Nnamdi Azikiwe University Journal of Civil Engineering (NAUJCVE)
Volume-2, Issue-2, pp-50-60
www.naujcve.com
Research Paper Open Access

Study on the Performance of Crumb Rubber Modified Asphalt Concrete Mixtures for Railway Application in the Tropics

Apeh Adejoh Samuel[1], Adeyeri Joseph Babatola[2] Amu Olugbenga Oludolapo[3]

[1,2, 3] Faculty of Engineering, Department of Civil Engineering, Federal University Oye, Ekiti, Nigeria.

[1]Corresponding Author: engrsamapeh@gmail.com

ABSTRACT :

Due to the rapidly growing number of vehicles in Nigeria, waste tyres have become a major environmental concern. The aim of using crumb rubber obtained from waste tyres, as an additive in hot mix asphalt mixture is to reduce environmental pollution in the society, promote sustainable construction and reduce the sensitivity of asphalt to temperature. This study utilised ground crumb rubber in ranges of 0%, 1%, 2%, 3% and 4% to modify asphalt in ranges of 3.5%, 4.0%, 4.5%, 5.0% and 5.5% as specified by relevant standards. The laboratory hot mix asphalt design tests were conducted by Marshal Method procedure. The study was conducted by comparing varying proportions of crumb rubber and asphalt in asphalt concrete mixtures to determine the Marshal stability, Flow value, Voids filled with asphalt, Voids filled with mineral aggregates and the Air void contents. From the results, the sample prepared with 3% crumb rubber content at 4.5% bitumen content satisfied the relevant standards. The results showed that crumb rubber is a good additive in asphalt mixtures because there was improvement in the engineering properties of the mixture, it reduced sensitivity of asphalt to temperature changes and increased the viscosity of the binder, thereby extending the temperature range of viscoelasticity. This study recommends the application of crumb rubber in modifying asphaltic railway sub-ballast, because it makes asphalt more resistant to temperature changes, and enhances its engineering properties.

KEYWORDS: *Crumb rubber modifier, Engineering properties, Environment, Granular and asphaltic subballasts, Sustainability, Temperature sensitivity*

Date of Submission: 1-08-2024 Date of acceptance: 10-08-2024

I. INTRODUCTION

Although Hot Mix Asphalt (HMA) mixes, which are frequently used in flexible pavements, are intended to endure for 20 years, bituminous pavements break down sooner than expected because of the emergence of heavier vehicles with higher axial loads and heavy urban and rural traffic [Nandal et al., 2021].

There are several environmental implications associated with the construction of a new flexible pavement, as it requires a significant amount of energy and resources. Additionally, the primary source of bituminous binder, being crude oil, has seen a significant increase in price in recent years. As a result, bituminous mixtures are now more expensive. The bituminous pavement industries may become more sustainable and cost-efficient by creating new materials and technologies that integrate waste, recycled resources, and greener components into the bituminous mix manufacturing cycle. Because people are more worried about the effects that pavement construction will have on the environment, sustainable materials are being used more and more in pavement construction.

In order to ensure the conservation and maintenance of the natural resource base as well as mitigation of the ecological issues associated with the disposal of hazardous solid waste, sustainable pavements are planned and built. The primary goal of sustainable

infrastructure development is violated by the widespread use of natural aggregates in pavement construction and maintenance [Li et al., 2021]. Some consequences of such neglect include greenhouse gas emission-related issues, depletion and near-exhaustion of non-renewable natural resources, and global warming [Faramarzi et al., 2018]. All types of pavement need to implement sustainability goals, but this research is particularly interested in flexible pavement since it is more commonly used in tropical regions like Nigeria and other parts of the world.
Sustainable and environmentally safe materials are used in the construction of a green flexible pavement [Li-ping et al., 2020].

In Europe and around the world, conventional ballasted track structures with granular trackbed is very common and popular, because it is cheap and easy to construct [Figure 1.1]. This kind of trackbed presents good results but, in most cases, require frequent maintenance to ensure adequate operating conditions. Whereas one of the main aims of railway companies is to limit track maintenance costs, therefore, the all-granular track needs to be replaced with a solution that gives better performance as well as lower costs of maintenance and operation. It is important to find alternative solutions that are cheaper to construct, and yet offer satisfactory performance. To achieve this objective asphalt layers are normally used in combination with granular layers in various configurations. The use of asphaltic sub-ballast may improve the performance of the railway infrastructure and contribute to the reduction of track maintenance needs [Rose et al., 2011].

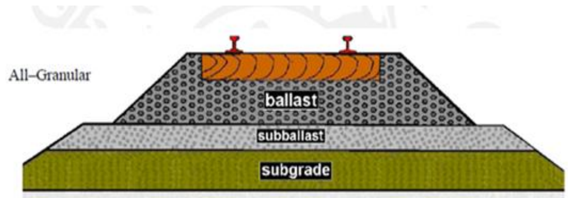

Fig. 1.1 : Typical ballasted (All-granular) track structure [Adapted from Rose et al., 2011]

However, the asphaltic layer is normally used together with granular materials, as an intermediate solution. It is laid between the ballast and subgrade [Figure 1.2]. This solution was employed in the first Italian high-speed line and also in Japan, for example. The experience obtained in Italy after 20 years showed a good long-term structural behaviour [Rose et al., 2011].
The limitation of bitumen as a paving material is due to the problems discussed below:

Temperature sensitivity: Conventional binders are highly sensitive to temperature variations, which significantly affect their stiffness and viscosity. This could worsen the pavement's vulnerability to rutting in hot weather and cracking in cold weather.

