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Assessment of the Effect of Nono-clay on Recycled Asphalt Mixtures Resistance to Moisture

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HIGHLIGHTS

- It was found that both RAP and MMT enhanced the compressive strength of the mixtures and produced a stiffer mixture.
- The introduction of MMT to RAP enhances the ITS values, where 5% MMT had the highest values.
- The nono-clay improved the moisture resistance, as proved by the IRS values and the TSR values, where 5% of MMT rated the highest.

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ABSTRACT

Introducing nanotechnology to the pavement industry witnessed a great interest due to the proven benefits of nanotechnology in various scientific fields. However, the reduction in the binder's characteristics might be disadvantageous to the durability of the recycled mixture, making it more susceptible to external factors such as moisture. Therefore, using nanotechnology is expected here to treat this issue. The goal of the current paper is to report on the influence of the nano-clay montmorillonite (MMT) powder (MMT k10) on the resistance to moisture in the hot recycled mixtures or the Reclaimed Asphalt Pavement mixtures (RAP mixtures). In this work, different proportions of rejuvenated RAP were employed. These proportions are 30, 40, and 50% as a percent of the overall weight of the mix. The percentages were mixed with a nano-modified neat binder with (0, 1, 3, and 5)% nono-clay MMT as a proportion of the bitumen's weight. Two types of mixtures are prepared and used in this paper: nano-modified RAP mixtures and unmodified RAP mixtures. On both types of mixtures, the compressive strength test, the index of retained strength (IRS), the indirect tensile strength tests (ITS), and the tensile strength ratio (TSR) were carried out to compare and evaluate the moisture resistance of rejuvenated RAP mixtures. The experimental test results indicated that using 5 percent nono-clay in regenerated RAP mixes provides better performance than not using it. where it increased moisture damage resistance by5.53% for IRS value and 3.66% for TSR for 50 percent RAP mixes.

1 Introduction

Reclaimed asphalt pavements are substances that result from road maintenance and renovation activities. It is made as an outcome of the milling process of a present pavement or by crushing substances removed from old asphalt pavements. Using Recycled Asphalt Ratio in road construction and resurfacing is both cost-effective and environmentally friendly[1]. As the cost of asphalt rises, aggregates of fine standards become scarce, and the demand to cut pollution necessitates using sustainable and environment-friendly materials such as RAP instead of neat materials. [2].

RAP material combined with virgin asphalt or recycling agents (rejuvenators) may be used for the recycling process of asphalt pavement to improve the features of RAP materials [3] no consense on whether HMA, which contains RAP, was improved or not compared to neat HMA. Therefore, the durability of recycled mixes to resist the damage of moisture was estimated and analyzed by various researches by tests of moisture susceptibility. Tabakovic et al. 2006 concluded in their experimental work that water impact was not a problem for the mixtures including 0, 10 and 20% of RAP[4]. Nevertheless, Several studies have found that utilizing RAP increases stiffness, which results to improve the value of Marshall stability for mixtures in comparison with neat mixtures [5, 6] from these researches it is fair to assert that increasing the RAP precentages can have a negative effect to the moisture resistance property and thus durability in general.

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On the other hand, Gardiner and Wagner, utilized the tensile strength ratio (TSR) which is the ratio of unconditioned tensile strength and moisture-conditioned tensile strength, to assest moisture suseptibilitty. They demonstrated that the addition of coarse RAP decreased moisture susceptibility [7].

Nanomaterials are a subset of nanotechnology that has piqued the curiosity of researchers. Nanotechnology is the creation of novel materials, systems, and devices at the level of molecular, a phenomenon connected with atomic and molecular interactions that have a significant impact on the macroscopic characteristics of materials [8]. Nanomaterials have been widely used in the field of asphalt pavement in latest years attribute to their unique characters such as large planar surface area and small size ranged from 1 to 100 nm, as well as their prospective to yield novel asphalt materials capable of increasing the durability and service life of flexible pavements [9].

