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Effect of Waste Foundry Sand as Partial Replacement of Fine Aggregate in Bituminous Concrete Mixture

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Research Article

Abstract

Solid waste management has become one of the global environmental issues of concern. The increase in industrial activities has led to a corresponding increase in industrial by-products which are mostly disposed to landfill as waste material. This leads to the reduction of useful land and also constitute nuisance to the environment. Also, the dwindling natural resources used in construction have pushed researchers/highway communities to seek utilization of readily available waste materials and by-products such as waste foundry sand as supplement materials in mortar, concrete and bituminous concrete mixtures. This will on the one hand reduce wastes in the environment and its effects on human health, on the other hand, it will reduce the cost of bituminous mixtures necessary for road construction as well as reduce the burden on natural resources used in the construction industry. In this study, waste foundry sand (WFS) was investigated for use as a partial replacement for fine aggregate in bituminous concrete mixtures. Physical properties test were carried out of the bituminous concrete constituent materials according to the American Society for Testing and Materials and British standard specifications and found to be satisfactory for use in bituminous concrete mix. Marshall method of mix design was used to the produced bituminous concrete at design bitumen contents of 4.5%, 5.0%, 5.5%, 6.0% and 6.5% without the incorporation of waste foundry sand (control) to determine the optimum binder content as specified by Asphalt Institute (1997), and ORN 19 (2003). An optimum binder content of 5.5% was found and consequently used to design bituminous concrete mixtures at varying percentages (5%, 10%, 15%, 20%, 25%, and 30%) replacement by weight of fine aggregate (river sand) with WFS. The results obtained show that maximum stability was attained at 30% WFS content with a value of 6.32kN and a corresponding flow of 3.1mm. Thus, from the Marshall stability-flow test analysis, the sample prepared with 30% WFS content as a partial replacement for river sand at OBC of 5.5% satisfied the specification requirements of the Federal Ministry of Works General Specification for Roads and Bridges.

Keywords	Article History	
Waste foundry sand; marshall stability and flow; optimum binder content; waste management.	**Received: –** August, 2018 **Reviewed: –** January, 2019	**Accepted: –** August, 2021 **Published: –** August, 2021

1. Introduction

Bituminous concrete mixtures commonly used for road pavement construction is a composite material that consists of binder and mineral aggregates in different proportion (Garber and Hoel, 2009).

Nowadays, due to environmental and economic concerns researchers have extensively investigated the use of waste materials in place of common virgin construction materials.

The evaluation of engineering waste aggregate materials as possible alternative/supplementary replacement of aggregate in the bituminous concrete mixture is of global interest because it supports global sustainability, reduces construction cost, conserves natural resources as well as reduce waste in the environment that poses a threat to the environment and human health.

Foundry is one of the most ancient methods of metal forming (Aramide et al., 2011). There are about 35,000 foundries in the world with an annual production of 69 million metric tons of castings per annum. In terms of the number of foundries, China has the highest score (9374), followed by India (6000) (Siddique and Sandhu, 2013). Metal foundries utilize high-quality sands in the production of metal castings. Foundries purchase virgin sand to create metal casting moulds and cores. The sand is reused numerous times within the foundry itself. Mechanical abrasion during the mould making process and sand reclamation, as well as exposure to high casting temperatures, cause the sand grains to eventually fracture. The fracturing changes the shape of the sand grains, thereby, rendering them unsuitable for continued use in the foundry (Rashid et al., 2014; US EPA Report, 2014). Foundry sand discarded by foundries is called waste foundry sand (WFS), used foundry sand (UFS) or spent foundry sand (SFS). A large quantity of waste foundry sand is generated from all foundries all over the world. U. S. Department of Transportation opined that for the production of 1 ton of casting, approximately 1 ton of foundry sand is required (Salim and Prasad, 2020).

According to Pacheco-Torgal and Jalali, (2010), waste foundry sand is a residue from the metal casting process and contains a variety of binders. Been a by-product of ferrous (iron and steel) and non-ferrous (copper, aluminium, and brass) metal casting industry, the physical and chemical properties of waste foundry sand (WFS) depends upon the 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 and Siddique 2012).

Aramide *et al*., (2011), submitted that only less than fifteen per cent (15%) of the annually produced waste foundry sand are safely and economically recycled. This is because previously, industrial and municipal by-products are traditionally viewed as wastes and disposed of as landfills, however, their application to soils and other use such as construction is now growing in many countries. Thus, leading to sustainable waste management. Also, diverting WFSs from landfills makes practical economic and environmental sense, since foundries can save on disposal costs, while end-users decreased demand for virgin aggregates which in turn alleviates the environmental burdens associated with mining activities (Alves et al., 2014).

The advantageous applications of used foundry sand are ranging from the road base material to the substitute to fine aggregate in high-performance self-compacting concrete. More generally, waste foundry sand in the range of 10–30% is best suitable as a partial substitute to regular sand in mortar and concrete making (Salim and Prasad, 2020). While most waste foundry sands (WFS) are not hazardous, regulatory agencies are often reluctant to permit their beneficial use in agricultural and geotechnical applications due to concerns over metal leaching (Alves *et al*., 2014).

Depending on the type of binder systems used in the metal casting process, waste foundry sands are classified as; clay bonded sand (Green sand) and chemically bonded sands.

