The Journal of Applied Sciences Research

Journal homepage: http://www.journals.wsrpublishing.com/index.php/tjasr

Online ISSN: 2383-2215 Print ISSN:2423-4400

Original Article

Performance Evaluation of Different Particle Sizes of Crumb Rubber to Modify Bitumen for Flexible Pavement

Apeh Ocholi Adejoh Samuel

Department of Civil Engineering, The Federal Polytechnic Idah, Kogi State, Nigeria

ABSTRACT

There are so much of waste tyres in Nigeria and disposal is not done properly. The wastes are usually burnt in the open space leading to environmental pollution. It is a very cheap commodity that can be used to modify bitumen in order to minimize the damage of pavement caused by increase in service traffic density, axle loading. The main aim of this study is to investigate the experimental performance of the bitumen modified with 10% by weight of crumb rubber varying its sizes. Marshall Stability Method was adopted for the mix design. Laboratory tests were performed on the modified bitumen using various sizes of crumb rubber and they were analysed. Four different categories of size of crumb rubber will be used, which are coarse (1 mm - 600 µm); medium size (600 µm - 300 µm); fine (300 µm150 µm); and superfine (150 µm - 75 µm). It was found that utilisation of waste tyres in highway construction can also reduce the frequency and cost of maintenance, this is very important for countries such as Nigeria with poor maintenance culture, the use of crumb rubber prolongs pavement life, driving comfort, the rheology of Crumb Rubber Modified Bitumen depends on crumb rubber quantity, particle size, type, bitumen composition, the mixing time, temperature, source and also the mixing process, either dry process or wet process. The researcher concludes that the best size of crumb rubber particle size for bitumen modification to obtain best results is the fine (0.3µm – 0.15µm).

Keywords: Bitumen, Crumb rubber Modified bitumen (CRMB), Marshall Stability Method, Flexible Pavement, Nigeria

INTRODUCTION

NIGERIAN ROAD TRANSPORT INFRASTRUCTURE

Road is an important infrastructure in a nation or community of people. It greatly affects the economy of any nation (Osuolale *et al.*, 2017). Roads must be properly designed and constructed. After construction, they need to be maintained to ensure that the objective of

ARTICLE INFO
Corresponding Author: Apeh Ocholi Adejoh Samuel <engrsamapeh@gmail.com>
How to Cite this Article: Samuel, A.O.A. (2020). Performance Evaluation of Different Particle Sizes of Crumb Rubber to Modify Bitumen for Flexible Pavement. *The Journal of Applied Sciences Research*, 7(1), 24-31.

Article History: Received: 2020-05-26 Accepted: 2020-07-01

safety, strength and durability are met. Failures on Nigerian roads, major and minor, had become a normal thing to the Nigerian populace. Road failure leads to accidents on Nigerian roads (Okigbo, 2009). Many newly constructed and rehabilitated roads in the country do not last long enough before failure. Roads are built to provide safe passage of vehicles and must be properly designed and constructed. After construction, there arise need for appropriate maintenance for the road to attain its design life and to ensure that the objectives of safety, strength and durability are met. The rate at which roads deteriorates in service ranges from the quality of materials used, workmanship standard and to the quality of design and supervision during the road construction (FERMA, 2013).

Nigeria has about 200,000 km of roads spread all over the country, these roads are made up of over 32,000 km of federal roads spread over the thirty-six states and the federal capital, over 30,000 km of state roads and over 130,000 km of local government roads". Within the states, the local government roads are further classified into urban and rural roads. According to ownership, Nigerian roads are classified into federal, state, and local government roads, (The Guardian, 2018). Federal roads are divided into federal trunk 'A' roads and the federal trunk 'F' roads. The federal trunk 'A' roads are those under the federal government ownership and they are developed and maintained by the federal government while the federal trunk 'F' roads are those that were formerly under the state ownership but were taken over by the federal government with a view to upgrading them to federal highway standards. State roads are classified as the state trunk 'B' roads and are under the ownership and management of the various state governments. Local roads classified as the local government trunk 'C' roads and are the roads under the ownership and management of the local governments in the country. These roads are divided into the urban, rural and village access roads (Heitzman, 1992 & The Guardian, 2018).

