# Effect of Crumb Rubber Modified Bitumen in Hot Mix Asphalt Concrete

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**ORIGINAL RESEARCH**

**Abstract-** Improving bituminous material using recycling waste (Crumb rubber) as modifier was emphasized in this paper. Crumb rubber (CR) waste was added by volume to the bitumen in 0, 5, and 7 %. The volumetric properties tests were conducted using the Marshall Test (ASTM D1559), others includes Characterization of Binder and Aggregate materials in HMA, (FTIR Analysis), Fundamental mechanical properties tests, also Rheological properties according with ASTM D7369-11, Dynamic Modulus Test, according with AASHTO R83-17, Rutting Test according with AASHTO T324-04, Fatigue Cracking Evaluation according with AASHTO TP124 and Flexural Beam Fatigue Beam Test according with AASHTO T 321-07. The result indicates that crumb rubber is very suitable as a modifier, with bitumen of 60/70 PEN grade. From the results, at the designed production temperature 135°C for unmodified 60/70 Bitumen, the modified admixed samples (0% and 5% CR) at the same binder content show a high void percentage for mixes (5% CR). This is an indication that the modified asphalt mixtures exhibited volumetric properties with higher voids and lower density due to change in viscosity caused by modification and requires compaction at higher temperature to be at par with regular unmodified bitumen grade. However, the air voids of mixtures fall within the specification range of 3% to 5%, and as such acceptable for use as a modifier in 60/70 PEN grade bitumen.

**Keywords-** Crumb rubber, Hot Mix Asphalt, Rheological properties.

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## 1 INTRODUCTION

This roadways are an integral aspect of transportation infrastructure. Road construction engineers must consider the primary user's requirements of safety as well as the economy. To achieve this goal, designers should take into account three fundamental requirements which include environmental factors, traffic flow, and asphalt mixtures materials (Mashaan *et al*, 2014). There are basically three methods used to achieve these, which are the Hveem, Marshall, and Superpave methods. All the methods are commonly used in other countries. Whereas, in Nigeria, the Marshall method mostly used to achieve the design and performance criteria. (FMW&H, 1997).

HMA mix design is the process of determining what aggregate to use, what asphalt binder to use, and what the optimum combination of these two ingredients ought to be. HMA mix should be designed to achieve the following properties: resistance to deformation, fatigue resistance, resistance to low-temperature cracking, durability, resistance to moisture susceptibility, skid resistance, and workability. In general, road pavement distresses are related to asphalt binder (bitumen) and asphalt mixture properties. Rutting and fatigue cracking are among the major distresses that lead to permanent failure of the pavement surface. The dynamic properties and durability of conventional asphalt, however, are deficient in resisting pavement distress. Hence, the task of current asphalt researchers and engineers is to look for different kinds of polymer-modified asphalt, such as, crumb rubber (Mahrez, 1999).

This research seeks to investigate the effect of crumb rubber on the bituminous mixtures that would further enhance the quality of Modified Hot Mix Asphalt produced._The use of Crumb rubber in asphalt giving origin to the term asphalt plastics has been an alternative to minimize the environmental impact, and simultaneously improve the mechanical properties of the asphalt mixture. This research has been conducted for investigating the effect of adding Crumb rubber in asphalt mix in different proportions to find out the optimum quantity of the additive that will give the best results. Temperatures have an influence on pavement, it becomes soft when the temperature is high and when temperature is low it gets hardened and crack. Hence, it is essential to improve the quality of bitumen by modifying with materials that can play a role in the bitumen to achieve the properties increased elasticity, reduction of temperature responsiveness, and aging resistance and higher softening point

The Job Mix Formula (JMF) for the designs in this study was developed according to the Federal Ministry of Works and Housing specification – Roads and Bridges (NGSRB) which specifies a 75-blow Marshall Design Method to achieve volumetric criteria – Air Voids, Marshall Stability, and Flow and specified Bitumen contents for Wearing and Binder course mixtures.

The reflection of cracks through pavement surface overlays and seals is recognized as a severe problem that may impact significantly on a country's road infrastructure network. Water ingresses through cracks causes the pumping of fines due to the repetitive action of vehicular wheel loads, leading to potholing, rutting deformation, and premature failure of road pavements. This situation is exacerbated by additional strains placed on these roads by ever-increasing traffic loading and climate change effects.

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**Section D-** MATERIAL/ CHECMICAL ENGINEERING AND RELATED SCIENCES
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These extreme conditions call for innovative solutions to ensure the sustainable performance of roads over time. Various studies have been carried out to improve the quality of bitumen used in bituminous road construction. One of the results of such studies is to use polymer modified bitumen (Farouq. 2014). There is need to know the effect of Crumb on Bitumen as modifier before the application of Polystyrene to the Modifier. Although it is very good in improving other properties like thermal susceptibility in bitumen, increased stiffness in asphalt, increased resistance to permanent formation and better behavior to fatigue cracking (Otuoze *et al.*, 2018). Therefore, combining these two materials Crumb Rubber (CR) and Bitumen in a given proportion will not only be a contribution to knowledge by confining the works of earlier researchers, but it is expected at the end to create a much-improved modifier.

This paper is aimed to investigate the effect of Crumb rubber on the properties Modified bitumen in hot Mix Asphalt Concrete, in order to determine the microstructure changes induced by such modification to asphalt binder, bearing in mind the following objectives.

