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ENHANCING THE PERFORMANCE OF WARM ASPHALT MIXES USING NANO-KAOLINITE

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ABSTRACT

Nanoparticles are now utilised in a wide range of applications due to their unique chemical and physical intrinsic qualities, such as high specific area, structure, and reactivity; as a result, They play a vital role in the enhancement of asphalt mixture properties. Furthermore, technologies like warm-mix asphalt (WMA) might have a number of economic and environmental advantages. The influence of various Nano-Kaolinite contents on the mechanical performance of warm mix asphalt was investigated in this study (WMA). Because Nano-Kaolinite is common, inexpensive, and simple to obtain and convert to nano size, it was employed as an additive. Based on the weight of bitumen, the mechanical and durability performance of WMA mixes incorporating Nano-Kaolinite was investigated at different Nano-Kaolinite percentages of 2, 4, 5, 6 and 8%. The WMA was created using Evotherm™ as a bitumen additive. Mechanical tests were performed, which included Marshall stability, Marshall flow, indirect tensile strength, and compressive strength. Crushed gravel, rough aggregate particles, and a medium gradation of aggregate were employed in the control mix in this investigation. The results showed that rising Nano-Kaolinite content increased mixture capabilities, increasing Nano-Kaolinite content decreased Marshall flow. Over all, Nano-Kaolinite content had a substantial impact on asphalt and mixture performance, and appeared to exacerbate the effect of warm asphalt. In addition, indirect tensile strength, the Marshall stability, and compressive strength were all raised by 30 %, 50 %, and 68 %, respectively, according to the findings. At the optimum additive percent, Marshall flow reduced by 9%. Rutting depth is also reduced when Nano-Kaolinite is added at any cycle number. Nanomaterials can enhance the effectiveness of warm mix asphalt by increasing compatibility and bonding between asphalt particles, resulting in increased economical and environmental benefits as well as more sustainable and long-lasting pavement solutions.

KEYWORDS: Warm mix asphalt, Nanomaterial, Nano-Kaolinite, Evotherm**™**

تحسين أداء الخلطات الإسفلتية الدافئة بإستخدام النانو كاولينت

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الملخص:

تستخدم مواد النانو في العديد من التطبيقات العلمية الحديثة بسبب صفاتها وخصائصها الكيميائية والفيزيائية الجوهرية والفريدة ، مثل المساحة السطحية الكبيرة والبنية التفاعلية التداخلية بين جزيئات الذرات ونتيجة لذلك ، فإنها تلعب دورًا رئيسيًا في تعزيز خصائص الخلطات الاسفلتية. بالاضافة الى أن تقنيات الرصف الجديدة مثل الخلطات الأسفلتية الدافئة (WMA) لها العديد من المزايا الاقتصادية والبيئية والتشغيلية. تمت دراسة تأثير محتويات النانو المختلفة على الأداء الميكانيكي للخلطة الاسفلتية الدافئة في هذه الدراسة. تم إستخدام النانو كاولينيت نظرا لتوفره وانخفاض تكلفته وسهولة الحصول عليه وتحويله إلى حجم نانو ، فقد تم استخدامه كمادة مضافة بنسب من وزن البيتومين ، تم فحص الأداء الميكانيكي والثبات لخلطات (WMA) التي تشتمل على النانو كاولينيت بنسب مختلفة ٢ و ٤ و ٥ و ٦ و ٨٪. تم انتاج خلطات أسفلتية دافئة باستخدام Evotherm™ كمادة مضافة للبيتومين. تم إجراء الاختبارات الميكانيكية ، والتي تضمنت ثبات مارشال ، وتدفق مارشال ، والشد غير المباشر ، وإجهاد الضغط. أظهرت النتائج أن ارتفاع محتوى النانو في الخليط يزيد من ثبات مارشال وقوة الشد غير المباشر وإجهاد الضغط. بشكل عام ، كان لمحتوى النانو-كاولينيت تأثير كبير على تحسن أداء الخلطات الاسفلتية الدافئة حيث ادي الي زيادة ثبات مارشال وقوة الشد غير المباشر وإجهاد الضغط بنسبة ٣٠ % و ٥٠ % و ٦٨ % على التوالي ، وفقًا للنتائج المعملية عند النسبة المئوية المثالية المضافة وهى ٥ % وأيضا إنخفض تدفق مارشال بنسبة ٩٪. أيضًا تم انخفاض عمق التخدد عند إضافة النانو كاولينيت عند كل أعداد دورات الاختبار. يمكن للمواد النانوية تحسين أداء مزيج الأسفلت الدافئ عن طريق زيادة التوافق والارتباط والتداخل بين جزيئات الخلطة مما يؤدي إلى زيادة الفوائد الاقتصادية والبيئية بالإضافة إلى حلول الرصف الأكثر استدامة وطويلة الأجل.