Greensand consists of 85 - 95% silica, 0 - 12% clay, 2 - 10% carbonaceous additives, such as seacoal, and 2-5% water. Greensand is the most commonly used moulding media by foundries. The silica sand is the bulk medium that resists high temperatures while the coating of clay binds the sand together. The water adds plasticity. The carbonaceous additives prevent the “burn-on” or fusing of sand onto the casting surface. Greensands also contain trace chemicals such as MgO, K2O, and TiO2 (Petavratzi and Wilson, 2007; Orfanullah and Er. Deepak, 2021; Bradshaw *et al.*, 2010).

Chemically bonded sand consists of 93 - 99% silica and 1 - 3% chemical binder. Silica sand is thoroughly mixed with the chemicals; a catalyst initiates the reaction that cures and hardens the mass. There are various chemical binder systems used in the foundry industry. The most common chemical binder systems used are phenolic-urethanes, epoxy-resins, furfuryl alcohol, and sodium silicates (Petavratzi and Wilson, 2007; Orfanullah and Er. Deepak, 2021; Bradshaw *et al.,* 2010). In this study, the green WFS used was that from the green sand. It was selected because it is common, cheap and readily available.

A considerable number of experimental works have been carried out by various researchers on the use of waste foundry sand as a replacement for mineral aggregates in the construction industry. Iqbal *et al*., (2019) conducted an experimental study to evaluate the reuse of WFS as a replacement of sand in structural fill and embankments. The sand was used to replace WFS at a replacement level of 0, 4, 6, 8 and 10% by weight. Geotechnical and environmental tests were performed to assess the durability and physical properties of WFS samples. The results of the California bearing ratio indicated that WFS having 10% sand replacement will make the hardest fill material. However, they recommended using WFS with 6% sand replacement since it met the geo-environmental criteria for use as structural fill, embankment and road sub-base material. Yazoghi-Marzouk *et al.,* (2014) studied the potentials of using waste foundry sand in road construction. They found out that WFS with 5.5% hydraulic binder did not show environmental impact by leaching and has desirable mechanical properties necessary for use as a sub-base layer in road construction. Sebki *et al*., (2019) studied the possibility of recycling WFS as a cementations additive and fine aggregate in self-compacting mortars (SCM). Firstly, sand was substituted by the foundry sand waste at dosages (0%, 10%, 30%, and 50%) by the weight of the sand. Secondly, cement was partially substituted by crushed foundry sand waste at different ratios (0%, 10%, 20%, 30%, and 50%) by the weight of cement. The results obtained show that up to 50%, WFS can be used as fine aggregate for mortars without affecting the essential proprieties of mortar. Petavratzi and Wilson (2007), investigated the use of foundry sand as a partial replacement for the primary sand in brick production. Results were positive regarding the inclusion of foundry sand at 2.5% and 5% as a primary sand substitute into bricks. Siddique and Sandhu (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 an increase in compressive strength and splitting tensile strength of self-compacting concrete by incorporating waste foundry sand at a partial replacement for sand up to 15%. Resistance of concrete against sulphate attack and rapid chloride permeability were also improved for concrete mixes. Doğan-Sağlamtimur, (2018) investigated the physical and mechanical properties of WFS-based geopolymer specimens activated by chemical binders (sodium hydroxide: NaOH and sodium silicate: Na2SiO3). In this study, the maximum compressive strength value of 12.3 MPa for the mixture with the incorporation of 30% Na2SiO3 at the curing temperature of 200°C in 28 days was obtained. The author concluded that the geopolymer material is suitable for use as a building wall material. In a recent study, Shuaibu et al., (2019), partially replaced cement mineral filler with WFS in bituminous concrete. They found out that cement filler can be replaced with WFS up to 60% by weight to meet the provision of the Nigerian General Specification for Road and Bridges (NGSRB) for use in the wearing course of flexible pavement.

Though considerable efforts have been devoted towards the use of WFS as mineral aggregate replacement in the construction industry, there are still limited studies in the use of waste foundry sand as sand replacement in pavement construction. More studies in this area will serve as an important reference for the development of cost-effective pavement material as well as solve environmental problems plaguing most countries.

2. Materials and Methods

2.1 Materials

The materials used for this study are as follows;
i. bitumen
ii. coarse aggregate
iii. fine aggregates (river sand and waste foundry sand)
iv. cement

The coarse aggregate selected for this study is ‘‘all in one’’ crushed stone obtained at the quarry opposite Nigerian College of Aviation Technology (NCAT), along Sokoto Road, Zaria, Kaduna State, while the fine aggregate is washed river sand obtained from Zaria River, Kaduna State, Nigeria. The cement used is Dangote 3x grade 42.5 Portland limestone cement sourced locally in Zaria, Kaduna State. Bitumen used in this study is penetration grade bitumen obtained from Nigerian National Petroleum Corporation (NNPC), Kaduna State. Waste foundry sand (WFS) was gotten from the Defense Industry Corporation of Nigeria (DICON), Kaduna State, Nigeria.

2.2 Methods

Physical properties test on bitumen, and mineral aggregates, as well as the chemical composition of WFS, was conducted to ascertain their suitability for use in bituminous concrete mixtures. These tests were conducted according to standard code specifications (ASTM and BS) relevant to evaluate the properties of the materials of concern. The following section provides information on the test performed and the code used. Except otherwise stated, all test were carried out in the Department of Civil Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria, Kaduna State.