Nigeria's transport infrastructure stock is inadequate for the size of the economy and constitutes a major cost and constraint for both large and small businesses. It lags behind its peers in terms of scale (i.e., road and rail density) and quality (Thisday Live, 2017). Nigeria can only boast of 22km of roads per every 100,000 km^2; compared with India, South Africa, and Kenya which have 158km, 62km, and 28km respectively of roads per 100,000 km^2. For the rail subsector, Nigeria until recently had only 4km of rail per every 1,000 square km compared to India, South Africa, and Kenya, which have 23km, 17km, and 6km respectively of rails per 1,000 km^2. With more than 90% of freight and passengers carried by the roads, Nigeria's road network is highly overused, leading to rapid deterioration. The railways, which catered for about 60%, freight movement at independence, now account for less than 1% land transportation in the country. The country's transport problem is exacerbated by the near total lack of maintenance of the road network at all tiers of Government (Federal, State, and Local Government) (Adams and Adetoro, 2013).

OWNERSHIP STRUCTURE OF NIGERIAN ROAD NETWORKS

LITERATURE REVIEW

Pavement is the structural materials laid down on an area in order to sustain vehicular or foot traffic, such as a road or walkway and its structure normally consists of a few layered materials arranged from the topmost (surfacing) in the order of strength to ensure adequate stability under traffic loads (Aisien, & Anyata, 2003).

Distresses in asphalt pavements are major service problems of roads as the main source of cause of accident in developing countries including Nigeria (Nwofor & Eme, 2010). Increasing vehicular traffic volume and high axle loading increased the economic woes and lack of return on investment as pavement fails to reach the design life and yield returns on investments (Nwofor & Eme, 2010), In Nigeria, corrupt practices where contractors and government officials connive to inflate contract costs, and still go ahead to deliver substandard jobs also contribute to rapid failure of road infrastructures. Researchers, governments and road agencies have been challenged to improve, strengthen and increase pavement life to yield good service quality and durability requirement (Ye and Wu, 2010). According to (Nwofor & Eme, 2010), pavement distresses such as fatigue cracking, rutting etc. and poor performance have led to increased use of polymer reinforcement (crumb rubber) for bituminous mixtures.

Researchers have been using polymers in asphalt mixes to improve both laboratory and field performance properties of asphalt. Polymer asphalt were known to mitigate traffic distresses and impart upon service life and durability of asphalt pavement.

An estimated eight hundred and fifty thousand (850,000) scrap tyres are generated in Nigeria and these wastes are not properly disposed, resulting in serious environmental problems, (Abdelaziz *et al.*, 2005). The use of scrap tyre rubber into asphalt concrete production as a modifier has the potential to solve this waste problem, because they could be used in the production of construction materials, especially in transportation infrastructures (Otuoze *et al.*, 2014). The use of scrap tyre-rubber as an additive for asphalt concrete has been developing for over thirty years, even though, it might increase the cost of construction, but the overall benefits far outweighs that, especially on some highways with peculiar problems (Otuoze *et al.*, 2014) (Figure 1 & 2).

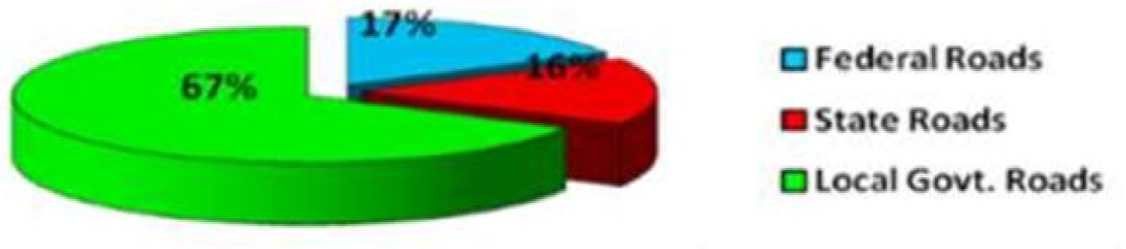

Figure 1: Ownership structure of Nigerian Road Networks (FERMA, 2013 & Ogundipe, 2008)