The nono-clay is a common type of multi-layered silicate, it is known to be inexpensive, durable and safe. The most popular used clay mineral is Montmorillonite (MMT), which is one of the most recent additions to enhance the asphalt mix's quality. [10]. MMT nono-clay modified asphalt binder can be 22-33 percent less expensive than asphalt binder modified by polymer [11]. The asphalt binder modified by MMT is an effective approach to improve the resistance to moisture of asphalt mixtures [12]. There were also a few more experiments with better binder qualities, employing nono-clay as a key asphalt binder component. The Nono-clay-modified binder has enhanced Marshall stability by reducing penetration, increasing softening point, increasing viscosity, and increasing viscosity. [13-15]. In their study, Church et al. found that the nono-clay-modified AC mixture contain plastic film demonstrated marginally greater indirect tensile strength (ITS) values, lower moisture susceptibility, and improved ageing resistance. These minor enhancements are justified by the samples' lower air void quantity, and as a result, they must be regarded as conservative.[16]. Ismael (2019) found that increasing the compressive strength value for the dry and wet specimens with increasing percent of RAP in HMA, this lead to improving the resist to moisture damage (index of retained strength), The moisture suseptibility test evaluated the ability of the mixtures which contain RAP to withstand moisture damage and thus the durability of them. The findings showed that the mixtures, which contain RAP, were not prone to water content harm and can withstand the damaging effects of water better than the neat mixture [17] and in other study, Ismael (2019) also found that The inclusion of nono-clay MMT by weight of asphalt cement resulted in a reduction in durability properties of the asphalt mixture as tensile strength ratio (TSR) values and (IRS) values increased.[15] The studies discovered in the literature spanned a dose from one to seven percent, and the influence of the alterations increased with the rise in dosage [16] that's why the MMT percentages used was within that limit taking into account that rising it above 5% can be disadvantageous to the recycled mixture. This study is done to investigate he effect of both RAP and nano MMT on the asphaltic mixture properties, since many researches proved their advantage separately on the HMA mixture , for this purpose the index of retained strength (IRS), the compressive strength test, the indirect tensile strength and the indirect tensile strength ratio (TSR) of recycled mixture of rejuvenated RAP mixed with a number of percentages nano clay powder and have been studied and compared with the unmodified RAP mixes .

This work concentrated on investigating the influence of nono-clay modified binder on the characteristics of hot recycled mixtures, and to gain the ultimate benefit of the resources, and that is due to the proven advantages of RAP and nanolay separately on the mixture properties (i.e. moisture resistance) according to what had been mentioned in previous studies, and thus it is expected that both materias can modify the durability of the mixtures and the pavement.

2 Materials

2.1 Reclaimed Asphalt Pavement (RAP)

RAP was collected from a milling a surface layer at Salah Al-Deen St., Al-Amiriyah, Baghdad. After performing the extraction test by solvent using the centrifuge extractor, the sphalt content was 3.8% as average value of 4 samples of the RAP stokpile tested according to ASTM D2172. Then the old aggregate gradation was found and compared to the grading limits of a conventional surface course mixture by (SCRB/R9) [18] as explained in Table 1 and Figure 1.

2.2 Virgin Binder

The general properties of neat bitumen of asphalt grade (40-50) that was brought from Al-Dorah Refinery are revealed in Table 2. The outcomes of the tests are consistent with the State Corporation of Bridges and Roads criteria (SCRB R9, 2003).

Table 1: Grading of RAP Aggregate Extracted from an Old Mixture

Sieve Size (in)	Sieve opening (mm)	ASTM Specification	Mid-point Gradation After Extraction % Passing
3/4"	19	100	100
1/2"	12.5	90-100	96
3/8"	9.5	76-90	87.4
No.4	4.75	44-74	68.7
No.8	2.36	28-58	46.7
No.50	0.3	5-21	18
No.200	0.075	4-10	7.1

Table 2: Physical Characteristics of Asphalt Cement

Property	Result value	Unit	ASTM Specification	SCRB Specification
Flash Point (Cleveland Open Cup)	243	^{O}C	D-92	Min. 232
Specific Gravity	1.044	-	D-70	-
Ductility (25 ^{O}C, 5 cm/min).	+140	cm	D-113	>100
Penetration (25 ^{O}C, 100g, 5 sec).	44	0.1 mm	D-5	(40-50)
Softening Point	53	^{O}C	D-36	-

2.3 Virgin Aggregates

Quarry Al-Nibaei provided the aggregates for this project. The nominal max aggregates size NMAS was taken for surface type A was 12,5 mm, according to the manufacturer's specifications (SCRB R9, 2003).

