Enhancement of the Rutting Resistance of Asphalt Mixtures Modified by Nano Clay and Crumb Rubber

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ABSTRACT

In recent years the increased traffic, axle load, tire pressure, and hot weather have hastened the spread of rutting in flexible pavements. Recent research indicates that nanomaterials and crumb rubber considerably alter asphaltic mixture characteristics. This research aims to examine the impact of Nano Clay (NC) combined with Crumb Rubber (CR) on the Marshall characteristics and the rutting resistance of HMA. It involves determining the optimal asphalt content, by using the method of Marshall design, as well as the rutting depth for asphalt mixes with varying amounts of NC (1%, 3%, and 5%) and CR (10%, 20%, and 30%) as a percentage of the asphalt binder. The optimal content of asphalt was 4.93% for the control mix. The Marshall stability was enhanced by the inclusion of NC and CR, with the combination of 5% NC and 30% CR exhibiting the most significant increase of 20.9%. Marshall flow was decreased by adding NC and CR. The control mix had a Marshall flow of 3.30 mm, but when using 3% of NC and 30% of CR, the flow decreased to 2.88 mm, which was the greatest reduction. The ideal proportion of NC and CR was 5% and 30%, respectively. This resulted in a 40.85% reduction in rut depth compared to the control mixture.

Keywords-rutting; wheel tracking test; marshall test; nano clay; crumb rubber

I. INTRODUCTION

Asphalt pavement rutting is unquestionably a significant problem in terms of pavement performance for both road users and road authorities [1-3]. When heavy loads are applied to the flexible pavement at high temperatures, a lasting and irreversible permanent deformation, occurs in the wheel path [4-6]. The latter is a common pavement distress taking place during its service life [7]. Conventional bitumen has a restricted ability to withstand various loads and temperatures occurring over the lifespan of a pavement. Consequently, it is necessary to alter traditional bitumen to endure the substantial loads and weather variations. Numerous compounds, including polymers and rubber, enhance the characteristics of bitumen and asphalt. Nano-scale materials are utilized as asphalt modifiers to meet the growing need for the improved qualities of asphalt concrete mixes [8]. For a safe and long-lasting road to be provided, it is crucial to study efficient strategies to decrease the rutting distress. Asphalt mixtures used to be altered by adding various chemicals, which increased stiffness, reduced moisture sensitivity, and enhanced temperature susceptibility [9]. Nanotechnology is a highly active field of study spanning several other scientific fields, involving civil engineering and construction materials [10]. Furthermore, it has been successfully utilized in the road paving field [11, 12]. To increase resistance against stress, nanotechnology has recently earned much interest [13]. Many researchers have proposed the utilization of nanomaterials to enhance asphalt pavement and extend its lifespan [14, 15]. The viscosity of the bitumen-nanoparticle combination increases as the proportion of the additives applied equivalently increases, indicating a possible enhancement in resistance to permanent deformation and rutting [16]. Authors in [17] found that adding nanoparticles to Asphalt Concrete (AC) wear courses increases the lifespan of pavement structures. Adding NC to asphalt improved its design life by 35.7% compared to that of the Control mix. Authors in [18] investigated the modification of asphalt with a 5.5% SBS and 0.5% NC powder addition, demonstrating the most advantageous results in the conducted tests. This modification effectively enhances the physical and mechanical properties of the asphalt binder and mixtures. Authors in [19], based on their results, revealed a decrease in the softening point, kinematic viscosity, and a reduction in the binder penetration. The most significant enhancements in the modified binders were achieved with a 6% NC concentration. Authors in [20] found that the inclusion of MMT improved the Marshall properties of asphalt mixtures. Incorporating 6% Montmorillonite (MMT) resulted in the highest Marshall stability, with values of 11.94 kN and 10.14 kN observed for Asphalt Cement AC (40/50) and AC (60/70), respectively. In contrast, the conventional mix yielded lower Marshall stability values of 9.45 kN and 7.93 kN. The inclusion of MMT led to a reduction in the Marshall flow, with a 4% MMT mixture demonstrating the most significant decrease of 2.87 mm in AC (40/50) compared to the 3.47 mm decrease in the control mixture. Moreover, a 2% MMT mixture induced the highest decrease of 3.38 mm in AC (60/70) compared to the 3.64 mm reduction in the control mixture. Authors in [21] studied the benefits of using montmorillonite NC as an asphalt additive in cold asphalt mixtures, enhancing gradation group stability at each dose added. Authors in [22] demonstrated that augmenting the NC content in the base bitumen enhanced the rheological characteristics and rutting resistance of the asphalt binder. The most significant enhancement was observed at a 6% NC content. In addition to NC, the researchers proposed the utilization of CR to modify bitumen. Incorporating CR in bitumen binder modification for road pavement construction, promotes sustainable development achieved by recycling waste materials [23, 24]. Crumb Rubber Modifier (CRM) has the potential to be used as an alternative polymer substance to enhance the performance of HMA [25]. Incorporating CR into the asphalt binder improves the pavement's capacity to withstand various forms of distress, including rutting, fatigue cracking, and low-temperature cracking [26]. Authors in [27] discovered that incorporating NC and CR into the mixture increased Marshall's strength. The highest level of strength was attained with 10% of CR and 5% of NC. Authors in [28] found that adding CR to modified bitumen lowered temperature sensitivity and boosted viscosity and penetration. After conducting Marshall and wheel track tests, it was determined that adding 10% of rubber crumbs increases Marshall's stability to 12.7 kN and reduces the rutting depth to 8.65 mm. Authors in [29] discovered that incorporating CR as a modifier improves the rheological characteristics of binders, such as penetration resistance and reduced permanent deformation. Authors in [30] discussed that using CR in the structure of HMA pavement is advisable, particularly in hot climatic zones like the Middle East, due to its ability to withstand high temperatures to a satisfactory extent. Authors in [31] found that the addition of NC to Asphalt Rubber (AR), which is a combination of bitumen and CR, provides advantages such as enhanced resistance to rutting, decreased noise from road tires, and prolonged lifespan. Authors in [32] demonstrated that the addition of CR reduced the penetration of the asphalt bitumen by 15% compared to the reference sample, while the softening point rose by 10%. In addition, the ductility experienced a reduction of 26%. Authors in [33] found that adding more CR to asphalt alters its penetration, ductility, softening point, and elastic recovery. As CR levels increase, penetration and ductility decrease compared to the control mix sample of 0%. Meanwhile, the softening and elastic recovery rise.