2.2.1 Test on coarse aggregates

Test conducted coarse on 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 (BS 812-103.2, 1985) and water absorption (BS 812 2, 1995).

2.2.2 Test on fine aggregates (river sand and WFS)

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).
Another test carried out on the WFS is X-ray Fluorescence (XRF). Elemental composition analysis was carried out in the Department of Chemistry, Faculty of Physical Sciences, Ahmadu Bello University, Zaria using the Energy dispersive spectrometer designed for detection and measurement of elements in a sample according to BS EN 196-2 (1995) and classified based on (ASTM C618, 2005).

2.2.3 Test on cement

Experimental test on cement is; 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) as well as sieve analysis (BS 812-103.2, 1985).

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).

2.2.5 Determination of optimum binder content

To obtain the optimum binder content necessary for the bituminous mixtures at different WFS replacements, The relationships between binder contents and the properties of mixtures such as stability, flow, bulk (VFB) at no replacement (control) was established. Fifteen (15) samples each weighing 1200 grams were prepared using five different bitumen contents (4.5, 5.0, 5.5, 6.0 and 6.5%) with 5.5% as design bitumen content as specified by Asphalt Institute, (1997), and ORN 19, (2003). Fifteen (15) samples were prepared using five different bitumen contents of 4.5%, 5.0%, 5.5%, 6.0% and 6.5% in order to determine the optimum bitumen content. The optimum bitumen content is the average of bitumen contents that meet optimum stability, maximum unit weight and 4% air voids.

2.2.6 Marshall mix design methods

Marshall Method for designing asphalt for paving mixtures was adopted for this study. According to Asphalt Institute, (1997), specimen compaction is a function of the design traffic category. Application of 35, 50 and 75 blows respectively on each side of specimen indicate light (< 104 EAL), medium (104 to 106 EAL) and heavy traffic (> 106 EAL) categories. Void in the mix (VIM) in the specimen correlates with the degree of compaction. Though a VIM range of 3 to 5 % which supports the use of additives is suggested by AASHTO 312 (2009), a moderate VIM of 4% shows that excessive cracking supported by upper limit (5% VIM) and plastic flow and bleeding supported by the lower limit (3 % VIM) can be mitigated. Overseas road note ORN 19, (2003) recommends 5% VIM for 75 blows if traffic is more than 5x106 Equivalent Axle Load (EAL). In the present study, 75 blows were applied on either side of the asphalt briquettes as they were designed for heavy traffic conditions. To determine the optimum binder 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 the mix (VIM) at no GSA 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 (1994) specifications. 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. The optimum blend of river sand-waste foundry sand in the bituminous concrete mixture was obtained by various percent replacement by weight (5%, 10%, 15%, 20%, 25%, and 30%) of river sand with WFS. Marshall stability-flow and void 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 Results of test on aggregates

Strength, shape, water absorption and specific gravity test were conducted on the coarse aggregate to access its suitability for use in a bituminous concrete mixture. Table 1 shows the results of the test on aggregates and code limits. The results obtained were compared to standard code specifications and the aggregates satisfy code requirements of toughness, strength, density and abrasion resistance that can serve the serviceability and durability needs of the bituminous concrete mixture

Table 1: Physical Properties of Coarse Aggregate

Test conducted	Results	Code used	Code Specification	Remark
Aggregate crushing value (%)	18.65	BS 812 part112, (1990)	< 30	OK
Aggregate impact value (%)	18.87	BS 812 part111, (1990)	< 30	OK
Specific gravity	2.70	ASTM C128, (2001)	2.55 - 2.75	OK
Water absorption (%)	0.46	BS 812 part 2, (1995)	-	

3.2 Results of the particle size distribution of coarse aggregates

In a bituminous concrete mixture, the nature of the aggregate skeleton impacts greatly on the strength and resistance of the finished product in service (Otuoze and Shuaibu, 2017) thus, particle sieve analysis is of great importance in a study of this nature. Figure 1 below shows the result of particle size analysis of the coarse aggregates used in this study. Coarse aggregate is material that is retained on the sieve of 2.36 mm. The result of particle size distribution above showed that the coarse aggregate is well-graded, thus, adjudged suitable for use in the bituminous concrete mixture.

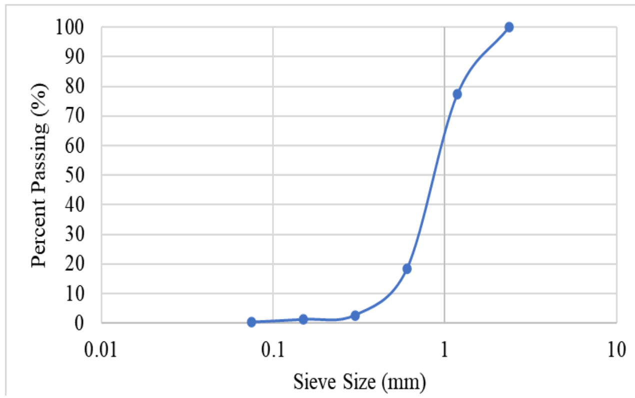

Figure 1: Particle size distribution of coarse aggregate

Table 2: Physical Properties of river sand

Test conducted	Results		Code used	Code Specification	Remark
	Fine sand	Fine sand			
Specific gravity	2.63	2.63	ASTM C127, (2005)	2.55-2.75	OK
Water absorption (%)	8.62	1.21	BS 812 part 3, (1995)	<15	OK

