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ORIGINAL RESEARCH ARTICLE

PROPERTIES OF ASPHALT CONCRETE CONTAINING WASTE FOUNDRY SAND (WFS) AS FILLER MATERIAL

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ABSTRACT

The high cost of primary construction materials such as cement, and increase in waste generation due to human activities coupled with environmental concerns has led to the incorporation of wide range of waste materials into asphalt concrete. Waste foundry sand (WFS) which is a by-product of ferrous and non-ferrous metal casting industry, has accumulated in stockpiles and landfills, occupying valuable space and causing nuisance in the environment. Consequently, it is imperative to devise a safe and economical solution to manage and utilize the waste. One way of achieving this is by recycling and using it for asphalt concrete production. This study investigated the strength and durability properties of asphalt concrete containing waste foundry sand (WFS) as alternative filler material in asphalt concrete. Marshall design method was adopted for the sample preparation and testing. Fifteen (15) compacted samples were prepared for strength and volumetric properties testing at varying bitumen contents of 4.5%, 5.0%, 5.5%, 6.0% and 6.5%, in accordance with Asphalt Institute and Nigeria General Specification for Road and Bridges to determine optimum bitumen content (OBC). OBC of 5.5% was obtained and used for the asphalt concrete mixes in the study. Eighteen (18) other briquettes were prepared to determine the optimum WFS content in asphalt concrete necessary for strength and durability of wearing course of flexible pavement. Cement as filler in asphalt concrete was partially replaced with WFS using the obtained OBC in the order of 10%, 20%, 30%, 40%, 50% and 60%. A total of thirty-three (33) standard specimens were prepared. From the Marshall stability-flow and void-density results, the sample prepared with 60% WFS as filler with OBC of 5.5% satisfies the provision of the Nigerian General Specification for Road and Bridges (NGSRB) for use in wearing course of flexible pavement. Based on the analysis of results obtained in this study and a logical comparison made with standard specifications, addition of up to 60% waste foundry sand (WFS) in asphalt concrete would lead to significant conservation of primary construction materials, divert substantial quantities of waste from landfills and present a cheap alternative of filler material necessary for sustainable asphalt concrete construction.

1.0 Introduction

The rapid industrial and agricultural activities of man has led to the generation of large tonnes of waste (such as scrap tires, foundry sand, glass, waste foundry sand, steel slag, plastics, construction and demolition wastes, rice husk, bagasse, coconut shell, mesocarp fibre, and others) which accumulate in stockpiles and landfills throughout the world. Aside not easily degraded, these wastes occupy valuable space and constitute nuisance to the environment.

Additionally, the construction industry relies hugely on conventional construction materials; such as sand, granite, cement and bitumen for mortar, concrete and asphalt production. The high cost and environmental hazard attributable to the production of materials, such as cement, has necessitated the incorporation of wide range of waste materials in the construction technology.

Consequently, there is high interest in the development and utilization of waste materials in asphalt production amongst researchers and highway practitioners to enhance pavement quality, reduce cost and curb negative environmental effects.

Ordinary Portland Cement (OPC) is a popular brand of cement widely used in the preparation of mortar, concrete, paste and asphalt concrete because of its high binding and filling characteristics. In most countries and particularly Nigeria, it is expensive and often time scarce (Tsado et al., 2014) and this has influence on the price of infrastructure construction.

Kaura et al. (2016), reported that the manufacturing process of ordinary Portland cement (OPC) which is convectional filler used in asphalt concrete contributes up to 7% of the CO_2 emission and this causes greenhouse effect on the environment. This trend is adding 1.6 billion tons of CO_2 into the atmosphere (Mehta, 2001). With considerable effort to reduce the global warming effect by reducing CO_2 emission, scarcity of landfill space from improper waste foundry sand (WFS) disposal, dependency and cost of cement for producing asphalt concrete, researchers have long been in a search for alternative material with pozzolanic properties to serve as supplement for cement (Kaura et al., 2016).

In general terms, "Pozzolana" as “a siliceous or siliceous and aluminous material, which in itself possesses little or no cementing property, but will in a finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties" (Malhorta and Mehta, 1996).

The efficient use of locally available materials is necessary in building of economically viable and sustainable roads. To this end, there is need for the design engineer to possess thorough understanding of each constituent material properties that affect pavement stability and durability (Brennan and O’Flaherty, 2002). Filler in bituminous mixes is defined as material with particle size less than 0.075 mm, which may originate from fines in the aggregate or added in the form of cement, lime and ground rock. Portland cement or hydrated lime is often added to natural filler (1 to 2 per cent by mass of total mix) to improve adhesion of bitumen and stiffening of bitumen-fine matrix (ORN 19, 2003). It also has a function of filling voids remaining after the other mineral aggregates present in asphalt concrete interlock. These functions of the filler are cardinal in contributing to the strength and deformation resistance of the asphalt concrete in service.

In recent times, a wide range of waste materials obtainable from agricultural and industrial activities in their natural or processed forms have been used in the production of asphalt concrete. Waste materials such as palm oil waste ash, rice husk ash, palm kernel shell ash, periwinkle shell ash, kaolin, metakaolin, corncob ash, millet husk ash, coal bottom ash, slag, fly ash and blast furnace slag (Murana et al., 2014; Sadeeq et al., 2014; Murana and Sani, 2015; Oluwaiwo and Owolabi, 2015; Nwaobaka and Agunwamba, 2014; Mistry and Roy, 2016; Suji et al.,

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2016; Abu Salem et al., 2017) have been assessed for suitability of incorporation into asphalt concrete. Nonetheless, literature report on the use of waste foundry sand in asphalt concrete is still very limited.

Tsado et al. (2014) reported that up to 70% of Portland cement can be replaced by using materials such as primarily fly ash silica fume, natural pozzolana, rice husk ash; wood ash and agricultural product ash.

These supplementary cementatious materials play an important role when added to Portland cement because they usually alter the pore structure of concrete to reduce its permeability, thus increasing its resistance to water penetration and water related deterioration such as reinforcement corrosion, sulphate and acid attack (Padmavathi and Preethika, 2016).

Foundry is one of the most ancient methods of metal forming (Aramide et al., 2011). Metal foundries utilize high quality sands in production of metal castings. The sand is recycled and reused multiple times in the process until it loses its characteristics and thus, discarded (Rashid et al., 2014). Foundry sand discarded by foundries is called waste foundry sand (WFS) or spent foundry sand (SFS) and they can either be recycled in a non-foundry application or used as landfills (Aramide et al., 2011).