(i) Characterization of Binder and Aggregate materials
(ii) Determination of the volumetric properties of Modified Hot Mix Asphalt Using the Marshall Test
(iii) Determination of the fundamental mechanical properties through (Mixture Performance Test: Deformation Resistance, Fatigue Life, Tensile strength and Stiffness).
(iv) Determination of the rheological properties through (Resilient Modulus Test, Dynamic Modulus Test, Rutting Test, Fatigue Cracking Evaluation, and Flexural Beam Fatigue Beam Test).

This research was limited to Laboratory tests of materials involved, using AASHTO and ASTM standard procedures, and was carried out at the McAsphalt Industries Limited (Toronto, ON) in. Canada.

## 2 MATERIALS

The Bitumen used was a 60/70 PEN grade equivalent, a PG 64-22, available in Nigeria, and with equivalence in other countries worldwide. The crumb rubber was a cryogenic grind sub 30 mesh size rubber from Federal Roads Maintenance Agency's Research and Development unit. Aggregates consist of both coarse and fine aggregates. To develop modified hot mixtures, three aggregate sizes were used to prepare a design blend:12.5 mm Crushed Stone, 9.5mm Crushed Stone, and Crushed Stone Dust. A Bitumen binder suitable for the climate and traffic conditions in Nigeria was used in combination with a combination of selected dosages of crumb rubber additive (0, 3,5 and 7) % respectively (Kolo, 2015).

## 3 ASPHALT MIX DESIGN

For Hot Mix Asphalt (HMA) manufacturing, target values of gradation and asphalt binder content are specified based on the mix design along with allowable specification bands to give room for inherent material and production variability. The successful mix design of aggregate and bitumen is shown in Table 1.

Table 1. Trials Mix Blend Gradation

| | Sieve Sizes (mm) | Control Mix **(CM)** | Crumb Rubber Mix **(CRM)** | FMW&H Specification |
|---|---|---|---|---|
| **JMF Blend Gradation % Passing** | 16 | 100 | 100 | 100 |
| | 13.2 | 98.6 | 98.6 | 85 - 100 |
| | 9.5 | 91.5 | 91.5 | 75 - 92 |
| | 6.3 | 76.2 | 76.4 | 65 - 82 |
| | 2.36 | 51.5 | 53.1 | 50 - 65 |
| | 1.18 | 36.4 | 36.6 | 36 - 51 |
| | 0.6 | 27.1 | 26.2 | 26 - 40 |
| | 0.3 | 21.6 | 20.3 | 18 - 30 |
| | 0.15 | 18.8 | 17.6 | 13 - 24 |
| | 0.075 | 8.5 | 8.0 | 7 - 14 |

## 4 RESULTS

### 4.1 CHARACTERIZATION OF BINDER AND AGGREGATE MATERIALS IN HMA

Results of Gradation for Bituminous Concrete Components in accordance with (ASTM C-136) are given in Table 2 while results of Aggregates Physical Properties are given in Table 3. Results of Asphalt Binder in accordance with (ASTM D6373) are given in Table 4. For the Volumetric properties, mixture volumetric testing and analysis results are presented in Table 5. For Marshall Stability, results of the Marshall stability and flow are presented in Figure 1. Results of the Marshall Flow values are presented in Table 5 and in Figure 2. Results of Air Voids or porosity are presented in Figure 3.

Table 2. Gradation for Bituminous Concrete Components (NGSRB, 1997)

| | **Sieve Size (mm)** | **12.5mm Stone Rockview Quarry** | **9.5mm Stone Rockview Quarry** | **Stone Dust (Filler) Rockview Quarry** | **Crumb Rubber Modifier Recovery Tech.** |
|---|---|---|---|---|---|
| Gradation % Passing (ASTM C-136) | 16 | 100 | 100 | 100 | 100 |
| | 13.2 | 83.8 | 100 | 100 | 100 |
| | 9.5 | 21.0 | 90.4 | 100 | 100 |
| | 6.30 | 5.8 | 20.6 | 96.5 | 100 |
| | 2.36 | 3.0 | 2.4 | 67.8 | 99.9 |
| | 1.18 | 2.7 | 2.0 | 47.3 | 51.7 |
| | 0.6 | 2.5 | 1.7 | 35.5 | 17.9 |
| | 0.3 | 2.2 | 1.5 | 28.2 | 2.2 |
| | 0.15 | 2.0 | 1.3 | 24.6 | 0.07 |
| | 0.075 | 1.8 | 1.2 | 17.9 | 0.00 |

Table 3. Aggregates Physical Properties

| **Test** | **ASTM Method** | **Result (%)** | **Specification** |
|---|---|---|---|
| Aggregate Crushing Value (CV) | ASTM C535 | 22 | < 30 |
| Aggregate Impact Value (IV) | ASTM D5874 | 16 | < 30 |
| Elongation Index (EI) | ASTM4791 | 5 | < 20 |
| Flakiness Index (FI) | ASTM D 4791 | 9.8 | < 20 |
| Water Absorption (ABS) | ASTM C1585 | 0.650 | 2 % max |
| Specific Gravity (SG) | ASTM C127 | 2.725 | 2.55 - 2.95 |
| Los Angeles Abrasion Value (LAAV) | ASTM C535 | 31.5 | < 40 |
| Sand Equivalency/Clay Content | ASTM C142 | 74.8 | 45 min |