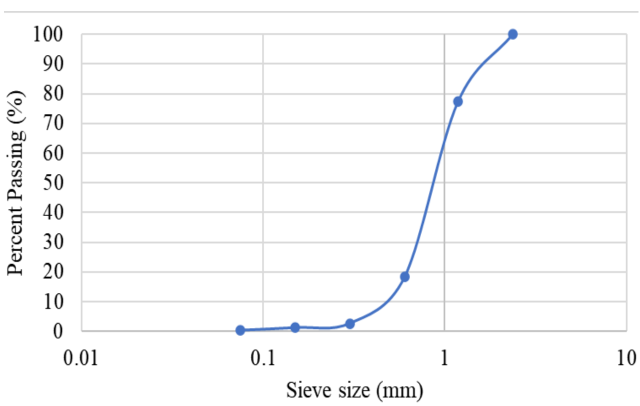

Figure 2: Particle size distribution of river sand

3.3 Results of test on fine aggregate (river sand and WFS)

Fine aggregate is the material that passes the sieve size 2.36 mm but is retained in the sieve size 0.075 mm. The results of the test conducted on the river sand are presented in Table 2 and Figure 2 above. The results of specific gravity and water absorption carried out on the river sand are with the limits of ASTM BS code specifications. Also, the particle distribution curve shows that the fine aggregate is well-graded. Thus, adjudged suitable for the production of bituminous mixtures. Figure 3 and Table 3 below shows the results of particle size distribution and chemical analysis conducted on the waste foundry sand.

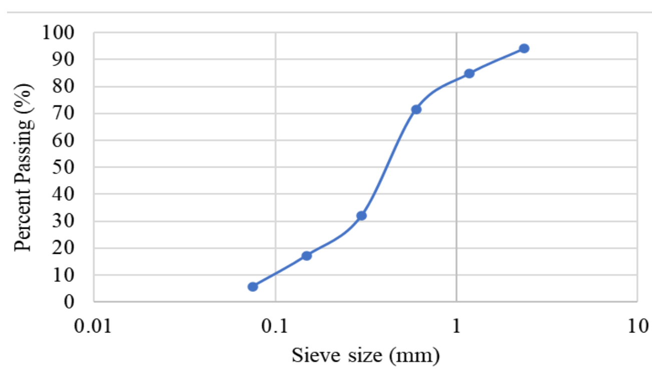

Figure 3: particle size distribution on WFS

The results of oxide composition on WFS shown in Table 3 and classified based on the ASTM C 618, (2005). The classification is based upon the summation of Silica (SiO_2), Alumina (Al_2O_3) and (Fe_2O_3). The sum of these oxides in WFS was 93.81 %. i.e. (65.59 + 21.29 + 6.93). Also considering the low values of loss on ignition (≤6 %) and SO3 (≤ 5 %), WFS can be classified as pozzolana in group N or F.

Table 3: Oxide Composition of Waste Foundry Sand (WFS)

Composition	Concentration (%)	Composition	Concentration (%)
Sodium oxide (Na_2O)	0.000	Potassium oxide (K_2O)	1.393
Magnesium oxide (MgO)	0.710	Calcium oxide (CaO)	2.003
Aluminium oxide (Al_20_3)	21.286	Tetanium dioxide (TiO_2)	1.473
Silicon dioxide (SiO_2)	65.590	Chromium III oxide (Cr_2O_3)	0.010
Diphosphorus pentoxide (P_2O_5)	0.085	Magnesium III oxide (Mn_2O_3)	0.060
Sulphur trioxide (SO_3)	0.357	Iron oxide (Fe_2O_3)	6.934
Chloride Cl	0.025	Zinc oxide (ZnO)	0.016
Strontium oxide (SrO)	0.027	LOI	0.091

3.4 Results of test on Mineral filler

To ascertain that the cement meets specifications to be used in bituminous mixtures, consistency test like initial setting time, final setting time and soundness test were carried out. Particle size distribution was also conducted. Generally, fillers are materials that pass through the 0.075mm sieve. Table 4 and Figure 4 below shows the summary of the preliminary test conducted.

From the results of the physical properties of cement, it could be deduced that the cement used for this study is Portland limestone cement (PC). Also, Figure 4 shows the results of percentage cement passing sieve 0.075 mm which is greater than 90. This indicates that the cement can be used as filler materials in the bituminous concrete mixture.

