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USING NANOCLAY HYDROPHILIC BENTONITE AS A FILLER TO ENHANCE THE MECHANICAL PROPERTIES OF ASPHALT

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Higher traffic loads on the wheels, increased traffic volumes, and exposure to changing weather conditions result in increasing the road stresses and strains, putting the paving layers in danger of degradation such as fatigue, stripping, cracking, and rutting. A tremendous number of studies and trials have been conducted to modify asphalt to have a longer service life, less maintenance, be cheaper, and be more environmentally friendly. Recently, nanotechnology has proven very beneficial in all industries, including asphalt. It can be used to enhance the asphalt's mechanical properties. Using nano clay in asphalt is expected to improve the mechanical properties and the service life of the asphalt. So the main objective of this study is to investigate the performance of nano clay hydrophilic bentonite in improving the physical characteristics of asphalt concrete. This study uses nano clay with various replacement ratios as fillers to the ordinary used limestone filler in asphalt concrete. The used replacement percentages were (0%, 20%, 40%, 60%, 80%, and 100). The experimental tests that were conducted in this study include Marshall Stability (MS), Marshall Flow (MF), voids in mineral aggregate (VMA), theoretical maximum specific gravity (Gmm) and air voids (AV).The results showed a noticeable enhansment in the behavior of the asphalt mix with increasing the replacement percentage by nanoclay. Also, it was found that the 60% replacement rate by nanoclay has the highest Marshall stability with an increase of 93%, also the lowest flow with a decrease of 25% compared to the control asphalt mix.

Key words: nanoclay, filler, asphalt, nanotechnology, mechanical properties

INTRODUCTION

A huge amount of asphalt is produced annually all over the world for construction projects. Every year, over 550 million tons of hot mix asphalt are produced in the United States alone (You et al. 2011). Since its physical properties are dependent on the loading rate and temperature, asphalt is the best material for road construction. At high temperatures or low loading rates, asphalt acts as a flexible material, similar to a low-viscosity fluid, while at low temperatures or high loading rates, it behaves as an extremely brittle and rigid solid. Increased traffic loads on the wheels, increased traffic volumes, combined with the exposure to weather changing results in increased pressures and strains on the roads, which puts the paving layers at risk of deterioration. The most important of these degradations in the asphalt layer are fatigue, stripping, cracking, and rutting (Golestani et al. 2015). So a lot of researchers are concerned about finding a modifier to improve the asphalt binder to provide asphalt with a longer service life, less maintenance, cheaper, and more environmentally friendly (Mahdi et al. 2013). Nano technology is a very promising technique that has been introduced recently in the materials industry. Due to the particle size of Nano materials, which ranges between 1 to100 nm, the resulting surface area is a lot more than the surface area of the particles of the same material on a micro scale. This leads to increased functional density, high sensitivity, special surface effects, large surface area, high strain resistance, and catalytic effects (Yang and Tighe 2013). Donegá (2014) stated that the nanoscale enables materials to behave differently from their macroscopic counterparts. Two factors can cause this behavior: the surface to volume ratio and spatial confinement.Many researchers begun to study the performance of Nano materials to modify asphalt mixes. Razavi and Kavussi (2020) Razavi and Kavussi (2020) suggested to use nano hydrated lime as replacement of the conventional filler in order to increase the bitumen resistance to water. Because of their abundance in nature, low cost of manufacturing, and tiny amounts required for asphalt modification, researchers have lately proposed the use of nanoclays (NC) as asphalt modifiers (Crucho et al. 2019). The Nano clay structure is composed of layered sheets of aluminosilicate of high effective surface area that can process a strong and extensive interaction between the asphalt binder and aggregates, which results in a considerable improvement in the properties of the asphalt binder. Iskender (2016) used 2%, 3.5% and 5% by weight of binder of nano clay modified asphalt mixture, which resulted in an increase in rutting resistance and tensile strength. According to Abdelrahman et al. (2014), the addition of nanoclay to asphalt caused significant changes in the physical behavior and nature of asphalt, which appear to be the consequence of molecular interactions between asphalt and nanoclay, and it has enormous potential to alter the properties of asphalt.

El-Shafie et al. (2012) concluded that using 6% of nano clay with asphalt binder give the best enhancement according to the test results of softening point, kinematic viscosity, penetration and tensile strength. The filler in asphalt concrete refers to the particles with a diameter

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of less than 75 micrometers. Despite its small size, the filler is one of the most critical and has a major impact on the asphalt mixture's properties. Therefore, the characteristics of the asphalt mixture are affected by the type and quantity of filler (Zulkati et al. 2012). Many researchers have attempted to modify asphalt by replacing the commonly used filler with other materials that may be more effective and provide better performance to asphalt concrete, such as Mistry and Roy (2016), investigated the use of fly ash and Chen et al. (2017) examined the use of steel slag as a filler in asphalt concrete. On the other hand, the studies that used nano materials as a filler replacement in asphalt concrete are not enough as a reference to apply this technique on a large scale. The objective of this study is to investigate the performance of nanoclay hydrophilic bentonite in improving the physical characteristics of asphalt concrete and to figure out the optimum percentage of filler that should be replaced with nano clay. The physical properties of varying percentages of nano clay filler replacement were compared to the physical characteristics of a control sample with no nano clay material.