الكلمات المفتاحية : الخلطات الاسفلتية الدافئة ، مواد النانو ، نانو كاولنيت ، إيفوثرم.

1. INTRODUCTION

Clay comes in a variety of shapes and sizes, based on its chemical content and nanoparticle morphology. Montmorillonite, bentonite, kaolinite, hectorite, and halloysite are the most common clays found in nature. Many researches have attempted to enhance the characteristics of asphalt using Nano clay. Nano montmorillonite and Nano bentonite are the most common forms of Nano clay employed by researchers. Nano kaolinite will be employed in this study to strengthen the characteristics of an asphalt mixture. The availability of raw material in Egypt and the low cost of production are two advantages of kaolinite. Farag Khodary used Styrene Butadiene Styrene to investigate the influence of Nano Clay on the properties of modified bitumen (SBS). The bitumen utilised was AC 60/70 penetration grade with 5% SBS added. Based on the weight of bitumen, the percentages of Nano clay were 2 percent, 4 percent, 6 percent, and 8 percent. The Transmission Electronic Microscope (TEM Clay) was used to examine the morphology of Nano Clay. The penetration test dropped and the softening point increased when the proportion of Nano Clay was raised, according to the findings of this study [1].

Ratnasamy Muniandy and et al, 2013, [4], investigated the effects of organic Montmorillonite Nano clay (OMMT) on the asphalt binder's physical and rheological properties. The asphalt was combined with 80/100 penetration grade asphalt and two types of (OMMT) N3 and N4. The percentages of Nano Montmorillonite utilised in this study were 0 percent, 3, 5, and 9% by weight of asphalt.

The asphalt was heated to 150°C 5°C, and the OMMT was slowly added at a rate of 1gm per minute before being mechanically mixed. Physical characteristics tests were performed on the base and modified asphalt, including penetration, softening point, and viscosity. Comparing to the base asphalt, the outcomes showed that the modified asphalt's physical attributes had developed. The N3 OMMT modified asphalt binder, on the other hand, outperformed the N4 binder [2].

Saeed Ghaffarpour Jahromiet al, 2010, also looked into the impact of Nano Clay on the rheological characteristics of bitumen and the mechanical qualities of asphalt mixtures. The penetration grade of asphalt cement 60/70 was used in this study. Cloisite 15A and Nanofill 15 were the two varieties of Nano Clay employed The loading frequency was 0.5 Hz, the pulse period was 500ms, and the recovery duration was 1500ms. The results showed that as the amount of Nano Clay was increased, the robust modulus increased. At all test temperatures, the Nano Clay modified mixture has a higher value than the unmodified mixture, according to the data. An Indirect Tensile test with diametric compressive loading was also used to conduct a Fatigue test. The purpose of this experiment was to see how Nano Clay affected Fatigue Life. Only 7% Nano Clay was utilised in this experiment. The resistance tests were carried out at temperatures of 5°C and 25°C. The results showed that unmodified mixtures performed better under fatigue at low temperatures than the Nano Clay modified combination. Otherwise, when compared to the original mixture, the changed mixture performed better under fatigue at a high temperature of 25°C. [3].

The performance of a porous asphalt (PA) combination that included Nano kaolin clay (NKC). The study looks at the basic features of PA, such as its shape, penetration, and softening point test. Cantabro loss and robust modulus tests were also investigated in relation to differences in PA mix design. The kaolin clay employed in this study was ground to generate NKC, with a percentage substitution of bitumen of 3 percent, 5 percent, 7 percent, and 9 percent, respectively. The usage of NKC improved the physical qualities of PA by lowering the penetration value while raising the softening point value, according to the findings. This shows that NKC increased PA's temperature susceptibility. The NKC modified binder also improved the durability and resistance to rutting and cracking of PA, according to the results. Furthermore, 5 percent NKC is thought to be the ideal NKC proportion. PA's physical and mechanical qualities can be improved with the use of NKC. As a result, it may be concluded that including NKC into the bitumen improves PA performance [4].

