Effect of Crumb Rubber Size on Asphalt Concrete Properties Using Marshall Test

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***Abstract*— In this research, 60/70 penetration grade bitumen was modified by adding crumb rubber to partially replace 12.5mm and 9.5mm aggregate sizes in 2%, 4%, 6%, 8%, and 10% of the aggregate content weight determined by Marshall Method following the dry process. The results of the density, stability, flow, voids in the total mix, voids filled bitumen, and void in the mixed aggregate from the modified samples and control sample were compared and analyzed. Values of properties of the conventional asphalt concrete (bulk density 2.36kN/mm, VTM 3.8%, VMA 18.1%, VFB 79.2%, stability 9.1kN and flow 4.2mm) and crumb rubber modified asphalt concrete (bulk density 2.35kN/mm, VTM 3.7%, VMA 18.0%, VFB 79.4%, stability 3.9kN and flow 4.0mm) at the optimum crumb rubber content are close except for the stability of conventional asphalt concrete which is higher. Still, the crumb rubber-modified asphalt concrete has a better flow value, and the stability is within the Nigeria specification for roads and bridges.**

Keywords*— *Asphalt concrete, Crumb rubber, Flow, Stability, Marshall test

I. Introduction

Compared with other modes of transportation, road transport is cost-effective, easily accessible, affordable, and flexible. Road transport is dependent on access to all other modes of transport. Commuters need road transportation for their day-to-day activities, to travel to their places of work or study, to transport their products, and for inter-city and intra-city travel. Nigeria's roads are in disrepair due to a lack of maintenance, poor drainage systems, inadequate pavement design, rapid urbanization, and overpopulation. Therefore, it is urgent to research how to improve pavement performance through additives, as the need for pavement improvement in Nigeria is paramount. Asphalt concrete pavements have a short life cycle, failing mainly due to temperature changes, traffic loading, and aging. Modified asphalt mixtures provide the technology to produce a bituminous binder with improved viscoelastic properties that remain balanced over a more comprehensive temperature range and loading conditions [1]. Recycling solid industrial wastes such as waste rubber tires will solve the global environmental problem and act as a promising modifier for improving the engineering characteristics of the asphalt pavement material [2].

Waste rubber tires represent a severe environmental concern on several fronts. Toxins released from tire decomposition, incineration, or accidental fires can pollute the water, air, and soil. Tires can collect water and become a breeding ground for mosquitoes and other pests, increasing the risk for vector-borne diseases such as encephalitis. Rodents may also find habitat in tires [3].

The number of vehicles on the highway has significantly increased, and better management of waste rubber tires is needed. Disposing of non-biodegradable rubber tires is more complicated.

Introducing crumb rubber to asphalt concrete may reduce hardening due to oxidation aging and increase mass loss [4]. The bitumen's penetration value and softening point improve significantly when asphalt concrete is modified with crumb rubber using the wet process [5]. Asphalt concrete modified with crumb rubber has improved resistance to deformation at high temperatures (stability) [6]. A comparative study of the laboratory and field performance of several applications of crumb-rubber modified (CRM) hot-mix asphalt was performed in Louisiana. The result of the study indicated that the conventional mixtures performed better in the laboratory. In contrast, the CRM asphalt mixture performed better regarding rut depth, fatigue cracks, and International Roughness Index (IRI) numbers than the corresponding control sections after five to seven years of traffic [7].

Asphalt concrete is modified with crumb rubber using two standard methods called the wet process, where rubber particles are mixed with asphalt at an elevated temperature before mixing with the hot aggregates, and the dry process, where rubber particles replace a small portion of the mineral aggregate in the asphalt mix before the addition of the asphalt [2]. Most research investigating crumb rubber in asphalt concrete employs the wet processing technique [1] [8] [9] [10].

