Performance and Microstructural Evaluation of Asphalt Concrete Produced with Hydrated Lime, Glass Powder and Cement Modifiers

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ABSTRACT: The increasing axle load arising from the growth in vehicular volume reduces the durability of road pavement, hence the need to further strengthen the road pavement. This research focuses on the determination of the performance of asphalt concrete in relation to the microstructural characteristics of the asphaltic concrete produced with hydrated lime, glass powder and ordinary Portland cement as modifiers. Asphalt Concrete (AC) mixes were prepared with Dangote 3X cement (D3C), Lafarge Superset cement (LSC), hydrated lime (HL) and glass powder (GP) in varying proportions of 20, 40, 60, 80 and 100%. The stability and morphology of the asphalt concrete produced were determined using Marshall stability test and scanning electron microscopy respectively. AC containing GP and HL showed maximum stability of 3.61 kN and 4.01 kN respectively. The maximum stability values obtained for the samples containing D3C and LSC as fillers are 4.21 kN and 5.10 kN respectively; these stability values meet the minimum Marshall Design criteria of the Asphalt Institute. The microstructural analysis of the asphalt concrete samples showed that GP has the lowest maximum pore value of 4.39 µm2 in which the inter-particulate spaces in the AC produced with GP are small and the agglomeration of the particles indicated that they are densely packed and are characterized with good strength.

KEYWORDS: Flexible Pavement, microstructural characteristics, fillers, asphalt concrete, bitumen

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I. INTRODUCTION

Hot-mix asphalt (HMA) contains aggregates of different sizes, binders (bitumen) and air voids. The aggregates act as a skeletal structure, bitumen provides adhesion of aggregate particles and contributes viscoelastic properties to the mixture (Read and Whiteoak, 2003). Aggregates larger than 2.36 mm are coarse aggregate, whereas those smaller than this are fine aggregates (TRB, 2011). Filler is a very fine powder used in the bituminous mix that significantly affects the performance of HMA. Playing a dual role in the mix, it fills the gaps between mineral aggregates and due to its fineness, it is mixed with bitumen forming a high-consistency bituminous mastic. This resulting mastic can affect the physical and mechanical properties of the mixture to a large extent (Mistry et al., 2018).

Glass powder (GP) is obtained from crushing and pulverizing waste glass to sizes that can pass through a 0.075 µmm sieve. In Nigeria, waste glass is generated by bottling, pharmaceutical, wine, breweries, cosmetics companies, market women, etc. Record has it that, 232 tonnes of waste glass powder were generated in Lagos alone in 2008 (Nzeadibe and Iwuoha, 2008). A study conducted at Bayero University Kano puts the estimate of glass waste generated in Nigeria at approximately 8.7% of the total wastes generated in Nigeria (Iriruaga, 2014). Glass wastes are not bio-degradable and, they are hazardous when they litter the environment. The need for safe disposal and the search for utility for unwanted glasses cannot be overemphasized, to stimulate a reduction of health risks and create an alternative way to convert this waste from the glass industry to beneficial use (Iriruaga, 2014). Hydrated lime, also known as calcium hydroxide ($Ca(OH)_2$) and traditionally called slaked lime is an inorganic compound that has been extensively used in hot mix asphalt and has been known as an additive for asphalt mixtures from the very beginning (Lesueur, 1999). Furthermore, Portland cement is the most common type of cement worldwide as an essential ingredient for concrete, mortar, etc.

Researchers have explored waste glass, hydrated lime, Portland cement, sawdust, red mud etc., as fillers in the modification and characterization of hot mix asphalt. The mechanical behaviour of asphalt mastics produced using waste stone sawdust was investigated by (Al-Khateeb et al., 2018), use of rice husk ash and fly ash as alternative fillers in hot-mix asphalt; experimental application of waste glass powder filler in recycled dense-graded asphalt mixtures (Simone et al., 2017), waste materials and by-products as mineral fillers in asphalt mixtures (Tarbay et al., 2018), the effect of retreated coal wastes as filler on the performance of asphalt mastics and mixtures (Xu et al., 2019), experimental study on rheological properties and moisture susceptibility of asphalt mastic containing red mud waste as a filler substitute (Zhang, et al., 2019). Findings from these researches have shown that these alternative fillers demonstrated higher

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resistance to fatigue, better rutting behaviour, reduced moisture sensitivity and stripping, improved stiffening of the asphalt binder and HMA, improved resistance to fracture at low temperatures, alters oxidation kinetics and interacts with products of oxidation to reduce their deleterious effect.