Table 4 Physical Properties of cement filler

Test	Test result	Code used	Code specifications	Remark
Initial setting time (minute)	125	BS EN 196 part 3, (1995)	Min 45	OK
Final setting time (minute)	205	BS EN 196 part 3, (1995)	Max 600	OK
Soundness (mm)	1.0	BS EN 196 part 3, (1995)	Max 10	OK
Specific gravity	3.10	ASTM C188, (2017)	Min 3.15	OK

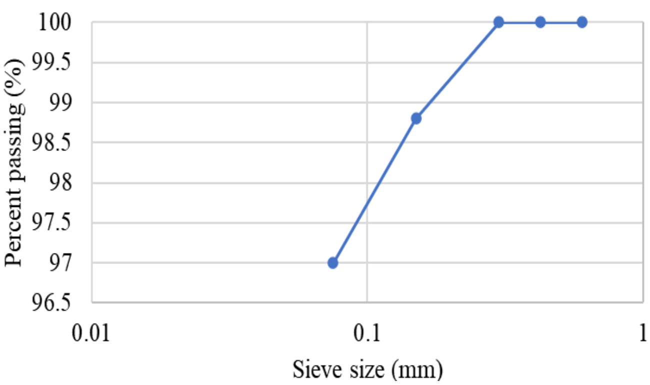

Figure 4: Particle size distribution for cement filler

3.5 Results of test on bitumen

The results of the physical properties of the bitumen are presented in table 5 below. The results show that the bitumen has penetration is 64.70 which is within the range for grade 60/70. Results of other physical properties; softening point, flash fire point, ductility, specific gravity, solubility, viscosity are also presented in Table 5 and the results show that results obtained are within the range specified by the codes. Therefore, the bitumen can be adjudged suitable for the production of bituminous mixtures.

Table 5: Results of physical properties test on bitumen

Test conducted	ASTM Code	Test Result	Code specifications	Remark
Penetration at 25^0C, 0.1mm	(ASTM D5, 2005)	64.7	60-70	OK
Softening point (^{0}C)	(ASTM D36, 2006)	48.5	46-56	OK
Flash point (Cleveland open cup) ^{0}C	(ASTM D92, 2005)	248	Min.232	OK
Fire point (Cleveland open cup) ^{0}C	(ASTM D92, 2005)	256	Min.232	OK
Ductility at 25^0C, cm	(ASTM D113, 2007)	116	Min.100	OK
Specific gravity at 25^0C, (g/cc)	ASTM D70	0.98	0.98-1.02	OK
Solubility in trichloroethylene, %	(ASTM D2042, 2015)	99	Min.99	OK

3.6 Aggregates materials sampling and grading for bituminous mixture production

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). Based on the estimated proportions of materials - coarse aggregate (55.5%), fine aggregate (38.0%) and filler (6.5%), the mix mineral materials were combined for blending as shown in Table 6 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 mixtures that can meet the stability and durability requirements in service.

Table 10: Combined material mix and range of specification requirement

Sieve size (mm)	Percentage retained	Cumulative % retained	Cumulative % passing	Asphalt Institute	Remark
25.00			100	100	OK
19.05	6.6	6.6	93.4	90-100	OK
12.5	14.9	21.5	78.4	-	
9.50	7.2	28.7	71.3	56-80	OK
6.30	11.7	40.4	59.6	-	
4.75	7.2	47.6	52.4	35-65	OK
2.36	5.6	53.2	46.8	23-49	OK
1.18	10.8	64.0	36.0	-	
0.60	22.4	86.4	13.6	-	
0.30	5.9	92.3	7.7	5-19	OK
0.15	0.7	93.0	7.0	-	
0.075	0.4	93.4	6.6	2-8	OK
Pan	6.5	99.9	0.1	-	

3.7 Marshall results of control for the determination of optimum binder content

The trend of Marshall test results of bituminous mixtures with different binder content (control) is as shown in Figures 1 to 6 below. The relationships between binder content and the properties of mixtures such as stability, flow, bulk density, air void (VIM), void in mineral aggregate (VIM), and the void filled with bitumen (VFB) were established. Optimum bitumen content was calculated as the average of bitumen values that correspond to maximum stability, maximum bulk density and median of the air void.