More research is needed on crumb rubber-modified asphalt concrete using the dry method. A research gap exists regarding using the dry method for incorporating crumb rubber into asphalt concrete mixtures commonly used in Nigeria. This study proposes an investigation into the effects of crumb rubber on such mixtures using the Marshall Mix Design methodology. The research will partially replace aggregate sizes 12.5 mm and 9.5 mm with crumb rubber in the dry process to evaluate its impact on the performance characteristics of the asphalt concrete.

Successful utilization of crumb rubber in asphalt will not only optimize the asphalt mixture but also help put waste tires to good use, thereby solving the problem that may arise from disposal and creating job opportunities [6].

II. Materials

A. Aggregates

The sizes of the aggregates used in this study are for pavement construction in Nigeria. The aggregates were from Kopek Construction Company in Ekiti State, Nigeria. Table I, Fig. 1, and Table II provide the sizes gradation curves and physical properties of the aggregate used in this study.

The sieve analysis results in Fig. 1 show that the gradation curve is between the maximum and minimum recommended values specified by specifications for roads and bridges [11].

B. Bitumen

This study used 60/70 penetration grade bitumen because it is mainly used in Nigeria. The bitumen was sourced from Kopek Construction Company in Ekiti State, Nigeria. Table III summarizes the physical properties measured for the bitumen used in this study. The results indicate that all properties conform to the specifications recommended by Specifications for Roads and Bridges [11].

C. Crumb Rubber

The crumb rubber used for this study was produced from waste tires obtained from a local vulcanizer in Ado Ekiti, Ekiti State, Nigeria. Crumb rubber from two size ranges, 12.5mm and 9.5mm, was used as a modifier at 2%, 4%, 6%, 8%, and 10% by total aggregate weight.

TABLE I. Sizes of Aggregates used

Aggregate type	Aggregates size (mm)
Coarse	12.5 (1/2 inch) 9.5 (3/8 inch)
Fine	Stone dust River sand
Filler	Non-plastic mineral material passing through a sieve size of 0.075μm

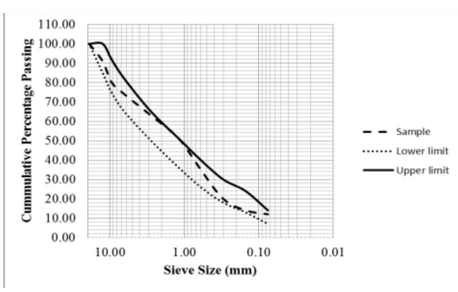

Fig. 1. *FMW Nigeria gradation curves limits and aggregates mixture gradation curve*

TABLE II. Properties of aggregate used Sizes of Aggregates used

Test	BS/FMWN Designation	Test Result	Specification limits
Crushing Value (%)	Cl. 6371	16.7	<30
Impact Value (%)	812-112	1.5	<30
Flakiness Index (%)	Cl. 6371	29.2	<35

TABLE III. Physical Properties of Bitumen used.

Test	Unit	FMWN Designation	Test Result	Specification Range
Specific Gravity	g/cm^3	Cl. 6371	1.02	1.01- 1.06
Softening Point	ºC	Cl. 6371	52	48-56
Penetration	0.1mm	Cl. 6371	66.3	60-70

III. Method

Using the Marshall Stability test, this study found that the optimum bitumen content (OBC) in regular asphalt concrete without crumb rubber was 6.2%. Therefore, a bitumen content of 6.2% by aggregate weight was used for all specimens regardless of the amount of crumb rubber added to the asphalt concrete mix. Table IV shows the properties of the control sample. Marshall Stability test procedure was used to prepare test specimens. A total of 20 crumb rubber-modified specimens were prepared. Two specimens of each crumb rubber-modified mixture were tested.