In Nigeria, asphalt is commonly produced with aggregate (fine and coarse), fillers (mineral or synthetic aggregate finer than 75 μm) and binder. The demand for the flexible pavement with improved performance and durability necessitated the search for sustainable and alternative materials. Therefore, this research focused on determining the performance of asphalt concrete in relation to the microstructural characteristics of the asphaltic concrete produced with hydrated lime, glass powder and ordinary Portland cement as non-conventional modifiers.

Portland cement as non-conventional modifiers.

II. MATERIALS AND METHODS

A. *Materials*

The materials used for this research were carefully selected to be of the highest grade and meet the minimum requirement for asphalt production. 60/70 penetration grade bitumen was obtained from ASCA, Warri in Delta State of Nigeria, the aggregate used was obtained from Zibo Quarry, Akure, Nigeria. Fillers used are stone dust (SD), Dangote 3X cement (D3C), Lafarge Supaset cement (LSC), hydrated lime (HL) and glass powder (GP). Figure 1 contains hydrated lime (HL), glass powder (GP), Dangote 3X cement (D3C) and Lafarge Supaset cement (LSC).

Figure 1: (a) Hydrated Lime (b) Glass Powder (c) Dangote3 X Cement (d) Lafarge Supaset Cement.

B. *Sample Preparation*

Sixty-three (63) cylindrical asphaltic concrete (AC) samples were produced with fillers, coarse aggregate and fine aggregate in 5, 55, and 45% proportions of 1200 g total weight. Asphalt concrete samples were produced separately in 20, 40, 60, 80 and 100% by weight of the proportion of each of D3C, LSC, HL and GP. Thorough mixing and stirring of the aggregates were done while heating to a temperature range of 100 - 120 ºC. The AC samples were poured into a cylindrical mould of 105 mm diameter by 115.4 mm height with an extension collar. The cylindrical mould and asphaltic concrete samples are shown in Figure 2.

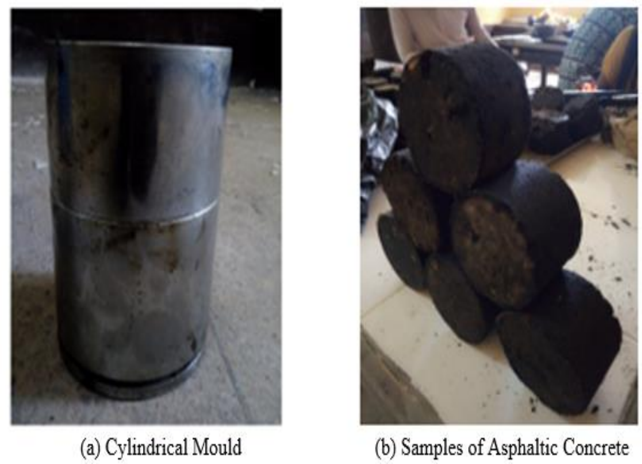

Figure 2: Cylindrical mould and asphaltic concrete samples.

A 4.54 kg rammer was used to compact the AC sample produced on the compaction pedestal, 50 blows were given to the sample on each side to ensure adequate compaction. The AC sample was carefully removed from the mould with the sample extruder.

C. *Method*

Tests were performed to relevant standards on the materials used to determine their properties and suitability in this research. Soundness Test (Le Chatelier's method) (BS EN 196-3:2016) and Fineness Test (BS EN 196-6:2018) were performed on cement to evaluate its properties. Penetration test (ASTM D5 / D5M-13), Ductility test (ASTM D113-17), Softening point test (ASTM D36 / D36M-14e1), Flash and fire point tests (ASTM D92-16b) and Water in bitumen test - Dean and Stark Method (ASTM D95-05) were performed on bitumen to determines its properties. The microstructural properties of the asphalt concrete produced with D3C, LSC, HL and GP was determined by performing Scanning Electron Microscopy (ASTM E986 - 04) while the strength properties of the asphalt concretes produced with D3C, LSC, HL and GP was determined by performing Marshall Stability Test (ASTM D6927-15).