2.4 Mineral Filler

As a filler, ordinary Portland cement had been chosen in this investigation. Table 3 displays the physical parameters of the filler used.

2.5 Nono-clay (NC)

The nono-clay powder used in this study is montmorillonite MMT K(10) ,it is also locally called bentonite. Sigma-Aldrich sourced it from the U.S. and manufactured it as a nono-clay. Table 4 demonstrated the overall properties of Nano clay Powder as stated by Karkush e. al. [19], the FESEM test (Field Emission Scanning Electrical Microscopy) outcome is shown in Figure 2 to evaluate the particle size of the nanomaterial of MMT powder, it should be noted that nono-clay appeared to be micro sized due to cluster effect.

2.6 The Rejuvenator

As a rejuvenator, a penetration grade (85-100) asphalt binder was used. It was also provided by the Al-Dora Refinery. The rejuvenator percent used was (2.5%) of RAP weight, which was proved to develop the properties of the old binder [20].

3 Preparation of Modified and Unmodified Recycled Mixtures

The design of Marshall Mix approach was utilized to evalutae the optimal binder content (OBC) for the virgin HMA mix. Which then helped to make the recycled mixture. Three RAP ratios were added to the neat HMA mix (30, 40, and 50% by weight of the mix). The RAP is heated to 110°C (230°F) for nearly two hours. The RAP aggregate was sieved to seperate aggregate sizes and replaced by the corresponding by the missing proportion of every Sieve, also it's vital to mind that the binder contributes to the RAP's weight.

For 1-2 hours, RAP was heated to 110°C to give it workability, greater parameters could influence some of the aged bitumen qualities. At 160°C, the neat aggregates and filler were preheated, whereas the neat bitumen and the rejuvenating factor was separately heated up to 130 °C before being introduced to the hot RAP and heated neat aggregates and firmly blended till the whole aggregate particles were surrounded by binder film. Two asphalt mixtures were utilized in this investigation. The first one is an unmodified recycled mix, while the second one is nano-modified recycled mix. The nono-clay MMT was blended for 60 minutes with a shear mixer at 3.000 round per minute (1, 3, and 5% binder weight)(these percentages were used based on previous studies) with asphalt cement that had been heated to 155^{o}C [21].

4 Characterization of Modified and Unmodified Recycled Asphalt Mixtures

4.1 Compressive Strength Test

This test is carried out on mixtures to determine their suitability for use in pavement under specified loads and environmental conditions. The samples are kept in an air bath at 25^{o}C for 4 hours after preparing and compaction, afer that the test was done by applying a compressive load at 5.08 mm/min (0.2 inches/min) as constant rate, to find the ultimate resistance load at failure according to ASTM D-1075 .The samples were made in accordance with ASTM D-1074 and consisted of a cylindrical specimen with a diameter of 101.6 mm and a height of 101.6 mm inches.

4.2 The Indirect-Tensile-Strength Test

This check is used to ascertain intensity of the mixture’s reaction to moisture according to ASTM D4867. Four Marshall sample are made by trial method to find the the amount of blows that create 71% air spaces with (40, 50, 60, and 70) blows independently. Then, for each proportion of RAP, six samples were prepared. Each set was divided into two subsets. The first samples are unconditioned were immersed in a bath of 25°C water for half an hour while the tensil strength of every sample was measured and the average indirect tensil strength of the samples was found. To remove the air, the other subset (conditioned) was placed in a vacuum vessel full of distilled water at temperature of 25 °C. Then, at -18°C temperature, store for 16 hours in the freezer. The thawing step begins after that, with the samples being placed in a 60 °C water bath for 24 hours. The second group's ITS was computed after it was removed and placed in another water bath at 25 °C for 1 hour. tensile strength ratio (TSR) is the proportion of conditional samples' average indirect tensile strength to unconditional subset average ITS. The tensile strength ratio (TSR) and indirect tensile strength (ITS) are found by using the method described by (ASTM-D6931-12). A baseline TSR ratio of 80% is required by the (ASTM D4867-09) standard.

