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ORIGINAL RESEARCH ARTICLE

AN EXPERIMENTAL STUDY ON THE PERFORMANCE OF BITUMINOUS CONCRETE MIXTURES WITH SILICA SAND AS FILLER REPLACEMENT

A. A. Shuaibu*, A. I. Mohammed, U. Hassan, B. H. S. Amartey, S. A. Wada, A. Mohammed and A. M. Rimi

Department of Civil Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria
**Corresponding author's email address: abdulshub4u@gmail.com*

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ABSTRACT

This study investigates the performance of silica sand as a partial replacement for cement filler in bituminous concrete mixtures. The physical properties of bituminous concrete mixture constituent materials were tested in accordance with American Society for Testing and Materials ASTM and British standard BS specifications and were found to be satisfactory. Marshall stability method of bituminous concrete mix design was adopted to determine the optimum binder content at no silica sand replacement (control) within the bitumen content range prescribed by Nigerian General Specifications for Roads and Bridges and Asphalt Institute for bituminous courses in flexible pavements and an optimum binder content (OBC) of 6% was obtained. The Marshall stability-flow and void-density analysis of bituminous concrete mixtures prepared with 6% OBC at varying percentages replacement (5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, and 45%) of silica sand was conducted to obtain the mixture with the best performance in terms of strength and waste utilization. The results obtained from the experiment shows that the replacement of cement filler with silica sand up to 45% meets the standard specifications of Nigerian General Specifications for Road and Bridges, Hence, silica sand up to 45% could be partially adapted as cement filler replacement in bituminous concrete mixes.

1.0 Introduction

Bituminous concrete mixtures, also known as; (i) hot mix asphalt (HMA), (ii) warm mix asphalt (WMA), (iii) cold mix asphalt (CMA), (iv) plant mix, and (v) asphalt concrete (Speight, 2016). It is mainly composed of mineral aggregates (fine, coarse and filler), asphalt binder, and additive, and has been widely applied in pavement construction (Zhang *et al.,* 2020). A typical bitumen concrete mixture contains 90 to 95% (w/w) of the total mixture as mineral aggregates and 5 to 10% (w/w) as binder (bitumen) (Speight, 2016).

Filler in bituminous concrete 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). "The filler is an important constituent of bituminous concrete as the type and amount play a significant role in ensuring the quality and durability of the bituminous concrete in service" (Sutradhar *et al.,* 2015). Although several materials have been used as filler, such as cement, lime dust, stone dust, granite powder, However, their production processes have detrimental effects on the environment and the use is expensive. Also due to the high cost, inconsistencies, scarcity and depletion of virgin construction materials as well as need to enhance the performance of bituminous concrete mixtures in service, such as ; resistance to permanent deformation, cracking, wear, stripping, ageing, there is dire need to seek alternative materials for sustainable construction and improved service life of the pavements.

Extensive research have been conducted on the incorporation of agricultural waste such as; rice husk ash, groundnut husk ash, guinea corn stalk ash, bagasse ash, mesocarp fibre ash (Boon Hoe *et al.,* 2014; Shuaibu *et al.,* 2020a; Shuaibu et al., 2020b; Murana and Sani, 2015; Shuaibu *et al.,* 2020c), industrial wastes such as fly ash, waste glass (Mistry and Roy, 2016; Simone *et al.,* 2017) as well as a blend of agricultural-industrial waste such as rice husk ash and fly ash, rice husk ash and slag (Mistry *et al.,* 2018; Akter and Hossain, 2017) in bituminous mixture. However, currently, attention has significantly shifted to the use of natural materials such as kaolin, metakaolin, waste foundry sand, foundry sand, silica sand etc; because of their abundance, low cost and pozzolanic activities.

"Silica sand consists of small grains or particles of minerals and rock fragments with quartz (composed of silica dioxide SiO_2) as the dominant mineral composition" (Duvuna and Ayuba, 2015). Thus, it is rich in silica necessary for hardness in bituminous mixes. "Silica sand deposits are most commonly surface-mined in open pit operations or obtained as riverine surface deposit due to erosion. Also, dredging and underground mining is also employed to obtain the sand" (Langer, 2003). Processing silica sand extracts to reduce impurities and sizing it to optimum particle size distribution is necessary for a wide range of applications (Langer, 2003).

Silica sand with an adequate quality level may be used for glass production, casting moulds in foundries, ingredients of ceramics batches, proppants in shale hydrocarbons extraction, fillers and extenders in polymers, paints and rubber, for water filtration, and many other uses (Burkowicz *et al.,* 2020). Our country Nigeria, is blessed with abundant silica sand deposits (Table 1) as cited by Chukwu (2019) in RMRDC, (2009) report.