Table 4. Selected Properties of Bitumen Binder

| Performance Measure | Test Method | Bitumen Test Results<br>Neat 60/70 | <br>Modified CRM (5%CR) | Specification Limit AASHTO |
|---|---|---|---|---|
| Non-recoverable Creep Compliance at 3.2 kPa, $J_{nr}$ (1/kPa) | AASHTO T at Testing Temperature of 58°C | 1.16 | 0.79 | 4.5 kPa max |
| Average Percent Recovery at 3.2 kPa ($R_{3.2}$) (%) | | 39.2 | 55.2 | 25% |
| Phase Angle at Constant Modulus, $\delta$ (°) | AASHTO T 315, Constant \|G*\| = 8967 kPa | 53.1 | 50.4 | N/A |
| The Secant Modulus to the Yield Point, $E_{YP}$ (kPa) | AASHTO TP 123-18, Method A | 12.5 | 13.6 | N/A |

Table 5. Mix Volumetric Properties Marshall Test (ASTM D1559)

| | Mixture | Control (CM) | Mixtures with Modifier Additive | | | FMW&H Nigeria |
|---|---|---|---|---|---|---|
| Modifier Dosage, % | | | 0.5% CR (CRM) | | | |
| Temp °C | Mixing | 145 °C | 145 °C | | | |
| | Compaction | 135 °C | 135 °C | | | |
| Mix Properties | | | | | | Specs. Limits |
| | | Average | 1 | 2 | Average | |
| Bulk Relative Density | | 2.406 | 2.391 | 2.393 | 2.392 | - |
| Mean Rut Depth | | 2.491 | 2.488 | 2.487 | 2.488 | - |
| Air Voids, % | | 3.4 | 3.9 | 3.8 | 3.9 | 3.0 – 5.0% |
| Stability, N | | 12,565 | 10,677 | 10,755 | 10,717 | 3,500 min |
| Flow, 0.25 mm | | 11.8 | 10.5 | 10.3 | 10.4 | 8 - 16 |
| Tensile Strength Ratio, % | | 83.1 | 85.8 | 84.7 | 85.3 | - |
| JMF Design Content | | 5.5% Bitumen | | | | 5.0 – 8.0% |

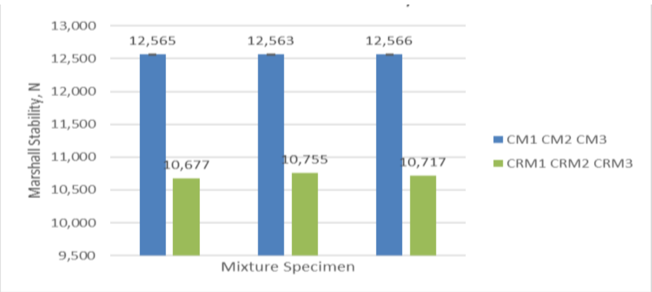

Fig. 1: Marshall Stability Results (CM 1 at 0, CM2 at 5 CM3 at 7) %

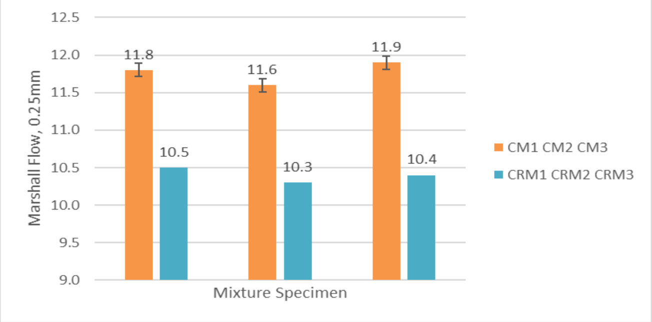

Fig. 2: Marshall Flow Results (CM 1 at 0, CM2 at 5 CM3 at 7) %

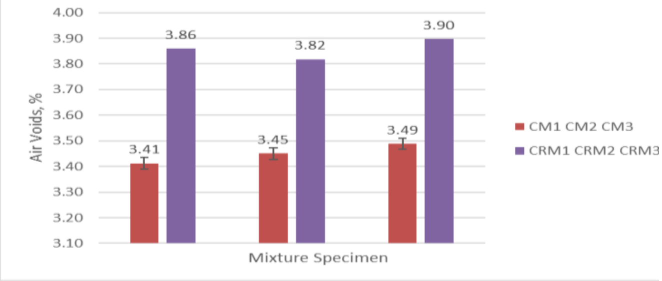

Fig. 3: Mixture Air Voids (CM 1 at 0, CM2 at 5 CM3 at 7) %

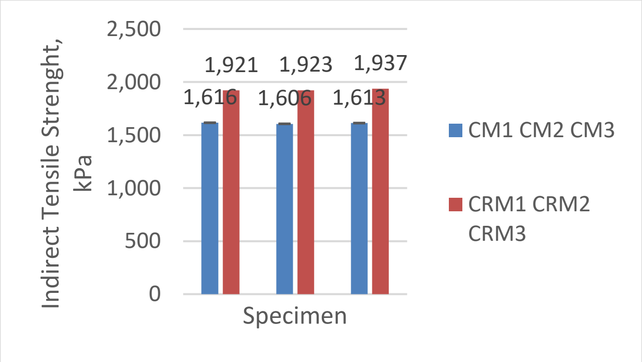

Fig. 4: Mixture Indirect Tensile Strength (CM 1 at 0, CM2 at 5 CM3 at 7) %

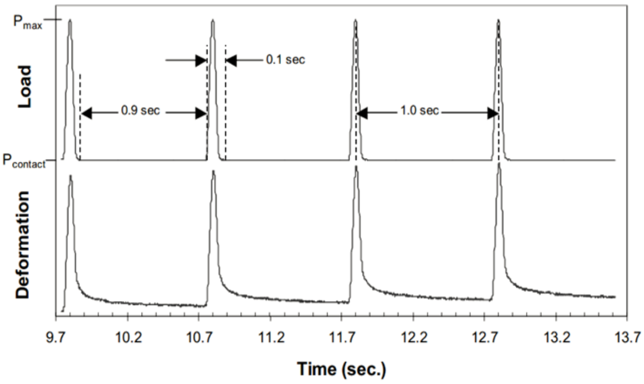

Fig. 5: Deformation and Load Values Recorded in Resilient Modulus Testing

For fundamental mechanical properties, Tensile strength according to (ASTM D6931-12) and results presented in Table 6 and Figure 4. In terms of Resilient Modulus Test (Deformation Resistance), the laboratory results on the resilient modulus by using ASTM D7369-11 are presented in figure 5 and Table 7.