To improve the characteristics of asphalt. Nano clay is one of the nano-materials used in the industrial sector. As a result, this research looked into the rutting resistance of asphalt that included Nano-kaolin. The asphalt was tested in both new and old conditions. Asphalt binders containing five different percentages of Nano-kaolin 0, 3%, 5%, 7%, and 9 % were created in this investigation. The inclusion of Nano-kaolin improved the rutting resistance of the binders, according to the findings. Furthermore, based on the results of the tests, the optimal asphalt composition was found to be 5% Nano-kaolin [5].

Kaolin were eliminated in by heating it to high temperatures for one and two hours. This heat-treated kaolin (HTK) was next tested in a Hot Mix Asphalt mix as a replacement for natural mineral filler (passing No. 200 sieve; 6% by total mass of aggregate) (HMA). The Marshall stability and flow test, as well as the Indirect Tensile Strength (ITS) test, were used to assess HMA mixture responses. On kaolin, X-ray diffractometry (XRD) and X-ray fluorescence (XRF) tests were performed (with and without thermal treatment). Temperature and exposure period effects on the HTK's penetration index (PI) and free swell index (FSI) are also discussed. When the natural mineral filler was totally replaced by the HTK, the resistance to monotonic load and moisture damage increased. When non-heated kaolin (K) is employed, however, resistance and damage are considerably reduced, especially in the presence of water [6].

QRSS was used to forecast the behaviour of asphalt mixes enhanced using nano-montmorillonite (NMMT) and nano silicon dioxide (NSD). At a temperature of 145°C, the nanomaterials were fully mixed with the binder. The conventional and rheological parameters of the penetration grade 60–70 control binder, and binders enhanced with 3, 5, and 7% NMMT and NSD, were determined. The best nanomaterial composition for each modifier was determined, and the Marshall method was utilised to prepare asphalt mixes. Finally, a Witczak 1-40D complex shear modulus (G*) based prediction model was used to estimate the dynamic modulus (E*) for the control and Nano asphalt composition. The field performance in terms of asphalt concrete (AC) layer rutting and fatigue cracking was predicted using the QRSS software for two main pavement sections and three different climatic zones in Egypt. (Alexandria, Cairo and Aswan) [7].

Because of the significant economic and environmental advantages, WMA technology and rejuvenators are now widely used. The impacts of WMA technology and rejuvenator on rutting resistance, cracking resistance, and moisture susceptibility of three mixuters of asphalt were investigated in this study. The three types of asphalt combinations were (a) a warm mixing containing 50% RAP, (b) an asphalt mixing containing 50 percent RAP and rejuvenator, and (c) an asphalt mixing containing 50 percent RAP and rejuvenator. The WMA mixes were made in a plant using a foaming method that is popular in the United States. The laboratory testing included , tensile strength ratio (TSR) test , the Superpave indirect tension (IDT) test, asphalt pavement analyzer

(APA) rutting test, Hamburg Wheel-tracking test (HWT), and semi-circular bending (SCB) test.According to research, the rejuvenator can improve moisture and crack resistance while also increasing rutting potentials and lowering indirect tensile strength. In comparison to a 50 percent RAP combination, WMA technology showed promise in terms of rutting resistance and moisture susceptibility. Furthermore, WMA technology adoption was more cost-effective [8].

WMA technology, particular, has been employed to assist reduce emmissions of asphalt over the last decade. However, there are still a number of outstanding concerns about the long-term capabilities of asphalt materials made with this technology. One of these concerns is the impact of these technologies on asphalt binders' healing behaviour, which could have a considerable impact on their performance The effect of different WMA technologies on the healing qualities of reqularly used asphalt binders, specifically, PG 64-22 and PG 70-22M, was evaluated using a nano-scale approach using atomic force microscopy (AFM) in this paper. Advera®, Evotherm™ M1, Sasobit®, and foamed WMA were among the WMA technologies evaluated. The Advera®, Evotherm™ M1, and foamed WMA technologies all increased the micro-crack closure rate in the asphalt binders studied in this study. Moreover, the Sasobit reduced the bonding energy in the asphalt binders, suggesting that it may have an unfavourable effect on their inherent healing [9].

