to deformation under load is its complex modulus, which can be found in nanomodified asphalt binders as well. The viscous behavior is represented by the imaginary part (loss modulus), and the elastic behavior is represented by the real part (storage modulus).

The type and amount of nanoparticles used for modification can have an impact on the complex modulus of asphalt binders that have been nanomodified. Researchers usually utilize rheological testing or dynamic mechanical analysis (DMA) to estimate the complex modulus. To describe the material's response to various loading circumstances, these tests involve exposing the material to a range of frequencies and temperatures.

The material's performance is anticipated to be improved by the addition of nanoparticles in the context of nanomodified asphalt binders. For example, ((Wu et al., 2021)),((Shafabakhsh et al., 2021)), (Ali et al., 2017) have described elaborately about the change in complex modulus at different temperatures and frequencies. Nano –TiO_2, Carbon Nanotubes (CNT) and Al_2O_3 have been used as nano-modifiers in asphalt binders in these articles. These three modifiers are used greatly in asphalt binders and proved to be very effective in both high and low temperature performance of asphalt binder.

The type, concentration, and testing circumstances of the nanoparticles employed in the nanomodified asphalt binders will determine the precise values of the complex modulus. To find these values for a specific customized binder, experimental testing and analysis are usually needed.

3.2 Phase Angle

The angular difference between the stress and strain waveforms in a dynamic mechanical analysis (DMA) test is known as the material's phase angle. The type and concentration of nanoparticles utilized, along with the testing conditions, can all have an impact on the phase angle when it comes to asphalt binders that are being influenced by them.

Research on the nanomodification of asphalt binders aims to enhance the performance of asphalt mixtures. Asphalt binders can be benefitted from the addition of nanoparticles, such as graphene oxide, carbon nanotubes, or different types of nanoclay, to improve their stiffness, strength, and resistance to aging and environmental conditions.

The phase angle is a crucial variable in DMA testing that might reveal information about the material's viscoelastic behavior. Changes in the material's capacity to release energy and withstand deformation may be indicated by a shift in the phase angle. (Raufi et al., 2020), (Xiao et al., 2011)), (Riyad et al., 2021)have broadly discussed about the modification of phase angle in asphalt binder for different percentages uses of nanomodifiers such as Nano –TiO2, Carbon Nanotubes (CNT) and Al2O3.

It's crucial to remember that the formulation, the testing circumstances, and the particular kind of nanoparticles utilized can all affect the specific phase angle values for nanomodified asphalt binders. To assess these modified binders' performance in various scenarios and characterize their rheological characteristics, scientists and engineers usually carry out laboratory experiments.

3.3 Aging

When asphalt binder gets introduced with nanoparticles, it undergoes changes in properties over time, which are referred to as aging of nanomodified asphalt binder. Through the use of nanomodified asphalt binders in RTFO and PAV tests, the evaluation of the behaviour of the materials under both short- and long-term aging simulations can be found. This knowledge aids in comprehending how nanomodification may enhance the toughness and functionality of asphalt pavements.

3.3.1 RTFO (Rolling Thin Film Oven):

- ⇒ The Rolling Thin Film Oven Test is a standard laboratory procedure used to simulate the short-term aging of asphalt binders during the mixing and compaction process.
- ⇒ The RTFO test involves exposing a thin film of asphalt binder to elevated temperatures and air flow, simulating the oxidative aging that occurs during the hot mix asphalt production process.

3.3.2 PAV (Pressure Aging Vessel):

- ⇒ The Pressure Aging Vessel is another laboratory test used to simulate the long-term aging of asphalt binders that occurs over the life of the pavement.
- ⇒ In the PAV test, asphalt binders are subjected to high pressure and elevated temperatures over an extended period, replicating the aging that takes place during the service life of a pavement.

When it comes to nanomodified asphalt binders, researchers are exploring the use of nanomaterials to enhance the properties of asphalt. The goal is to improve the performance of asphalt, including its resistance to aging, cracking, and deformation.

4. RESULT & DISCUSSION

4.1 DSR (Dynamic Shear Rheometer)

The dynamic shear test proves useful in comparing the temperature susceptibility of reinforced and original binders. In this test, a dynamic shear rheometer (DSR) is employed to characterize the asphalt binder, determining both the complex shear modulus (G*) and the phase angle (δ) of the binder at high and intermediate service temperatures. The asphalt control undergoes repeated shearing in the DSR, expressing the binder's resistance to deformation through a complex modulus. It's essential to determine the phase angle (δ) because two asphalt binders with the same numerical complex modulus may exhibit different elastic and viscous behaviours.