According to Jalali (2009), waste foundry is a mixture of sand residues from metal casting process and variety of binders. It is the by-product of ferrous and non-ferrous metal casting industry, its physical and chemical properties depends upon: type of metal being poured, casting process, type of binder system, type of furnaces and type of finishing process like grinding, blast cleaning and coating (Singh et al., 2012).

There are about 35,000 foundries in the world with annual production of 90 million tonnes. In terms of number of foundries, China has the highest score (9374), followed by India (6000) (Siddique et al., 2013). Aramide et al. (2011) submitted that only less than fifteen percent (15%) of the annually produced waste foundry sand can be safely and economical recycled. This is a clear indication that this waste need to be evaluated for its suitability in construction industry applications where its use can be maximized. Depending on type of binder systems used in metal casting process, waste foundry sands are classified as; clay bonded sand (Green sand) and chemically bonded sands (Petavratzi and Wilson, 2007).

Green sand is the most common type and it consists of silica sand, bentonite clay (~ 10% by weight), 2 to 5% water and about 5% coal dust (improves casting finish) (Petavratzi and Wilson, 2007). Green sand is normally reused and can therefore contain burnt fines, coke residues and residual clays. Chemically bonded sand involves the use of organic and inorganic binders in conjunction with catalysts and different hardening/setting procedures (Petavratzi and Wilson, 2007). The type of WFS used in this study is the green sand.

A considerable amount of experimental work have been carried out by various researchers on the use of industrial waste product as replacement of mineral aggregates in the construction industry. Siddique and Kaur (2013) partially replaced natural sand with waste foundry sand to evaluate the strength and durability properties of self-compacting concrete; they observed that there is increase in compressive strength, splitting tensile strength of self-compacting concrete by incorporating waste foundry sand as partial replacement for sand up to 15%. Resistance of concrete against sulphate attack and rapid chloride permeability were also improved for concrete mixes. Petavratzi, and Wilson, (2007), investigated the use of foundry sand as partial replacement for the primary sand. Results obtained were positive regarding the inclusion of foundry sand within 2.5 and 5% as a primary sand substitute into bricks. They concluded that foundry sand could replace primary sand in brickworks.

Joni, and Zghair, (2016), carried out research on the effect of adding used foundry sand as alternative to fine and filler materials in hot mix asphalt. To evaluate the mechanical properties, the Marshall Mix design was adopted to design mix which contained foundry sand as filler and a comparison was made with mix containing two other types of fillers (ordinary Portland cement and lime stone dust). The results from the study revealed that foundry sand can be used in asphalt concrete as partial replacement of fine aggregate and total replacement of filler material.

Though, considerable efforts have been devoted towards the use of industrial by-product for asphalt production, there have been scarcity of information on the use of waste foundry sand (WFS) in asphalt concrete production in Nigeria. The focus of this study therefore, is to investigate the possibility of recycling and using waste foundry sand for sustainable cost-effective construction of wearing course of roads in Nigeria. The above aim was achieved through the following objectives:

i. performance of physical properties tests on waste foundry sand (WFS) to ascertain its suitability for use in asphalt concrete.

ii obtaining the chemical composition of waste foundry sand (WFS) using x-ray fluorescence (XRF) and classify it based on (ASTM C618, 2003) classification of pozzolana.

iii. determination of optimum binder content (OBC) for asphalt concrete production and finally find out the effect of adding different percentage of waste foundry sand (WFS) on the stability-flow and void-density properties of asphalt concrete to be used in highway wearing course.

The findings of this study could lead to a probable solution to waste management problem plaguing every country, reduction in demand for cement, freeing of valuable land space and ultimately enhancing cost effective production of road infrastructure with improved performance.

2.0 Materials and Methods

2.1 Materials

Materials used for this study are as follows;

- bitumen
- coarse aggregate and fine aggregate
- mineral filler (waste foundry sand WFS and cement)

The coarse and fine aggregates were obtained from Nagarta local quarry, Sokoto road, Zaria, Kaduna State, Nigeria. The Ordinary Portland Cement used is that of Dangote 3X brand and obtained from Samaru market in Zaria, Kaduna State. Bitumen used is penetration grade bitumen obtained from Nigerian National Petroleum Cooperation (NNPC), Kaduna State. Waste foundry sand (WFS) was gotten from Defense Industry Corporation of Nigeria (DICON), Kaduna State.

2.2 Methods

The section briefly discussed the methods employed in the experimental tests carried out to determine the physical properties of bitumen, coarse aggregate, fine aggregate, cement and the

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chemical properties of waste foundry sand (WFS). Also, the method adopted for sample preparation and testing was highlighted.

2.2.1 Test on coarse aggregates

Test conducted on the coarse aggregates are (Aggregate impact value/hardness test (BS 812 PART 111), Aggregate crushing value (BS 812 PART 112), Aggregate specific gravity (ASTM, C127), Size and gradation (BS 812-103.2).

2.2.2 Test on fine aggregates

The tests conducted on the fine aggregates are: specific gravity (ASTM 128), sieve analysis (BS 812-103.2) analysis, and water absorption (BS 812 Part 3)

2.2.3 Test on Mineral aggregate (cement and WFS)

Experimental test on cement are; Initial and final setting time (BS EN 196 part 3), Soundness test (BS EN 196 part 3), and specific gravity (ASTM C188).

Test on waste foundry sand are; bulk relative density (ASTM D854), and specific density (ASTM D854).

Another test carried out on the WFS is X-ray Fluorescence (XRF). Elemental analysis on WFS was conducted in Chemistry Department, Ahmadu Bello University, Zaria using energy dispersive spectrometer designed for detection and measurement of elements in a sample. The analysis was carried out according to (ASTM C618).

2.2.4 Test on Bitumen

Tests on bitumen are: Penetration test (ASTM D5), Solubility test (ASTM D4), Viscosity test (ASTM D2170), Ductility test (ASTM D113), Flash and fire point test (ASTM D92), Specific gravity test (ASTM D70) and softening point (ASTM D36).

2.3 Marshall Test experimental plan and specimen preparation

Asphalt Institute (1994) recommendations were used to prepare specimens weighing 1200g, 101.5 mm diameter and 63.5 mm height compacted with 75 hammer blows on each side to simulate heavy traffic situation. The specimens are tested for bulk specific gravity in accordance with ASTM D1559 (2000). The specimens are kept immersed in water in a thermostatically controlled water bath at 600^{0}C for 30 to 40 minutes and transferred within 30 seconds to the Marshall Test head where they are tested for Marshall stability and flow in accordance with ASTM D1559 (2000). The volumetric test carried out are CDM, VMA, VIM and VFB. Theoretical Maximum Specific Gravity of the Mix (Gmm) were determined using ASTM D 2041-95 and Bulk Specific Gravity or Compacted Density of the Mix (CDM) using ASTM D1188-96. 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.