II. MATERIALS AND METHODS

This section provides an overview of the selected materials and analyzes where they were sourced from.

1) Asphalt Cement

Road paving typically involves the utilization of AC with a penetration grade of 40/50. The primary supplier of this type of AC is the refinery of Al-Dourah, which is located in Baghdad. Table I presents the test results of the asphalt cement.

TABLE I. ASPHALT CEMENT TEST RESULTS

Test	**Unit**	**Results**	**SCRB 2003 specification [34]**	**ASTM specification [35]**
Penetration at 25 °C, 100 gm, 5 s	1/10 mm	46	40 – 50	D5
Ductility at 25 °C, 5 cm/min	cm	160	≥ 100	D113
Softening point	°C	52	–	D36
Flash point	°C	240	232 min.	D92
Specific gravity at 25 °C	-----	1.04	–	D70
After the Thin-Film- Oven- Test (ASTM D 1754)				
Retained penetration of original	%	62	55 (Min)	D5
Ductility at 25 °C, 5 cm/min	cm	81	> 25	D113

2) Fine and Coarse Aggregates

The crushed coarse aggregate (4.75 mm-19 mm sieve) and fine aggregate (No.4-No.200 mm sieve) for the wearing course, were locally sourced from Al-Obaidi Complex for Asphalt Paving. The laboratory determined the aggregates' fundamental qualities. The test results were in accordance with the specification restrictions established by [35].