III. RESULTS AND DISCUSSION

A. *Test on Aggregates*

1) *Soundness test*

The soundness test in Table 1 showed that the average soundness of the two types of cement used is 0.95 and 1.27 for D3C and LSC respectively. The two types of Portland cement namely D3C and LSC, have average soundness values of 0.95 mm and 1.27 mm respectively. However, the standard requirement is that the value must not exceed 10 mm as contained in British Standard specifications (BS EN 197-1:2011) for composition, specifications and conformity

Table 1: Soundness test.

Type of Cement	D3C			LSC		
Samples	**1**	**2**	**3**	**1**	**2**	**3**
Initial Diameter (mm)	30.00	30.00	30.00	30.00	30.00	30.00
Final Diameter (mm)	28.82	29.33	29.01	29.00	29.10	28.10
Soundness (mm)	1.18	0.67	0.99	1.00	0.90	1.90
Average Soundness (mm)		0.95			1.27	

criteria for common cements. The value obtained falls below the 10 mm maximum value; this is an indication that the amount of unburnt lime during cement manufacturing process is small which makes them suitable for use in AC production.

2) Fineness test

The result of the fineness test on the two types of cement (D3C and LSC) used is presented in Table 2.

Table 2: Fineness test.

Sample	D3C	LSC
Initial weight (g)	100g	100g
Final Weight (g)	98g	96g
Fineness (%)	2	4

The result showed that the two types of cement have fineness indices of 2% and 4% respectively. Cement should have fineness less than 5 % according to British Standard specifications (BS EN 197-1:2011) for cement; this implies that the cement is suitable for AC production since their respective fineness is within the specified maximum limit of 5%.

B. Result of Tests on Bitumen

1) Penetration test

The result of this test on bitumen is shown in Table 3.

Table 3: Penetration test.

Samples	A	B	C
Final Penetration (dmm)	70	80	69
Initial Penetration (dmm)	0	11	0
Penetration (dmm)	70	69	69

The average penetration value of bitumen is 69.33 (decimillimetre) dmm, confirming the grade of the bitumen used to be 60/70 penetration grade bitumen.

2)Flash and fire point test

The test is performed to determine the temperature at which a bituminous material will give a flash of fire and burns for a minimum of five (5) minutes. The result is shown in Table 4. The average flash point obtained from the test result is 287.7ºC; this is within the acceptable limit of the recommended range of 280^{O}C to 300ºC. In the same vein, the average fire point obtained is 316.7ºC. This value lies within the specified limit of 300ºC to 320ºC and it indicates that the bitumen can be used for the production of asphalt.

Table 4: Flash and fire point test.

Samples	A		B		C	
	Flash Point	**Fire Point**	**Flash Point**	**Fire point**	**Flash Point**	**Fire Point**
Final Temperature (^{O}C)	289	316	287	316	287	318
Initial Temperature (^{O}C)	0	0	0	0	0	0
Temperature (^{O}C)	289	316	287	316	287	318

C. Tests on Asphaltic Concrete

1) Marshall stability test

The flow and Marshall Stability values of moulded cylindrical AC samples are presented in Figures 3 and 4. The result indicated that when 100% SD was used as fillers, the stability value is 3.42 kN. The highest stability value of 5.10 kN was obtained at 100% replacement with LSC and the lowest value is obtained at 0% when SD was used as filler. The typical Marshall design criteria as required by the Asphalt Institute (1997) are contained in Table 5.

Table 5: The asphalt institute typical marshall design criteria.