Aging and oxidation: Conventional binders lose favourable qualities as a result of aging and oxidation processes that take place over time. Because of this, the pavement's viability and performance may be negatively impacted by stiffer, less susceptible to cracking, and less durable binder.

Environmental issues: Crude oil, a limited resource, is used to make traditional binders. Their use and manufacturing increase air pollution, greenhouse gas emissions, and dependency on fossil fuels. These ecological factors require that work be done to find workable alternatives.

Rutting and fatigue cracking: Conventional binders struggle to survive these common distresses in pavement systems, rutting and fatigue cracking. This might result in early pavement collapse, which would increase maintenance costs and shorten the pavement's lifespan.

Limited recyclability: Traditional binders have little chance of being recycled because of the challenges associated with doing so. This reduces the possibility of using circular economy and sustainable practices when building pavement.

Researchers are experimenting with several strategies, such as mixing additives with bitumen, to enhance the sustainability, longevity, and performance of binders in flexible pavement. These attempts to reduce temperature susceptibility, enhance ageing resistance, decrease environmental impact, raise rutting and fatigue resistance, and improve binders' recyclability will ultimately lead to sustainable and resilient pavement solutions [da-Silva et al., 2022]. The rubber employed in the current study was crumb.

Laboratory test results have shown that crumb rubber modified asphalt mixture could enhance the properties of asphaltic mixtures [Behnood, 2019]. Crumb rubber does not have only good durability, abrasion resistance, and resistance to cracking deformation, but also capable of maintaining good stability in high temperature or low temperature performance [Wong and Wong, 2007]. Furthermore, modified asphalt is impervious and possesses waterproofing properties [Marques et al., 2011].

This study therefore evaluated the performance of crumb rubber modified asphaltic concrete. The choice of crumb rubber is important in order to protect the environment, promote sustainable construction, and reduce the sensitivity of asphalt to temperature changes.

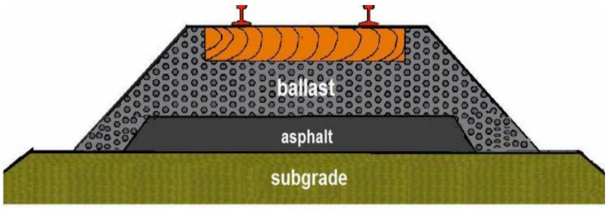

Fig. 1.2. Aspect of asphaltic trackbed for railway track [Rose et al., 2011]

II. MATERIALS AND METHDOLOGY

A. MATERIALS

The materials used for the mix, were coarse aggregate with 100% passing the 25.0mm sieve sourced from Zerberced quarry in Abuja. BS standard method was used to sample fine aggregate from river Kaduna, ordinary portland cement produced at Obajana in Kogi state, bitumen 60/70 penetration grade used was collected from Kaduna refinery and subjected to bitumen tests, and crumb rubber used was collected from Kuje in Abuja. The crumb rubber size used in this study was 0.3 mm. After sampling the materials, laboratory tests to determine the physical properties were conducted, grading of aggregates and sieve analysis of the aggregates used for the mix were carried out.

B. METHODOLOGY

A. Physical Properties of Materials

To confirm the suitability of the materials, coarse aggregate, fine aggregate, ordinary Portland cement, bitumen 60/70 grade and crumb rubber, several tests were carried out in accordance to BS 812 on the sampled materials before using them. The tests conducted on coarse aggregate were: Specific gravity, Water absorption, Crushing value, Impact value, and sieve analysis tests on fine aggregate, cement, crumb rubber and bitumen. Results for the tests are shown in Tables 3.1 - 3.8, while grading envelopes of the materials are shown in Figures 3.1 - 3.6.

a) **Test on Coarse Aggregates** - The crushed, granitic aggregate was subjected to Water Absorption [BS 812, Part 2, 1990], Aggregate crushing value [BS 812, Part 112, 1990], Aggregate Impact Value [BS 812, Part 110, 1990], Elongation Index; Flakiness Index; in accordance with [BS EN 933-2/3, 1997]. It was found to be suitable for use according to relevant standard testing methods [Table 3.1].

b) **Tests on Fine Aggregate** - Fine aggregate was tested for Specific Gravity Test [ASTM C128, 2000] and Water Absorption test in accordance with [BS 812, Part 3, 1990] and it met the standard requirements [Table 3.3].

c) **Tests on Crumb Rubber** - The crumb rubber powder was tested for the maximum specific gravity and maximum density. The maximum density of the crumb rubber was determined using the hydrostatic procedure with pycnometer outlined in [ASTM C128, 2015]. The material was found suitable for use [Table 3.4].