3) Mineral Filler

Limestone dust was added to the asphalt mixture as a filler. Since it helps stiffen and toughen an asphalt binder, it is a crucial ingredient in the aforementioned combination. Materials that pass through a No. 200 sieve (0.075 mm) are considered fillers. Table II shows the physical parameters of the mineral filler.

TABLE II. PHYSICAL PROPERTIES OF MINERAL FILLER

Test	Result
Bulk specific gravity	2.69
Passing No.200, %	98

4) Nano Clay (NC)

Nano Clay (NC), evidenced in Figure 1, is the nanomaterial utilized for this study. In both the local and commercial sectors, this nanomaterial is also known as montmorillonite. The particle size of the NC was assessed using Atomic Force Microscopy (AFM) through laser analysis to ascertain if the former had reached the nanoscale. The investigation determined that the particles' average diameter was 21.51 nm, satisfying the requirements regarding measurements in the nanometer range. Figure 2 illustrates the NC shape as determined by AFM. Figure 3 displays the particle size of the NC. X-Ray Fluorescence (XRF) was employed to ascertain the fundamental composition of NC. The chemical composition of NC is clearly outlined in Table III.

TABLE III. THE CHEMICAL COMPOSITION OF NC

Symbol	Element	Concentration
Na_2O	Sodium	0.30 %
MgO	Magnesium	2.893 %
Al_2O_3	Aluminum	15.94 %
SiO_2	Silicon	49.78 %
K_2O	Potassium	0.62 %
CaO	Calcium	2.34 %
TiO_2	Titanium	0.35 %
Fe_2O_3	Iron	5.26 %

Fig. 1. Nano Clay (NC).

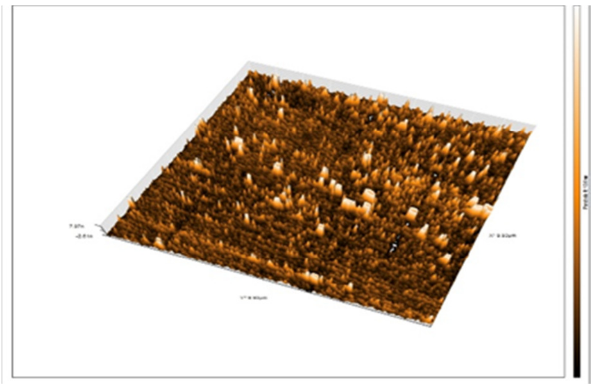

Fig. 2. The morphology of the particle size of NC.

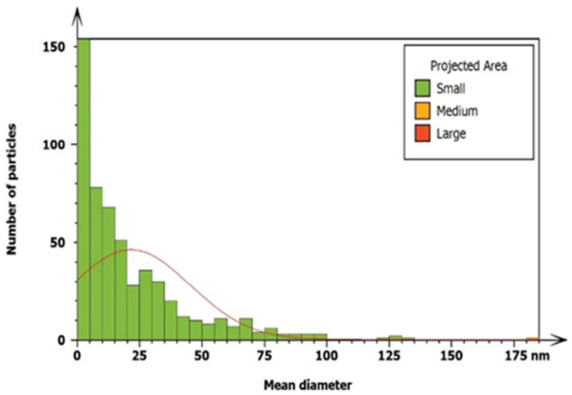

Fig. 3. The average diameter of particle size of NC.

5) Crumb Rubber (CR)

Crumb Rubber (CR) is produced from recycled waste tires that are ground into different particle sizes [36]. In this study, the CR utilized as an additive consists of black particles sourced from a nearby tire recycling factory in the Owiriej industrial region. The factory generates CR by recycling automobiles and truck tires, through mechanical grinding processes carried out at conventional temperatures. The grinding machine for rubber is depicted in Figure 4.

Figure 5 displays that the CR retained on sieve No. 50 was used after the process of sieving.