To determine the optimum bitumen content, the relationships between binder content and the properties of mixtures such as stability, flow, bulk density, voids filled with bitumen (VFB), void in mineral aggregate (VMA) and void in mix (VIM) at no WFS replacement (control) were established. Three (3) specimens each were made for five bitumen content (4.5, 5.0, 5.5, 6.0 and 6.5%) in accordance with Asphalt Institute specifications, making a total of twelve (15) samples. The optimum binder content is selected as the average binder content for maximum density, maximum stability and specified percent air voids in the total mix.

Furthermore, same procedure of designing asphalt paving mixture was followed to prepare samples with different waste foundry sand and utilizing the optimum binder

3.0 Results and Discussion

3.1 Bitumen test

The preliminary test conducted on bitumen revealed that the bitumen is of 60/70 penetration grade. It satisfies various codes requirements for ductility, softening point, specific gravity, solubility and flash and fire point tests. Thus, the bitumen is adjudged suitable for asphalt concrete production.

The result of test carried out on bitumen is as presented in Table 1 below.

Table 1: Preliminary Test Result and Code Limits on the Bitumen

Test conducted	ASTM Code	Test Result	Code Limit
Penetration at 25°C, 0.1mm	ASTM D5-97	64.7	60 – 70
Softening point (°C)	ASTM D36-95	48.5	46 – 56
Flash point (Cleveland open cup) °C	ASTM D92-02	248	Min. 232
Fire point (Cleveland open cup) °C	ASTM D92-02	256	Min. 232
Ductility at 25°C, cm	ASTM D113	116	Min. 100
Specific gravity at 25°C, (g/cc)	ASTM D70	0.98	0.97 – 1.02
Solubility in trichloroethylene, %	ASTM D2042	99	Min. 99

3.2 Preliminary Tests on Aggregates

''Aggregate suitability affects physical and mechanical properties and durability of asphalt. Mineralogy cum petro-graphic nature of rock formation as well as shape and size impart on strength, traffic wear and weather resistance of aggregates in asphalt'' (Otuoze and Shuaibu, 2017). Strength tests carried out on fine and coarse aggregates as presented in Table 2 below and the results satisfied relevant codes recommendations adjudging that the material is strong, tough, dense and abrasion resistant and can stand the test of both serviceability and durability requirements of asphalt mixtures within the designed life.

Table 2: Test results on the Aggregates Materials

Test Conducted	Code Used	Test Result	Code Limit
Aggregate Crushing Value (%)	BS 812 Part 112	18.65	Max. 25
Aggregate Impact Value (%)	BS 812 Part 111	18.87	Max. 25
Specific Gravity of Coarse Aggregate	ASTM C127	2.70	2.55 – 2.75
Density of Coarse Aggregate	ASTM C127	168.52	>160
Specific Gravity of Fine Aggregates	ASTM C128	2.63	2.55 – 2.75
Density of Fine Aggregates	ASTM C127	164.15	>160
Water Absorption for Coarse Aggregate (%)	BS 812 Part 2	0.46	< 2
Water Absorption or Fine Aggregate (%)	BS 812 Part 3	8.62	< 15

3.2.1 Particle Size Distribution of Aggregates

The graph of particle size gradation for the aggregates is as shown in figures 1 and 2 below

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Aggregate grading is a very crucial factor in ascertaining the bond, interlocking packing and packing density. In asphalt concrete, the nature of the aggregate skeleton impart greatly on the strength and resistance of the finish product in service. Figures 1 and 2 below shows that the aggregates are well-graded as they satisfy ASTM D3515 code limits, thus, suitable for production of asphalt concrete

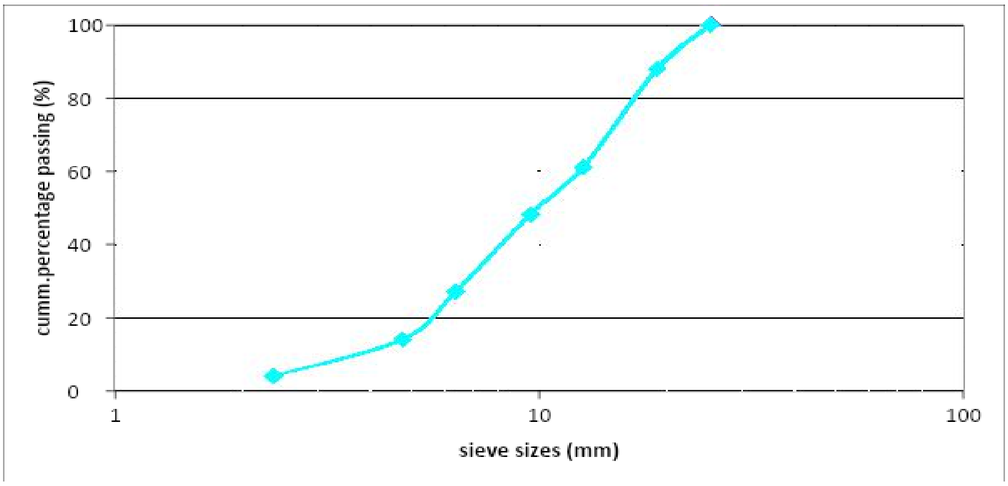

Figure 1: Sieve Analysis for Coarse Aggregate

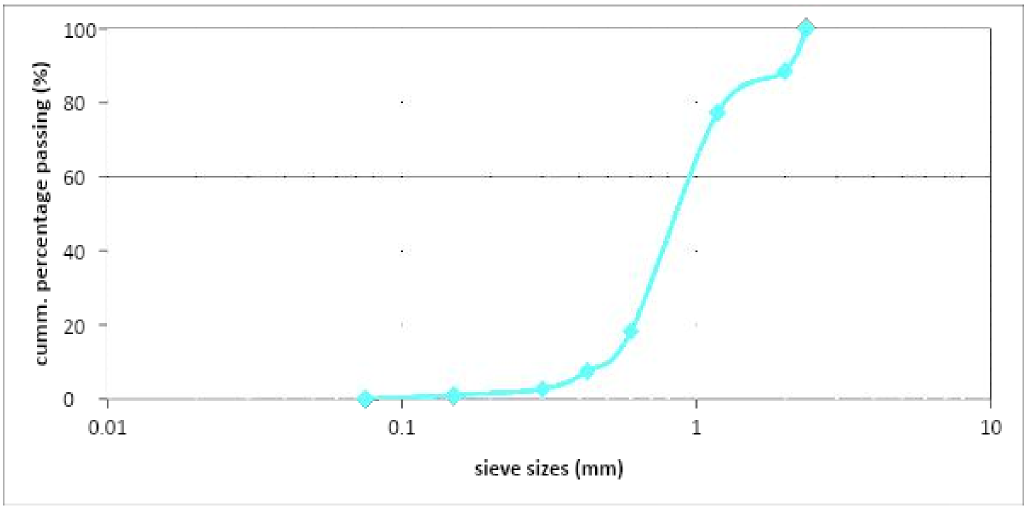

Figure 2: Sieve Analysis for Fine Aggregates

3.3 Test on Filler (cement and WFS)

The physical properties test performed on cement revealed that the cement is ordinary Portland cement. The chemical composition using x-ray fluorescence test (XRF) and other physical properties on waste foundry sand shows that it is a pozzolana of class N with specific gravity value of 2.43.