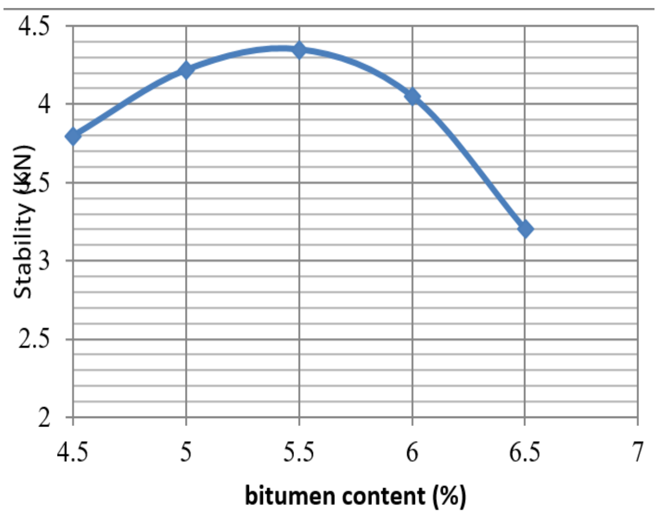

Figure 5: Variation of stability with bitumen content

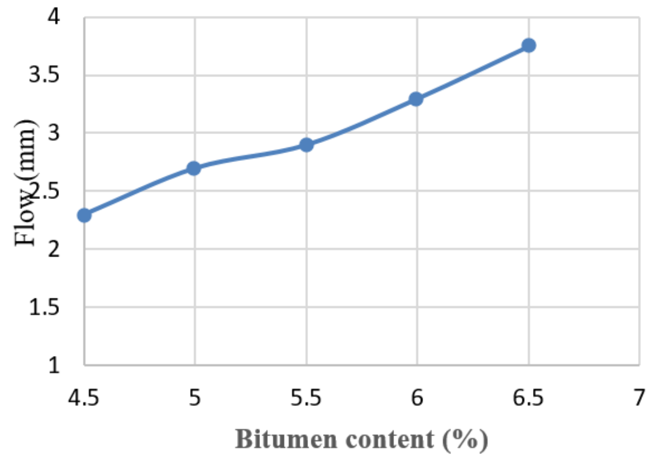

Figure 6: Variation of flow with bitumen content

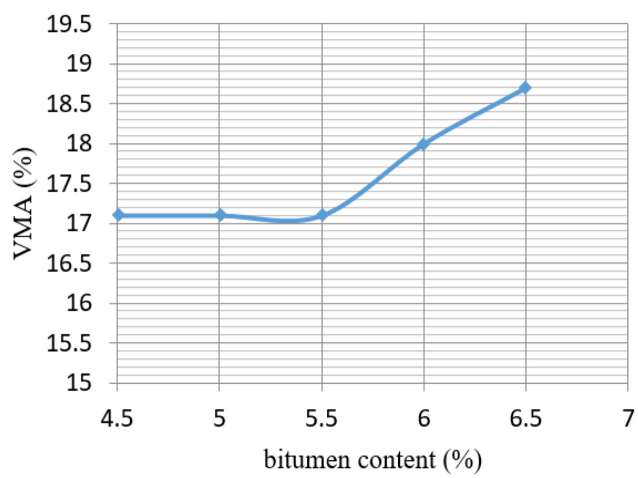

Figure 7: Variation of VMA with bitumen content

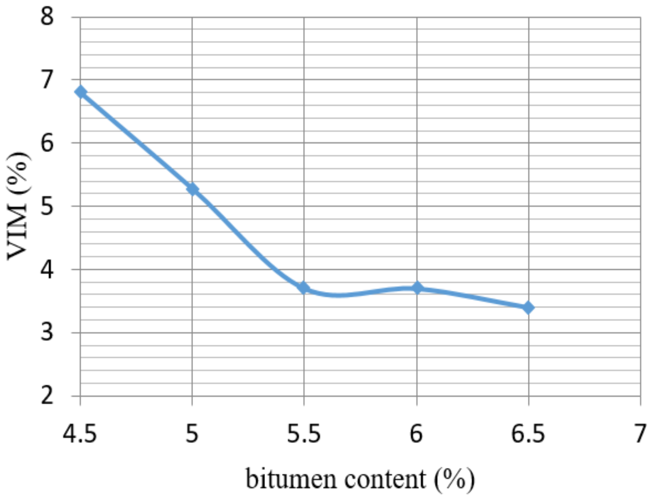

Figure 8: Variation of VIM with bitumen content

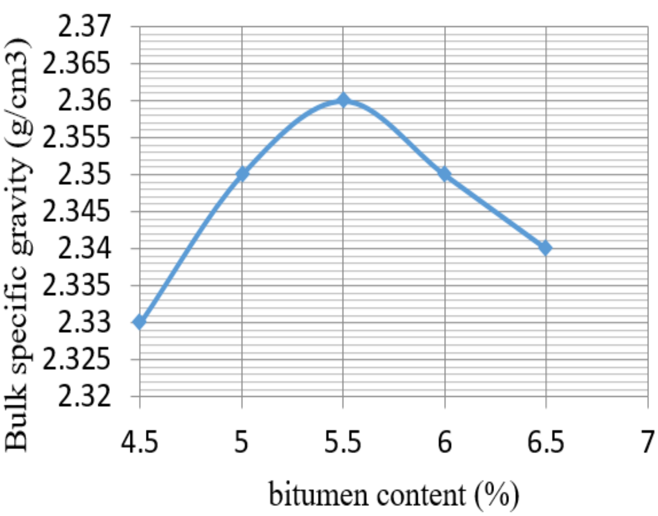

Figure 9: Variation of bulk SG with bitumen content

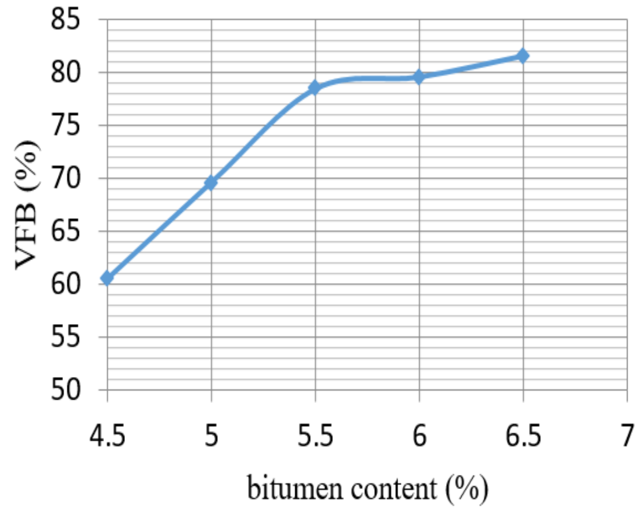

Figure 10: Variation of VFB with bitumen content

From Figures 5, 8 and 9, the following was obtained

- Bitumen content at the maximum stability = 5.5 %
- Bitumen content at the maximum value of bulk density = 5.5%
- Bitumen content at the median percent of air voids = 5.4%

The optimum binder content (OBC) is calculated as; OBC= Average of max. stability, max. bulk density and median VIM (usually taken as binder content at 4% VIM).