In preparation of the specimens, 3000 g of the dry aggregates (mix composition) were measured as shown in Tables V and VI and mixed thoroughly. The aggregates were placed in a pan and heated in an oven at 1350C for 2 hours. The optimum bitumen content (OBC) with properties as stated in Table IV was determined and used by the weight of the total mix. The aggregates and each percentage of crumb rubber were mixed in a pan for a few minutes, and the required amount of bitumen was added to it and thoroughly mixed until the aggregates were fully coated. The mix was placed in a mould and compacted by a hammer with 75 blows on either side. It was repeated for all the percentages of the crumb rubber. The bulk densities of the samples were determined by weighing them in air and water. The samples were immersed in a water bath at 60℃ for 30 minutes and placed in a Marshall stability testing machine. The Marshall stability value (maximum load carried in kg before failure) and the flow value (the deformation the sample underwent during loading up to the maximum load in 0.25mm units) were noted. The following results were determined: bulk specific gravity (Gb), percentage void of volume filled with bitumen (VFB), percentage void in mineral aggregate (VMA), stability, and flow. Also, the void and density were analyzed.

TABLE IV. Control HMA properties

Test	Test Result	FMWN range	
		Min	Max
Optimum Bitumen Content (%)	6.2	5.0	8.0
Stability (KN)	9.19	3.5	
Flow (mm)	4.2	2.0	4.0
Void in total Mixture (VTM) (%)	3.8	3.0	5.0
Void filled with Bitumen (VFB) (%)	79.2	75	82

TABLE V. Mix Composition for 12.5mm aggregate replacement

Materials	Specimens Control (%)	1 (%)	2(%)	3(%)	4(%)	5(%)
12.5mm	17	15	13	11	9	7
9.5mm	15	15	15	15	15	15
River sand	28	28	28	28	28	28
Quarry Dust	30	30	30	30	30	30
Filler	10	10	10	10	10	10
Crumb Rubber	0	2	4	6	8	10
60/70 Bitumen (% of total mix)	6.2	6.2	6.2	6.2	6.2	6.2

TABLE VI. Mix Composition for 9.5mm aggregate replacement

Materials	Specimens Control (%)	1 (%)	2(%)	3(%)	4(%)	5(%)
12.5mm	17	17	17	17	17	17
9.5mm	15	13	11	9	7	5
River sand	28	28	28	28	28	28
Quarry Dust	30	30	30	30	30	30
Filler	10	10	10	10	10	10
Crumb Rubber	0	2	4	6	8	10
60/70 Bitumen (% of total mix)	6.2	6.2	6.2	6.2	6.2	6.2

IV. Results and Discussions

The result analysis gives samples with crumb rubber as partial replacement of aggregate sizes 12.5mm and 9.5mm that met the specifications for roads and bridges [11] for Marshall Stability, flow, void in the total mix (VTM), and the void-filled with bitumen (VFB).

1) Marshall Stability: The effect of crumb rubber as a partial replacement for aggregate size 12.5mm on the stability of hot mix asphalt (HMA) is in Fig. 2.; the stability of the mixes increased with crumb rubber content to a maximum value of 4.8 KN at 10.0% crumb rubber content. The stability value for samples 3, 4, and 5 (6%, 8%, and 10%) content of crumb rubber used meets specifications for roads and bridges [11] thus making crumb rubber partial replacement of 12.5mm aggregate size at these percentages in HMA recommended in asphalt concrete while in size 9.5mm, the stability is in Fig. 3., it increased with crumb rubber content to maximum value of 6.2 KN at 10.0% crumb rubber content. The stability value for samples 3, 4, and 5 (6%, 8%, and 10%) content of crumb rubber used meets specifications for roads and bridges [11], thus making crumb rubber a partial replacement of 9.5mm aggregate size at these percentages in HMA recommendable in asphalt concrete.