Mix Criteria	Light Traffic (< 10^4 ESALs)		Medium Traffic (10^4 – 10^6 ESALs)		Heavy Traffic (> 10^6 ESALs)	
	Min.	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
Compaction (number of blows on each end of the sample)	35	-	50	-	75	-
Stability (minimum) (N)	2224	-	3336	-	6672	-
Flow (0.25 mm (0.01 inch))	8	20	8	18	8	16
Percent Air Voids %	3	5	3	5	3	5

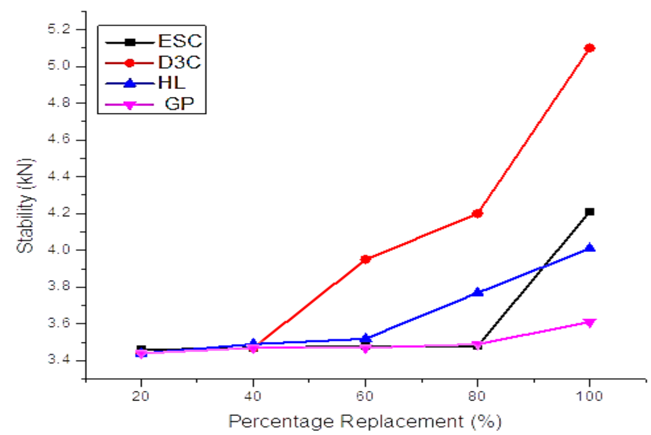

Figure 3: Stability of fillers used in AC.

The performance of other materials used as fillers showed relative stability values as clearly indicated in the graphical representation of the stability results for 20% and 40% partial replacements. At 60%, 80% and 100% partial replacements, LSC gave the highest stability values of 3.95 kN, 4.20 kN and 5.10 kN respectively. This is because of its fineness and soundness. However, in all circumstances, the stability values met the minimum criteria stipulated in Table of typical Marshall design criteria of the Asphalt Institute for light and medium traffic roads with $10^4 - 10^6$ estimated single axle loads (ESALs). The flow values for all partial replacements are shown in Figure 4. The values ranged between 3 – 18 mm. the fillers meet the minimum requirement of Asphalt Institute for use in AC.

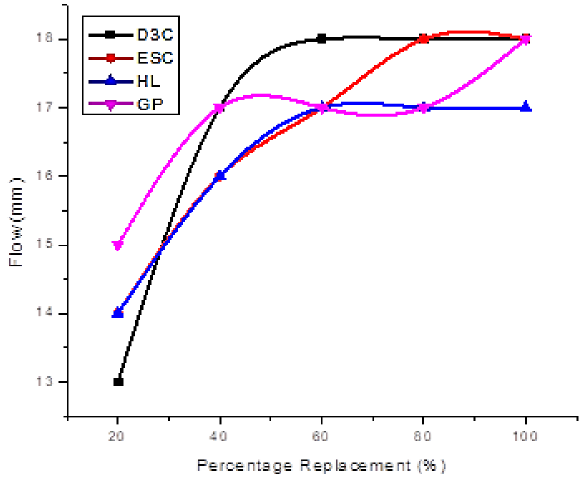

Figure 4: Flow graph of fillers used in AC.

2) The scanning electron microscope test

The Scanning Electron Microscope (SEM) test was performed on AC samples produced with different fillers (D3C, LSC, HL and GP) to determine their respective microstructural characteristics. Figures 5 to 8 obtained from SEM are monographs showing the AC produced with all the fillers' 500, 1000, and 1500 magnifications.

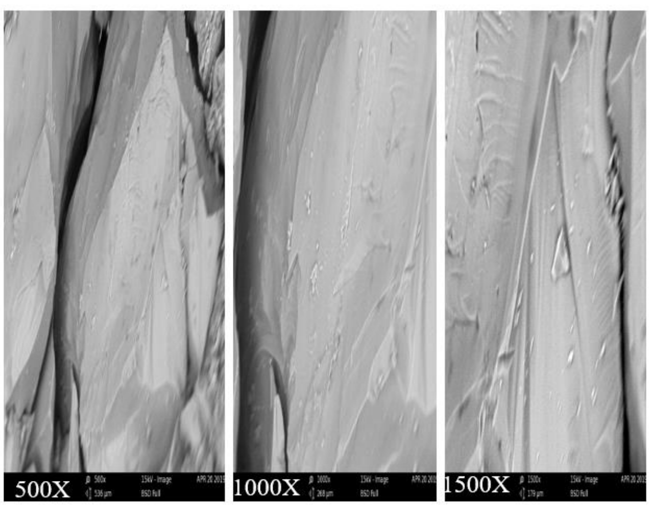

Figure 5: Monograph of AC produced with HL.