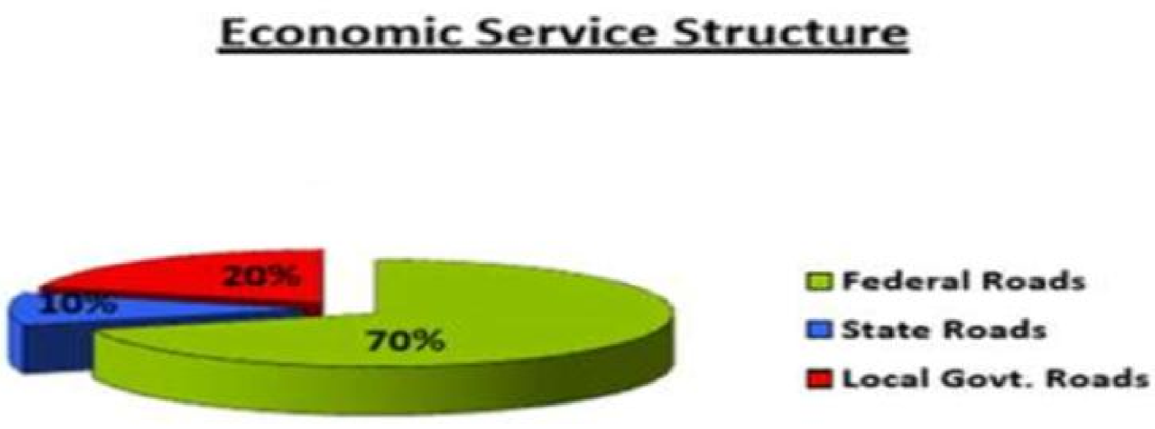

Figure 2: Economic service structure of Nigerian Road Network (FERMA, 2013 & Ogundipe, 2008)

MATERIALS AND METHOD

SAMPLE COLLECTION

The aggregates were collected from Avookee Quarry in Lokoja, Kogi State, Nigeria. This source was chosen because of its proximity to Idah. The aggregates supplied consisted of 25 mm – 6.30 mm granite chippings and quarry sand. The scrap tyres used in this research were collected from a scrap tyre dump at Idah, Nigeria. These tyres were cleaned through washing with water and then dried. The clean tyres were shredded into sections freed from steel breeds and later the sections were cut into small pieces with aid of knives and hacksaw. Dangote cement produced at Obajana in Kogi state was used as filler. The shredded tyres were also grinded using electric grinding machine which reduced them into rubber particles of sizes (1 mm - 600 µm); medium size (600 µm - 300 µm); fine (300 µm150 µm); and superfine (150 µm - 75 µm). The bitumen used in this research was collected from the building material market at Kuje, Abuja, Nigeria.

Mixing Of Crumb Rubber With Plain Bitumen

In the process of preparing the modified binders, about 500 g of the bitumen was heated to fluid condition in a 1.5 litre capacity metal container. Before crumb rubber partices was blended with bitumen, bitumen was heated to a temperature of 165 °C and then crumb rubber was added. For each mixture sample 10% of crumb rubber by weight of four different sizes were added, i.e., coarse (1 mm - 600 µm); medium size (600 µm - 300 µm); fine (300 µm-150 µm); and superfine (150 µm - 75 µm). The blend was mixed manually for about 3-4 minutes. And the mixture was then heated to 165 °C. The whole mass was stirred gradually using a mechanical stirrer for about 55 minutes. Extra care was taken to ensure that the temperature between 160 °C to 170 °C was maintained throughout the process of blending. The modified bitumen is cooled to room temperature and suitably stored for testing.

PREPARATION OF BITUMINOUS MIX BY THE WET PROCESS

Three specimens of Marshall Moulds and one loose mix (uncompacted) were prepared for each size of crumb rubber. Aggregates were oven dried and sieved according to BS gradation and separated. The amount of each size of fraction required to produce a mixed aggregate of 1200gm as per gradation was weighed. Bitumen and aggregate was heated separately to 160 °C and 150 °C respectively. Then bitumen was poured into aggregate. Then the mixture was stirred until a uniform coating was obtained on aggregate. Extra care was taken to ensure the temperature at which mixture was heated together did not exceed maintained 170 °C. The specimens mould and compaction hammer were thoroughly cleaned and the mould assembly was heated in hot air oven to a temperature about 160 °C. A little grease was rubbed on the mould before the mix was placed in the mould using spatula. Seventy five 75 blows were applied on both sides of the mould manually. The specimen was extracted after 24 hours.