The particle size distribution of cement and WFS showed similar grading curve, this implies that their sizes are similar in nature and can be used together.

The results obtained from these testing and limits of code specifications are presented in Tables 3 and 4 and Figures 3 and 4 below.

Table 3: Test Result on Filler Materials

Test	Code Used	Value	Code Limit
Initial Setting Time of cement (minute)	BS EN 196 PART 3	68	>45
Final Setting Time of cement (minute)	BS EN 196 PART 3	255	<375
Soundness of cement (mm)	BS EN 196 PART 3	3.0	<10
Specific Gravity of cement	ASTM C188	3.1	3.15
% of cement passing 0.075 mm sieve	ASTM C117	97	>90
Specific Gravity of waste foundry sand	ASTM D854	2.43	2.39 – 2.55
Bulk relative density of WFS	ASTM D854	152	<160
% of waste foundry sand passing 0.075 mm sieve	ASTM C117	94	>90
Pozzolana class	ASTM C618	N	N or F

Table 4: X-Ray Fluorescence (XRF) Concentration of Waste Foundry Sand (WFS)

Element	Concentration (%)	Element	Concentration (%)
Na_2O	0.00	CaO	2.00
MgO	0.71	TiO_2	1.47
Al_20_3	21.29	Cr_2O_3	0.01
SiO_2	65.59	Mn_2O_3	0.06
P_2O_5	0.08	Fe_2O_3	6.96
SO_3	0.36	ZnO	0.02
Cl	0.03	SrO	0.03
K_2O	1.39		

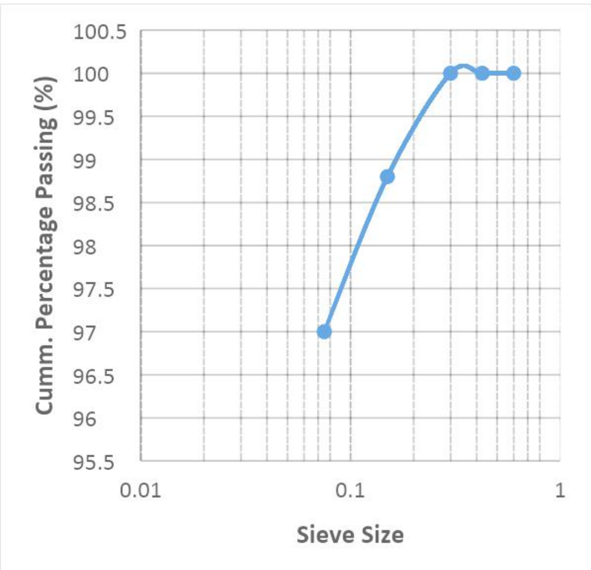

Figure 3: Sieve Analysis for Cement

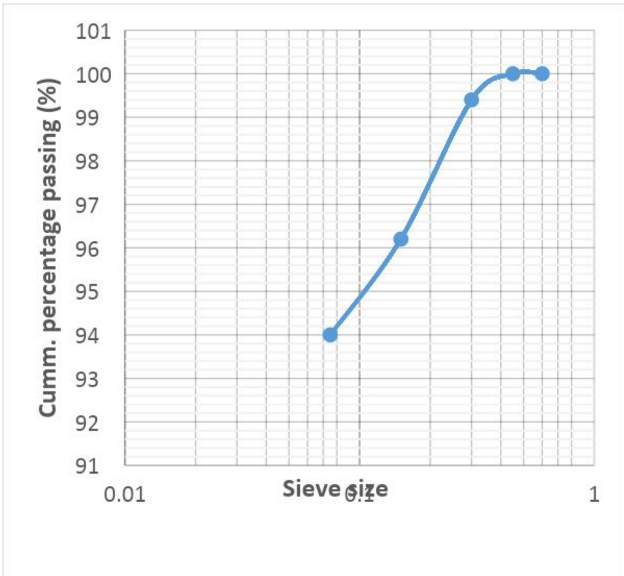

Figure 4: Sieve Analysis for Waste Foundry Sand

3.4 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).

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Table 5 below, shows the combined aggregate envelope, distribution and blending of the materials which have been sandwiched between the Asphalt Institute code upper and lower limits. This is implies compliance with code specifications, thus, adjudged good for production of asphalt concrete that can meet strength and durability requirements in service.

Table 5: Combined Material Mix and Range of Specification Requirements

BS Sieve Size (mm)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Cumulative Percentage Passing (%)	Asphalt Institute (1994)
25.4	-	-	100	100
19.05	6.6	6.6	93.4	90 – 100
12.7	14.9	21.5	78.5	-
9.52	7.2	28.7	71.3	56 – 80
6.32	11.7	40.7	59.3	-
4.76	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	-
0.6	22.4	86.4	13.6	-
0.3	5.9	92.3	7.7	5 – 19
0.15	0.7	93.0	7.0	-
0.075	0.4	93.4	6.5	2 – 8
Pan	6.5	99.9	0.1	-

3.5 Optimum Binder Content (OBC)

In order to obtain the optimum binder content necessary for the asphalt paving mixture for different WFS replacements, fifteen (15) samples each weighing 1200 g, 101.5mm diameter and 63.5mm height compacted were prepared using five different bitumen contents (4.5, 5.0, 5.5, 6.0 and 6.5%) as specified by Asphalt Institute, (1997), and ORN 19, (2003). The relationships between binder content and the properties of mixtures such as stability, flow, bulk density, voids filled with bitumen (VFB), void in mineral aggregate (VMA) and void in mix (VIM) at no WFS replacement (control) were established and optimum binder content was calculated.

Table 6 and figures 5-10 below present a summary of result obtained for the control specimen.