d) **Tests on Bitumen** - To assess the quality of bitumen, the following tests were conducted: Penetration at 25 ^{0}C [ASTM D5-97, 2005], Penetration Index [ASTM D5-97, 2005], Flash point [ASTM D92-02, 2005], Fire point [ASTM D92-02, 2005], Softening point [ASTM D36-95, 2006], Specific gravity [36- ASTM D2042, 2015], and Ductility [ASTM D117, 2007]. It was found suitable for use [Tables 3.5 and 3.6].

e) **Tests on Ordinary Portland Cement** - Filler (Dangote Portland Cement) were subjected to the following tests: Initial setting time [BS EN 196,-3, 1995], Final setting time [BS EN 196-3, 1995], Soundness test [BS EN 196-3, 1995], and Specific gravity test [ASTM C188, 2017]. It is expected that more than 75% of the material passes through sieve 0.075 mm sieve [ASTM C177, 2017]. It equally satisfied the requirements of relevant standard testing methods [Table 3.8].

ii. Preparation of Unmodified and Modified Hot Mix Asphalt (HMA)

In accordance with [AASHTO T166, 2022], the samples were made utilizing the Marshal Design Procedure for asphalt concrete mixtures. As part of the procedures, several test specimens for various asphalt (bitumen) and crumb rubber contents were prepared. The experiments were conducted using bitumen content increments of 0.5 percent. For every set of bitumen and crumb rubber content employed, three replicate test samples were produced in order to deliver precise data.

In order to prepare the asphalt concrete samples, the aggregates were first cleaned and heated to 180 0C, which took around 5 minutes. For every specimen, a distinct aggregate sample was combined and then oven dried at 110±5°C to a constant weight. Table 3.2 contains the combined material mix, while Figure 4.5 shows the combined mix's gradation.

Modified asphalt binder mixes were prepared incorporating 3.5%, 4.0%, 4.5%, 5.0% and 5.5% bitumen and blended with crumb rubber of 0%, 1%, 2%, 3% and 4% of the asphalt by weight. An unmodified (0% crumb rubber) asphalt binder was also prepared for use as the control asphalt binder.

At a temperature of 150–160 °C, the asphalt binders and aggregates were measured and combined accordingly. The mixture was thoroughly mixed for a minimum of three minutes to achieve a homogenous mix. To make the modified asphalt binders, the heated asphalt was mixed with crumb rubber.
Using an oven, standard marshal cylindrical moulds with dimensions of 101.5 mm in diameter and 63.5 mm in height were heated to 135 ºC. With a spatula, a little grease was applied to the mould before the mixture was poured into it. Using a 6.5 kg rammer that fell freely from a height of 450 mm, each face of the hot mixture was manually compacted with 75 blows on both sides of the mould with a marshal hammer to simulate or reflect heavy traffic. Until the final sample was completed, this process was repeated. The compressed sample was tested for air voids, stability, flow, and the percentage of total voids filled with mineral aggregates and asphalt. The results obtained are shown in Tables 3.11a – 3.15a and Tables 3.11b – 3.15b.

- **Marshal Stability Test -** The Marshal stability test is used to calculate how quickly asphalt will deteriorate as a result of axle load. For every % of crumb rubber, three samples were made, and the average was taken. Results are contained in Tables 3.11b, 3.12b, 3.13b, 3.14b, 3.15b.
- **Determination of Bulk Specific Gravity and Unit Weight of Compacted Asphalt Mixtures -** In compliance with [Ashalt Institute, 1993], Method A, Bulk Specific Gravity of Compacted Bituminous Paving Mixtures, compacted samples were made for every % of crumb rubber to ascertain the specimen's bulk specific gravity [Gmb] using dry, saturated surface specimens. Three identical test samples were made for every set of modified asphalt content that was used.

A sample was dried to a constant mass and cooled to room temperature, then the dry mass was weighed to the nearest 0.1 g, and recorded as A.

(i) The sample was submerged or immersed in 77 ^{0}C ± 2 ^{0}F [25 ± 1 ^{0}C] water bath for 4 ± 1 minutes, then it was weighed and the submerged sample mass was recorded as C.

(ii) The saturated or immersed sample was removed from the water bath, it was quickly damp dried with a damp absorbent towel [Figure 3.5], weighed as quickly as possible, and the surface dry sample was recorded as B. Any water that seeps from the sample during the weighing operation is considered as part of the saturated sample/specimen. Results are shown in Tables 3.11a, 3.12a, 3.13a, 3.14a, 3.15a.

C Formulae:

The bulk specific gravity (Gmb) was calculated using the sample weights of A, B, and C:

i. $Gmb = \frac{A}{B-C}$……………………Eq. [1].

where;
A = Mass of dry specimen, B = Mass of the saturated surface dry (SSD) specimen, and C = Mass of submerged specimen in water

ii. $Gmm = \frac{Pmm}{\frac{ps}{Gse}+\frac{Pb}{Gb}}$………………Eq. [2].