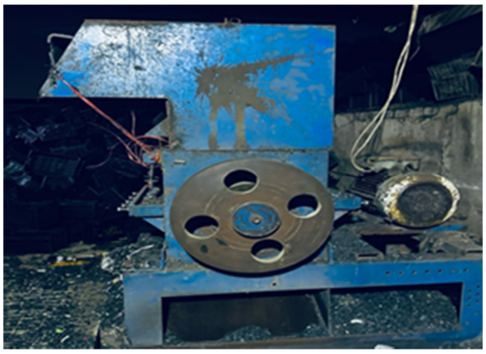

Fig. 4. The grinding machine for CR.

Fig. 5. The Crumb Rubber (CR).

III. EXPERIMENTAL METHODOLOGY

A. Marshall Test

After having been heated to 150 °C, AC was mixed with NC in a variety of percentages (1%, 3%, and 5% by asphalt cement weight). The mixer had been working at a speed of about 3000 rpm for 45 min. At first, the CR was combined with AC at different weight percentages (10%, 20%, and 30%). After that, it was mixed with the NC-modified AC. With the mixer operating at a speed of 3000 rpm for one hour, each percentage of CR was added to all the percentages of NC. The Marshall test, conducted according to ASTM D6926, was used as the primary method for the design of the asphalt mix. The objective was to determine the optimal content of asphalt and Marshall properties. Subsequently, the bulk specific gravity was determined following the ASTM D2726 standard, while the ASTM D2041 standard was utilized to ascertain the theoretical maximum specific gravity for the mixtures.

B. Wheel Tracking Test

A wheel tracking device was utilized to predict the rutting depth. A small, loaded wheel machine was deployed in the simulation experiments to evaluate the HMA quality by repeatedly rolling it through a prepared HMA sample. The test was carried out at a pressure of 70 psi on rectangular slabs produced by using a Dyna compactor, with dimensions of 30 cm × 40 cm × 5 cm, complying with the EN 12697-33 standards. The stress level was applied at 55 ˚C for 10000 cycles (20000 passes). Marshall and slab specimens were compacted and tested, as portrayed in Figure 6.

Fig. 6. The Marshall and wheel tracking test specimens.

IV. RESULTS AND DISCUSSIONS

A. Marshall Test

The results of the Marshall test, which was conducted on the mixtures that contained NC and CR in varied amounts, are detailed in Table IV. From the table mentioned above, there is a clear indication of the volumetric result values (V.M.A, V.F.A, and A.V). The optimal amount of asphalt was raised due to the increased amount of NC, as shown in Figure 7. Compared to the control mixture, including 1%, 3%, and 5% of NC to AC resulted in increases of 3.25%, 5.88%, and 7.51%, respectively. The optimal asphalt content was increased by 4.67%, 6.09%, and 9.74% by adding 10%, 20%, and 30% of CR along with 1% of NC to the asphalt cement, respectively. Meanwhile, increases of 7.30%, 8.72%, and 10.34% were achieved when 10%, 20%, and 30% CR combined with 3% NC were added to the asphalt cement, respectively. Adding 10%, 20%, and 30% CR to 5% NC yielded 8.52%, 11.16%, and 13.79% increases, respectively. Adding NC to the asphalt resulted in a denser mixture due to the increased surface area, leading to a rise in the bulk density. The bulk density rose by 0.78%, 1.03%, and 1.14% with the addition of 1%, 3%, and 5% of NC, respectively. Figure 8 indicates that the Marshall stability rose as the amount of NC and CR in the mixture increased. Figure 9 illustrates a reduction in flow as the NC and CR content increased. The high flow suggests that the asphalt mixture has less resistance when traffic loads are applied. An increased concentration of asphalt cement results in an increase in the Marshall flow. The achieved results are in accordance with the findings of other studies. [20, 27, 28].