Optimum Bitumen Content, OBC $= \frac{5.5+5.5+5.4}{3} = 5.47 \cong 5.5$

3.8 Marshall test results for various replacements of river sand with WFS at optimum binder content

Marshall samples containing waste foundry sand as replacement for river sand were prepared using six different WFS content; 5%, 10%, 15%, 20%, 25%, and 30% by the weight of total fine aggregates in the mixtures at and 5.5% bitumen content. Marshall stability-flow test and density-void analysis were carried out to ascertain the strength and durability requirements of the bituminous concrete mixtures. The results are as shown below in figures 11 to 16.

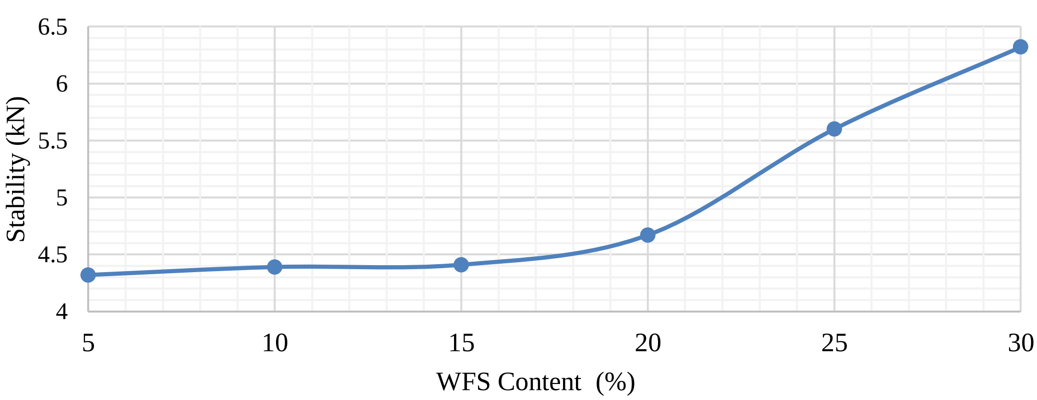

Figure 11: Variation of stability with WFS content

Figure 11 shows the stability values at varying WFS contents. Stability increases with increasing WFS contents with maximum stability of 6.32 kN obtained at 30% WFS replacement. This could be as a result of the fine attributes of the WFS which are dispersed uniformly in the mixture, thus, produces higher contact points between aggregates, thereby leading to a decreased air voids and and increase in higher density. Consequently, higher stability was obtained with increasing WFS contents. The stability results were obtained at all the WFS content except that at 5% (4.32 kN) replacement surpassed that of the control (4.35 kN). However, the results of stability at all the WFS replacements exceeds the 3.5 kN specified by Nigerian general specification for road and bridges (NGSRB, 1990) for use in wearing surface. This result is in agreement with previous studies of Dalloul, (2013) that investigated the effect of using crushed glass as fine aggregate and finer material in bituminous concrete mixtures.

Figure 12 above shows the variation of flow with WFS. Flow values increased with increasing WFS content and peak at 15% WFS content with a maximum flow value of 3.53mm before decreasing gradually to a minimum of flow of 3.10 mm at 30% WFS content. The reduction in flow is a result of the decrease in the void in the mixture due to the increasing content of WFS, thereby leading to a gradual stiffening of the mix to retard flow. All the values of flow obtained from 0% to 30 % WFS content satisfies the limit of 2 – 4 mm specification by Nigerian general specification of road and bridges. (NGSRB, 1997). The result of flow is similar to that obtained by Shuaibu *et al.*, (2019) that introduce waste foundry sand as filler replacement in the bituminous concrete mixture.