Table 1: Silica sand deposit locations in Nigeria

S/No	State	Location
1	Abia	Ukwa, Aba, IsialaNgwa, Azumili
2	Akwa Ibom	Ikwo, Ukem, Ibeno
3	Anambra	Onitsha, Coastal area of Ulasi River
4	Bayelsa	Sagbama, Ijaw
5	Benue	Buruku, Gboko, Guma, Kast
6	Bornu	Dikwa, Gwoza, Jere
7	Cross River	Ikom, Mfamosing
8	Delta	Ughelli, Aniocha, Burutu, Ethiope
9	Enugu	Enugu, Ekulu, Igbo Eze, Udi
10	Gombe	Yamaltu-Deba, Dukku
11	Imo	Ihiagwa, Obinze, Isu, Njaba
12	Jigawa	Kangama, Kasaure
13	Kaduna	Kaduna
14	Kano	Dambatta, Makoda
15	Kastina	Zango
16	Lagos	Apapa, Badagry, Epe, Lekki
17	Nasarawa	Lafia, Doma, Nasarawa
18	Niger	Gbako, Gurara, Mokwa, Bida
19	Ondo	Ogun waterside, Obafemi
20	Ogun	Igbokada, Akata, Agbala
21	Rivers	Etche, Obio, Okirika, Oyigbo
22	Sokoto	Sabo, BiriniWamako
23	Taraba	Jalilingo, Bali, Takum
24	Yobe	Ngeji, Fita, Damaturu, Nguru, Tarmuwa
25	Zamfara	Jamuri, Gumi S

Source: RMRDC, (2009)

"Many of the Nigerian silica sands are associated with the coastal plain of sedimentary areas of the southern parts of the country. However, few deposits of the sand occur in the northern regions of the country as seen in Table 1 above (Chukwu, 2019)".

Despite the huge deposits of silica sand in almost all Nigerian States, there are currently very scarce studies that have incorporated silica sand into bituminous concrete production in Nigeria. Employing silica sand as an admixture in bituminous concrete production will improve pavement performance and lead to the development of locally available materials for sustainable concrete production. This in turn will reduce cost and burden placed upon conventional construction materials.The aim of the current study is to experimentally evaluate the performance of bituminous concrete mixtures with the incorporation of silica sand as filler in wearing surfaces.

The above aim was achieved through the following objectives:

i. Determination of physical properties of mineral aggregates (fine, coarse), bitumen, and cement to ascertain their suitability for use in the bituminous concrete production;
ii. Determination of the chemical properties (oxide composition) of silica sand using x-ray fluorescence and classify it based on ASTM C618, (2003) classification of pozzolanas;
iii. Determination of OBC necessary for the production of bituminous concrete and find out the effect of adding the different percentage of silica sand on the stability-flow as well as void-density properties of bituminous concrete to be used in highway wearing course using the OBC.

2. Materials and Methods

2.1 Materials

Materials used in the mix design of bituminous concrete include:
i. Filler materials (Silica sand and Portland cement),
ii. Aggregates (fine and coarse) and
iii. binder (bitumen).
The aggregates (fine and coarse) were locally sourced from Nagarta quarry, along Sokoto Road, Zaria, Kaduna State. The Cement which is Dangote 3X brand was obtained from open market, Zaria, Kaduna State. The bitumen used was obtained from Gidan Coal tar adjacent to NARICT, Basawa, Zaria, Kaduna State. Silica sand was obtained from Babban Mutum in Daura, Katsina State.

2.2 Methods

Physical properties tests were conducted on bitumen, aggregates, cement, bitumen, silica sand as well as marshall test on bituminous concrete mixes in the Department of Civil Engineering, Ahmadu Bello University, Zaria, except oxide composition of Silica sand that was conducted in Chemistry Department, Ahmadu Bello University, Zaria. The test carried out on the constituent materials of bituminous mixture and code specifications are as follows:

2.2.1 Test on coarse aggregates

Test conducted on coarse aggregates are; aggregate impact value/hardness test (BS 812 part 111, 1990), aggregate crushing value (BS 812 part 112, 1990), aggregate specific gravity (ASTM, C128, 2001), size and gradation analysis (BS 812-103.2, 1985) and water absorption (BS 812 2, 1995).

2.2.2 Test on fine aggregates

The tests conducted on the fine aggregates are; specific gravity (ASTM C127, 2005), sieve analysis (BS 812-103.2, 1985), and water absorption (BS 812 3, 1995).

2.2.3 Test on Mineral aggregate (cement and silica sand)

Test on cement are; Initial and final setting time (BS EN 196 part 3, 1995), Soundness test (BS EN 196 part 3, 1995), and specific gravity (ASTM C188, 2017).

Test on silica sand are; bulk relative density (ASTM D854, 2014), and specific density (ASTM D854, 2014). Another test carried out on the silica sand is X-ray Fluorescence (XRF) to determine the oxide composition. Oxide composition analysis was carried out using in an energy dispersive spectrometer designed for detection and measurement of elements in a sample according to BS EN 196-2 (1995) in the Department of Chemistry, Ahmadu Bello University, Zaria. Furthermore, the classification of the silica sand into the pozzolana group was done based on ASTM C618, (2005) specifications.