Table 6: Summary of Marshall Test Results for Control Specimens (0% WFS Replacement)

Percentage of bitumen (%)	Stability (KN)	Flow (mm)	Bulk specific gravity (G) (g/cm^3)	VIM (%)	VMA (%)	VFB (%)
4.5	3.80	2.30	2.33	6.8	17.1	60.6
5.0	4.22	2.70	2.35	5.2	17.1	69.7
5.5	4.35	2.90	2.36	3.7	17.1	78.5
6.0	4.05	3.40	2.35	3.7	18.0	79.6
6.5	3.20	3.75	2.34	3.4	18.7	81.6

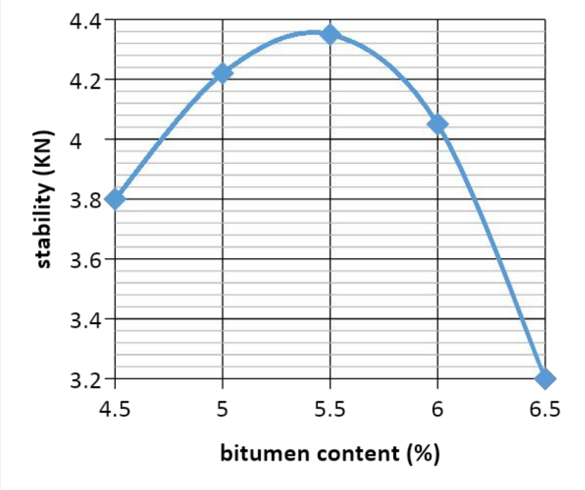

Figure 5: Stability against bitumen Content at 0% WFS

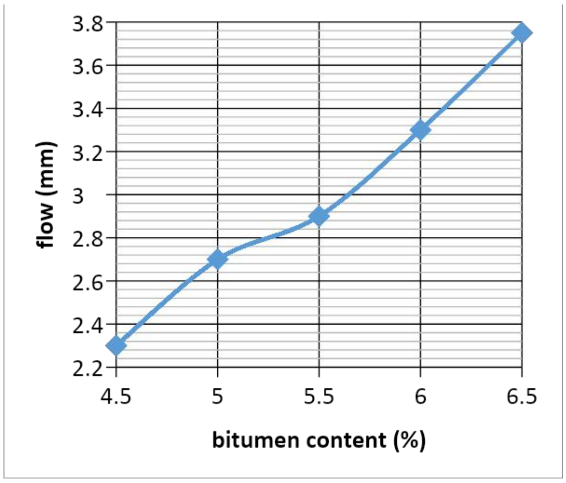

Figure 6: Flow against bitumen content at 0% WFS

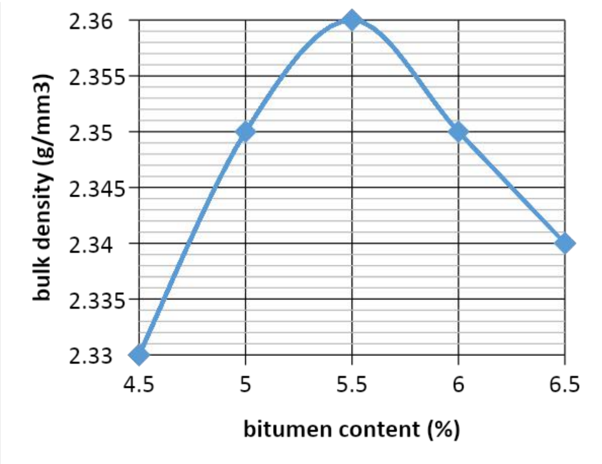

Figure 7: Bulk Density against Bitumen Content at 0% WFS

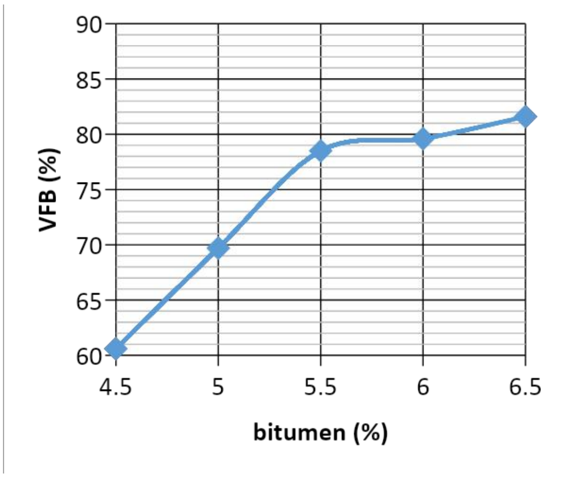

Figure 8: VFB against Bitumen Content at 0% WFS

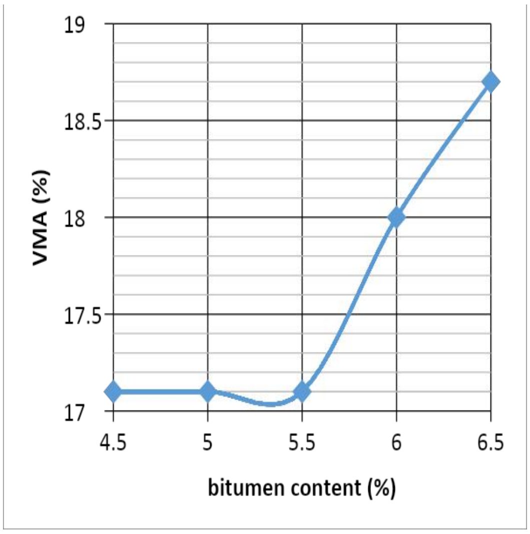

Figure 9: VMA against Bitumen Content at 0% WFS

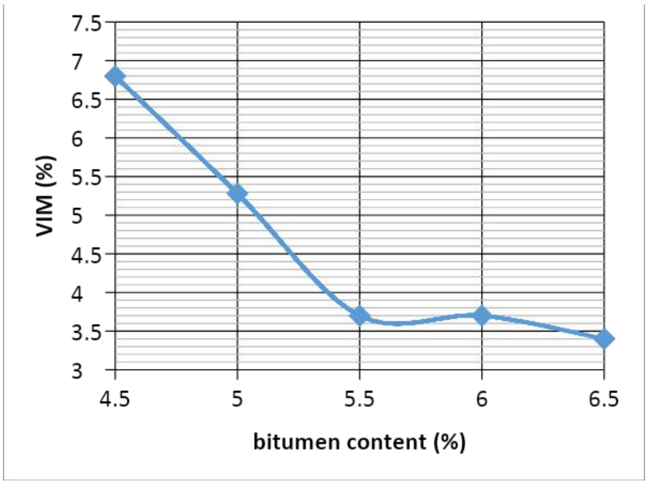

Figure 10: VIM against Bitumen Content at 0% WFS

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From the foregoing, the optimum bitumen content was found to equal 5.5% which was calculated as average of bitumen contents obtained at maximum stability, maximum bulk density and median per cent of air void as specified by Asphalt Institute, (1997).