Rubber asphalt was combined with nano-organic montmorillonite (NOMMT) to improve its high-temperature performance, anti-aging performance, and storage stability. At low temperatures, the macroscopic effects of NOMMT on rubber asphalt were evaluated using penetration, rotational viscosity, softening point, ductility, dynamic shear tests, and bending beam rheology experiments on rubber asphalt with various NOMMT contents. Then, using scanning electron microscopy (SEM), infrared spectroscopy (IR), and differential scanning calorimetry, the microscopic mechanism of NOMMT was investigated (DSC). The analysis indicate that after NOMMT was injected, the rubber particles were smoother, uniform, and dispersed, and the compatibility between NOMMT and crumbed rubber powder was good. In the composite modified asphalt, several stable structures were produced. The absence of the alcohol phenol and an increase in related groups such as alkane, benzene, and hydrocarbon indicated that NOMMT and rubber asphalt underwent a chemical reaction, resulting in changes in the quality of the composite modified system, such as antiaging properties, improved high-temperature stability, and storage stability, but decreased low-temperature performance. [10].

2. MATERIAL CHARACTERIZATION

Preparation of samples begins with an estimation, based on experience and previous studies, of what the optimal binder content would be. In laboratory-scale mixtures with binder content above, and below the approximate optimum in increments of 0.5%.Several trial blends of aggregate and asphalt binder are prepared for stability and flow measurements. The bulk specific gravity is measured according to ASTM D2726/ AASHTO T 166. [11].

2.1 Aggregate properties

The crushed dolomite limestone was used in this research as coarse aggregate. The coarse aggregate was a combination of: course aggregate A with specific gravity 2.573, course aggregate B with specific gravity 2.549. The fine aggregate C and D with specific gravity 2.508. The sieve analysis for course aggregate and fine aggregate, as well as the filler were done according to AASHTO T (27-06) and T (37-07), respectively. **Table ١** shows the gradation of course aggregate, fine aggregate and filler.

Table 1 : The Gradation of Coarse Aggregate, Fine Aggregate, and Filler

Sieve No.	Coarse Aggregate		Fine Aggregate		Filler	Design Gradation
	A	B	C	D		
"1	100	100	100	100	100	100.0
4/3"	74	100	100	100	100	97.4
2/1"	2	17	87	100	100	80.6
8/3"	0	2	18	100	100	72.0
#4	0	1	0	44	100	54.4
#8	0	0	0	9	100	43.3
#16	0	0	0	0.7	100	29.0
#30	0	0	0	0.2	100	20.5
#50	0	0	0	0.1	98	13.6
#100	0	0	0	0	95	9.4
#200	0	0	0	0	83.3	6.8

2.2 Asphalt Binder (Bitumen Properties)

The Bitumen used in this study was penetration grade 60/70 (PG 70-22), which was obtained from Suez Nasr Petroleum Company (NPC). The bitumen and asphalt mixtures were tested at the General Authority of Roads and Bridges and Land Transportation (GARBILT) laboratory. **Table ٢** displays the typical physical characteristics of the base asphalt.

Table 2 : Physical Properties of the Base Asphalt.

Binder grade	Penetration @25°C (mm)	Softening Point, (ºC)	Viscosity @135°C	Flashpoint, (Cº)
60/70	62	49	439	268

2.3 NANO- Kaolinite

To characterize the Nano Kaolinite, the images from the Transmission Electron Microscope (TEM) were used to determine the shape and size of the Nano-Kaolinite particles. The TEM images of the Nano Kaolinite illustrate that the shape of the particles is irregular, and almost spherical. The size of the Nano Kaolinite particles range from 15 to 50 nm, as shown in **Fig. 1**.

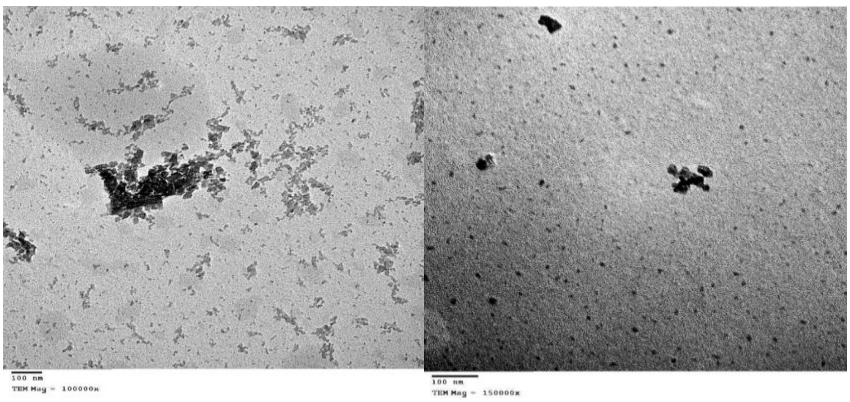


Fig. 1 : Transmission Electron Microscope (TEM) images of Nano Kaolinite.