2.2.4 Test on Bitumen

Tests on bitumen are: Penetration test (ASTM D5, 2005), Solubility test (ASTM D2042, 2015), Ductility test (ASTM D113, 2007), Flash and fire point test (ASTM D92, 2005), Specific gravity test (ASTM D70, 2003) and softening point (ASTM D36, 2006).

2.3 Optimum binder content (OBC)

To determine the optimum binder content, the relationships between binder content and the properties of bituminous concrete mixtures such as stability, flow, bulk density, voids filled with bitumen (VFB), void in mineral aggregate (VMA), and void in the mix (VIM) at no silica sand replacement (control) were established. Three (3) specimens each were prepared for five bitumen content (4.5, 5.0, 5.5, 6.0, and 6.5 %) in accordance with Asphalt Institute (1994) and FMWH, (1997) specifications. The optimum binder content is calculated as the average binder content for maximum density, maximum stability, and specified percentage air voids in the total mix.

2.4 Marshall test specimen preparation

Asphalt Institute (1994) and FMWH, (1997) recommendations were used to prepare standard specimens with 1200g weight, 101.5 mm diameter, and 63.5 mm height compacted with 75 hammer blows on each side to simulate heavy traffic situation. To obtain the optimum blend of cement-silica sand in bituminous mixtures, various percentage replacement by weight (5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, and 45%) of cement with silica sand was used to produced bituminous mixes. The specimens were tested for bulk specific gravity in accordance with ASTM D1559 (2000).

Furthermore, the specimens were kept immersed in water in a thermostatically controlled water bath at 60°C for 30 to 40 minutes before been transferred within 30 seconds to the Marshall test head and tested for Marshall stability and flow in accordance with ASTM D1559 (2000). Also, void analysis such as; Compacted Density of the Mix (CDM), void in mineral aggregate (VMA), void in mix (VIM) and void filled with bitumen (VFB) was carried out. 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. Marshall stability-flow and void-density analysis were performed and checked against the limits specified by the Nigerian General Specifications for Roads and Bridges (FMWH, 1997) for use as wearing course of the heavily-trafficked road.

3. Results and Discussion

3.1 Result of test on aggregates

Table 2 shows the results of the physical properties test on the aggregates (coarse and fine aggregates), standard specifications used for each test, and results obtained.

Table 2: Aggregates physical properties

Property	Code Specifications	Results obtained	Code limits	Remarks
Aggregate crushing value (%)	BS 812 part112 (1990)	20	Max. 25	OK
Aggregate impact value (%)	BS 812 part111 (1990)	22.2	Max. 25	OK
Specific Gravity (Coarse)	ASTM C127 (2005)	2.61	2.55-2.75	OK
Specific Gravity (Fine)	ASTM C128 (2001)	2.63	2.55-2.75	OK
Water absorption (coarse) (%)	BS 812 Part 2, (1990)	0.45	< 2	OK
Water absorption (fine) (%)	BS 812 Part 3, (1990)	8.62	< 15	OK

From Table 2, all the results obtained from the tests conducted on aggregates fall within the specified limits provided in the specification of codes, therefore, the aggregate meets the requirement for use for the design of bituminous concrete mixtures.

3.2 Results of particle size distribution for aggregates

Aggregate grading is a very crucial factor in ascertaining the bond, interlocking packing and packing density The nature of the aggregate skeleton imparts greatly on the strength and resistance of the finished product in service (Otuoze and Shuaibu, 2017). Figures 1 and 2 shows the results of the gradation of the aggregates (fine and coarse) used in this study. Materials retained on sieve 2.36 mm are referred to as coarse aggregates while those that pass sieve 2.36 mm but retained in sieve 0.075 mm are referred to as fine aggregates (Shuaibu *et al.,* 2020a). The grading of each of these constituent materials is very cardinal in ensuring a mix of desired engineering properties is obtained.