Where;

Pmm = percent by mass of total loose mixture (100), Ps = aggregate content, percent by the total mass of mixture, Pb = asphalt content, percent by total mass of mixture, Gse = effective specific gravity of aggregate

Gb = specific gravity of asphalt, and Gmm = Theoretical maximum specific gravity of paving mixture (no air voids).

iii. Air voids (Va) = $(\frac{Gmm-Gmb}{Gmm})$ x 100 …………………………Eq. [3].

Where;
Gmm = Theoretical maximum specific gravity,
Gmm= Theoretical maximum specific gravity

iv. Voids filled with mineral aggregates [VMA] was calculated thus:

$100 - \frac{Gmb \; x \; Ps}{Gsb}$ x 100………………………………………………Eq. [4].

where;
Gsb = bulk specific gravity of total aggregate, Gmb = Bulk specific gravity, and

Ps = Aggregate content, percent by the total mass of mixture

v. Voids filled with asphalt (VFA) was calculated thus:100 x $\frac{VMA - Va}{VMA}$………Eq. [5].

where;
VMA = Voids filled with aggregates, Va = Air voids

III. RESULTS AND DISCUSSION

- **Result of Test on Coarse Aggregates -** The physical properties of the aggregate used in this study and its gradation curve from sieve analysis can be found in Table 3.1 and Figure 3.1. The aggregate has a specific gravity of 2.70%, flakiness index of 15.80%, elongation index of 18.50%, aggregate impact value of 18.86%, aggregate crushing value of 18.64%, and water absorption of 0.46%. Table 1 shows that the aggregate satisfied the recommended specification by ASTM and BS, therefore, it is suitable to be used to prepare Hot Mix Asphalt.

Table 3.1. Preliminary Test Values on Samples of Coarse Aggregates

Source of Collection	Specific Gravity (%)		Flakiness Index (%)		Elongation Index (%)		Aggregate Impact Value (%)		Aggregate Crushing Value (%)		Water absorption (%)	
	Code Limit	Test Result	Code Limit	Test Result	Code Limit	Test Result	Code Limit	Test Result	Code Limit	Test Result	Code Limit	Test Result
Zerberced Quarry Abuja	2.55 to 2.75	2.70	<35	15.80	<35	18.50	<25	18.86	<25	18.64	<2	0.46

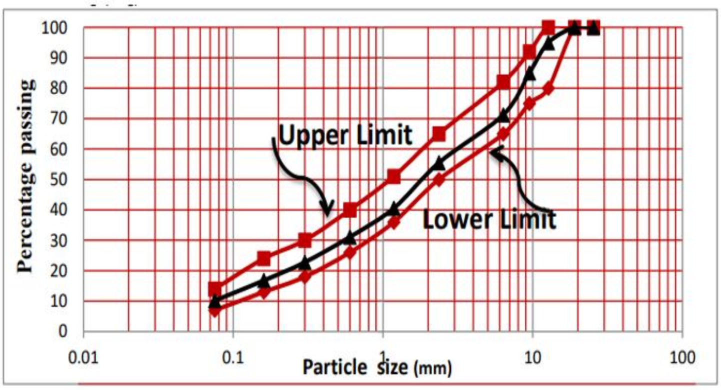

Fig. 3.1: Gradation of final aggregate mix [ASTM specification]

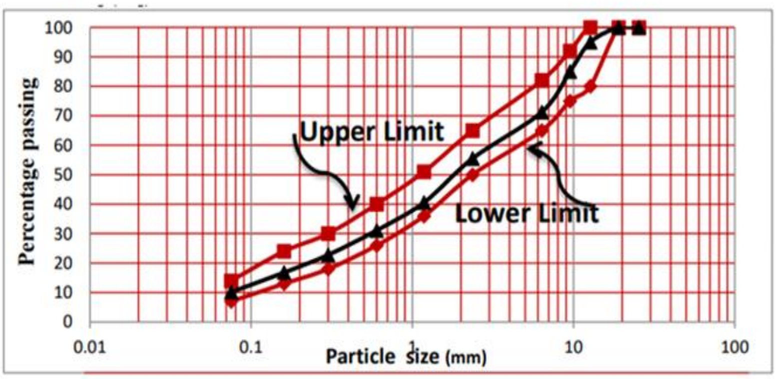

Fig. 3.2: Particle sieve analysis [combine material mix]

Results on Combined Aggregates Materials Sampling and Grading - The materials were sampled to meet the recommendations of [BS EN 933-1, 2012] and the particle size distribution was carried out meet the recommendations of [Asphalt Institute, 1997]. From the estimated proportions of materials – coarse aggregate was 53.3%, fine aggregate 40.2%, filler 6.5% the mix mineral materials were combined to be blended as found in Table 3.2. The results of the combined material mixes fall within the lower and upper limits recommended by [O'Flaherty, 2002], it is suitable for use for asphalt concrete.