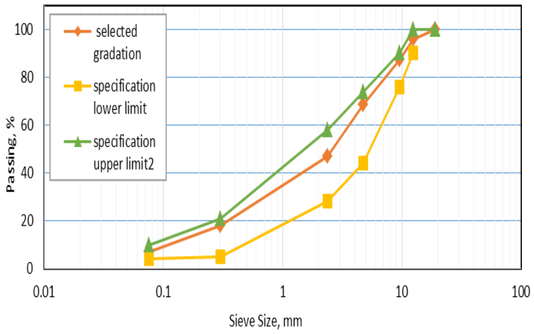

Figure 1: Specification Limits and RAP Gradation of (SCRB R9, 2003) for Surface Course Layer After Extraction.

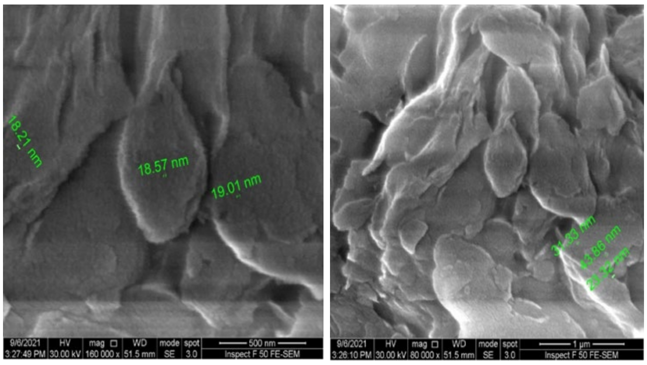

Figure 2: Field Emission Scan Electronic Microscop (FESEM) photo for Nano clay.

Table 3: Physical Characters of the Ordinary Portland Cement Filler

Property	value
Percent Passing Sieve No. 200	97%
Bulk Specific Gravity	3.2

Table 4: Chemical Properties and Physical Characteristics of nano clay . [19]

characteristic	Value	Oxide Composition	Content, %
Specific Surface Area (m^2/g)	220-270	SiO_2	50.95
kind of Mineralization	Montmorillonite	Na_2O	0.98
Particle Size (nm)	1-2	Al_2O_3	19.60
Density (g/cm^3)	0.5 – 0.7	MgO	3.29
Electrical Conductivity Value (µS/cm)	-25	K_2O	0.86
IonExchange Coefficient	48	CaO	1.97
Specific-Gravity	3-3.7	LOI	15.45
Colour	Pale-Yellow	TiO_2	0.62
Humidity (%)	1 –2	Fe_2O_3	5.62

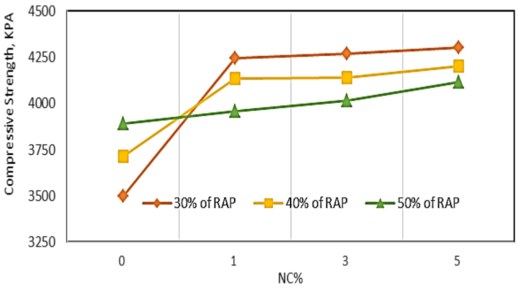

Figure 3: The Impact of Nono-clay Content on Compressive Strength for the Unconditioned Sample

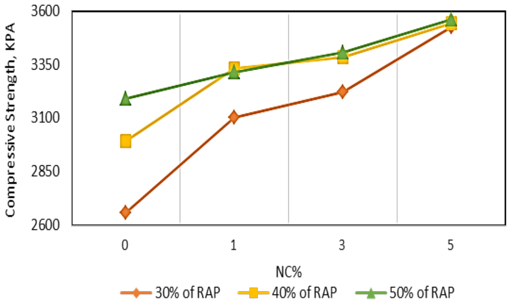

Figure 4: The Impact of Nono-clay Quantity on Compressive Strength for the Conditioned Sample.