The X-Ray Fluorescence (XRF) was done according to ASTM C11A-00 at Housing and Building National Research Center Laboratory to determine the chemical composition of Nano Kaolinite. The results indicated that the main components in Kaolinite are SiO2 and Al2O3, which represent approximately 85% of the weight of Kaolinite, as shown in **Table ٣**.

Table 3 : Chemical analysis of Nano-Kaolinite (XRF)

Oxides	SiO_2	Al_2O_3	MnO	Cao	K_2O	TiO_2	Fe_2O_3	MgO	Na_2O_3
Weight %	45.01	40.30	0.004	0.12	9.59	2.55	0.89	0.15	0.16

2.4 Warm Mix Asphalt Technologies

2.4.1 Introduction

The previous researches showed that asphalt binder is quite often modified by various additives (polymers, fibers, rubber, nanomaterials, lime, combinations of fibers and polymers …. etc.) which may enhance the properties of bitumen and mix. Recently, modern techniques used waste tire rubber and mineral fiber in modifying the HMA. They succeeded in improving the resistance of asphalt mixtures against cracks and rutting. The American Concrete Institute (ACI) defines SF as very fine non-crystalline silica produced in electric arc furnaces as a byproduct of the production of elemental silicon or alloys containing silicon. It can exhibit both pozzolanic and cementitious properties and is produced by the reduction of high purity quartz with coal in the production of ferrosilicon alloys. SF has been used in the improvement of the cement concrete compressive strength, bond strength, abrasion resistance and reducing permeability. As originally discussed by Davidson, Tighe, and Croteau [12], several methods have been developed to minimize hot mix asphalt mixing and compaction temperatures. These processes are known as asphalt warm mixes. Reduced temperatures can contribute to lower emissions from plants and lower fuel consumption. There are many technologies to convert hot mix asphalt to Warm mix asphalt by one of the next additives and technologies.

- Aspha-min® zeolite developed by Eurovia
- Sasobit® developed by Sasol International
- WAM Foam by Shell and Kolo Veidekke
- Low Energy Asphalt by Fairco and Appia
- Evotherm™ developed by MeadWestvaco

Table 4 shows the reduction percentages in emissions during the construction of WMA compared to conventional HMA projects.

Table 4 : Reduction percentages in emissions during the construction of WMA compared to conventional HMA

	Warm Mix Asphalt Processes			
	Aspha-Min	Sasobit	Evotherm™	WAM-foam
SO_2 (%)	17.60%	-	81%	n/a
CO_2 (%)	3.20%	18%	46%	31%
CO (%)	n/a	n/a	63%	29%
NOx (%)	6.10%	34%	58%	62%
THC (%)	35.30%	n/a	n/a	n/a
VOC (%)	n/a	8%	25%	n/a

2.4.2 Evotherm ™

One of the first North American WMA products, produced by MeadWestvaco (MWV) Asphalt Developments, is Evotherm™. The product consists of a chemistry kit designed to improve coating, adhesion, and lower temperature workability. The first generation of the product, Evotherm™

Emulsion Technology (ET), is an emulsion that is used as a direct asphalt binder substitute. The emulsion has a residue content of high asphalt binder of approximately 70%. In the form of a steam-producing foamed asphalt that aids in the coating of the aggregates and water, about 30% of the emulsion, is flashed off.

3. PREPARATION OF MODIFIED ASPHALT MIXTURES

3.1 Design of Asphalt Concrete Mixtures

According to ASTM D-6927 – 15 & AASHTO T-245 – 2012. [11], Stability and flow are assessed for each compacted sample of the asphalt paving mix, while the unit weight and air voids are determined the optimum asphalt material content and the result of Marshall testes are shown in **Table ٥**.