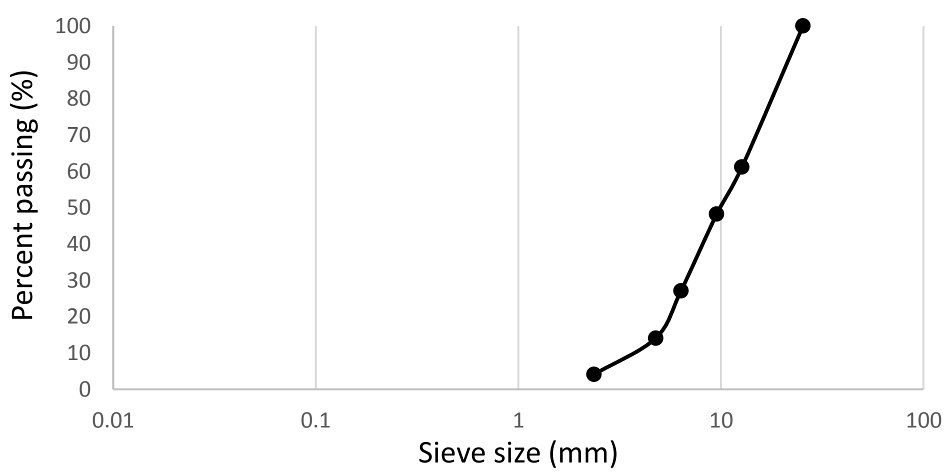

Figure 1: Particle size distribution curve for coarse aggregate

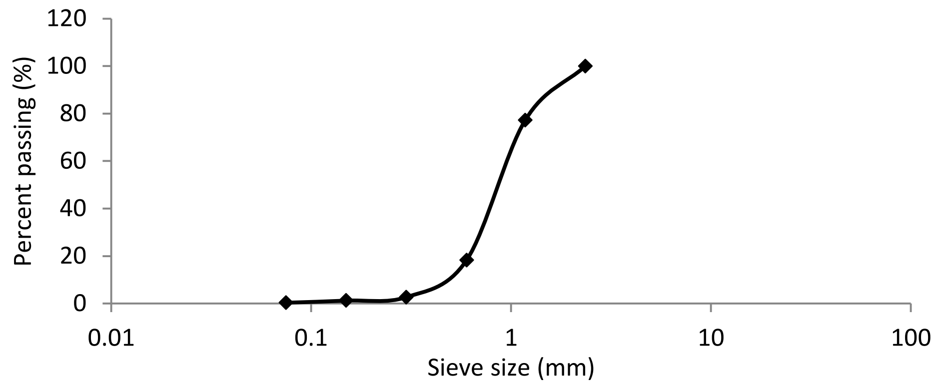

Figure 2: Particle size distribution curve for fine aggregate

The results of the particle size distribution (Figures 1 and 2) obtained for the fine and coarse aggregates shows that the aggregates are well-graded and satisfy the specifications of BS 812-103.2, (1985). Thus, suitable for the production of bituminous mixtures.

3.3 Results of test on Bitumen

The test results on the physical properties test on bitumen are shown in Table 3. The results obtained fall within the limits of the ASTM code specifications, therefore, the bitumen can be adjudged suitable for use in the production of bituminous mixtures.

Table 3: Preliminary test results on bitumen

Test Conducted	ASTM code	Results	Code Limits	Remarks
Penetration at 25°C, 0.1mm	ASTM D5, (2005)	87.2	80-100	OK
Flash & Fire Point (min)	ASTM D92, (2005)	252	Min. 232	OK
Solubility in trichloroethylene, (%)	ASTM D2042, (2015)	99	99	OK
Specific gravity at 25°C, (g/cc)	ASTM D70, (2003)	0.98	0.97-1.02	OK
Ductility at 25°C, cm	ASTM D113, (2007)	115	Min. 100	OK
Softening Point	ASTM D36/D36M, (2009)	49.5	46-56	OK

3.4 Results of test on filler (Silica sand and cement)

Test on the physical properties of cement and silica sand was performed. In addition, chemical properties of silica sand was performed to check the oxide composition necessary for classification into the groups of pozzolanas. The results obtained are as follows:

3.4.1 Physical properties of silica sand

Table 4 and 5 present the results of the physical and chemical properties test on silica sand respectively. The physical properties (specific gravity and water absorption) obtained were compared to the code limits. The results obtained meet the limits of the code specifications. It is important to state at this point that for any material to be used as filler in bituminous mixtures more than 75 per cent of such material must pass through 0.075mm sieve and the silica sand meet these requirements.

Table 4: Physical properties of Silica Sand

Test conducted	Code used	Results	Code Limits	Remarks
Specific gravity	ASTM C128 (2001)	2.5	2.55-2.75	OK
Water absorption (%)	BS 812 Part 3, (1990)	8.92	< 15	OK

3.4.2 Oxide Composition of Silica Sand

Table 5 shows the oxide composition of silica sand used in this study. The composition of the various oxides present in silica sand including the portion of loss on ignition to give a total of 100%. It is worth mentioning that the high SiO_2 content above 95% is what make the silica sand special.