MATERIALS AND METHODS

Materials

In this research, aggregates were gathered from local quarries in Karbala city. The material properties require-ments were in accordance with the Road and Bridge Standard Specification (SCRB. 2003). The physical proper-ties of course and fine aggregate used in this analysis are shown in Table (1). Fine and coarse aggregates were sieved and then separated and classified so as to have a gradient compatible with the requirements of the surface layer and according to the mentioned Iraqi specifications as ilustrated in Figure (1).

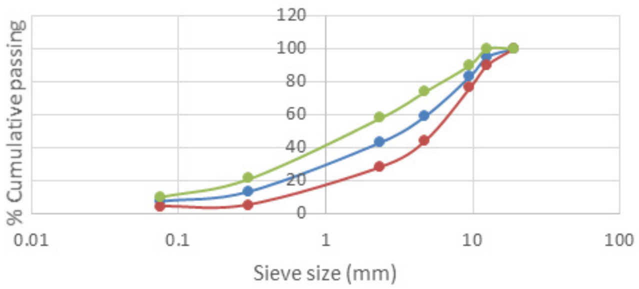

Figure 1: Gradation curve for the used aggregates in this study for surface coarse

The bitumen used in this study was also collected from a local source with physical properties that satisfied the standard specifications of ASTM, including the penetration of 4 mm, the flash point of 235 Co, ,fire point of 340 Co, the ductility of 40 cm, and the specific gravity of 1.045.

Limestone

Limestone was used as a conventional filler material, and it was sourced from Karbala quarries. Table 2 shows the physical parameters of limestone used as a filler in the asphalt mix.

Table 2: Limestone filler physical properties

Sieve Diameter	Property	Standard
0.75 >	Specific gravity =2.71	ASTM C 127
	Saturated specific gravity = 2.69	
	Water absorption = 0.12	

Nanoclay montmorillonite

The used asphalt modifier in this study is nanoclay montmorillonite hydrophilic bentonite. Montmorillonite is the most common natural nanomaterial utilized by industry and it is a smectite clay substance produced from bentonite ore (Tolinski 2015). It features a layered structure with a silica tetrahedron linked to an alumina octa-hedron, coordinated by oxygen atoms or hydroxyl groups, with a single layer thickness of 1nm (Forbes 2015). The raw nanoclays are changed by substituting metal cations for the interlayer and stacked in a multilayer (Fig-ure 2) for easier dissipation of the nano clay hydrophilic particles in asphalt. The X-Ray analysis and the chemi-cal composition of the used nano clay material are illustrated in Figure 3 and Table 3.

Testing Methods

The asphalt mixtures were prepared in accordance with the Marshall Method and ASTM standards. The mechanical tests that were conducted in this study are including Marshall Stability (MS), Marshall Flow (MF), Voids in Mineral Aggregates (VMA), Voids Filled with Asphalt (VFA), Air Voids (VA), and Theoretical maximum specific gravity (Gmm).

Table 1: Aggregate properties

Property	ASTM Standard	Results
Coarse aggregate specific gravity (g/cm^3)	ASTM C127	2.732
Fine aggregate bulk specific gravity (g/cm^3)	ASTM C128	2.641
coarse aggregate absorption (%)	ASTM C127	0.450
Aggregate Impact Value (%)	ASTM C131	12.90
Los Angeles Abrasion Value (%)	ASTM C131	16.70

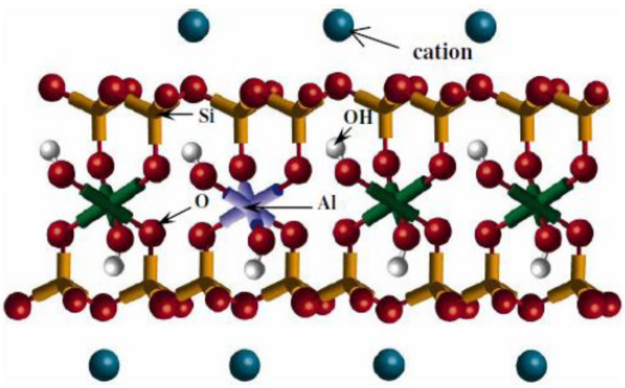

Figure 2: Schematic Representation of montmorillonite (Gehlot 2018)