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Table 6. Indirect Tensile Strength Results

| Mixture ITS Results | Control Mix (CM) | | | Modified Mix (CRM) | | |
|---|---|---|---|---|---|---|
| Specimen | CM1 | CM2 | CM3 | CRM1 | CRM2 | CRM3 |
| Density | 2.385 | 2.384 | 2.382 | 2.394 | 2.396 | 2.397 |
| Height, t(mm) | 64.4 | 64.5 | 64.4 | 63.6 | 63.5 | 63.4 |
| Diameter, D(mm) | | 101.4 | | | 101.4 | |
| Total Load at Failure, P(N) | 16,569 | 16,489 | 16,450 | 19,450 | 19,435 | 19,550 |
| Indirect Tensile Strength, $S_t$ (KPa) | 1,616 | 1,606 | 1,613 | 1,921 | 1,923 | 1,937 |
| | | **1,616** | | | **1,921** | |

Table 7. Resilient Modulus Results (Mpa)

| Resilient Modulus and Poison's Ratio - ASTM D7369 | | | | | | | |
|---|---|---|---|---|---|---|---|
| | $0^0$ | | $90^0$ | | | | |
| | Plane 1 | Plane 2 | Plane 1 | Plane 2 | Mean | STDV | CV % |
| | Last 5 Pulse Average | | | | | | |
| **Control Unmodified Mix (CM)** | | | | | | | |
| Resilient Modulus, ($M_R$), MPa | 3696 | 3690 | 3659 | 3656 | **3675** | 17.9 | 3.20 |
| Poisson Ratio | 0.29 | 0.29 | 0.30 | 0.29 | **0.29** | 0.0 | 1.71 |
| **Crumb Rubber Modified Mix (CRM)** | | | | | | | |
| Resilient Modulus, ($M_R$), MPa | 3096 | 3090 | 3155 | 3159 | **3125** | 32.1 | 1.01 |
| Poisson Ratio | 0.29 | 0.29 | 0.28 | 0.29 | **0.29** | 0.0 | 1.74 |

Table 8. Selected Dynamic Modulus (E*) Data at 10 Hz

| Mix Name | Dynamic Modulus, E*, MPa at 10 Hz<br>Testing Temperature, ºC | | | Phase Angle (Degrees)<br>Testing Temperature, ºC | | |
|---|---|---|---|---|---|---|
| | **4ºC** | **20ºC** | **40ºC** | **4ºC** | **20ºC** | **40ºC** |
| Control Mix (CM) | 7352.5 | 2969.96 | 392.3 | 15.4 | 24.1 | 34.8 |
| Crumb Rubber Mix (CRM) | 8071.7 | 2570.09 | 406.1 | 17.5 | 28.3 | 34.5 |

As per Rheological properties, Dynamic Modulus Tests results, according to AASHTO R83-17, are presented in Table 8 and Figure 6. Rutting Tests results according to AASHTO T324-04, are presented in Table 9.

Table 9. Hamburg Wheel Tracking Device (HWTD) Measured Rutting Depth

| **Control Mix (CM)** | | |
|---|---|---|
| **Modifier** | **-** | |
| Samples | Air Void (%) | Rut Depth (mm) |
| A | 7.3 | 4.30 |
| B | 7.2 | 4.00 |
| C | 7.3 | 4.5 |
| Average | 7.3 | 4.27 |
| SD | 0.05 | 0.21 |
| **CR Mix (CRM)** | | |
| **Modifier** | **5% Crumb Rubber** | |
| Samples | Air Void (%) | Rut Depth (mm) |
| A | 7.1 | 4.90 |
| B | 7.2 | 4.70 |
| C | 7.5 | 3.70 |
| Average | 7.3 | 4.43 |
| SD | 0.21 | 0.64 |

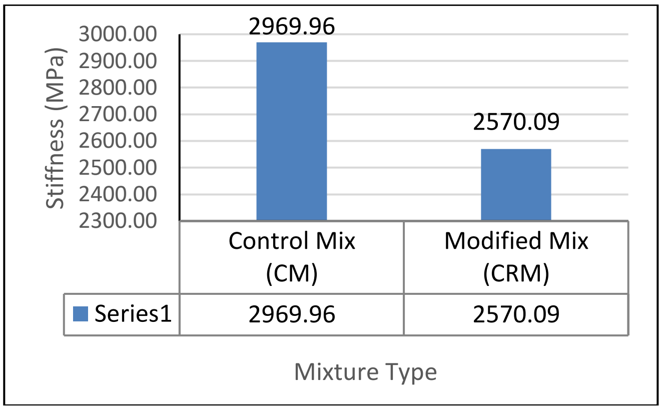

Fig. 6: Mixture Stiffness Values at 20°C

## 4.2 DISCUSSION

### 4.2.1 Characterization of Binder and Aggregate Materials in HMA

**Results of Gradation for Bituminous Concrete**: Components in accordance with (ASTM C-136) are given in Table 2. It was observed from Table 2 that all the aggregates were found to be within the specified range. The Crumb rubber was also found to pass the gradation test according to ASTM C-136. This initial aggregate materials test is very important as it was a perquisite to other series of tests