The SEM analysis of AC produced with HL and GP showed smooth and wavy profiles respectively, and the profile is characterized by close agglomeration of the particles. LSC and D3C fillers displayed a rough profile compared with that of the HL and GP. However, they are both characterized with a close agglomeration of particles with small porosity. The monographic details indicate that all the four fillers have their particles closely packed together. This is a confirmation of the agglomeration of the particles of the AC. The pore histograms obtained from the SEM analysis of the material are presented in Figures 9 to 12.

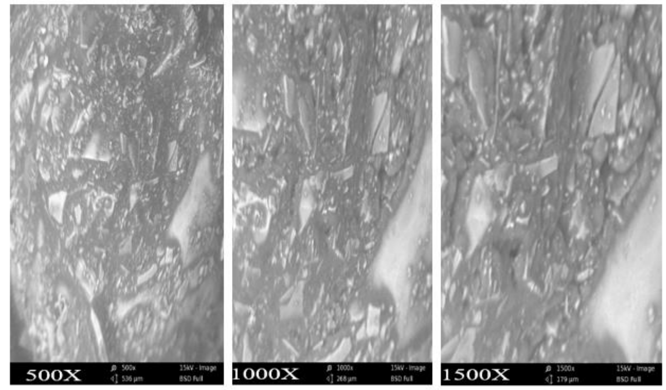

Figure 6: Monograph of AC produced with GP.

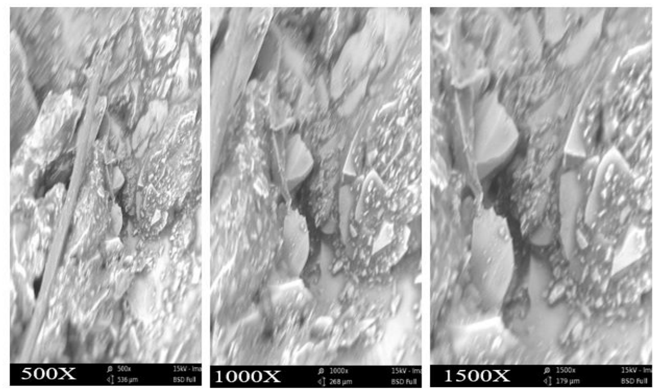

Figure. 7: Monograph of AC produced with LSC as filler.

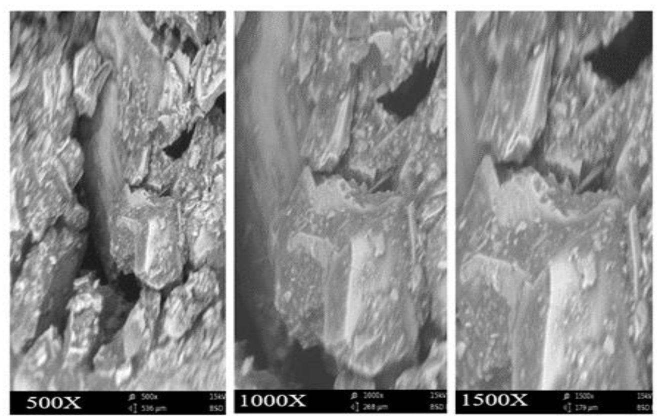

Figure 8: Monograph of AC produced with D3C as filler.

The pore histogram showed that HL has a minimum pore value of 1.65 µm^2, an intermediate value of 39.55 µm^2 and a maximum of 1259.42 µm^2. GP has a minimum pore value of 1.92 µm^2, an intermediate value of 2.83 µm^2 and a maximum value of 4.39 µm^2. Likewise, LSC cement has a minimum pore value of 1.65 µm^2, an intermediate value of 50.49 µm^2 and a maximum value of 4704.10 µm^2. D3C has a minimum pore value of 0.18 µm^2 and an intermediate value of 7.49 µm^2 and a maximum value of 269.38 µm^2.

In summary, GP has the lowest maximum pore value of 4.39 µm^2 which indicates small interparticle pore spaces within the AC produced with GP characterized with a close agglomeration and dense packing together of the particles of the asphalt produced with GP.