Table 3.2.Combined Aggregates Material Mix (Coarse aggregate, fine aggregate, and cement

Sieve size (mm)	Percentage retained	Cumulative percentage retained	Cumulative percentage passing	Percent passing [46].
25.00	-	-	100	100
19.00	6.7	6.7	93.4	90-100
12.50	14.9	21.5	78.5	-
9.50	7.2	28.7	71.3	56-80
6.30	11.7	40.7	59.3	-
4.75	7.2	47.6	52.4	35-65
2.36	5.6	53.2	46.8	23-49
1.18	10.8	64.0	36.0	-
0.60	22.4	86.4	13.6	-
0.30	5.9	92.3	7.7	5-9
0.15	0.7	93.0	7.0	-
0.075	0.4	93.4	6.5	2-8
Pan	6.5	100.0	-	-

- **Result of Test on Fine Aggregate -** The physical properties of the fine aggregate and its gradation curve from sieve analysis can be found in Table 3.3. The fine aggregate has specific gravity of 2.69%, and water absorption of 8.60%. Table 3.3 shows that the fine aggregate satisfied the recommended specification of [ASTM C128, 2000] and [BS 812, Part 3, 1990] and therefore suitable to be to prepare Hot Mix Asphalt.

Table 3.3. Preliminary Test Values on Fine Aggregate

Test Conducted	Code used	Code Limits	Average Test Results
Specific gravity	[28]	2.55-2.75	2.69
Water absorption	[29]	≤15%	8.60

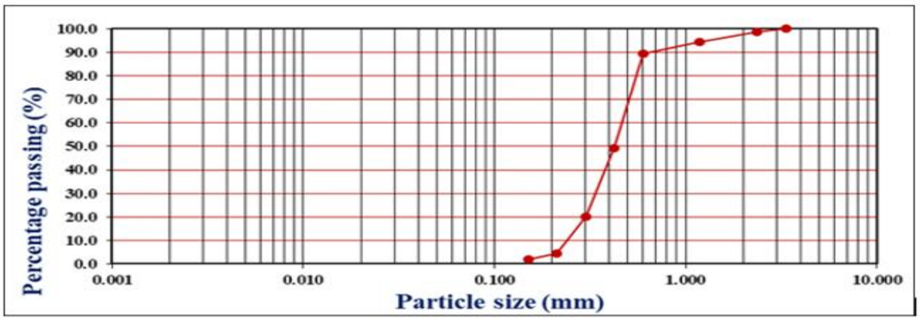

Fig. 3.3. Sieve analysis of river sand

- **Results of Test on Crumb Rubber -** The results in Table 3.4 shows that the bulk density crumb rubber is 302.5 kg/m^3, the maximum specific gravity is 1.12 kg/m3, the unit weight is 702 kg/m3, the moisture content is 0.52%, and the metal content is 0.42%. The results show that all the values fall within the range specified by the codes. It is therefore suitable as a modifier.

Table 3.**4.** Preliminary Test Values on Crumb Rubber

Test conducted	Code Limits	Average Test Results
Bulk density	260-460kg/m^3	302.5kg/m^3
Max. Specific gravity	1.15±0.05	1.12
Moisture content [%]	<0.75	0.52
Metal content [%]	<0.65	0.43

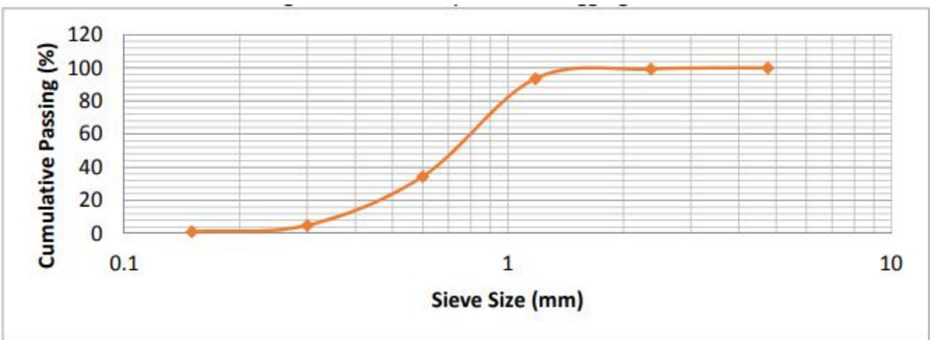

Fig. 3.4. Sieve analysis of crumb rubber

- **Result of Test on Bitumen -** The results in Table 3.5 shows the bitumen penetration is 66.70 ^{0}C. Results of other physical properties; softening point, flash point, fire point, ductility, specific gravity, and viscosity can also be found in Table 3.5, and results show that all the values fall within the range specified by the codes. Thus, the bitumen suitable to be used as a binder in hot mix asphalt. Results in Table 3.6 showed improved penetration index, with the addition of crumb rubber.This reduced the sensitivity of asphalt to temperature, and consequently increased the viscosity of the binder, thus, extending the temperature range of viscoelasticity.