5 Results and Discussions

5.1 Results of Compressive Strength Test

as it noticed in Figure 3 and 4, the compressive strength increased with the addition of NC. For unconditioned samples test, 30% of RAP recorded the highest values of the compressive strength where it increased by 23% by adding 5% NC, followed by 40% and 50% subsequently where the increment was 13% and 5.7% respectively. After that the increment in compressive strength values becomes steadier.

Same style of results occures for the conditioned samples, all RAP percentages increased with the increases of NC percent. But, 50% RAP had the highest values of compressive strength with steady increment of 4%, 6.8% and 11.6% when adding 1,3 and 5% NC, and 11.3%, 13% and 18.3% for 40% RAP ,whereas for 30% RAP, the increase was steep where it recorded 16.7%, 21% and 32.6% increment. These results can be attributed to the stiffness that RAP gives the mixture. This is because RAP aggregate is almost filled with an old binder, and the inclusion of nono-clay was proven to raise the viscosity of the neat binder, increasing the compression strength.

In Figure 5, the addition of NC increased the IRS values where all percentages of RAP had a direct raise of IRS with NC amount in the mix, only with one exception of 30% RAP at 1% NC where it decreased by 3.9% just to rise again by 3.2% at 3% NC and by 8.7% for 5% NC, whereas the other RAP percentages showed a steady increment. This leads to increase in moisture resistance since almost all the IRS values were above 80%, these results are similar to the findings of Ismael (2019) [15, 17]. The IRS values increases as the NC content increase within RAP mixtures this is might be due to the reinforcement that the nanostructure gives to the binder and stimulate the flexibility to the aged binder and thus increase the moisture resistance.

5.2 Results of Indirect Tensil Strength Test

in Figure 6, the ITS value for unconditioned samples was raised with increasing of MMT percentage, With the addition of 1, 3, and 5% of MMT, it grew by 12.2, 15, and 18.8%, respectively, for a 30 percent RAP. For 40 percent RAP, by 1.9, 10.3, and 16 percent; for 50 percent RAP, by 7.3, 19.2, and 34.5 percent; and for 1,3 and 5% MMT.

The same was true for conditioned subset, where the raises for 30 percent RAP were 12.5, 20.4, and 27.7%, correspondingly, when adding 1, 3, and 5% of MMT. Nevertheless, the ITS values for 40 percent RAP enhanced by 2.6, 11.6, and 18.7% with the inclusion of 1, 3, and 5% MMT, corespondingly, whereas for 50 percent RAP grew by 9.1, 22.7, and 39.4% for exact arrange of MMT percents, as shown in Figure 7. This could be responsible for higher viscosity caused by the inclusion of nono-clay, increasing the indirect tensil strength value and water damage strength of the old asphalt because it is more dependent on asphalt bilayers.

Figure 8 shows how recycled mixtures modified by MMT gained a decent resistance to water damage because TSR values were higher than (80 %), and that represents the bare minimum of requirements. For 30% RAP, TSR rised by 0.2, 4.7, and 7.5%, while a slight raise of 0.7, 1.2, and 2.3% is observed in 40% RAP, whereas for 50% RAP, TSR increased by 1.7, 3, and 3.7 %, by the inclusion of 1, 3 and 5% of MMT correspondingly for every RAP percentage, and this goes along with the findings of Ismael (2019) [15], and Church et al.(2019) [16]. This could ba attributed to the rise in RAP percentage that results in an increment of the old binder content which increase the total viscosity of binder and that supplies the RAP mix with better resistance to moisture damage or stripping. This is due to the inability of water to penetrate the mix.