**Results of Aggregates Physical Properties are given in Table 3:** It should be noted that all aggregate particles are free from coatings of clay, silt, or other objectionable matter. The six different aggregate sources used for this study were tested to determine their conformity to the code as the aggregate physical property requirements with respect to various ASTM standards specifications. A

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summary of the test result of bulk relative densities, absorption, aggregate crushing values (CV), Aggregate Impact Value (IV), etc., are listed in Table 3. The laboratory result for the Aggregate Crushing Value (CV) according to ASTM C535 was found to be 22 which was less than 30 maximum as shown in Table 3, while Aggregate Impact Value (IV) in accordance to ASTM D5874 was 16 < 30 the Maximum, Elongation Index (EI) in accordance to ASTMD 4791 was 5 < 20, Flakiness Index (FI) in accordance to ASTMD 4791 was 9.8 < 20, Water Absorption (ABS) ASTM C1585 was 0.650% against 2 % maximum. The Specific Gravity (SG) in accordance to ASTM C127 was 2.725 which was just within the envelope of 2.55 - 2.95. Also, Los Angeles Abrasion Value (LAAV) ASTM C535 was 31.5 < 40, while Sand Equivalency/Clay Content ASTM C142 was 74.8 greater than 45 which was the minimum. The laboratory result for the aggregate test satisfied and conformed to the work done by Mamo1 *et al*, (2019) and Yongjun *et al* (2022).

**Results of Asphalt Binder in accordance with (ASTM D6373) are given in Table 4:** The modified binder was formulated to also ensure that it conforms to the requirements of ASTM D6373 for performance grade PG 64-22 (PEN 60/70). The Modified Bitumen Binder was fine-adjusted based on two main parameters - phase angle at constant modulus and the secant modulus to the yield point. These two parameters are key indicators of bitumen performance. Phase angle at a constant modulus represents a chemical fingerprint of the bitumen. In a study, by Kriz *et al*, (2016). it was observed that there is good correlation between phase angle at a constant modulus, and this supported the hypothesis that phase incompatibility impedes stress relaxation, reduces phase angle, and contributes to cracking susceptibility.

From Table 4, It was also observed that non-recoverable Creep Compliance at 3.2kPa, $J_{nr}$ (1/Kpa) was 1.16 kPa for the neat bitumen while Crumb Rubber Modified Bitumen (CRM) at 5% was 0.79 kPa against 4.5 kPa max, Average Percent Recovery at 3.2 kPa (R3.2) (%) for the neat Bitumen was 39.2% and that of (CRM) was 55.2% against 25% min according to AASHTO specification. The Phase Angle at Constant Modulus, δ (°) for the neat bitumen was 53.1 which was higher than 50.4 for the CRM sample, meanwhile, the value of the Secant Modulus to the Yield Point, $E_{YP}$ (kPa) for the neat bitumen was 12.5, lower than CRM 13.6, but confirming to the improvement in the bitumen by the Modifier.

### 4.2.2 Volumetric Properties

**Mixture volumetric testing and analysis results are presented in Table 5**: modified Marshall mixes were evaluated based on criteria for wearing course surface designed referencing specifications from FMW&H standard listed in table 1. All Marshall mixes in this study incorporate 100 % crushed coarse and fine aggregate and a PG 64-22 (pen 60/70) bitumen, modified by McAsphalt engineering services by incorporating waste crumb rubber additive. In accordance with (ASTM d1559), the mixes were designed at 5.5 % optimum bitumen content (OBC), meeting the required FMW&H specified bitumen binder content of between 5.5 to 6.5%. The average of the (CRM) samples at a mixing temperature of 145°c and compaction temperature of 135°c for both the bulk relative density (BRD) and mean rut depth (MRD) of (2.392, 2.488) cm respectively, was observed too a little bit less than that of the control mixture (CM) which were 2.406 and 2.491 respectively. The bitumen design content was 5.5% which was within the limit of (5 – 8) % the result in table 5 was found to be as (Suliman *et al*, 2016) and (Farouq, 2014).

**Marshall Stability:** The Marshall stability and flow tests are empirical tests used to quantify an HMA's potential for permanent deformation. HMA fatigue properties are important because one of the principal modes of HMA pavement failure is fatigue-related cracking, called fatigue cracking. Therefore, an accurate prediction of HMA fatigue properties would be useful in predicting the overall pavement life. The Marshall stability values for the mixture in this study are presented in Table 5. In all samples, the stability value increases with the addition of modifying additives. As observed from Figure 1, the stability in all mixes increases with increasing the CRM content until a certain percentage and with the addition of waste CRM it decreases. The decreases in stability while increasing CRM content may be attributed to the decrease in the adhesion between aggregate and bitumen. The average Stability (N) value for the (CRM) was 10,717 although less than the value of the (CM), but far more than the minimum Specification allowable value of 3,500min, and the result was found to be in conformity with (Suliman *et al*, 2016)

**Marshall Flow:** The Marshall Flow values result followed a special trend. The results are tabulated in Table 5 and presented in Figure 2 showing that flow values decreased with the addition of a modifier. The addition of 0.5% CRM decreased the flow value for the optimum binder content compared to the control sample. Hence it appears that adding CRM to the mix has a remarkable effect in decreasing the flow of the mix. The value obtained for the Flow was 10.4 which is within the Specification limits of (8 – 16). The result was found to be in conformity with (Suliman *et al*, 2016)