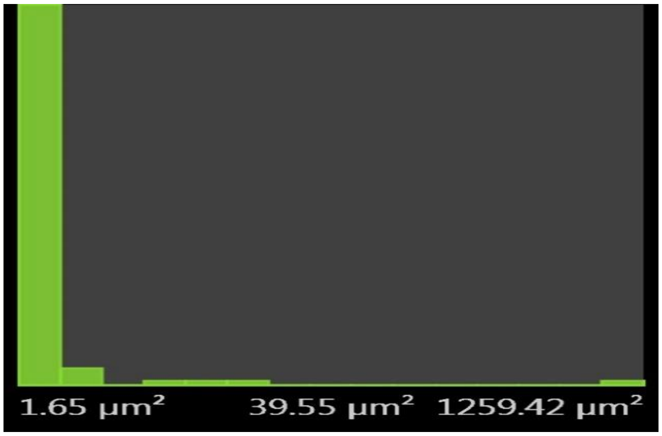

Figure 9: Pore Histogram of AC produced with HL.

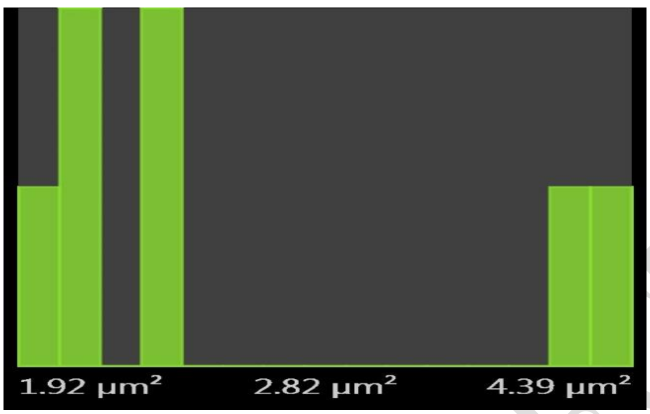

Figure 10: Pore Histogram of AC produced with GP.

Figure 11: Pore Histogram of AC produced with LSC.

IV. CONCLUSION

The AC containing D3C, LSC GP and HL fillers showed maximum stability values of 4.21 kN, 5.10 kN, 3.61 kN and 4.01 kN respectively. These Marshall Stability values meet the requirements of the Asphalt Institute and validates their suitability for use in production of asphalt concrete for the

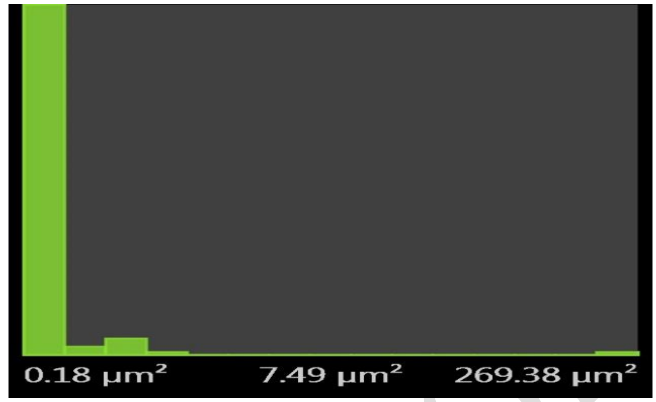

Figure 12: Pore Histogram of AC produced with D3C.

construction of medium traffic roads (10^4 – 10^6 ESALs) with minimum expected stability value of 3.33 kN. However, the stability values for AC with D3C and LSC which are Portland cements used as fillers are close. This is a demonstration and confirmation of the similarities between the two materials.

The monographic details obtained from SEM indicated that all the fillers used have similar fibre contents. The pore histogram showed that HL has a minimum pore value of 1.65 μm^2, an intermediate value of 39.55 μm^2 and a maximum value of 1259.42 μm^2. GP has a minimum pore value of 1.92μm^2, intermediate value of 2.82 μm^2 and a maximum value of 4.39 μm^2. LSC has a minimum pore value of 1.65 μm^2, an intermediate value of 50.49 μm^2 and a maximum value of 4704.10 μm^2. D3C has a minimum pore value of 0.18 μm^2, an intermediate value of 7.48 μm^2 and a maximum value of 269.38 μm^2. The sample with waste GP has the smallest pore space, which is of the best structural arrangement and strength. The fibre distribution of the fillers used in this research exhibit close structural arrangement and strength similarities.