Table 3.5. Preliminary Test Values on unmodified Bitumen 60/70

Test conducted	**Code Limits**	**Average Test Results**
Penetration at 25^{0}C	60-70	66-70
Penetration Index	-2 to +2	-0.61
Softening Point ^{0}C	46-56	49.10
Flash Point	Min. 233	295.20
Fire Point ^{0}C	Min. 232	306.50
Ductility at 25^{0}C	Min. 50	122.40
Specific gravity at 25^{0}C	0.97-1.06	1.04
Viscosity at 135^{0}C	Min. 320	358.00

Table 3.6. preliminary Test Values on Modified Bitumen 60/70 Grade

Test conducted	**Unit**	**Average Test Results**
Penetration rate at 25^{0}C	mm	61.5
Penetration index	-	-0.42
Softening point	^{0}C	51.80
Viscosity at 135^{0}C	Cst	425.00

Table 3.7 Penetration rate at 25 ^{0C} and softening points values for unmodified and modified bitumen 60/70 PG [Extract from Tables 4.5 and 4.6]

Parameter	Unmodified Bitumen	Modified Bitumen	Penetration Index
Penetration rate at 25^{0}C	66.70	61.50	-0.61
Softening point	49.10	51.80	-0.42

- **Result of Test on Cement -** The results in Table 3.8 shows the specific gravity of cement is 3.10, initial setting time is 68 minutes, the final setting time is 255 minutes, the soundness of the cement is 3.0 mm, and the % passing 0.075 mm sieve is 96. The results show that all the values fall within the range specified by the codes. Therefore, the cement is suitable to be used as a filler in hot mix asphalt.

Table 3.8. Test values of Ordinary Portland Cement

Test conducted	Results obtained	Code limits
Specific gravity [minutes]	3.10	3.15
Initial setting time [minutes]	68	Min. 45
Final setting time [minutes]	255	Max. 375
Soundness [mm]	3.0	10
% passing 0.075 mm sieve	96	>90

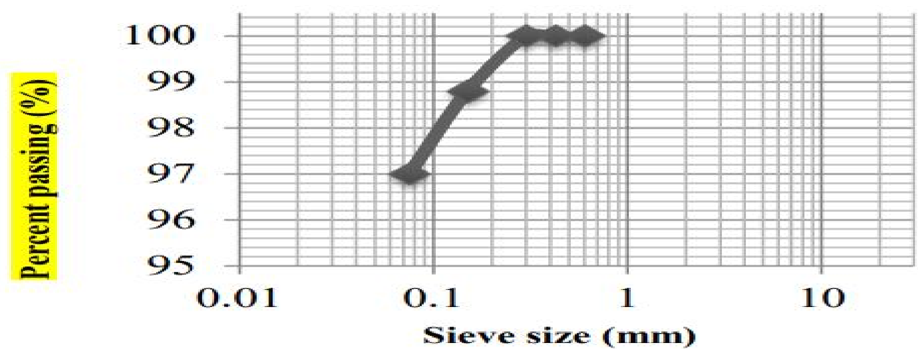

Fig. 3.6. Particle size distribution of cement

Table 3.9 Stabilisation of bitumen with 0% crumb rubber

CR %	Number of samples	% of Bitumen	Sample A	Sample B	Sample C	Gmm	Gmb	Va	VMA	VFA	Stability	Flow
0	3	3.5	1229.2	1229.8	720.1	2.53	2.42	5.60	12.30	60.51	6.72	3.41
	3	4.0	1228.0	1229.1	720.1	2.51	2.41	5.78	12.50	61.20	7.10	3.49
	3	4.5	1228.3	1229.7	720.2	2.49	2.41	4.20	12.62	61.34	7.51	3.56
	3	5.0	1229.2	1230.1	720.8	2.47	2.41	3.79	12.82	62.21	7.60	3.62
	3	5.5	1229.0	1230.2	720.6	2.45	2.41	3.53	13.40	62.89	7.73	3.81

Table 3.10 Stabilisation of bitumen with 1% crumb rubber.

CR %	Number of samples	% of Bitumen	Sample A	Sample B	Sample C	Gmm	Gmb	Va	VMA	VFA	Stability	Flow
1	3	3.5	1230.1	1230.8	723.4	2.52	2.42	5.40	12.77	61.92	7.01	3.39
	3	4.0	1230.0	1231.3	724.7	2.51	2.43	5.21	12.56	62.60	7.22	3.46
	3	4.5	1230.1	1231.0	724.7	2,49	2.43	3.58	13.02	64.49	7.31	3.61
	3	5.0	1228.6	1229.0	724.8	2.48	2.44	3.62	13.12	72.78	7.67	3.65
	3	5.5	1229.1	1230.3	724.9	2.46	2.43	3.32	13.90	75.22	8.25	3.71

Table 3.11 Stabilisation of bitumen with 2% crumb rubber

CR %	Number of samples	% of Bitumen	Sample A	Sample B	Sample C	Gmm	Gmb	Va	VMA	VFA	Stability	Flow
2	3	3.5	1227.1	1228.0	725.3	2.53	2.44	5.06	12.17	62.65	7.11	3.27
	3	4.0	1227.2	1228.3	725.1	2.51	2.44	4.79	11.73	68.07	7.39	3.31
	3	4.5	1227.8	1228.1	725.3	2.49	2.44	4.10	13.63	76.16	7.52	3.47
	3	5.0	1228.0	1228.8	725.1	2.47	2.44	3.41	13.09	87.76	8.51	3.56
	3	5.5	1228.2	1229.2	725.5	2.45	2.44	3.20	13.51	91.60	9.09	3.69