The rutting parameter, G*/sinδ, serves as an indicator of the asphalt binder's resistance to permanent deformation. A high complex modulus (G*) and a low phase angle (δ) contribute to the high-temperature performance of the asphalt binder, reducing flow deformation at high temperatures and enhancing resistance to permanent deformation seen in rutting. These properties are crucial for optimizing the performance of asphalt binders under varying temperature conditions.

4.1.1 Complex Modulus

Table 1: Data for Complex Modulus at Different Percentages and Temperature

Temperature (degree)	Complex Modulus (kPa) at 0 %	Complex Modulus (kPa) at 0.5 %	Complex Modulus (kPa) at 1%	Complex Modulus (kPa) at 2%
40	34.73	116.19	224.12	388.78
50	7.60	38.88	105.26	167.78
60	1.78	10.31	29.73	78.80
70	0.49	2.35	4.94	19.60

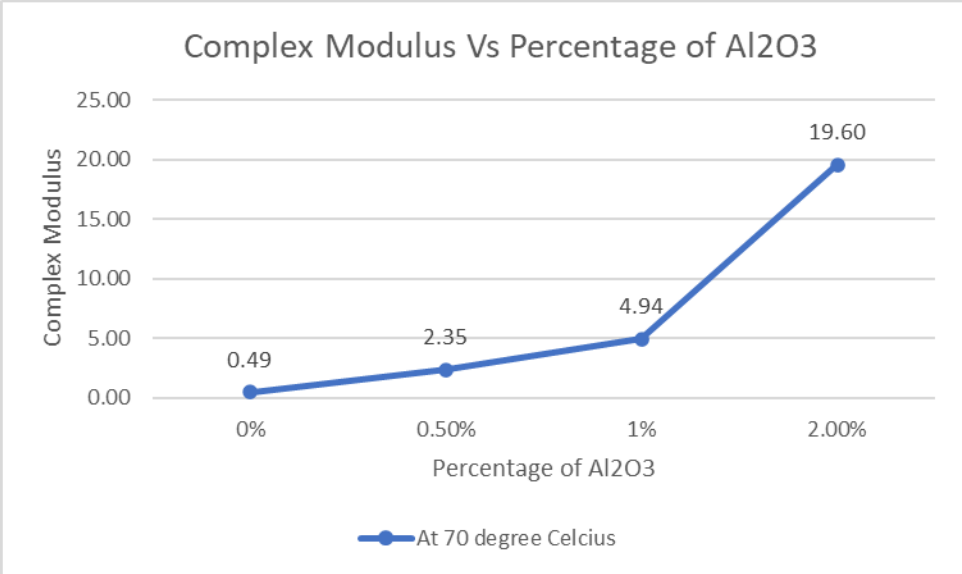

Figure 1: Complex Modulus Vs. Percentage of Al_2O_3 (Bhat & Mir, 2021)(Ashish & Singh, 2018)

Table 2: Data for Complex Shear Modulus at Different Percentages and Temperature

Temperature (degree cel.)	Complex Shear Modulus (KPa) at 0%	Complex Shear Modulus (KPa) at 0.4%	Complex Shear Modulus (KPa) at 0.75%	Complex Shear Modulus (KPa) at 1.5%	Complex Shear Modulus (KPa) at 2.25%
52	24	33.9	43.5	45.7	42.3
58	10.1	15.9	19.1	20	19.4
64	4.7	7.2	8.6	9.6	9.2
70	2.1	3	3.9	4.9	4.5
76	1.6	1.6	2	2.3	2.2
82	0	0	0	1.2	1.1