REFERENCES

Al-Khateeb, G. G.; T. S. Khedaywi and M. F. Irfaeya. (2018). Mechanical Behavior of Asphalt Mastics Produced Using Waste Stone Sawdust. Advances in Materials Science and Engineering, 2018: 1 - 10.

ASTM D113 (2017). Standard Test Method for Ductility of Asphalt Materials. ASTM International, West Conshohocken, PA. www.astm.org.

ASTM D36 / D36M-14e1 (2014). Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus). ASTM International, West Conshohocken, PA, www.astm.org.

ASTM D5 / D5M (2013). Standard Test Method for Penetration of Bituminous Materials. ASTM International, West Conshohocken, PA, www.astm.org.

ASTM D6927 (2015). Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures. ASTM International, West Conshohocken, PA, www.astm.org.

ASTM D92 (2016). Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester. ASTM International, West Conshohocken, PA, www.astm.org.

ASTM D95 (2005). Standard Test Method for Water in Petroleum Products and Bituminous Materials by Distillation. ASTM International, West Conshohocken, PA, www.astm.org.

ASTM E986-04 (2017). Standard Practice for Scanning Electron Microscope Beam Size Characterization. ASTM International, West Conshohocken, PA, www.astm.org

BS EN 196-3 (2016). Methods of testing cement. Determination of setting times and soundness. British Standards Institution, 389 Chiswick High Road, London, www.bsigroup.com.

BS EN 196-6 (2018). Methods of testing cement: Determination of fineness. British Standards Institution, 389 Chiswick High Road, London, www.bsigroup.com

BS EN 197-1 (2011). Cement. Composition, specifications and conformity criteria for common cements. British Standards Institution, 389 Chiswick High Road, London, www.bsigroup.com

Iriruaga, E. T. (2014). Solid Waste Management in Nigeria. Available online at: http://www.d-waste.com/new-infographics/item/124-solid-waste-management-in-nigeria.html?start=1. Accessed on March 7, 2020.

Zhang, J.; C. Sun; P. Li; M. Liang; H. Jiang and Z. Yao. (2019). Experimental study on rheological properties and moisture susceptibility of asphalt mastic containing red mud waste as a filler substitute. Construction and Building Materials, 211: 159 –166.

Lesueur, D. and Little, D. N. (1999). Effect of hydrated lime on rheology, fracture and aging of bitumen. Transportation Research Record, 1661: 93 – 105.

Mistry, R.; S. Karmakar and T. Kumar Roy. (2018). Experimental evaluation of rice husk ash and fly ash as alternative fillers in hot-mix asphalt. Road Materials and Pavement Design, 1–12. Road Materials and Pavement Design, 20 (4): 979 – 990.

Nzeadibe, T. C. and Iwuoha, H. C. (2008). Informal Waste Recycling in Lagos, Nigeria. Communications in Waste and Resource Management, 9 (1): 24 - 30.

Xu, P.; Z. Chen; J. Cai; J. Pei; J. Gaa; J. Zhang and Z. Jialin. (2019). The effect of retreated coal wastes as filler on the performance of asphalt mastics and mixtures. Construction and Building Materials, 203: 9 -17.

Read, J. and Whiteoak, D. (2003). The shell bitumen handbook. London. Thomas Telford Publishing. ICE Publishing, Westminster, London.

Simone, A.; F. Mazzotta; S. Eskandarsefat; C. Sangiorgi; V. Vignali; C. Lantieri and G. Dondi. (2017). Experimental application of waste glass powder filler in recycled dense-graded asphalt mixtures. Road Materials and Pavement Design, 20 (3): 592 - 607.

Tarbay, E. W.; A. M. Azam and S. M. El-Badawy. (2018). Waste materials and by-products as mineral fillers in asphalt mixtures. Innovative Infrastructure Solutions, 4 (5): 1 - 13.

The Asphalt Institute (1997). Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types (MS-2). The Asphalt Institute, 6th Ed.

Transportation Research Board. (2011). A Manual for Design of Hot Mix Asphalt with Commentary (NCHRP Report 673, Final Report). Washington, DC: National Research Council.