Table 3.12 Stabilization of bitumen with 3% crumb rubber

CR %	Number of samples	% of Bitumen	Sample A	Sample B	Sample C	Gmm	Gmb	Va	VMA	VFA	Stability	Flow
3	3	3.5	1228.1	1229.2	723.0	2.52	2.43	3.57	11.98	70.20	8.20	3.12
	3	4.0	1228.2	1229.1	725.8	2.51	2.45	2.40	11.71	79.50	8.80	3.26
	3	4.5	1231.2	1232.1	724.2	2.49	2.42	2.81	13.25	78.79	10.22	3.38
	3	5.0	1233.1	1234.0	724.7	2.47	2.43	1.62	13.34	87.86	11.35	3.46
	3	5.5	1229.2	1231.3	724.2	2.45	2.42	1.22	13.09	90.68	8.42	3.62

Table 3.13 Stabilisation of bitumen with 4% crumb rubber

CR %	Number of samples	% of Bitumen	Sample A	Sample B	Sample C	Gmm	Gmb	Va	VMA	VFA	Stability	Flow
4	3	3.5	1228.1	1231.5	724.0	2.52	2.42	3.57	12.91	67.75	7.88	3.08
	3	4.0	1231.1	1232.1	724.1	2.50	2.42	3.62	12.76	72.92	7.93	3.11
	3	4.5	1228.8	1230.4	724.3	2.49	2.43	3.51	12.66	81.26	8.15	3.18
	3	5.0	1227.4	1229.5	725.3	2.47	2.43	2.82	13.31	87.83	8.21	3.23
	3	5.5	1226.6	1227.1	725.4	2.45	2.44	2.38	13.41	94.94	8.52	3.58

- **Results of Test on Marshal Stability and Flow -** The maximum stability of the asphalt mix was 11.35 kN at 3% crumb rubber content, and the lowest stability was 7.01% at 1% crumb rubber content. The highest and lowest flow of the asphalt mix was at 1% and 4% crumb rubber content.
- **Results of Test Air Voids Content -** From Tables 3.11 -3.15, the air voids content decreased with increase in bitumen or asphalt content, which was as a result of more voids percentage being filled with bitumen in the mix. Air voids content of 1-3% is recommended for railways [Rose et al., 2011]. However, 3% air voids content was used in this study.
- **Results of Tests on Voids in Mineral Aggregates [VMA] -** In this study, voids in the mineral aggregate [VMA] in Tables 3.11-3.15, decreased as the bitumen or asphalt content increased, because of lesser inter-granular voids existing between the aggregate particles in the compacted mixture, such as the air voids and the effective bitumen or asphalt content.
- **Results of Tests on Voids Filled with Asphalt [VFA]** Tables 3.11-3.15, is the percentage of the inter-gran void space between the aggregate particles [VMA] that filled with bitumen or asphalt [AASHTO T209]. The VFA% increased as bitumen or asphalt content increased as the bitumen or asphalt content increased, because more effective bitumen or asphalt was already available in the mix to fill available voids existing between the intergranular spaces.

III. CONCLUSION

The results of this study show that:

- Tests conducted on the constituent materials fulfilled the ASTM and BS specifications, thus, can be used in hot mix asphalt production.
- The penetration index, PI of original bitumen which is 0.61 and the penetration index, PI of modified bitumen with 3% crumb rubber is 0.42. Thus, the PI of modified bitumen is less than PI of unmodified one, which means that crumb rubber modification has the potential to reduce temperature susceptibility of bitumen.
- The outcomes of the laboratory tests showed that bitumen mixed with crumb rubber demonstrated a high level of resistance to rutting and permanent deformation. Test results for penetration, ductility, viscosity, flash and fire points, and softening points indicate that the material became more resistant to temperature variations. Bitumen treated with crumb rubber will have a

greater softening point and be more resistant to rutting and pavement deformation than bitumen that contains no crumb rubber. Additionally, using crumb rubber to modify bitumen that could help in removing waste tyres from the society, thus, improving environmental protection.

Moreover, the asphaltic mixture's marshal stability was enhanced by the addition of crumb rubber to bitumen. Since stability is an indicator of a bituminous mixture's capacity to withstand deformation caused by applied loads. it could therefore be concluded that crumb rubber modified asphaltic mixtures possess the capability to withstand such distortions. This study recommends the use of crumb rubber with 3% optimum content.

Acknowledgement
This research was funded by the Tertiary Education Trust Fund, Nigeria.

REFERENCES

AASHTO T166 [2022]. AASHTO T166. Standard method of test for bulk specific gravity.

AASHTO T209. Standard method o test for the determination of maximum specific gravity [GMA] and density of uncompacted aphalt mixtures.

Asphalt Institute, Lexington, KY. Asphalt Institute, [1990]. Asphalt Mix Design and Modelling.

Asphalt Institute, [1993]. Mix Design Methods for Asphalt Concrete of Particle.