TESTS ON BITUMEN

The tests were conducted according to relevant recommendations of code standards for the 60/70 penetration bitumen and they all met the requirements of good control of quality of bitumen used (Table 1).

PRELIMINARY TESTS ON MINERAL AGGREGATES

Table 2 shows aggregate quality control and their recommended respective codes.

Consistency Tests On Cement Filler

The tests were found to have satisfied the quality of cement filler, which implied that it will have influence on density and bond enhancement. That means that it will improve the stability of asphalt and the overall strength (Table 3).

Aggregate Material Sampling, Grading, Proportioning And Blending

Aggregate materials were sampled according to the recommendation of BS EN932-1 (2003) and particle size distribution was done according to BS EN 933-1 (2003). The passing sieve diameter (PSD) for coarse, fine aggregates and cement filler are shown in the table below (Table 4).

The results obtained showed that combined aggregate falls within aggregate envelope safe zone formed by standard specification range. They could be good enough for aggregate parking and interlocking.

Table 1: Test values of Bitumen Sample

Test Concluded	ASTM Code	Code values	Test values
Penetration at 25° C, 0.1 MM	ASTM D5-97	60-70	67.9
Penetration Index (PI)	-	-2 to +2	-0.336
Softening point (°C)	ASTM D36-95	46-56	50.3
Flash point (Cleveland open cup)(°C)	ASTM D92-02	Min. 232	294.2
Fire point (Cleveland cup)(°C)	ASTM D92-02	Min. 232	305.8
Ductility at 25° C (cm)	ASTM D113	Min. 50	123.5
Specific gravity at 25° C (g/cc)	ASTM D70	0.97-1.02	1.028
Solubility in trichloroethylene (%)	ASTM D2042	Min. 99	99.09

Table 2: Preliminary Test Values of Aggregate materials

Test conducted	Code used	Code Limits	Test Result
Aggregate Crushing Value (%)	BS 812 Part 112	Max. 25	23.4
Aggregate Impact Value (%)	BS 612 Part 111	Max. 25	17.2
Aggregate Los Angeles Abrasion Value (%)	ASTM C131	Max. 30	19.8
Specific Gravity (Coarse Aggregate) (Gc) (g/cc)	ASTM C127	2.55-2.75	2.70
Aggregate Moisture Absorption (%)	BS 812 Part 2	Max. 2	1.3
Coarse Aggregate Flakiness Index	BS 812 Part 105	<35	27.2
Specific Gravity (Fine Aggregate) (Gf) (g/cc)	ASTM C128	2.55-2.75	2.68
Specific Gravity of Mix Aggregates (Gsb) (g/cc)	ASTM C127	-	2.72

Table 3: Preliminary Test Values of Cement Filler

Test Conducted	Code used	Code Limit	Result obtained
Specific gravity	ASTM C188	3.15	3.16
Initial setting time (minutes)	BS EN 196 Part 3	Min. 45	97.8
Final setting time (minutes)	BS EN 196 Part 3	Max. 375	232
Soundness (mm)	BS EN 196 Part 3	Max. 10	3.5

Table 4: Combined Aggregate Mix and Range of Specification Requirements

Sieve Size (mm)	Percentage Retained	Cummulative Percentage Retained	Cummulative Percentage Passing	Percent Passing (ASTM D3515)
25.00	-	-	100	100
19.00	2.7	2.7	97.3	95-100
12.50	9.7	12.4	87.6	82-92
9.50	9.2	21.5	78.5	73-86
6.30	12.7	34.3	65.7	-
4.75	10.3	44.7	55.3	49-67
2.36	10.9	55.4	44.6	33-53
1.18	12.0	67.6	32.4	-
0.60	10.0	77.5	22.5	14-36
0.30	7.7	86.2	13.8	11-28
0.15	6.2	91.6	8.4	-
0.075	2.1	92.5	7.5	6-11
Pan	6.5	100	-	-