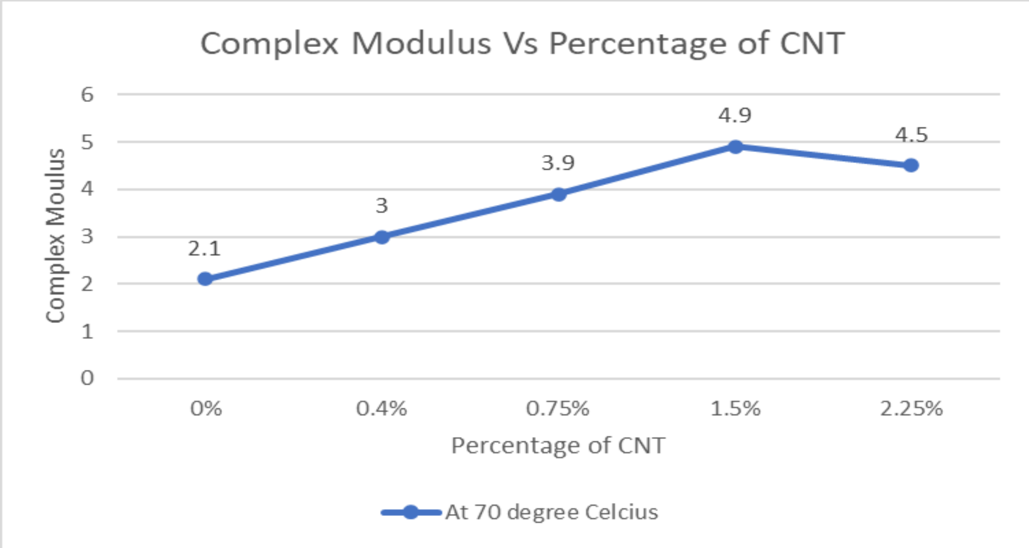

Figure 2: Complex Modulus Vs. Percentage of CNT

According to the author's article, the complex modulus decreases with an increase in temperature for a nano-modified asphalt binder. Also, when the same percentage of nano modifier is used and the temperature is held constant, Al2O3 yields a higher complex modulus value compared to CNT. Additionally, an increase in the percentage of nano modifier leads to an increase in the complex modulus.

4.1.2 Phase Angle

Within Superpave specifications, the phase angle is delineated as the temporal delay between strain and stress during traffic loading, and its value is significantly influenced by both temperature and loading frequency. This parameter serves as an informative gauge for the viscosity and elasticity of binders. Under typical pavement temperatures and traffic loads, asphalt binders exhibit traits of both viscous liquids and elastic solids. In this study, different author's article was reviewed and their result's data was compared to identify new findings.

Table 3: Data for Phase Angle at Different Percentages and Temperature

Temperature (degree cel.)	Phase Angle at 0% (degree)	Phase Angle (degree) at 1%	Phase Angle (degree) at 2%
40	78.99	54.26	47.23
50	83.29	64.32	60.86
60	86.54	74.38	70.92
70	88.53	81.72	77.84

Table 4: Data for Phase Angle at Different Percentages and Temperature

Temperature (degree cel.)	Phase Angle at 0% (degree)	Phase Angle at 1% (degree)	Phase Angle at 2% (degree)
46	38.86	36.40	29.35
52	57.43	52.67	47.74
58	68.24	65.25	61.37
64	78.53	74.48	70.95
70	84.76	80.36	77.89
76	87.83	87.65	83.25

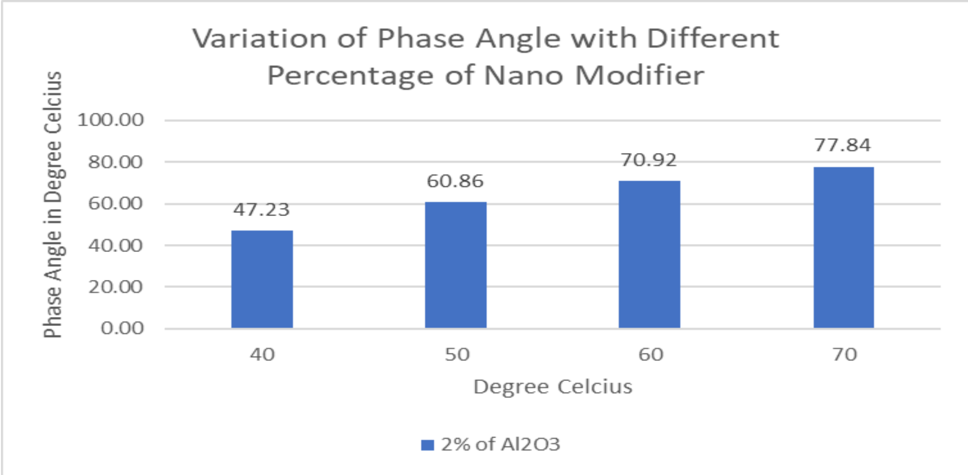

Figure 3: Variation of Phase Angle with Different Percentage of Nano Modifier(Bhat & Mir, 2021)