Table 5: Chemical composition of silica sand

Oxide	Composition (%)	Oxide	Composition (%)
Sodium Oxide (Na_2O)	0.066	Sulphur trioxide (SO_3)	0.659
Magnesium oxide (MgO)	0.313	Chloride (Cl)	0.046
Aluminium oxide (Al_2O_3)	5.913	Potassium oxide (K_2O)	0.198
Silicon dioxide (SiO_2)	91.221	Calcium oxide (CaO)	0.062
Diphosphorus pentoxide (P_2O_5)	0.406	Tetanium dioxide (TiO_2)	0.729
Chromium III oxide (Cr_2O_3)	0.002	Manganese III oxide (Mn_2O_3)	0.009
Iron oxide (Fe_2O_3)	0.317	Zinc oxide (ZnO)	0.000
Strontium oxide (SrO)	0.005	Loss on ignition (LOI)	0.054

Based on the ASTM C 618, (2005) in Table 6 classification, the summation of Silica (SiO_2), Alumina (Al_2O_3), and (Fe_2O_3) present in silica sand was compared to that of the code and the class of pozzolana which silica sand belongs to was deduced. From Table 5, the summation of these oxides in silica sand is 97.451%. i.e. (91.221+ 5.913+ 0.317). Also considering the low value of SO_3 (≤ 5 %), silica sand can be classified as pozzolana in group N or F.

Table 6: ASTM C 618, (2005) Classification of Pozolana

Chemicals	Class			Test result
	N	F	C	
Silicon dioxide (SiO_2), + Aluminium Oxide (Al_2O_3), + Iron Oxide (Fe_2O_3), min. (%)	70.0	70.0	50.0	97.451
Sulphur Trioxide (SO_3), max,(%)	4.0	5.0	5.0	0.659

3.4.3 *Results of test on Cement*

The results of the physical properties tests carried out on the cement are presented in Table 7. It can be seen that the cement used in this study meet all the code specified limits of Portland cement, Thus, it can be concluded that the Dangote 3x brand of cement used in this study is Portland cement.

Table 7: Physical properties of cement

Test	Code used	Results	Code limits	Remarks
Initial Setting Time (minutes)	BS EN 196 part 3, (1995)	125	> 45	OK
Final Setting Time (hr)	BS EN 196 part 3, (1995)	3.42 hrs	< 10 hrs.	OK
Soundness (mm)	BS EN 196 part 3, (1995)	3.0	< 10	OK
Specific Gravity	ASTM 188, (2017)	3.10	3.15	OK

3.5 Aggregate Proportioning and Blending for production of bituminous mix

The aggregates materials were sampled according to the recommendation of BS EN932-1 (1996) and particle size distribution was conducted according to BS EN 933-1 (2012). To obtain proportion and blending of individual constituent material; coarse aggregate (material retained on 4.75 mm sieve with a maximum aggregate size of 25 mm), fine aggregate (material passing 4.75 mm sieve and retained on 200 µm sieve), and mineral filler (material passing 200 µm sieve) necessary for the production of the bituminous concrete mix were achieved by trial and error and blended until an all-in-aggregate satisfying code requirement is obtained as presented in Table 8 below.

The results of combined material mixes fall within the lower and upper limits specified by Asphalt Institute (1997), thus, adjudged suitable for use in the production of bituminous concrete mixtures that meets strength and durability requirements in practice.

Table 8: Result of the combined material mix (coarse aggregate, fine aggregate, and silica sand/cement) with limits of code specifications

BS Sieve size (mm)	Percentage retained (%)	Cumulative percentage retained (%)	Cumulative percentage passing (%)	Asphalt Institute, (1997)
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	-

3.6 Determination of Optimum Binder Content (OBC)

To obtain the optimum binder content necessary for the asphalt paving mixtures at different silica sand replacements, the relationships between binder contents and the properties of bituminous mixtures such as stability, flow, and bulk density, void in mix, void in mineral aggregate, and void filled with bitumen at no replacement (control) were established. Three samples were produced at each bitumen content (5, 5.5, 6, 6.5, 7.0%) as specified by Asphalt

Institute (1997) and ORN 19, (2003) and the average of the results obtained for the strength and void properties are presented in Table 9.

Table 9: Summary of the Marshall Test Results for Control Specimens

Bitumen Content (%)	Stability (kN)	Flow (mm)	Bulk specific gravity (G) (g/cm^3)	VIM (%)	VMA (%)	VFB (%)
5.0	8.30	2.40	2.29	6.30	18.00	68.60
5.5	8.45	3.10	2.31	5.00	18.00	75.30
6.0	8.51	4.23	2.24	3.00	17.30	84.70
6.5	8.10	6.84	2.33	2.40	17.90	91.60
7.0	7.81	8.16	2.31	2.80	19.20	93.00

The optimum binder content is calculated as the average binder content that corresponds to maximum stability, maximum unit weight, and 4 % air voids.

- Bitumen content at the maximum stability = 5.5 %
- Bitumen content at the maximum value of bulk density = 6.5%
- Bitumen content at 4 % air voids = 5.25 % (obtained by interpolation from table 6)

Thus, Optimum Bitumen Content (OBC) = 5.5 + 6.5 + 5.25 /3 = 5.75%

An optimum binder content of 6.0% was adopted for the production of bituminous concrete mixtures at varying silica sand/cement contents. The OBC used in this study is within the limits of 5.0 – 8.0% specified by FMWH, (1997).