Marshal Stability Test

Marshall Test experimental plan and specimen preparation. Asphalt Institute (1994) recommendations were used to prepare specimens weighing 1200g weight, 101.5mm diameter and 63.5mm height compacted with 75 hammer blows on each side to simulate heavy traffic situation of greater than 106 ESALs. The specimens are kept immersed in water in a thermostatically controlled water bath at 600C for 30 to 40 minutes and then transferred within 30 seconds to the Marshall Test head and tested for both Marshall Stability and flow. The volumetric tests carried out are VMA, and VFB. ASTM D3203-94 was used to estimate Void in the Mix (VIM). ASTM D1559 (2004) was used to determine the stability and flow of specimens (Table 5).

Table 5: Marshal tests results on plain bitumen

Bitumen content %	Unit wt.	Stability Kg	Flow mm	Air voids %	VMA %	VFB %
4.0	2.36	1219.19	2.59	6.34	17.16	62.64
4.5	2.44	1291.50	3.17	5.56	16.86	67.24
5.0	2.39	1369.51	3.58	4.49	16.78	73.42
5.5	2.37	1210.43	4.19	3.88	17.96	78.28
6.0	2.35	997.60	5.24	3.97	18.91	79.13

Determination Of Optimum Bitumen Content (OBC)

The bitumen content corresponding to 4% air voids was taken as Optimum Bitumen Content (OBC). The Optimum Bitumen Content (OBC) of 5.33% was obtained by plotting a graph of Bitumen Content Vs Air Voids. With that OBC the Marshall tests were repeated for the Crumb Rubber Modified Bituminous Mixes prepared using four different sizes of crumb rubber as stated earlier. And the results were analysed and compared to identify the best size of crumb rubber to be used for the modification of bitumen (Figure 3).

Using Optimum Bituminous Content (OBC) of 5.33% as obtained in Figure 3; three Crumb Rubber Modified Bituminous Marshall Samples and One Loose Mix (uncompacted) are prepared taking 5.33% by weight of modified bitumen. Then Marshall Stability tests and density void analysis tests are performed as mentioned earlier for the plain bitumen and the results are tabulated as below (Table 6).