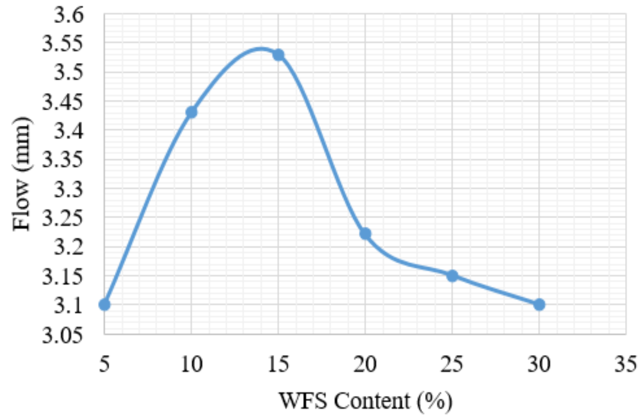

Figure 12: Variation of flow with WFS content

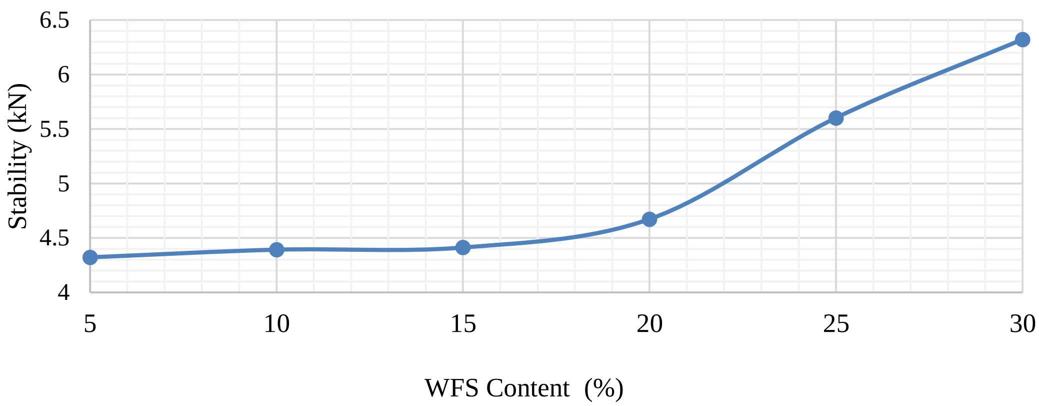

Figure 13: Variation of bulk specific gravity with WFS content

The bulk specific gravity of the bituminous concrete mixture is crucial because it influences the strength and volumetric properties of the bituminous concrete mixture. Figure 13 shows the graph of bulk specific gravity values at varying WFS contents. The bulk specific gravity increases with an increase in WFS contents from 2.24 g/cm3 at 5% WFS content to 2.33g/cm3 at 30% WFS content. The higher bulk density recorded at higher WFS contents is not unconnected to the void filling properties of the WFS in the mixture, whereby a more compact aggregate skeleton is formed (with lesser air voids) that leads to an increase in bulk density.

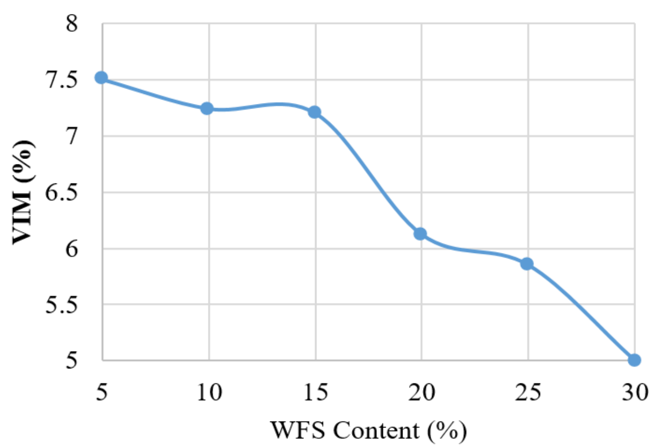

Figure 14: Variation of VIM with WFS content

Figure 14 shows the result of void in the mix at various WFS content. The total volume of air expressed as the percentage of the bulk volume of the compacted mixture is the void in the mix (VIM). The air void in the mix decreased as the WFS content increased. This decrease in air void in the mixture could be attributed to the achievement of a compacted aggregate skeleton where the void spaces (in fine and coarse aggregates) not filled with bitumen are occupied will WFS. This result correlates with that of increasing stability at higher contents of WFS. It should be noted that only the void in the mix at 30% WFS contents satisfies Nigerian General Specification for road and bridges of void content between 3% and 5% for use in wearing surface.

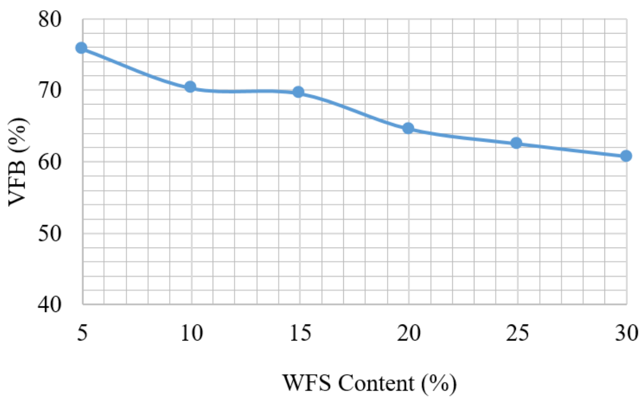

Figure 14: Variation of VFB with WFS content

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. Figure 14 show the graph of void filled with bitumen values at varying WFS contents. This could be due to WFS particles having more voids in compacted dry-state (higher Rigden voids) than river sand particles. According to Faheem *et al*., (2012); Melotti, et al., (2013), materials with higher Rigden voids are known to produce stiffer mastics, increase air voids at constant binder content, and reduce inter-granular voids filled with bitumen. Only the value obtained at 5% replacement of sand by weight with WFS satisfy NGSRB of 75 - 82%.

4. Conclusions

The results of the experimental study show that;
The physical properties test conducted on the bituminous mixture constituent materials conform to the ASTM and BS code specifications, therefore, can be used in bituminous mixture design. The-ray-Fluorescence test conducted confirms that WFS is a pozzolana in either N or F. Marshall parameters for the mixture containing up to 30 % WFS gave improved stability of 6.32 kN and 3.1mm, which surpasses the specification of Nigerian general Specification for roads and Bridges.

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