Table 5 : Marshall Mix Design Criteria

VMA %	VFA %	G_{mb}%	AV%	Stability (kg)	Flow (mm)
13.7	82.3	2.334	2.4	1417	3.375

3.2 Preparation of Modified Bitumen

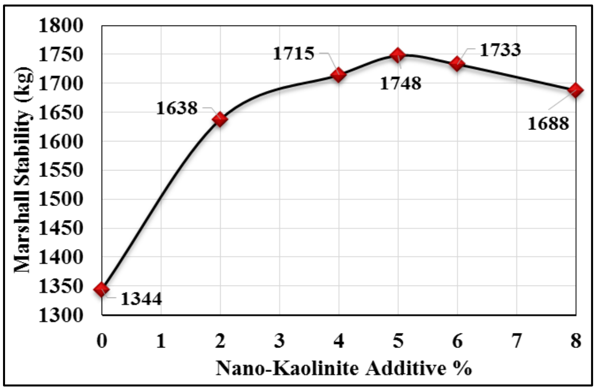
Asphalt content was heated to 150 C^o ± 5 C^o alone to prepare the changed bitumen, and then the Evotherm^{TM} was added by 0.5 % of bitumen weight [12]. Then selected percentages of Nano-Kaolinite 2 %, 4 %,5%, 6% and 8 % by weight of bitumen were added to produce modified bitumen. The Low Shear Mixer with a constant speed of 600 rpm was used for 45 minutes to ensure the production of a homogeneous mixture.

4. EXPERIMENTAL INVESTIGATIONS

4.1 Marshall Tests

The Marshall test according to ASTM D6927 was conducted as shown in **Fig. 2** to determine the stability and flow for modified and unmodified warm asphalt mixtures. The results were recorded as shown in **Fig. 3-a & Fig.3-b**.

Fig. 2: Marshall Tests



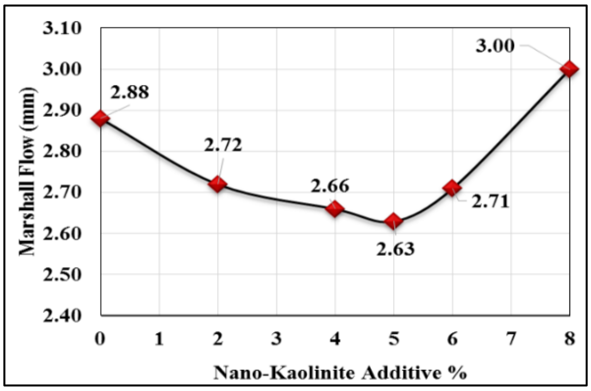


Fig. 3-a: Marshall Stability test Results **Fig. 3-b:** Marshall Flow test Results

Overall, according to Marshall stability tests, figures are raised gradually from 1344 kg by zero percent Nano Kaolinite to peak at 1748 kg at 5% Nano Kaolinite before dropped gradually to 1688 kg at 8% Nano Kaolinite. Regarding Marshall flow, the behavior is in the opposite direction. Initially, Marshall flow is declined gradually from 2.88 mm at zero percent Nano Kaolinite to bottom at 2.63 mm by 5% Nano Kaolinite before increased to 3.00 mm at 8% Nano Kaolinite.

4.2 Indirect Tension Test

One of the most common tests used for HMA and WMA mixture characterization in the evaluation of pavement structures is the indirect tensile test. Since the 1960s and, to a lesser degree, in WMA mixture design testing, the indirect tensile test has been used extensively in structural design research for flexible pavements. The indirect tensile test was carried out according to ASTM D6931-17, Standard as shown in **Fig. 4**

Fig. 4: Indirect Tensile Test during Loading and at Failure.

Fig. 5, shows the indirect tensile strength raised gradually from 1.38 MPa by zero percent Nano Kaolinite to peak at 2.08 MPa by 5% Nano Kaolinite before dropped to 1.23 MPa at 8% Nano Kaolinite.

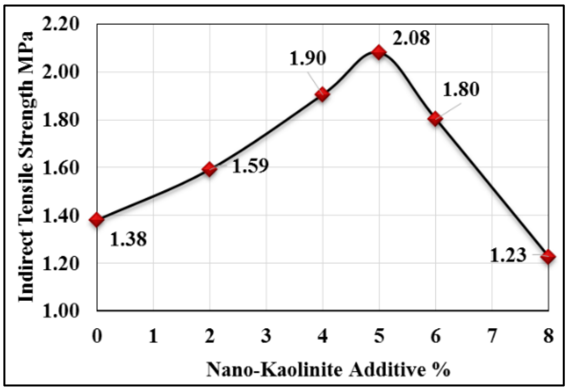


Fig. 5 : Indirect Tensile Test Results

4.3 Compressive Strength

A compressive strength test was conducted according to ASTM D6931 – 12. [11]. The axial strain was derived via two linear variable differential transducers measuring platen-to-platen displacement. The recording equipment consists of a digital interface unit connected to a computer that is utilized to monitor and record data as shown in **Fig. 6**.