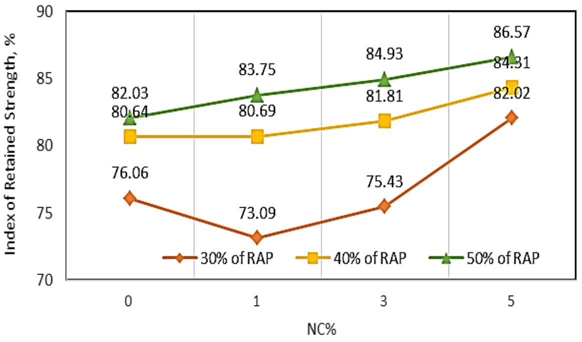

Figure 5: The Impact of Nono-clay Content on the Index of Retained Strength

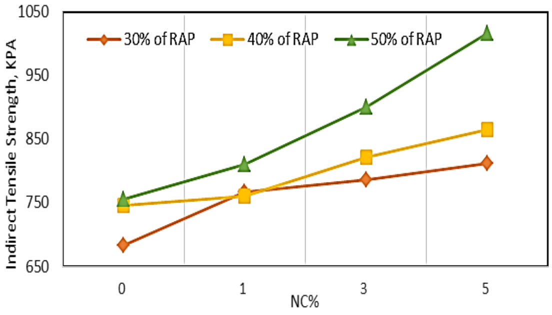

Figure 6: Influence of Nono-clay percent on the Indirect Tensil Strength for theUnconditioned Sample.

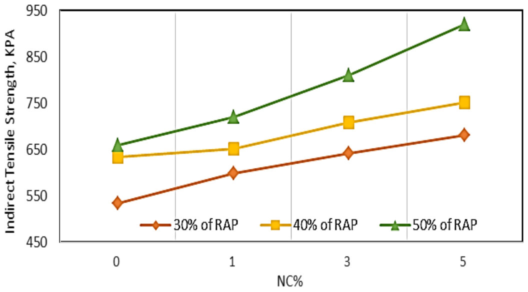

Figure 7: Influence of the amount of Nanocly on the Indirect Tensile Strength for the Conditioned Sample.

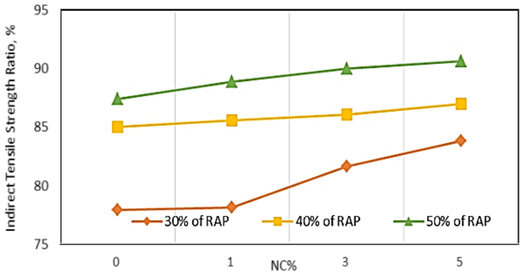

Figure 8: Influence of Nono-clay percent on Indirect Tensil Strength Ratio.

6 Conclusion

For the mixes studied in this study, the following findings are drawn:

1. It was found that both RAP and MMT enhanced the compressive strength for the mixtures and produced a stiffer mixture where 30%RAP produced the highest increment with 5% MMT where it 23% then 13 % and 5.7% for 40% and 50% RAP respectively for unconditioned samples, and increased by 32.6%, 18.3% and 11.6% for conditioned samples for same ratios.
2. The nono-clay improved the moisture resistance, as proved by the IRS values, by 8%, 4%, and 6% for 3%, 40%, and 50% RAP. The highest values were rated for 5% of MMT, which increased by 8.7%.
3. The introduction of MMT to RAP enhances the ITS values where 5% MMT had the highest values, for unconditioned samples it was raised by 18.8%, 16% and 34.5% and by 28%, 19% and 39% for conditioned samples, both per 30,40 and 50% RAP respectively.
4. The sensitivity of the moisture of asphalt cement mixture is decreased as the TSR rises by introducing MMT to the asphalt cement by weight. With the concentration of 5% MMT, the TSR increased across all RAP percentages by 7.5%, 2.3% and 3.7% for 30,40 and 50% RAP respectively.
5. In conclusion, adding nano MMT to RAP mixtures is useful, since it enhanced moisture resistance, and this results in a much more durable mixture.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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