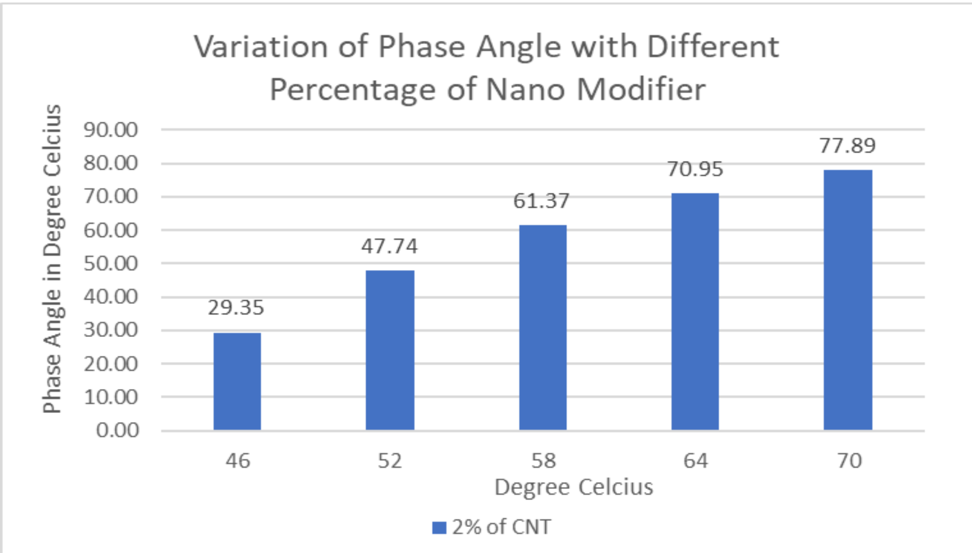

Figure 4: Variation of Phase Angle with Different Percentage of Nano Modifier

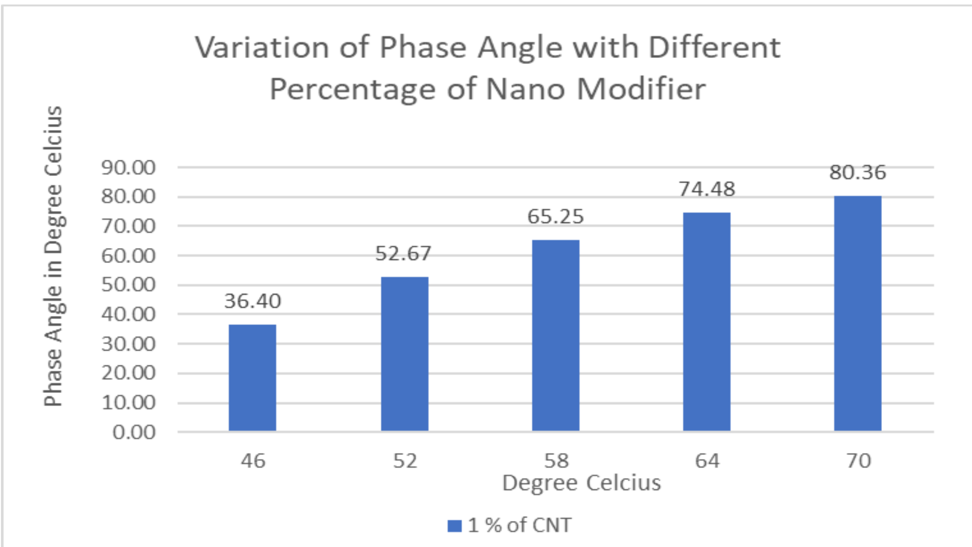

Figure 5: Variation of Phase Angle with Different Percentage of Nano Modifier(Gong et al., 2018)