TABLE IV. RESULTS OF THE MARSHALL TEST

NC (%)	CR (%)	O.A.C (%)	Stability (kN)	Flow (mm)	V.M.A (%)	A.V (%)	V.F.A (%)
0	0	4.93	9.83	3.30	16.48	4.91	73.10
1	0	5.09	10.07	3.32	16.61	3.85	74.87
	10	5.16	10.31	3.28	16.68	3.80	77.86
	20	5.23	10.57	3.16	16.74	3.77	78.08
	30	5.41	10.89	2.95	16.77	3.60	80.14
3	0	5.22	10.97	3.11	16.80	3.56	76.72
	10	5.29	11.20	3.05	16.83	3.51	74.50
	20	5.36	11.34	2.97	16.89	3.48	75.81
	30	5.44	11.52	2.88	16.92	3.39	76.04
5	0	5.30	11.39	3.29	15.24	3.49	77.32
	10	5.35	11.55	3.15	15.28	3.42	77.19
	20	5.48	11.68	3.04	15.33	3.38	78.35
	30	5.61	11.89	2.96	15.41	3.31	79.19
SCR B 2003 limits	-	4-6	8 Min	2-4	14 Min	3-5	-

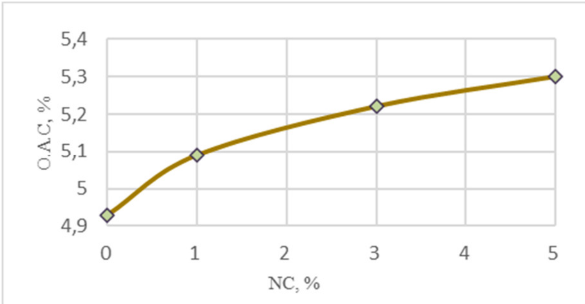

Fig. 7. The impact of NC on O.A.C.

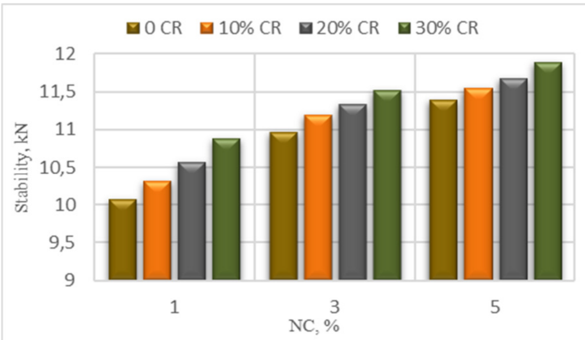

Fig. 8. The impact of NC on stability.

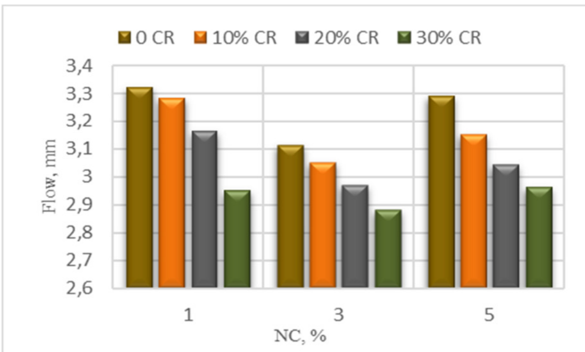

Fig. 9. Effect of NC and CR on the flow.

B. Wheel Tracking Test and Dynamic Stability

A total of 13 slabs, each measuring 400 mm × 300 mm × 50 mm, were manufactured and then tested at a temperature of 55°C. The testing process included applying a dynamic load of 700 N using a moving wheel for a total of 10,000 cycles, which is equivalent to 20,000 repetitions. The study analyzed the rutting behavior of asphalt mixes by assessing their dynamic stability. The latter was determined by measuring the number of cycles required to induce 1mm of permanent deformation in the last quarter of an one-hour wheel tracking test [37]. Due to the extended duration of the test, (1) was employed to ascertain the dynamic stability [38].

$$DS = \frac{C_{10000} - C_{7500}}{RD_{10000} - RD_{7500}} \quad (1)$$

where DS = Dynamic Stability (cycle/mm), C10000 = Cycles 10000, C7500 = Cycles 7500, RD10000 = Rut Depth at 10000 cycles, RD7500 = Rut Depth at 7500 cycles. The ultimate Rut Depth at 10,000 cycles and DS, are outlined in Table V and Figures 10 and 11. The results obtained in this study demonstrate a high level of concordance with previously published research findings [22, 28, 31].