Bitumen content at the maximum stability = 5.5 %

Bitumen content at the maximum value of bulk density = 5.5%

Bitumen content at the median per cent of air voids = 5.4%

Optimum Bitumen Content (OBC) = 5.47 (5.5 approximately).

3.6 Marshall Test Results Asphalt at Varying Percentage Replacement of Cement with Waste Foundry Sand (WFS) at Optimum Binder Content of 5.5%

The results of stability-flow and volumetric analysis (VIM; void in mix, VMA; void in mineral aggregate and VFB; void filled with bitumen) at varying replacement of WFS are shown in Figures 11 to 16.

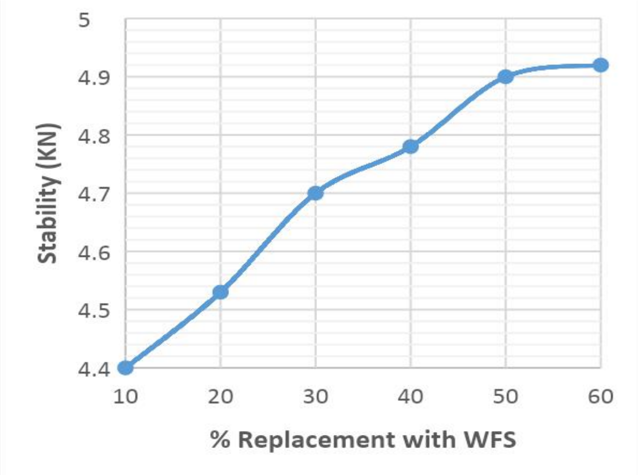

Figure 11: Stability against different percentage replacement of WFS

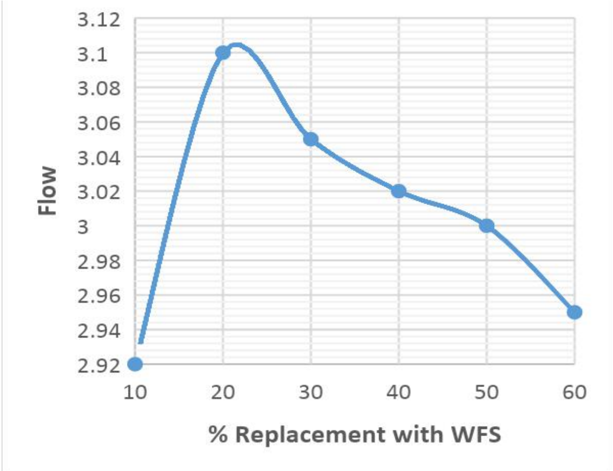

Figure 12: Flow against different percentage replacement of WFS

From the plot in Figure 11 above, the maximum load a compacted specimen can carry at a standard temperature of 60°C is the stability. The stability increases with increase in WFS from a value of 4.38 kN at 10% to a value of 4.92 kN at 60%. The increase in strength could be attributed to the hardness properties of SiO_2 and Al_2O_3 which are the major constituent of WFS and also their ability to fill void spaces leading to denser mixture. The stability value of 4.92kN obtained at 60% replacement with WFS satisfies the Nigerian General Specifications for Roads and Bridges (FMWH, 1997) of 3.5kN for use as wearing course.

Flow is the measure of flexibility by the change in diameter of the test sample in the direction of load application between the start of loading and the time of maximum load. From Figure 12 above, flow behaves in similar manner with that of the control mix due to the insignificant amount of WFS at 10%. The decrease in flow from 20% to 60% replacement is connected to the increase in stiffening of the mixture as WFS replacement increases, thus, producing a mixture that is less susceptible to deformation. The value of flow obtained ranges between 2.95 mm and 3.10 mm. This satisfies the requirement of Nigerian General Specifications for Roads and Bridges (FMWH, 1997) of between 2 mm and 4 mm for wearing course.

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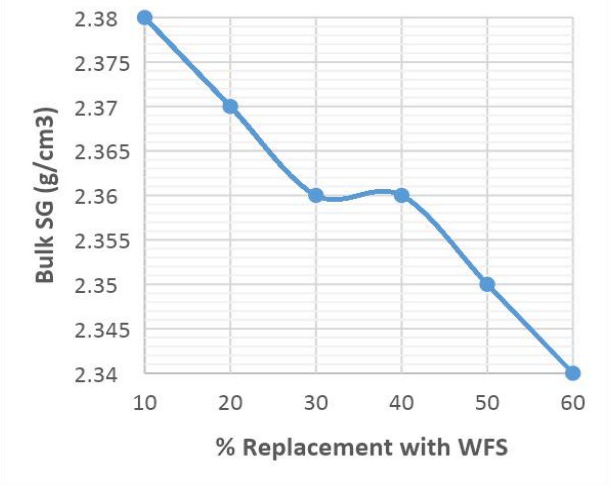

Figure 13: Bulk specific gravity (G) against different percentage replacement with WFS

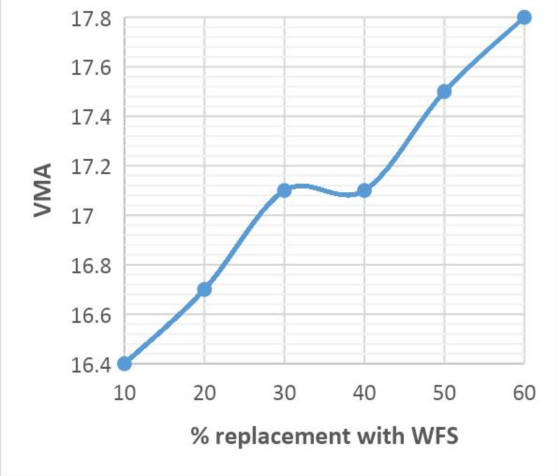

Figure 14: Void in mineral aggregates against different percentage replacement with WFS

From Figure 13 above, the bulk specific gravity decreased with increase in percentage replacement of WFS. This could be attributed to the lower specific gravity of WFS (2.43) compared to that of cement (3.1). Therefore, a given weight percentage of WFS will occupy a greater volume than that of a conventional filler material, thereby, producing a mixture with low specific gravity.