**Air Voids:** The durability of the bituminous mix has a relationship with the Air Voids or porosity. The lower the air voids, the more durable the mix and vice versa. Higher air voids provide passageways through the mix for entrance of air and water. Too low porosity can lead to flushing where the excess bitumen flow out of the mix to the surface. Therefore, the mix should be low enough in voids to be durable and impermeable and high enough to prevent the bitumen pumping under the action of traffic and high temperature. Table 5 show the effect of the CRM content at optimum binder content on the Air Voids of the mix and presented in Figure 3. Generally, for any CRM content, with increasing the binder content, the air voids increased. This could be due to absorption of some of the

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bitumen, leaving out voids between aggregates. The average percentage of the Air voids of the (CRM) was 3.9%, though higher than that of the (CM) but was found to be within the specification ranges of (3.0 – 5.0) %. The result was found to be in the conformity with (Suliman *et al*, 2016).

**Tensile Strength Ratio (TSR):** The next step in the Modified mix design process was to evaluate the moisture sensitivity (TSR) of the design mixture. This was accomplished by performing test method AASHTO T283, "Resistance of Compacted Bituminous Mixtures to Moisture Induced Damage" on the design mixture aggregate blend at the design asphalt binder content. Test specimens for this test are compacted to 7% air voids, ±0.5%. One subset, consisting of three specimens, was considered the control set. The other subset of three specimens was conditioned. These specimens are subjected to partial vacuum saturation and then followed by a 24-hour thaw cycle at 60°C. All specimens were tested to determine their indirect tensile strengths. The moisture sensitivity was determined as a ratio as in Equation (1)

TSR = 100 x Avg. tensile strength, conditioned samples,
Avg. tensile strength, control samples (1)

The criterion for tensile strength ratio (TSR) is 80%, minimum, the mix designs produced using the evaluated modified mixtures, all resulted to TSR value over 80%. The average Tensile Strength Ratio for the (CRM) was 85% which was observed to be more than 83.1% for the CM.

### 4.2.3 Fundamental Mechanical Properties

**Tensile strength tests according to (ASTM D6931-12):** The tensile strength was determined by using the Indirect Tensile Strength (ITS) apparatus in accordance with ASTM D6931-12. The strength testing was performed by applying an axial force at a rate of 50 mm/min until the maximum load was reached. The indirect tensile strength was then calculated by using Equation (2):

$$S_t = \frac{2000P}{\pi t D} \qquad (2)$$

where:

St = Indirect Tensile Strength, kPa
Pmax = applied load at failure, kN,
D = diameter of the specimen, mm,
t = thickness of the specimen, mm.

Six specimens were compacted using a Superpave gyratory compactor to a target percentage of air voids (7 ± 0.5 percent), each measuring 150 mm in diameter and 100 ± 5 mm in height. The compacted specimens were then separated into two subsets: conditioned and unconditioned. From the test results shown in Table 6 and also in Figure 4, it was observed that the Indirect Tensile Strength (ITS) value for the Crumb Rubber Modify (CRM) 1,921kPa was greater than that of Control Mix (CM) which was 1,616 kPa, this indicates an improvement in the (CRM) material as regard to ITS.

**Resilient Modulus Test (Deformation Resistance):** The laboratory results on the resilient modulus by using ASTM D7369-11 carried out on specimen at the temperature of 25 °C are presented in Table 7 and Figure 5. From the test data it is noted that the crumb rubber-modified bituminous mixture has the highest modulus (STDV) values of 32.1 against the control mix (CM) which was just 17.9, this means that using crumb rubber (CRM) in the bituminous mix the resilient modulus of the mix increases. Hence it increases the resistance to plastic flow and rutting, therefore improving the resistance to deformation of the bituminous mix. It is apparent that in 5.0% binder content by weight of aggregate, all the mixes yielded stiffness modulus for the three mixtures that are close with no significant difference.

### 4.2.4 Rheological Properties

**Dynamic Modulus Test, according to AASHTO R83-17:** Dynamic modulus testing was performed using the IPC Global Asphalt Mixture Performance Tester (AMPT). Three replicates of each mix were tested. Samples were prepared to 7 ± 0.5% percent air voids and prepared in accordance with AASHTO R83-17, "Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)". The mixtures were tested in accordance with AASHTO T 378-17, "Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)" with the temperatures and frequencies recommended by AASHTO R 84-17. Dynamic modulus data from three selected test conditions (at 4°C, 20°C, and 40°C) are presented in Table 8. In Figure 6, the stiffness value was predicted for the conditions of 20°C using a frequency of 10 Hz. Rutting is more likely to occur at higher temperatures and under lower frequency loading conditions. At 10 Hz, which is suggested to be equivalent to highway speed, and a reference temperature of 40°C, the CRM mix showed relatively higher dynamic modulus compared to the control CM and CRPS mixes. This may suggest relatively better resistance to rutting. This also indicates that the (CM) value of 2,969.96 may exhibit brittle behaviour which may reduce its resistance to fatigue cracking as compared with the (CRM) mixtures.