Asphalt Institute, [1997]. Mix Design Methods for Asphalt, Manual Series No. 2 [MS-02].

ASTM C188 [2017]. ASTM C188, (2017). Standard Test Method for Density of Hydraulic Cement.

ASTM C177 [2017]. Standard Test Method for Materials Finer than 75-um [No. 200] Sieve in Mineral Aggregates by Washing, ASTM International, West Coshoshocken, PA, USA.

Size Distribution, Sieving Method, British Standard Institution, United Kingdom.

ASTM C128, [2001]. Standard Test Method for Density, Relative Density, Specific Gravity, and Absorption of Fine Aggregate, ASTM International, West Coshoshocken, PA, USA.

ASTM C128 [2015]. Standard Test Method for Relative Density, Water Absorption of Fine Aggregates, Maximum Specific Gravity of Cement.

ASTM D5-97 [2005]. Standard Test Method for Penetration of Bituminous Materials, West Coshoshocken, PA, USA.

ASTM D92-02 [2005]. Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester, West Coshoshocken, ASTM International, Phildelphia, PA, USA.

ASTM D36-95 [2006]. Standard Test Method for Softening Point of Bitumen [Ring and Ball Apparatus], ASTM International, West Coshoshocken, PA, USA.

ASTM D2042 [2015]. Standard Test Method for Solubility of Bituminous Materials, West Coshoshocken, PA, USA.

ASTM D113 [2007]. Standard Test Method for Ductility of Bituminous Materials, West Coshoshocken, PA, USA.

Behnood A. (2019). Application of crumb rubber to improve the rheological and mechanical properties of asphalt binders and mixtures: a review. J. Clean. Prod., 231, pp. 171-182.

BS 812, Part 3, [1990]. The Standard for Testing Aggregates – Methods for Determination of Ten Percent Fine Values. British Standard Institution.

BS EN 932-1 (2003): Tests for General Properties of Aggregates, Part 1.

BS EN 933-1 [2012]. Tests for Geometrical Properties of Aggregates, Determination

BS 812, Part 2 [1995]. Methods for Determination of Denssity, Water Absorption, British Standard Institution, London, United Kingdom.

BS 812, Part 112, [1990]. Methods for Determination of Aggregate Impact Value [AIV], British Standard Institution, London, United Kingdom.

BS 812, Part 110, [1990]. Methods for Determination of Aggregate Crushing Value [ACV], British Standard Institution, London, United Kingdom.

BS EN 933-2/3, [1997]. Standard Test Method for determination of Geometrical Properties of Coarse Aggregates (Particle shape, Elongation Index and Flakiness Index).

BS EN 196-3 [1995]. Methods of Testing Cement – Part 3: Determination of Setting Times, Soundness, British Standard Institution, London, United Kingdom.

da Silva,S.R, Cimadon, F.N, Borges, P.M, Schiavon, J.Z, Possan, E, de Oliveira Andrade, J.J. (2022). Relationship between the mechanical properties and carbonation of concretes with construction and demolition waste. Constr. Mater. 16.

Faramarzi, M, Lee, K.W., Kim, Y, Kwon, S. (2018). A case study on a cement treated RAP containing asphalt emulsion and acryl polymer. Const. Mater., 16

Li,,W, Han, S, Han, X, Yao, Y. (2021). Experimental and numerical analysis of mechanical properties of geocell reinforced reclaimed construction waste composite base layer. Constr. Build. Mater., 304 (2021), Li-Ping, G, Miao, W, Cong,D, Li-Juan, C. (2020). Effect of incorporating reclaimed asphalt pavement on macroscopic and microstructural properties of high ductility cementitious composites. Constr. Build. Mater., 260 (2020),

Marques, J.A, Lopes, J.G, and Correia, J.R. [2011]. "Durability of the adhesion between bituminous coatings and self-protection mineral granules of waterproofing membranes," Construction and Building Materials, vol. 25, no. 1, pp. 138–144. https://doi.org/10.1016/j.-conbuildmat.2010.06.047.

Nandal, M, Mor, N, Sood, H. (2021). An Overview of Use of Artificial Neural Network in Sustainable Transport Systemm Eng, Springer, Singapore, Singapore (2021), pp. 83-91

0'Flaherty, C. [2002]. 'Highway, The Location, Design, Construction, and Maintenance of Road Pavements' 4th Ed. Jordan Hill-Butterworth-Heinemann, Oxford, UK. ISBN 13: 9780750650908.

Rose, J.G, Teixeira, P.F, Ridgway, E, and Nithin, D. [2010]. "Utilization of Asphalt/Bituminous Layers and Coatings in Railway Tackbeds–A Compendium of International Applications". Prepared for the 2010 Joint Rail Conference, Urbana, IL, USA. DOI:10.1115/JRC2010-36146.

Wong C.C, and Wong, W.G. [2007]. "Effect of crumb rubber modifiers on high temperature susceptibility of wearing course mixtures," Construction and Building Materials, vol. 21, no. 8, pp. 1741–1745. https:doi.org/10.1007/978 981-15-1193-6-5.