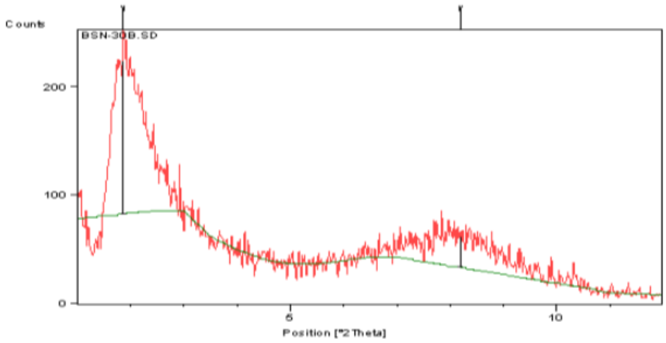

Figure 3: Nanoclay analysis X-Ray

Table 3: Physical and chemical properties

Physical properties		
Appearance		Powder
Ph		2,5 - 3,5
Bulk density		300 - 370 kg/m^3
Chemical composition		
O		52.6%
Si		18.5%
Fe		10.0%
Al		9.4%
Mg		2.3%
Na		2.0%
Ca		1.9%
K		1.7%
Ti		1.6%

Test Plan

Asphalt concrete samples were prepared using six different replacements of limestone filler by nanoclay including (0%,20%, 40%, 60%, 80% and 100%) as shown in Table 4. Three samples were prepared for each percentage to determining the amount of optimum percentages of the filler materials (NC and LS).

Table 4: Asphalt mixture adopted in this research

Mix No.	Sieve No.						Filler 7%	
	3/4	½	3/8	NO.4	NO.8	NO.50	LS	NC
1	100	95	83	59	43	13	100	0
2	100	95	83	59	43	13	80	20
3	100	95	83	59	43	13	60	40
4	100	95	83	59	43	13	40	60
5	100	95	83	59	43	13	20	80
6	100	95	83	59	43	13	0	100

RESULTS

The results of the Marshall stability and Marshall flow tests of HMA comprising different filler percentages are demonstrated in Figure 4 and Figure 5, respectively. From these results, it can be said that all the test results satisfied the related requirements of Marshall stability and flow according to ASTM standards. It can be observed from Figure 4 that the MS values of all the asphalt mixes containing nano clay are much higher than the control mix. The MS values increased gradually with the increase in the percentage of nano clay till 60% replacement by nano clay, where the MS value increased by 194% compared to the control mix. After 60%, there is a small gradual decrease in the values of MS with an increament by 175% for the NC-100%.

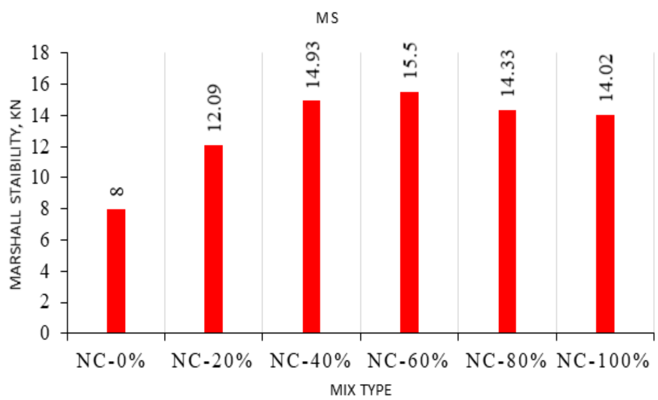

Figure 4: Comparison of Marshall stability with different filler percentages

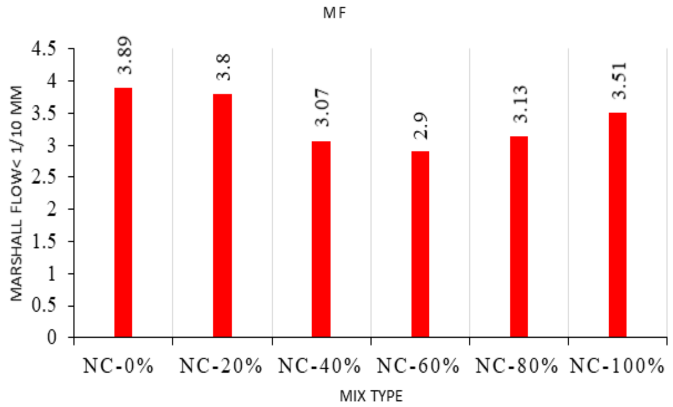

Figure 5: Comparison of Marshall flow with different filler percentages

Figure 5 shows that the MF values for all the asphalt mix samples with nano clay are less than the control sample. These values decreased gradually with the increase in nano clay till 60% replacement, which resulted in a decline of 25% from the control sample. Also, by increasing the nano clay percentage by more than 60%, the MF values increased, reaching a decline of only 10% for NC-100%. The effect of using nanoclay as filler material on the air voids between the components of the asphalt mix is il-lustrated in the Figure (6) , which showed a decrease in AV percentages with the increase in the replacement percentage of nanoclay. For mix NC-100%, the void ratio is the lowest among the other asphalt mixes.