**Rutting Test according to AASHTO T324-04:** After short-term oven conditioning, 150-mm-diameter by 63-mm-thick specimens were compacted in the Superpave Gyratory Compactor (SGC) to an air void content of 7±0.5% measured in accordance with AASHTO T 331. Duplicate 150 mm diameter by 63 mm thick cylinder specimens for the asphalt mixtures were tested with the Hamburg Wheel Track Testing equipment. The rutting resistance of compacted asphalt mixes was evaluated by tracking a 705 N (158 lb) load hard-rubber wheel across the surface of gyratory compacted specimens submerged in a hot water bath at 64°C. A Linear Variable Differential Transducers (LVDT) device was used to measure the depth of the impression of the wheel as rutting depth. For best results, the LVDT was calibrated before each use. Table 9 indicates the results of the HWTT on the mixes. In general, both mixes showed high rutting resistance of

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average values of 4.27mm for (CM) and 4.43mm for (CRM), although there was a significant change in Standard Deviation (SD) which was 0.21 and 0.64 respectively. The SD data show that (CRM) mix has a higher value compared to (CM) mix. These results are consistent with the E* property at the 40$^{o}$C temperature presented earlier.)

**Fatigue Cracking Evaluation according to AASHTO TP124:** The fatigue cracking properties of the mixtures were evaluated using two test procedures: (a) AASHTO TP124 “Semi-Circular Bend (SCB) Flexibility Index” and (b) AASHTO T321 “Flexural Beam Fatigue”. The short-term conditioning was completed after conditioning loose mixtures for 4 hours at 135°C. Fatigue cracking tests were conducted on long-term conditioned asphalt mixtures. The long-term conditioning was completed after conditioning loose mixtures for 24 hours at 135°C to simulate the late life, greater than 10 years, aged condition of the asphalt mixture. The (CRM) mix with the value of 11.0875 showed a better performance than the (CM) mix which was 8.2375, since it reached more cycles to failure as shown in Figure 8. This result is in tandem with Trejos *et al*, (2018)

**Semi-Circular Bend (SCB) Test in accordance with AASHTO TP 124:** The Illinois SCB test was used to determine Illinois Flexibility Index (I-FI) in accordance with AASHTO TP 124, “Determining the Fracture Potential of Asphalt Mixtures Using Semicircular Bend Geometry (SCB) at Intermediate Temperature” (AASHTO, 2016). For this test, specimens were cut from the middle of the gyratory sample to the thickness of 50 mm. Strength and displacement were recorded during a 50 mm/min deformation rate. Testing was performed at 25°C and each SCB sample also has a 15.0 mm notch depth to initiate the location of the crack. The FI was then calculated by dividing the fracture energy by the slope of the post-peak load-displacement curve at the inflection point shown in Figure 8 by using equation 3. In general, as the SCB Flexibility Index (FI) value increases, the asphalt mixture’s fatigue cracking resistance increases. The SCB Flexibility Index fatigue cracking test results are shown in figure 7 while the error bars represent one standard deviation from the average value of four replicates tested. The test results show that the modified asphalt mixture had almost seven times more flexibility than a conventional control mixture.

## 5 CONCLUSION

It can be concluded from this work that the values of Aggregates’ Physical Properties (ASTM C535, ASTM C535, ASTM D5874, ASTM D 4791, ASTM C1585, ASTM C127, ASTM C535, and ASTM C142) obtained from the test were within the specification limits, and as such, characterization of aggregate materials HMA was achieved as specified in the stated objective. It was also observed that there was an increase in the values obtained from the Asphalt Binder (ASTM D6373) test for (i) Non-recoverable Creep Compliance, (ii) Average Percent Recovery at 3.2 kPa (R3.2) (%), and (iii) Secant Modulus to the Yield Point, EYP (kPa) for the CRM, confirming the improvement in the bitumen by the Modifier Characterization of Binding materials in HMA, although the Phase Angle at Constant Modulus, δ (°) for the CM was higher than that of the (CRM) sample.

Determining the Technological properties of Modified Hot Mix Asphalt Using Marshall Test (ASTM D1559) as indicated in the objective; the values of Marshall stability, Marshall Flow, Air Voids, and Tensile Strength Ratio (TSR) for the CRM mixture were observed to have a significant change when compared with that of CM mixture indicating an improvement in quality of Bitumen material. Changes that were observed from the test results of Tensile strength (ASTM D6931-12) and Resilient Modulus Test (Deformation Resistance) ASTM D7369-11 confirmed objective three (iii) of this research, which is a determination of Fundamental mechanical properties. The results also favoured the use of 5% Crumb Rubber as a Modifier material in HMA. The results obtained from the determination of Rheological properties of the materials using the Dynamic Modulus Test, AASHTO R83-17, Rutting Test AASHTO T324-04, Fatigue Cracking Evaluation AASHTO TP124, Fatigue Cracking Evaluation AASHTO TP124 and Flexural Beam Fatigue Beam Test AASHTO T 321-07 justified the essence of using Crumb Rubber to improve bitumen in HMA production, since all the results of CRM were found to be better than that of the CM mixture.

## 6 RECOMMENDATIONS

From the results, at the designed production temperature of 135$^{O}$C for unmodified 60/70 Bitumen, the modified admixed samples (5% CR) at the same binder content, a (5% CR) is observed to be adequate as a modifier. To achieve a better result, the modified HMA requires compaction at a higher temperature to be at par with regular unmodified bitumen grade. It’s recommendable to conduct the flow number test with confined samples if a rutting model is going to be obtained since it better represents the field conditions.

## REFERENCES

ASTM International, "Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures ASTM D6931," in Annual book of ASTM standards, West Conshohocken, PA, 2012.

American Association of State Highway and Transportation Officials, (2000.) AASHTO M320. Standard Specification for Performance Graded Asphalt Binder.