3.7 Marshall test results for various replacements of cement with Silica sand at optimum binder content

Figures 3 to 8 show the results of Marshall stability-flow, and void-density properties at various percentage replacement by weight of Portland cement with silica sand (5%,10%,15%, 20%,25%, 30%,35%, 40%, and 45%) using the optimum binder content of 6%.

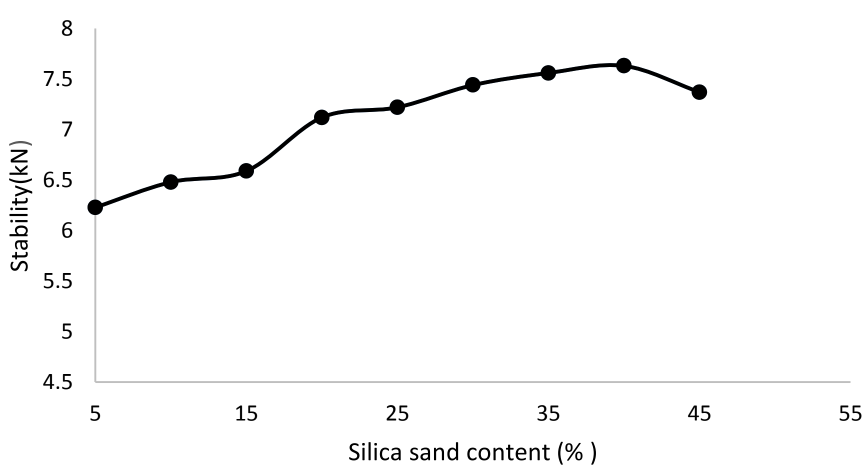

Figure 3: Variation of stability with silica sand content

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Figure 3 shows the variation of Marshall Stability with different silica sand content. Marshall Stability is a measure of HMA resistance to deformation and distortion under traffic loading. This resistance is mainly derived from cohesion (provided by the binder material) and internal friction (provided by interlocking and frictional resistance of aggregates) (Shuaibu *et al.,* 2020b). From Figure 3, the Marshall stability increases with the increase in the silica sand content. This could be attributed to the ability of silica sand to fill void spaces in the bituminous concrete mix by gaining increased contact points with other constituent materials, thereby, resulting in a denser mix. Also, the presence of high content of Sio_2 enhances hardness. It should be noted that at silica sand content above 40%, the stability started dropping and this could be attributed to excess silica sand content in excess of the optimum which resulted in weak cohesion. However, the Marshall stability results obtained at all the silica sand contents satisfied the requirements for Nigerian Specification for roads and bridges (FMWH, 1997).

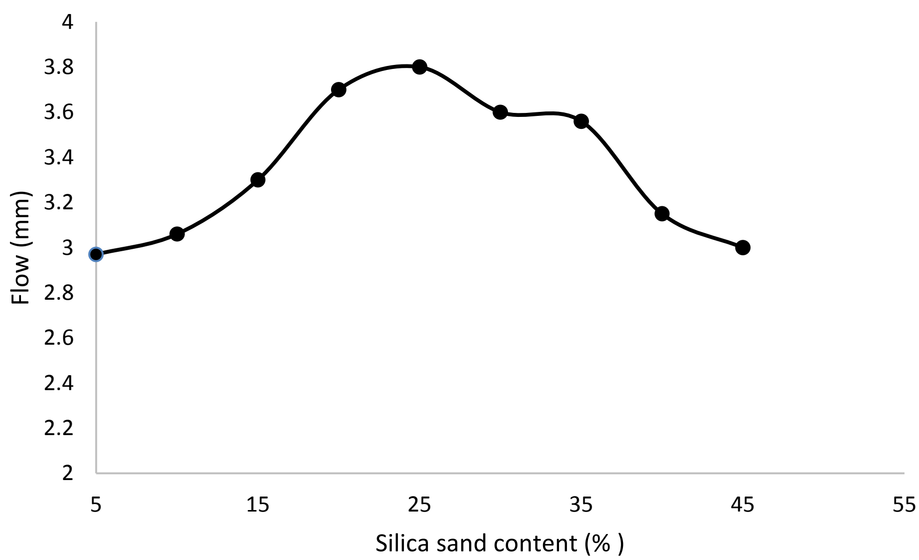

Figure 4: Variation of flow with silica sand content

Figure 4 shows the result of flow variation at varying silica sand content. 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 (Shuaibu *et al.,* 2019). The flow value increases gradually at 5% (2.97mm) silica sand content until it peaked at 25% (3.8mm) silica sand content, then, it gradually started to decrease. The initial increase in flow could be due to the insufficient content of silica sand in the mix to retard the flow. However, as the silica sand content increases, the stiffening of filler-bitumen mastic occurred, consequently reducing the flow. The flow values obtained at all the silica sand contents falls with the 2 to 4mm Nigerian General Specifications for Roads and Bridges specification FMWH, (1997) margin for use in wearing course of the heavy-trafficked road.