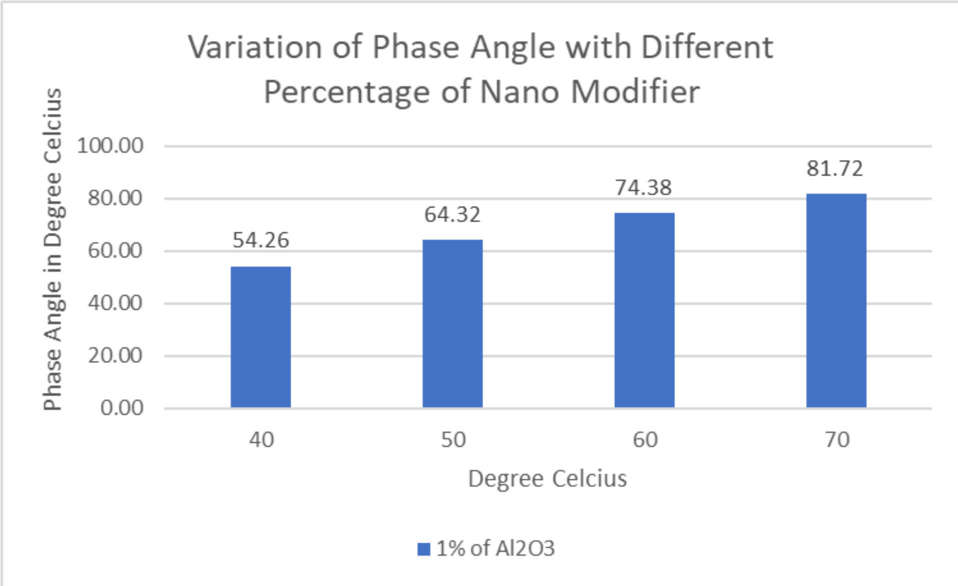

Figure 6: Variation of Phase Angle with Different Percentage of Nano Modifier(Gong et al., 2018)

Phase Angle Graph in Figure 3 and 4,

According to the author's article (papers 6 and 4), it has been identified that at a fixed temperature, the phase angle value decreases with an increasing percentage of Nano modifier. Additionally, for the same percentage, Al2O3 demonstrates a higher phase angle compared to CNT.

Phase Angle Graph in Figure 5 and 6,

Furthermore, another observation is that the phase angle value increases with the elevation of temperature for a specific percentage of nano-modified mixing in asphalt binder. Specifically, at a 1% percentage of both Al2O3 and CNT, we noted that the phase angle value becomes larger with the temperature increase, compared to CNT. This trend persists for 2% of both Al2O3 and CNT as well.

4.2 Aging

Rutting Factor - Due to the inherent physical traits of standard asphalt materials, asphalt concretes are prone to rutting in elevated service temperatures, particularly when the asphalt binder exhibits lower viscosity, making them more susceptible to deformation under heavy traffic loads. In Superpave specifications, the parameter G*/ sin δ serves as a crucial determinant in characterizing the permanent deformation of an asphalt binder at high-performance temperatures.

Table 5: Data for Rutting Factor at Different Percentages and Temperature

Temperature in (Degree Celcius)	**G*/ sind at 0% (KPa)**	**G*/ sind at 1 % (KPa)**	**G*/ sind at 2% (KPa)**
46	10.7	65.6	113.1
52	5.4	50.4	86.3
58	1.1	29.9	54.9
64	0.3	15.1	36.5
70	-1.2	7.2	22.7
76	-0.6	2.9	12.4

Table 6: Data for Rutting Factor at Different Percentages and Temperature

Temperature in Degree Celcius	G*/ sind (KPa) at 1 %	G*/ sind (KPa) at 2%
46	91.7	84.8
52	71.4	66.1
58	54.1	48.2
64	41.5	31.1
70	27.3	18.3
76	13.7	5.3