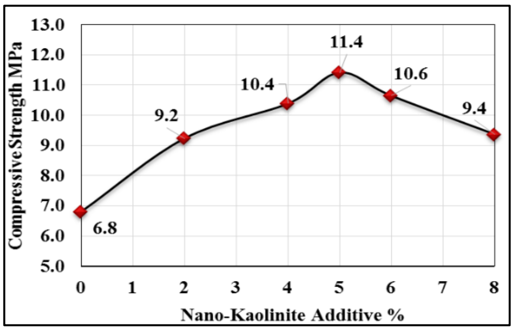


Fig. 6: Compressive Strength Test during Loading and at Failure.

Fig. 7 : Compressive Strength Test Results

Generally, according to the compressive strength test, strength is raised gradually from 6.8 MPa by zero percent Nano Kaolinite to peak at 11.4 MPa by 5% Nano Kaolinite before dropped smoothly to 9.4 MPa at 8% Nano Kaolinite as shown in **Fig. 7**.

4.4 Wheel Tracking Test (WTT)

As per AASHTO (T324-04), the WTT test was conducted at the laboratory of the General Authority of Roads and Bridges and Land Transport (GRBLT). This test measures the rate of permanent deformation caused by a moving focused force. To prepare slab specimens, a laboratory compactor was created. The test used to detect whether WMA is susceptible to premature failure owing to aggregate structure weakness, insufficient binder stiffness, or moisture degradation. This test determines the rutting depth, as well as the number of passes or the time it takes to reach the final rutting depth. The test is carried out on both control and treated specimens containing 5% Nano-Kaolinite.**Fig. 8** & **Fig. 9** are show the Wheel Tracking Test machine and results.

Fig. 8 : Wheel Tracking Test

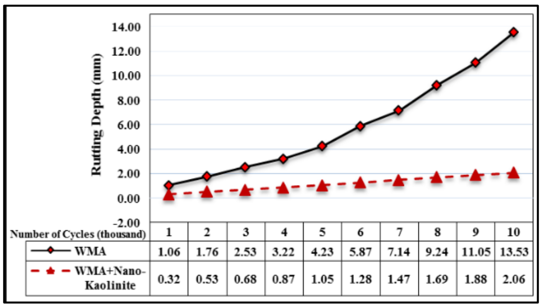


Fig. 9 : Wheel Tracking Test Results

Regarding rutting depth in mm with an increasing number of cycles for both cases WMA and WMA with Nano Kaolinite. Looking at the WMA curve, however, rutting depth is increased dramatically from 1.06 mm at 1000 cycles to reach 13.53 mm by 10,000 cycles, the curve of WMA with Nano Kaolinite has noticed a slight increase from 0.32 mm at 1000 cycles to reach 2.06 mm by 10,000 cycles. According to the great positive enhancement from the results of the laboratory experiments shown above, which is due to the interconnectedness, and complementarity between nanoparticles and bitumen particles, which led to a remarkable and effective improvement in the properties of bitumen on the one hand and the characteristics of warm asphalt mixtures on the other hand.

5. CONCLUSION

This research compares the effect of adding Nano Kaolinite to asphalt binder by several percentages of Nano Kaolinite to enhance its mechanical and physical properties. The effectiveness of using additives in WMA is very critical to achieve high environmental and economic benefits. Moreover, it has a crucial role in a sustainable direction. The results indicated that:

- The mechanical properties (Marshall stability, flow, indirect tensile strength, and compressive strength) of WMA can be enhanced by adding Nano- Kaolinite to WMA mixtures.
- Rutting depth is decreased by adding Nano- Kaolinite at all number of cycles.
- The optimum Nano- Kaolinite content was 5% that leaded to improve the properties of WMA mixtures. Marshall stability, ITS, and compressive strength increased by 30%, 50% and 68% respectively. Also the Marshall flow decreased by 9%.

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