Corresponding author's e-mail address: abdulshub4u@gmail.com

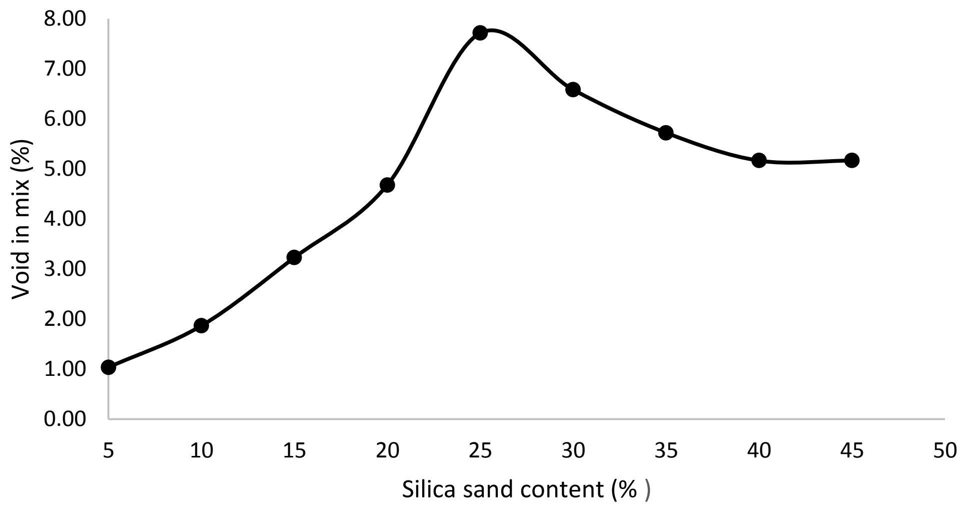

Figure 5: Variation of Void in the Mix (VIM) with silica sand content

Figure 5, show the variation of void in mix (VIM) at different silica sand contents. The void in mix increases gradually from 5% silica sand until it peaked at 25% silica sand content then gradually started decreasing. This initial increase could be attributed to silica sand particles' having greater ability to convert free bitumen to structural bitumen than Portland cement (P.C) particles. Structural bitumen here refers to the bitumen that fills the voids among filler particles. This conversion reduces the amount of free bitumen required to lubricate aggregates and fill inter-granular voids (Shuaibu *et al.,* 2020b). The reduction in percent air voids beyond 25% could be due to the sufficient filling of the void space between aggregates. It is important to note that a balance must be attained with the percentage air void content to achieve desirable engineering properties in service. The Nigerian General Specifications for Roads and Bridges specification FMWH, (1997) specifies a margin of 3 to 5% air void in mix, however, the values of VIM obtained at 25, 30 and 35% silica content does not meet this specification.

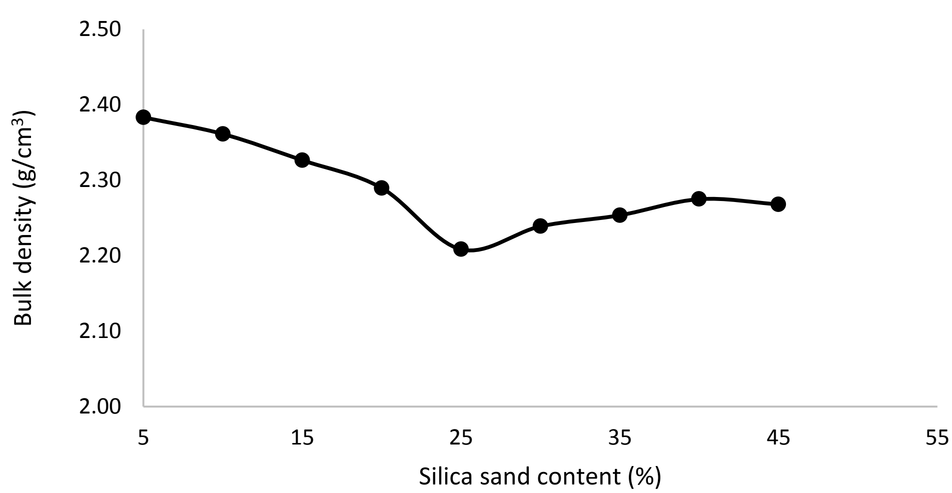

Figure 6: Variation of bulk density with silica sand content

Figure 6 show the result of bulk density at varying silica sand contents. The bulk density decreases with the increasing content of silica sand. The maximum value of bulk density recorded is 2.38g/cm^3 at 5% silica sand content. The reduction in bulk gravity could be due to the lower specific gravity/large surface area (i.e higher volume) of the silica sand compared to that of cement (Shuaibu *et al.,* 2020a) . Silica sand has large surface area and it requires more binder for coating, hence, the bulk density dropped.