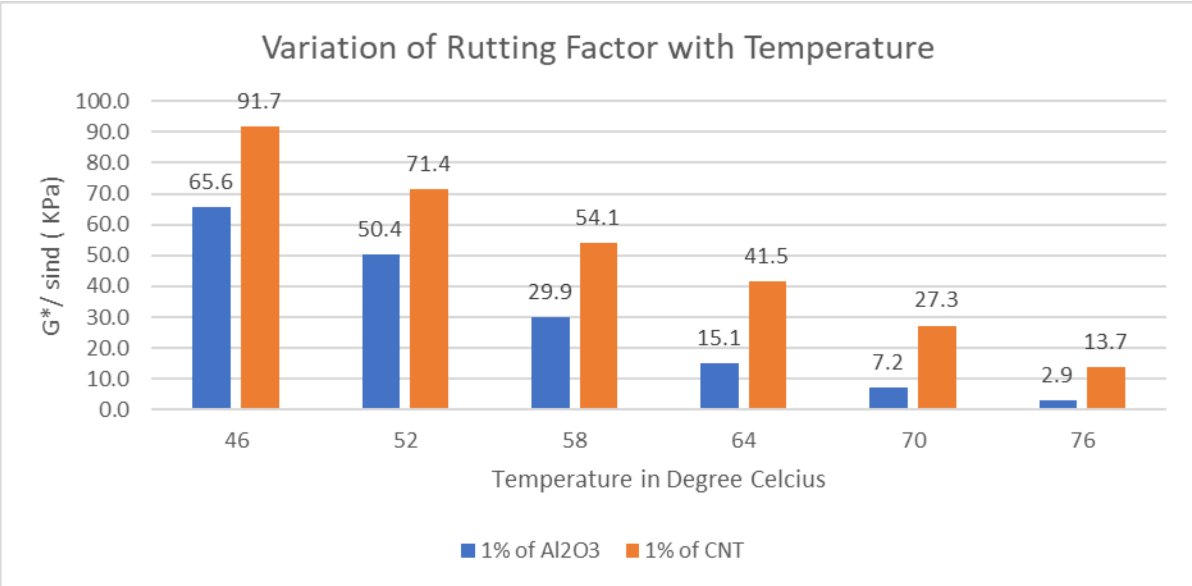

Figure 7: Variation of Rutting Factor with Temperature (Bhat & Mir, 2021)(Gong et al., 2018)

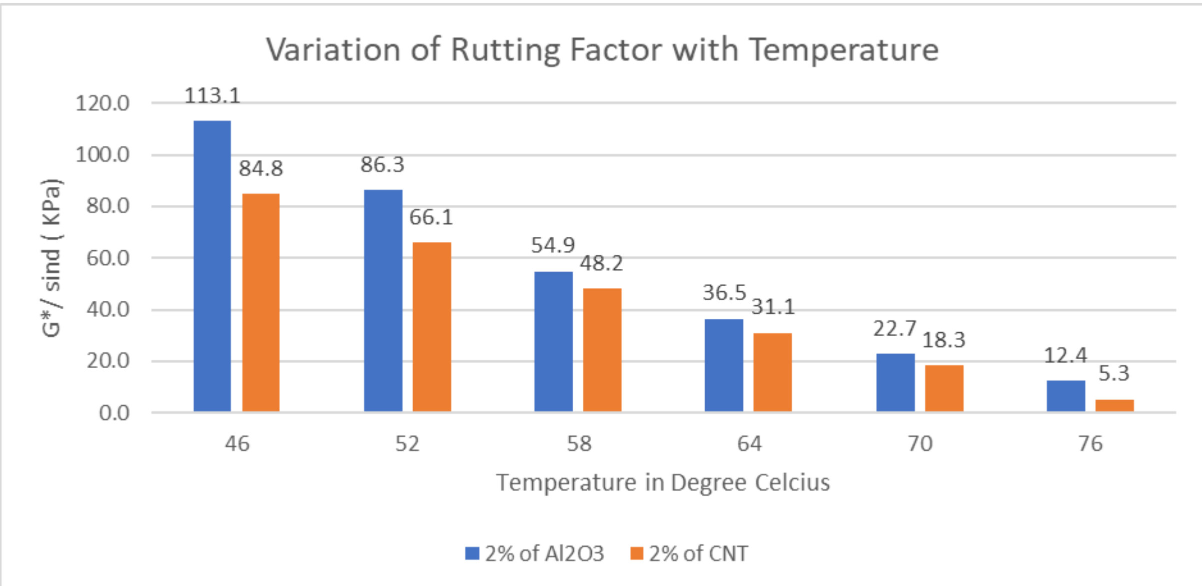

Figure 8: Variation of Rutting Factor with Temperature

As per the author's article, the rutting factor diminishes as the temperature rises for a consistent percentage of nano modifier in the asphalt binder. Notably, when comparing Al2O3 to CNT, a higher rutting factor value is observed for Al2O3.

Certainly, the incorporation of nanoparticles proves advantageous in enhancing the resistance of RTFO (Rolling Thin Film Oven) asphalt binders to rutting. The conclusion drawn is that the substantial surface area of nanoparticles contributes to a more rigid.

5. CONCLUSIONS

Upon examining various parameters through Dynamic Shear Rheometer and Rolling Thin Film Oven tests, it is evident that temperature significantly influences the behavior of modified asphalt binders at different usage percentages. Morever, it can be seen that nanomodified asphalt binders enhance the performance of virgin asphalt with limited dosage. However, this observation suggests that further studies are necessary to better comprehend how to enhance the quality of nanomodified asphalt binders. The focus of these studies should aim at achieving green concrete, indicating an interest in environmentally friendly and sustainable practices in asphalt binder modification.

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