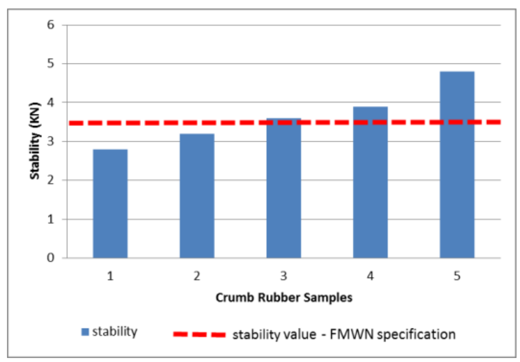

Fig. 2. *Marshall Stability of crumb rubber partially replacing 12.5mm aggregate size.*

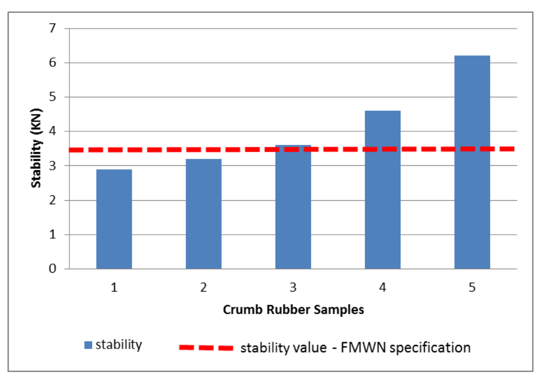

Fig. 3. *Marshall Stability of crumb rubber partially replacing 9.5mm aggregate size.*

2) Flow: Fig. 4 and 5 show the relationship between HMA and crumb rubber flow values as partial replacement of 12.5mm and 9.5mm aggregate sizes, respectively. Flow values of samples 1, 2, 3, and 4 (2%, 4%, 6%, and 8%, respectively) in Fig. IV are within the specification given by specifications for roads and bridges [11], while flow values of samples 1, 2, 3 and 4 (2%, 4%, 6% and 8% respectively) in Fig. 5, are within the specifications for roads and bridges [11].

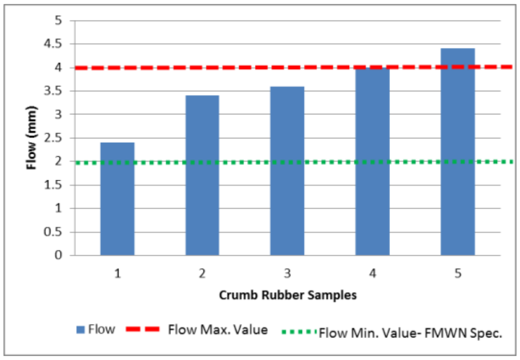

Fig. 4. *Flow result of Crumb rubber partially replacing 12.5mm aggregate size*

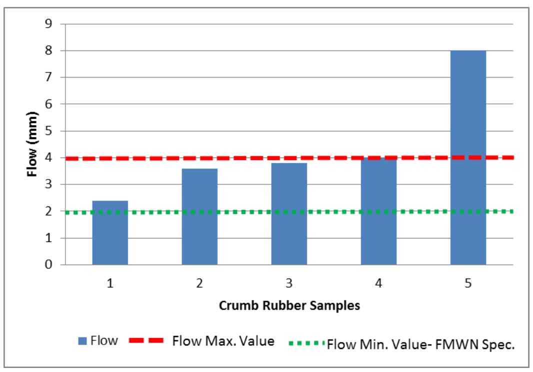

Fig. 5. *Flow result of Crumb rubber partially replacing 9.5mm aggregate size*

3) Void in Total Mix (VTM): According to Fig. 6 and 7, which show the relationship between the Void in Total Mix (VTM) of the mix with crumb rubber partially replacing 12.5mm and 9.5mm aggregate sizes, samples 3, 4, and 5 (i.e., 6%, 8%, and 10%). Furthermore, samples 1 and 2 (i.e., 2% and 4%) are within specifications for roads and bridges [11].

4) Void filled with Bitumen (VFB): The relationship between the percentage of crumb rubber used to replace 12.5mm aggregate size partially and the void filled with bitumen (VFB) in Fig. 8 shows that samples 3, 4, and 5 (6%, 8%, and 10%) are within specification [11], while the relationship between the percentage of crumb rubber used to replace 9.5mm aggregate size partially and the void filled with bitumen (VFB) in Fig. 9 shows that samples 1 and 2 (2% and 4%) are within specification [11].