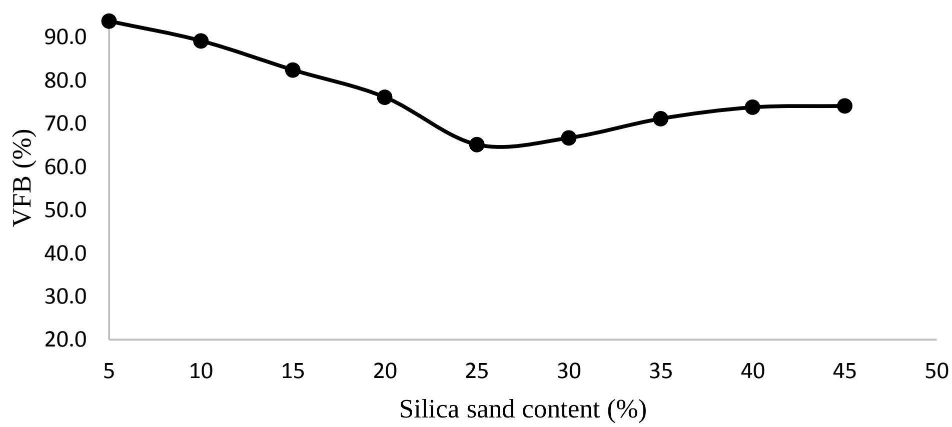

Figure 7: Variation of void filled with bitumen (VFB) with silica sand content

Figure 7 shows the result of VFB at varying silica sand contents. The 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 (Shuaibu *et al.,* 2020c). The void filled with bitumen decreases as percentage replacement of silica sand increases and this is because the particles of the silica sand take up the effective bitumen and in turn reduces it. Only the VFB results obtained at silica sand contents of 5, 10, 15 and 20% conformed to the Nigerian General Specifications for Roads and Bridges specification FMWH, (1997) of 75 to 82% for use in wearing course.

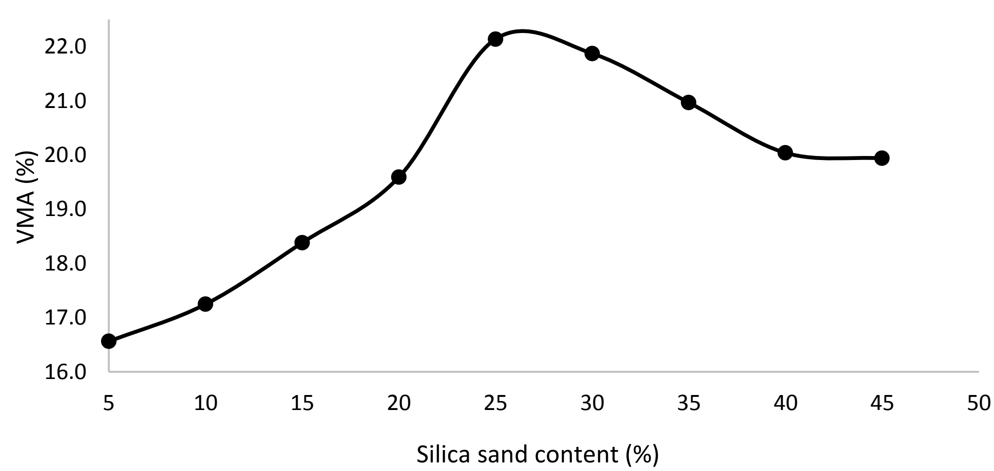

Figure 8: Variation of voids in mineral aggregate (VMA) with silica sand Content

Figure 8 shows the results of void in mineral aggregate with silica sand content. Voids in mineral aggregate (VMA) is bituminous concrete design parameter that defines the sum of the volumes of air voids (voids in total mix) and the unabsorbed bitumen (effective binder content) in a compacted bituminous concrete sample (Shuaibu *et al.,* 2020b). Minimum requirements on VMA are set to ensure that sufficient voids are present in the compacted mix to avoid durability problems. The VMA aggregates increases gradually from 5% silica sand content, peaked at 25%, and gradually decreased. The later decreasing trend observed in VMA is due to the ability of silica sand to fill up spaces between the mineral aggregates.

4. Conclusions

From the results of the experimental study, the following conclusions can be deduced;

i. The preliminary test conducted on bituminous concrete constituent materials (cement, fine and coarse aggregates, bitumen) conforms to the ASTM and BS code specifications, therefore, adjudged suitable for the production of bituminous mixtures for wearing course.

ii. Oxide composition test conducted on silica sand confirmed that it is pozzolanic in group N or F, thus, can be used as an admixture in the bituminous concrete mix.

iii. Marshall stability results showed that of bituminous concrete mix containing up to 45% silica sand improved the stability value beyond 3.5kN specified by the code. Also, the flow values recorded at all silica sand contents are within the 2-4mm limits specified by codes.

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