TABLE V. RUTTING DEPTH AND DYNAMIC STABILITY RESULTS

NC (%)	CR (%)	Rutting depth (mm) @10000 Cycle	Dynamic stability (Cycle/mm)
0	0	12.19	896
1	0	9.56	1068
	10	8.83	1173
	20	8.31	1288
	30	8.02	1359
3	0	8.78	1147
	10	8.35	1232
	20	8.16	1309
	30	7.85	1429
5	0	8.12	1256
	10	7.81	1445
	20	7.58	1634
	30	7.21	1773

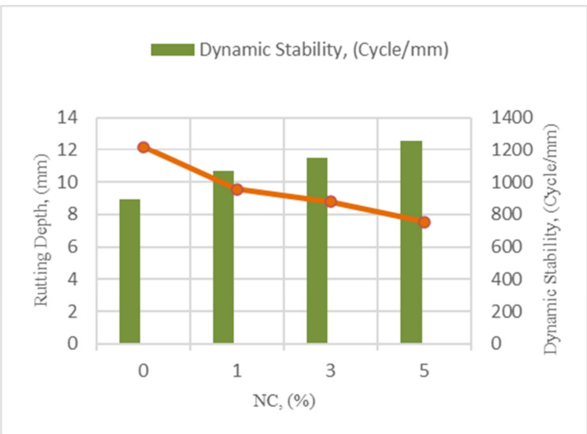

Fig. 10. Effect of NC on dynamic stability and rutting depth.

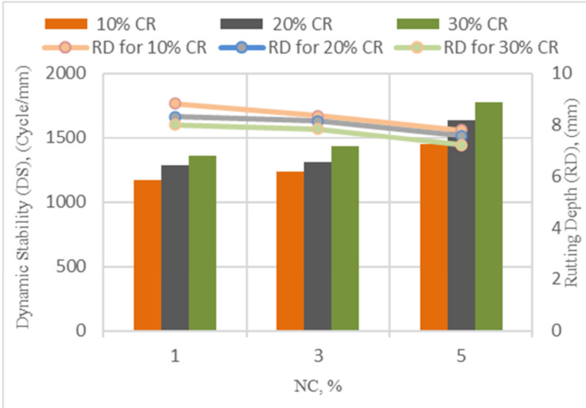

Fig. 11. Effect of NC and CR combination on dynamic stability and rutting depth.

V. CONCLUSIONS

Asphalt pavement rutting is a significant problem for road users and authorities. It is therefore considered a research gap that must be solved. In the current study the asphalt was modified with NC and CR for its resistance against rutting to be increased. This study examines the impact of combining NC and CR to examine the Marshall properties and rutting resistance of HMA. The main conclusions drawn are:

- The addition of NC and CR improved The Marshall characteristics of the asphalt mix. The inclusion of 5% NC and 30% CR to the asphalt cement AC (40/50) resulted in a maximum Marshall stability of 11.89 kN, whereas the control mixture had a Marshall stability of 9.83 kN. The addition of NC and CR led to a decrease in the Marshall flow. The most significant reduction was found when using 3% of NC and 30% of CR, where the Marshall flow decreased to 2.88 mm compared to the 3.30 mm reduction observed for the control combination.
- Compared to the control mixture, the asphaltic mixture's VMA may be increased due to the addition of CR particles, which do not dissolve in bitumen but instead adhere to the aggregates with the bitumen. This can lead to an increase in the thickness of the bitumen layer around the aggregates.
- The wheel tracking test results indicated that the modified asphalt mixes with NC and CR, exhibited greater dynamic stability values in comparison to the conventional mixture.
- The combination that included 1% NC had the greatest rutting depth, which was 21.57% more than the control mix.
- Compared to previous research, the analysis of the data collected in this study verified the positive influence of NC and CR on the ability of asphalt to resist rutting.

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