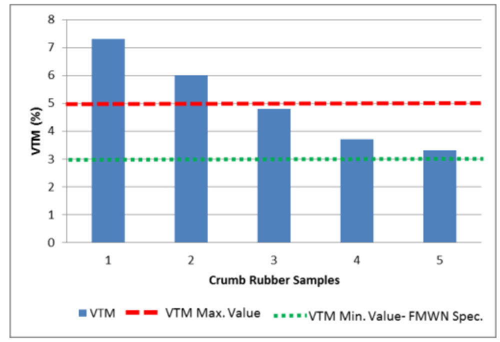

Fig. 6. *VTM of crumb rubber partially replacing 12.5mm aggregate size*

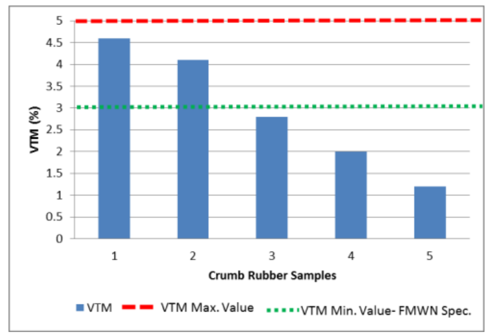

Fig. 7. *VTM of crumb rubber partially replacing 9.5mm aggregate size.*

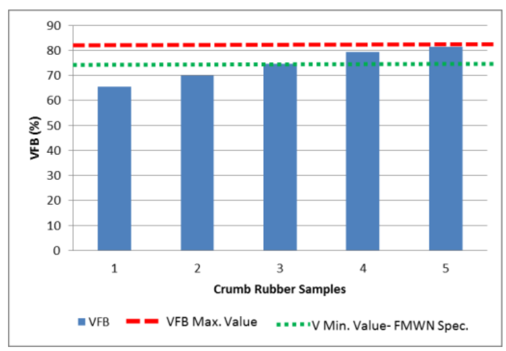

Fig. 8. *VFB of crumb rubber partially replacing 12.5mm aggregate size*

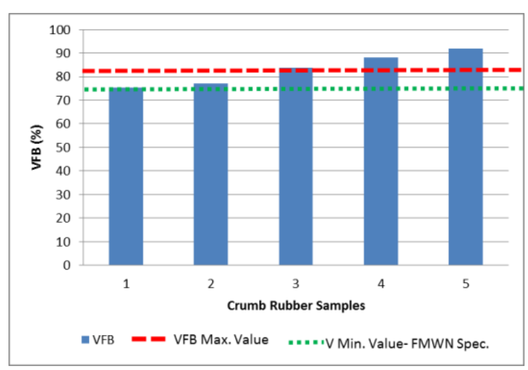

Fig. 9. *VFB of crumb rubber partially replacing 9.5mm aggregate size.*

V. Conclusion

This study performed a series of laboratory tests to investigate the feasibility of using crumb rubber as a partial replacement for coarse aggregate in HMA production. The following conclusions are from the study. Crumb rubber with an aggregate size of 12.5 mm at 8% can partially replace coarse aggregate in HMA production. Values of properties of conventional HMA (bulk density 2.36KN/mm, VTM 3.8%, VMA 18.1%, VFB 79.2%, stability 9.1KN and flow 4.2mm) and crumb rubber modified HMA (bulk density 2.35KN/mm, VTM 3.7%, VMA 18.0%, VFB 79.4%, stability 3.9kN and flow 4.0mm) at the optimum crumb rubber content, which is at 8% of crumb rubber partially replacing aggregate size 12.5mm, are close except for the stability of conventional HMA which is higher. However, the crumb rubber-modified HMA has a better flow value, and its stability is also within specification by the Nigerian specifications for roads and bridges [11].

Acknowledgment

We want to acknowledge God, who made it possible to carry out this research successfully, and everyone who contributed to making it a reality.

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