The voids in the mineral aggregate, VMA, is defined as the intergranular void space between the aggregate particles in a compacted paving mixture that includes the air voids and the effective bitumen content, expressed as a per cent of the total volume (O'Flaherty, 2002). From Figure 14 above, the void in mineral aggregate VMA increased as the WFS replacement increased. This can be attributed to the excess WFS present in the mix which the bitumen cannot sufficiently coat to bind with other mineral aggregate. Generally in marshal test, the VMA decreases with increase in bitumen content until a minimum value of VMA is obtained. Any further increase of bitumen will increase VMA, indicating that the asphalt structure is becoming overfilled with bitumen, and result in been susceptible to plastic deformation (ORN 10, 2003). In this case, the void in mix actually increased because there is no enough binder present in the mix, thus, the ability of the constituents' mineral aggregate to pack together decreases as WFS increases

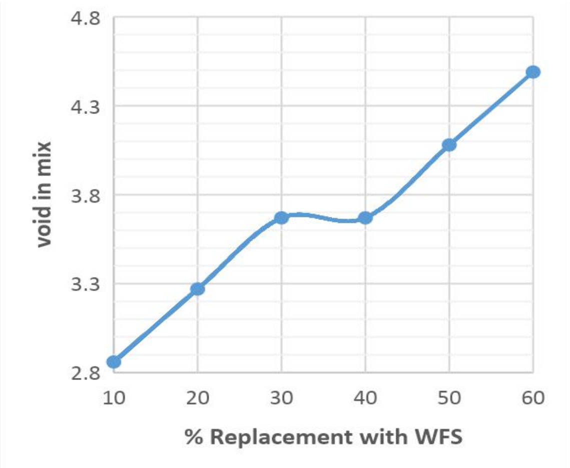

Figure 15: Void in mix (VIM) against different percentage replacement with WFS

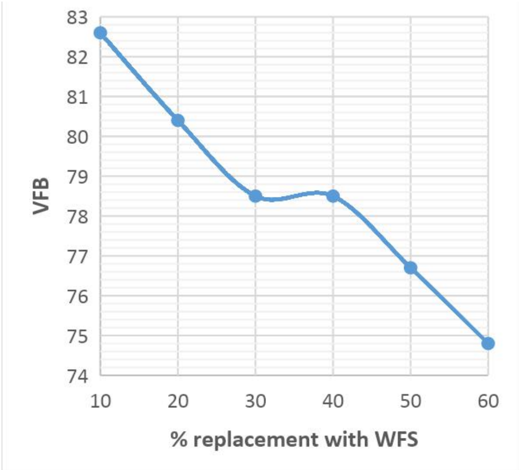

Figure 16: Void filled with bitumen against different percentage replacement with WFS

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The total volume of air expressed as percentage of the bulk volume of the compacted mixture is the void in mix (VIM). This increase as void in mineral aggregates will generally increase that of the total mix. Though the void in mix increases as seen from Figure 15 above, the results obtained for void in mix satisfy the Nigerian General Specifications for Roads and Bridges (FMWH, 1997) of 3% - 5% for wearing course, except for 10% replacement of WFS.

Void filled with bitumen VFB is defined as the portion of the volume of void space between the aggregates particles that is occupied by the effective bitumen. From Figure 16 above, the void filled with bitumen decreased as the replacement of cement with WFS increased. The results obtained at various replacements conformed to the Nigerian General Specifications for Roads and Bridges (FMWH, 1997) of 75 - 82% except at 10% replacement.

4.0 Conclusion

From the results obtained in this study, the following conclusions were drawn

The results of physical properties testing conducted on bitumen as regards its penetration, viscosity, flash and fire point, ductility and solubility all conforms to those of the ASTM standard specification for the design of asphalt concrete. Thus, the bitumen meets its requirements for durability, safety and purity.

The aggregate Crushing Value, aggregate Impact Value, Specific Gravity of coarse aggregate, water absorption of coarse aggregate, Specific Gravity of fine aggregate, water absorption of fine aggregates are within specifications. Thus, the aggregates meet the strength, toughness, hardness and resistance to wear requirements for use in asphalt concrete production.

The physical and chemical (X-Ray Fluorescence XRF test) property tests performed on foundry sand confirmed it is a pozzolana of class N according to ASTM C618 requirement and suitable for use in asphalt concrete production.

The stability, flow, VMA, VIM and VFB obtained at 60% replacement of cement with foundry sand at 5.5% bitumen content indicates an enhanced strength and durability properties of asphalt concrete. Thus, inclusion of WFS in asphalt is a viable solution for solid waste management and cost-effective asphalt concrete production for wearing course of flexible pavement necessary for sustainable development.

References

AASHTO. 1965. Standard specification for materials for aggregate and soil-aggregate subbase, base and surface courses. American Association of State Highway and Transportation Officials. Washington, D.C.

AASHTO. 312- 2001. Preparing and Determining the Density of Hot-Mix Asphalt (HMA) Specimens Means of the Superpave Gyratory Compactor. Standard Test Method for Transportation by Materials and Methods of Sampling and Testing, Part II-Tests, Twentieth Edition, American Association of State Highway and Transportation Officials. Washington, D.C.

AASHTO. 2006. Standard Specifications for Transportation Materials and Methods of Sampling and Testing. American Association of State Highway and Transportation Officials. Washington, D.C.

Abu Salem, ZT., Khedawi, TS., Baker, M S. and Abendeh, R. 2017. Effect of Waste Glass on Properties of Asphalt Concrete Mixtures, Jordan Journal of Civil Engineering, 11(1): 117–131.

American Foundry Men's Society, 1991. Alternative utilization of foundry waste sand. Final Report (Phase I) prepared by American Foundry men's Society Inc. for Illinois Department of Commerce and Community Affairs, Des Plaines, Illinois.

American Foundry's Men Society. 1963. Foundry Sand Hand Book, pp. 2026. Des Plaines, Illinois.

Aramide, FO. Aribo, S. and Folorunso, DO. 2011, Optimizing the Moulding Properties of Recycled Ilaro Silica Sand. Leonardo Journal of Sciences, 19(1): 93-102.

Asphalt Institute, 1981. The Asphalt Handbook, the Asphalt Institute, 6th Edition, Lexington, KY.

Asphalt Institute, 1994. Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types (MS-2). Asphalt Institute, Lexington, KY.

Asphalt Institute, 1997. Mix Design Methods for Asphalt, Manual Series No. 2 (MS-02). The Asphalt Institute. Lexington, KY.

ASTM, 1994. Annual Books of American Society for Testing and Materials Standards, ASTM International, West Conshohocken, PA, USA.

ASTM, 2003. Road and Paving Materials; Vehicle Pavement System, Annual Book of ASTM Standards, American Society for Testing and Materials, ASTM International, West Conshohocken, PA, USA.

ASTM C188, 2017 Standard Test Method for Density of Hydraulic Cement, ASTM International, West Conshohocken, PA, USA.

ASTM C117, 2003, Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing, ASTM International, West Conshohocken, PA, USA.

ASTM D854 – 2014, Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer, ASTM International, West Conshohocken, PA, USA.