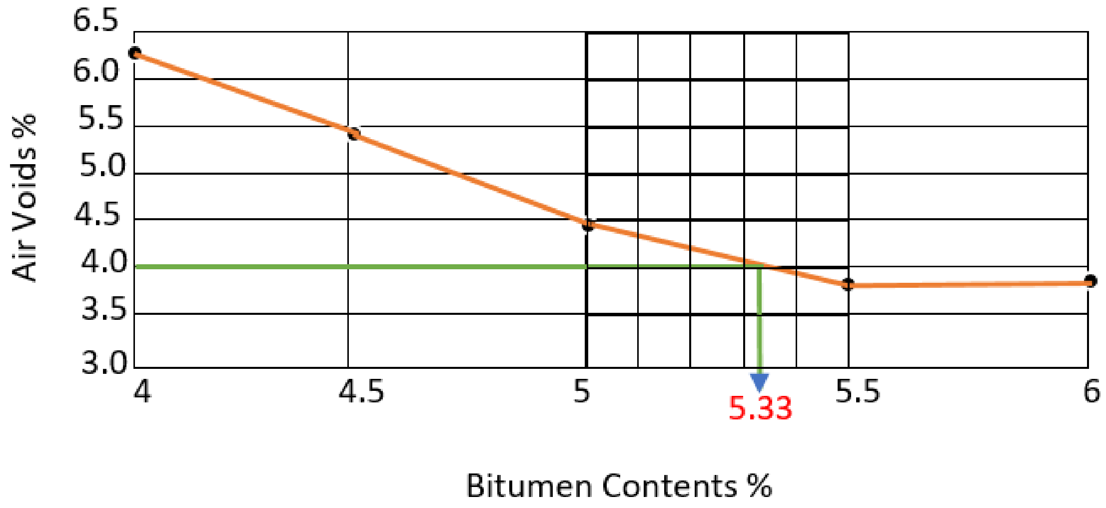

Figure 3: Bitumen Content Vs Air Voids

Table 6. Marshal Stability Tests on Crumb Rubber Modified Bituminous Mix

Crumb Rubber Size	Unit weight	Stability Kg	Flow mm	Air Voids %	VMA %	VFB %
1-0.6	2.29	1318.23	3.78	4.57	18.66	80.86
0.6-0.3	2.26	1515.78	4.26	3.97	19.65	76.51
0.3-1.5	2.36	1587.74	3.36	4.86	16.82	71.10
0.15-0.075	2.32	1233.46	4.92	2.35	17.84	86.87

CONCLUSIONS

Looking critically at the results of laboratory tests on plain bitumen and crumb rubber modified bitumen, it is clear that the penetration values and other parameters of plain bitumen were improved significantly by modifying it with addition of crumb rubber which is a major environment pollutant. From the table 4 it can be observed that the sample prepared using crumb rubber size (0.3-0.15mm) gave the highest stability value of 1587.74 kg, minimum flow value of 3.36 mm, maximum unit weight of 2.36, maximum air voids of 4.86%, minimum VMA of 16.82 % and minimum VFB of 71.10% values. Therefore, the researcher concludes that the best size to be used for crumb rubber modification is (0.3-0.15mm) size for commercial production of CRMB.

REFERENCES

Adams, J.O. and Adetoro A.E. 2013. Analysis of Road Pavement Failure caused by soil properties along Ado Ekiti - Akure Road. *Nigeria International Journal of Novel Research in Engineering and Applied Sciences* (IJNREAS), 1 (1).

Aisien, F.A. & Anyata, B.U. 2004. Comparative study of the effect of conditioning environment on the mechanical properties of asphaltic concrete. *Nigerian Journal of Industrial and Systems Studies*, 1, 12-17

Federal Roads Maintenance Agency (FERMA). (2013). Current state of Nigerian Road Networks, Nigeria

Heitzman, M. 1992. An overview of design and construction of asphalt paving material with crumb rubber additives. Proceedings of Transportation Research Board, Washington D.C., pp. 2-7.

Mahrez, A., Karim, M.R. and bt Katman, H.Y., 2005. Fatigue and deformation properties of glass fiber reinforced bituminous mixes. *Journal of the Eastern Asia Society for Transportation Studies*, *6*, pp.997-1007

Nwofor, T.C. & Eme, D.B. 2010. Stability of concrete work with partial substitute of rice husk ash (RHA) for cement in Nigeria. J*ournal of Chemical, Mechanical and Engineering Practice*, 1(2&3), pp.42-47.

Ogundipe O.M. 2008. Roads pavement failure caused by poor soil properties along AramokoIlesha Highway, Nigeria. *Journal of engineering and applied sciences*; 3(3), 239-241.

Okigbo, N. 2009. Road maintenance in Nigeria, the way forward. *International journal of research in engineering science*. *Pan African journal series, Accra, Ghana.*

Osuolale, O. M., Oseni, A. A. and Sanni, I.A. 2017. Investigation of Highway Pavement Failure along Ibadan - Iseyin Road, Oyo State, Nigeria. International.

Otuoze H.S., Shuaibu A. A., Ahmed, H.A., Garba, A., Yusuf, O.K. 2014. Binding properties of poly-vinyl chloride thermoplastic waste modified bitumen for flexible pavement mix. Proceedings of 2014 Nigeria Engineering Conference, Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria, 502 – 512.

The Guardian . 2018. State of Nigeria’s Roads’ The Guardian November 8, http://guardian.ng/opinion/state-ofnigerias-roads/ (accessed on 15/12/18).

Thisday Live . 2017. The Rush Hour? Hour Gridlock at Lekki Toll Plaza’. Thisday Live, April 15, http://www.thisdaylive.com/articles/the-rush-hour-gridlock-at-lekki-tollplaza/113749/ (accessed on 29/6/2017).

Ye, Q., & Wu, S. 2009. Rheological properties of fibre reinforced asphalt binders. Indian Journal of Engineering and Material Sciences, 16, 93-99.