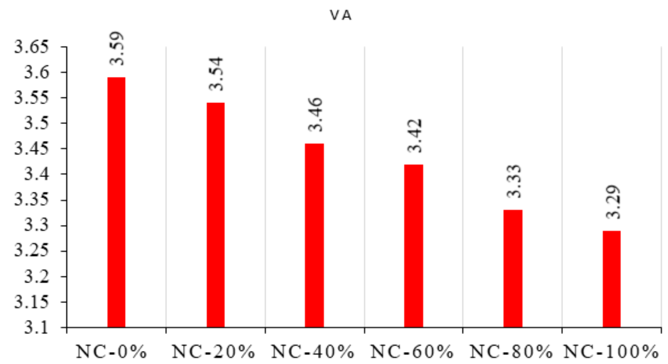

Figure 6: Comparison of air voids with different filler percentages

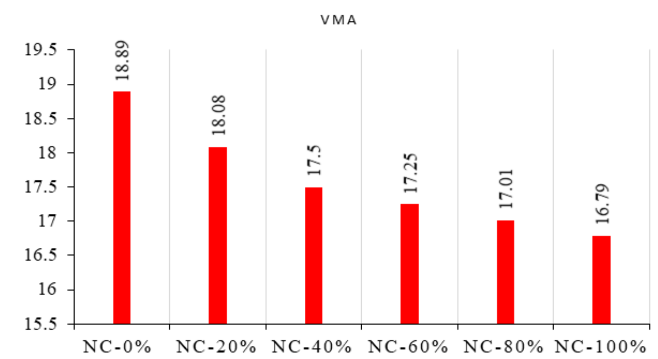

Figure 7: Comparison of voids in mineral aggregate with different filler percentages

Figure 7 indicates that as the percentage of nano clay replacement increases, the percentage of voids in mineral aggregate VMA de-creases, similar to the findings of air voids. The lowest VMA % is achieved by using 100 percent nanoclay as a filler. Figure 8 represents the theoretical maximum specific gravity. There is a positive relationship between the GMM values and the percentage of the nanoclay filler in the asphalt mix. This is because of the decrease in the percent of voids as mentioned before in Figures 6 and 7.

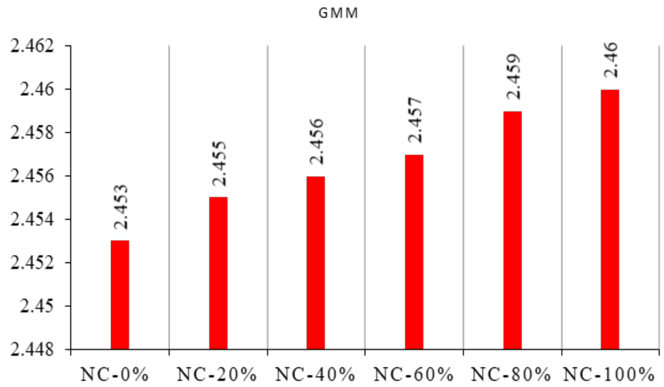

Figure 8: Comparison of theoretical maximum specific gravity with different filler percentages

CONCLUSION

It can be concluded from the findings of this study that:

1. All the modified asphalt concrete samples using different percentages of nano clay have gained high enhancement in the physical properties in comparison with the non-modified asphalt samples.
2. The test results that were conducted in this study indicate that all asphalt mixes with any percentage of nano clay are acceptable according to ASTM standards.
3. Increasing the percentage of nano clay as a filler decreases the VA % and VMA % in the asphalt mix because of the size of the small particles of nano clay that have a large surface area, which improves the bond of asphalt and gives more confinement to the structure. Consequently, the GMM values have a direct proportional relationship with the percentage of nano clay. For the asphalt mix with 100% nano clay, the GMM value was the highest while the VA% and VMA% were the lowest among all asphalt mixes.
4. The optimum percentage of nano clay is 60%, which gives the highest Marshall stability with 14.02 KN more than the non-modified sample by 94% and also the lowest Marshall flow of 2.9 less than the non-modified sample by 25%.
5. The use of nano clay in asphalt mixes in very small quantities can offer asphalt with higher physical properties and more durability, which can provide a much longer service life of asphalt. As a result, it reduces the high cost of maintenance or reconstruction.

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