American Association of State Highway and Transportation Officials, (2020.) AASHTO T315 "Standard Method of Test for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer,"

American Association of State Highway and Transportation Officials, (2009). AASHTO T 53, Standard Method of Test for Softening Point of Bitumen (Ring-and-Ball Apparatus).

"American Society of Testing Materials (ASTM) D6931. "Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures" Annual Book of ASTM Standards, Road and Paving Materials; Vehicle-Pavement Systems, 04.03, West Conshohocken, Pennsylvania".

"American Association of State Highway and Transportation Officials (AASHTO) T 378 – 17, “Standard Method of Test for Determining the Dynamic Modulus and Flow Number for

Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)", Standard Specifications".

"American Association of State Highway and Transportation Officials (AASHTO) T 324, "Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt". Standard Specifications for Transportation Materials and Methods of Sampling and Tes".

American Association of State and Highway Transportation Officials (AASHTO) T321. "Determining the Fatigue Life of Compacted Hot Mix Asphalt (HMA) Subjected to Repeated Flexural Bending". Standard Specifications for Transportation Materials and Methods".

American Association of State Highway and Transportation Officials TP124. " Determining the Fracture Potential of Asphalt Mixtures Using Semicircular Bend Geometry (SCB) at Intermediate Temperature ", AASHTO Provisional Standards, Washington, D.C., (2016)".

Buttlar, W. and Roque, R. (1994) Development and Evaluation of the SHRP Measurement and Analysis System for Indirect Tensile Testing at Low Temperatures. Transportation Research Board Meeting."

California Department of Transportation, Caltrans (2007) "Flexible Pavement Preservation" 2nd Edition, Volume 1 Chapter 8. Page 6 – 20

Farouq. Z.U. (2014) "A study of Crumb Rubber Modified Asphalt Slurry Seal Emulsions", M.Sc. Thesis Department of Civil Engineering, Faculty of Engineering Ahmadu Bello University, Zaria.

Federal Ministry of Works & Housing (1997) Specification for Roads and Bridges Vol. II. FMW&H, Ministry of Works and Housing, Abuja.

Kolo S.S, (2015), Evaluation of Natural and Artificial Aggregates in Hot Mix Asphalt Production Department of Civil Engineering, Federal University of Technology, Minna, Nigeria.

Kriz P., Grant D, Boussad N, Gausson D, Cointe F., Toulemonde C, Shirts R. (2016) "Assessment of Performance Specification tests for Rheologically simple Bitumens" Research Department, Imperial Oil Limited, Sarnia, ON, Canada European Technology Centre, Esso S.A.F., Notre Dame de Gravenchon, France Esso S.A.F., Courbevoie, France ExxonMobil Corp., Spring, TX, United States

Mamo1 A.A. Dagoye M.B, Tessema A.R (2019) Determining the Physical Properties of Aggregate Products and its Suitability for Road Base Construction, Ethiopia Civil Engineering Department, Wolaita Sodo Univeristy, Ethiopia

Nigeria General Specification for Roads and Bridges (1997)

Otuoze H.S, Ejeh S.P, Amartey Y.D, Manasseh J , Shuaibu A.A, and Oziohu K.Y. (2018) "Rheology and Simple Performance Test (SPT) Evaluation of High-Density Polypropylene (HDPP) Waste-Modified Bituminous Mix" Civil Engineering Department, Ahmadu Bello University, Zaria, Nigeria Jordan Journal of Civil Engineering; Irbid Vol. 12, Iss. 1,

Romanoschi A. S, Nicoleta I. D. and Octavian D. (2006). "Resilient Modulus and the Fatigue Properties of Kansas Hot Mix Asphalt Mixes" The Kansas Department of Transportation Topeka, Kansas and Kansas State University Manhattan, Kansas

Road Sector Development Team (RSDT), (2013) Road Sector Development Highway manual‟ Part1: Design, Volume 3; Pavements and Material Design, Federal Ministry of Works, Abuja.

Rust, FC. (1984)"Load-Associated Crack Movement in Road Pavements". In: Bitumen- Rubber - review of developments in South Africa. Proceedings of the Fourth Annual Transportation Convention, Pretoria

Rust, FC and I Akhalwaya (2018.) "Retarding Crack Reflection Using Bitumen-Rubber Seals and Overlay – Historic Overview of CSIR Research", Rubberized Asphalt <> Bitumen Rubber,

Suliman A.B.A, Mohd I.M.M, Musbah A. "Evaluation of volumetric properties of asphalt mixture by using Batu Pahat Soft Clay as filler" Department of Civil Engineering (JTKA), Universiti Tun Hussein Onn Malaysia. Ahmed does research in Civil Engineering. Their current project is 'Urban Panning for libyan Cities'.

Trejos C. A. C. Sebaaly P.E., Elie Y. Hajj E. Y., Hand A., Lowman J. and David W. Z. (2018) "Performance Evaluation of Asphalt Mixtures with Tire Rubber Modified Binder" A thesis submitted in partial fulfillment of the Requirements for the degree of Master of Science in Civil and Environmental Engineering University of Nevada, Reno

(United Nation Educational Scientific and Cultural Organisation (2008). Introduction to Highway Engineering‟ (Technical and Vocational Education, Version 1). P 5-40.

Yongjun M., Tiany Y., Yaseen M., Ing Li. (2022) "Study on the performance and sustainability of modified waste crumb rubber and steel slag powder/SBS composite modified asphalt mastic." Journal of Cleaner Production Vol. 338, College of Civil Engineering and Architecture, Guangxi University, Nanning, Guangxi, 530004, China.

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