ASTM C618-2017a Standard Specification For Coal Fly Ash And Raw Or Calcined Natural Pozzolan For Use In Concrete, ASTM International, West Conshohocken, PA, USA.

ASTM D5 - 97 Standard Test Method for Penetration of Bituminous Materials, ASTM International, West Conshohocken, PA, USA.

ASTM D36 - 95(2000) Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus), ASTM International, West Conshohocken, PA, USA.

ASTM D 113 – 07 American Association State Standard Test Method for Ductility of Bituminous Materials, ASTM International, West Conshohocken, PA, USA.

ASTM D70 - 03 Standard Test Method for Specific Gravity and Density of Semi-Solid Bituminous Materials (Pycnometer Method), ASTM International, West Conshohocken, PA, USA.

ASTM D2042 - 15 Standard Test Method for Solubility of Asphalt Materials in Trichloroethylene, ASTM International, West Conshohocken, PA, USA.

Brennan, MJ. and O'Flaherty, CA. 2002. Materials used in road pavements. In Highways: The Location, Design, Construction and Maintenance of Pavements, 4th edition (CA. O'Flaherty Ed.). pp. 115, Jordan Hill-Butterworth-Heinemann, Oxford, U.K.

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BS EN196-3. 1995, Methods of testing cement — Part 3: Determination of setting time and soundness, British Standard Institution, London, UK.

B.S 8110: Part 2, 1985. Structural use of concrete: Code of practices for design and construction, British Standard Institution, London, UK.

FHWA, 2004. Foundry sand facts for Civil Engineers. Federal Highway Administration, FHWA, Department of Transportation, U.S.A

FMW, 2007. Pavement and Materials Design. in Highway Manual Part 1: Design, Volume 3, Federal Ministry of Works, Abuja, Nigeria.

FMWH, 1990. General Specifications for Roads and Bridge. Federal Ministry of Works and Housing, Highway Manual Volume II: Maintenance Works. Abuja, Nigeria.

FMWH, 1997. General Specifications for Roads and Bridge. Federal Ministry of Works and Housing, Federal Republic of Nigeria. Abuja, Nigeria.

Garber, J. and Hoel, A. 2009. Traffic and Highway Engineering. Fourth Edition, Cengage Learning, Inc. Toronto, Canada.

Jalali, S. 2009. Reusing Ceramics Waste in Concrete. Concrete Construction and Building Materials, 24 (5): pp. 832-838.

Kaura, JM., Amartey, YD., Shuaibu, AA. and Rabilu. A. 2016. Strength and Microstructure of Cement Mortar Containing Metakaolin. Nigerian Building and Road Research Institute (NBRRI) 2016 International Conference, Abuja. 24th – 26th May 2016 pp: 243-253.

Malhotra, VM. and Mehta, PK. 1996. Pozzolanic and Cementitious Materials. Gordon and Breach Publishers, SA.

Mehta, PK. 2001. Reducing the Environmental Impact of Concrete. Concrete International. 23(10): 61-66.

Mistry, R. and Roy, TK. 2016. Effect of using fly ash as alternative filler in hot mix asphalt. Perspectives in Science, 8(2016): 307—309.

Murana, AA. and Sani, A. 2015. Partial Replacement of Cement with Baggase Ash in Hot Mix Asphalt. Nigerian Journal of Technology, 34(4): 699-704.

Murana, AA., Olowosulu, AT. and Ahiwa, S. 2014. Performance of Metakaolin as Partial Replacement of Cement in Hot Mix Asphalt. Nigerian Journal of Technology, 33(3): 387-393.

Nwaobakata, C., and Agunwamba, JC. 2014. Effect of Palm Kernel Shells Ash as Filler on the Mechanical Properties of Hot Mix Asphalt. Archives of Applied Science Research, 6(5): 42-49.

O'Flaherty, CA. 2002. Highways: The Location, Design, Construction and Maintenance of Pavements (4th edition). pp. 332-340, Jordan Hill-Butterworth-Heinemann, Oxford, U.K.

Olutaiwo, A. and Owolabi, A. 2015. Investigation of the Effects of Partial Replacement of Coarse Aggregate with Graded Palm Kernel Shell in Asphaltic Binder Course. British Journal of Applied Science and Technology 10(3): 1-13.

ORN, 19. 2003. A Guide to the Design of Hot Mix Asphalt in Tropical and Sub Tropical Countries. Overseas Road Note, Department for International Development (DFID). Published By TRL Limited, Crow Thorne. Berkshire, United Kingdom pp: 13-21.

Otuoze, HS. and Shuaibu, AA., 2017. An Experimental Study on the Use of Polypropylene waste in bituminous mix. Nigerian Journal of Technology, Faculty of Engineering, University of Nigeria, Nsukka. 36(3): 677-685.

Padmavathi, S. and Preethika, D. 2016. Experimental Investigation of Concrete with Groundnut Shell Ash as a Partial Replacement of Cement with Sisal Fibers. International Journal on Applications in Civil and Environmental Engineering 2(3): 2395 –3837.

Petavratzi, E. and Wilson, S. 2007. Characterization of Mineral Wastes, Resources and Processing Technologies – Integrated Waste Management for the Production of Construction Material, Case Study: Foundry Sand in Facing Bricks, Mineral Industry Research Organization, University of Leeds, Leads, United Kingdom.

Sadeeq, JA., Kaura, JM., Ochepo, J. and Rabilu, A. 2014. Recycling of Reclaimed Asphalt pavement (RAP) with Rice Husk Ash (RHA)/Ordinary Portland cement (OPC) Blend as Filler. Jordan Journal of Civil Engineering, 8(4): 473-481.

Siddique, R. and Kaur, G. 2010. Waste Foundry Sand and its Leachate Characteristics. In Resources, Conservation and Recycling, Elsevier, 54(2010): 1027-1036.

Siddique, R. and Kaur, R. 2013. Properties of Self-Compacting Concrete Incorporating Waste Foundry Sand. Leonardo Journal of Sciences, 23: 105-124.

Singh, G. and Siddique, R. 2012. Effect of Waste Foundry Sand as Partial Replacement of Sand on the Strength, Ultra Sonic Pulse Velocity and Permeability of Concrete. Construction and Building Materials. 26(1): 416–422.

Suji, D., Poovendran, S. and Prabhakar, P. 2016. Experimental Study on Partial Replacement of Waste Foundry Sand in Flexible Pavements. International Journal of Civil and Structural Engineering Research, 4(1): 188-197.

Tsado, TY., Yewa, M., Yaman, S. and Yewa, F. 2014. Comparative Analysis of Properties of Some Artificial Pozzolana in Concrete Production International Journal of Engineering and Technology 4(5): 251-255

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