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Influence of Locally Sourced Waste Foundry Sand on Workability and Compressive Strength of Normal-Strength Concrete

Ash-Shu'ara Marafa SALMAN, Mutiu Adelodun AKINPELU, Abdulrahman ABDULRASAQ, Ezekiel Adeyemi ADETORO

Department of Civil & Environmental Engineering, Kwara State University, Malete, Kwara State, Nigeria
ashshuara.salman@kwasu.edu.ng/mutiu.akinpelu@kwasu.edu.ng

abdkay4me@gmail.com/yemmieadyt@yahoo.com

Corresponding Author: ashshuara.salman@kwasu.edu.ng, +234(0)8033700365

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Abstract: *Since the early nineteenth century, sustainable utilization of industrial by-products and agro-residue ashes have been at the forefront of researches owing to the impacts of rapid urbanization and development. This study presents experimental work on the re-utilization of already discarded waste foundry sand (WFS) sourced from local iron pot maker in Osogbo, Osun State. Fine aggregate was partially replaced with three different compositions of WFS (0, 10, 20 and 30%) using batching by weight method. The slump cone test was performed on the fresh concrete samples in order to determine their workabilities while the compressive strength test was performed at 7th, 21st and 28th-day curing ages. The compressive strength test is most used to assess the load-bearing capacity of concrete. The hardened densities for the concrete samples were also established at 7th, 21st and 28th-day curing ages. Results from the compressive strength test showed that as more WFS was incorporated into concrete mixes, so does the compressive strength increases across all curing ages. The results also showed a marginal increase in compressive strengths at 28th-day curing age in concrete samples containing WFS. Slump values for the concrete samples increase as more WFS is incorporated into mixes with exception of 30% WFS whose slump value decrease slightly compared to samples containing 10% of WFS. The hardened densities of concrete samples fall within 2200 - 2600kg/m^3 which is regarded as the density of normal-weight concrete across all curing ages. Based on these results, WFS sourced locally can effectively and efficiently be utilized to produce plain concrete.*

Keywords: *WFS, Local iron port maker, Strength, Osogbo, Fine aggregate.*

1. INTRODUCTION

In recent times, the attention of researchers have focused on utilization of sustainable waste materials such as agro-residues and industrial wastes [1]. Chief among these industrial wastes is Waste Foundry Sand (WFS). Due to rapid urbanization and industrialization, the demands for fabricated metallic materials have been unprecedented, hence, fabrication of these metallic materials lead to the production of millions of tons of WFS in countries like the US, China, India, Australia, Taiwan etc. [2]. It is estimated that about 100 millions of tons of sand are used annually while 6 - 10 million tons of waste foundry sand are generated annually by foundry industries in the USA alone [2,3]. With annual generated waste foundry sand put at around three million tons, Brazil occupies the seventh position in terms of production of WFS in the world [4].

Foundry is the widest use process around the world in moulding and casting of ferrous (cast iron, steel etc.) and non-ferrous (aluminium, copper, bronze, brass etc) materials [5]. WFS is categorized into two groups; greensand and chemically bonded foundry sand [6–9]. This process includes metal melting, pouring of molten metal in the moulds and solidification of molten metal to form desired characteristics/features/shapes of the moulds. Greensand uses bentonite clay as a binder and additives to ensure firmness and resistance of the moulds [4,5] while chemically bonded sand uses chemicals such as phenolic urethanes, furfuryl alcohol, epoxy resins, sodium silicates as a binder [6,10]. After several usages of foundry sand, it becomes undesirable due to accumulations of metal, additives and resin, which will impair negatively on the moulds, and hence results in the development of "Waste foundry sand" [11]. WFS is disposed of as industrial waste used purposefully for landfilling. This constitutes environmental hazards for present and future generations. It is also known with many nomenclatures such as spent foundry sand (SFS), used foundry sand (UFS) [12,13]. Physio-chemical properties of WFS depend largely on casting processes, utilized binder types, poured molten metal, types of furnace and finishing processes [11,12,14]

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2. REVIEW OF RELATED LITERATURE

Interestingly, recent studies have demonstrated that many of these wastes generated from manufacturing processes, industrial activities, agricultural by-products, municipal and domestic wastes etc. can be recycled and reused as sustainable materials in civil/structural engineering works [1,10,15–18]. This will save costs and protect our environment.

Furthermore, WFS can sustainably be utilized in geotechnical and highway engineering either as pavement subbases [19], footpaths bases [20] or as hydraulic barrier beds utilized in landfill caps [21]. Arulrajah et al. [16], evaluated the effects of WFS as a sustainable subgrade filling material on California bearing ratio (CBR), maximum dry density (MDD), optimum moisture content (OMC) and permeability signalled that WFS performed satisfactorily in the pipe-bedding application as well as filling materials for embankments.

Numerous research studies had also illustrated the positive influence of partial/full replacement of WFS with fine aggregate on fresh properties, mechanical properties (i.e. modulus of elasticity, compressive, splitting tensile and flexural strengths), durability indexes (i.e. water absorption, porosity, abrasion resistance, carbonation, water permeability, sulfate resistance, chloride ion penetration, surface electrical resistivity, alkali-silica reaction etc.) and weight of concrete samples [6,7,11,12,23–27]. Several concrete mixtures containing varying percent of WFS was partially replaced with fine aggregate from 5 to 60% by weight of fine aggregate. The outcomes of the researches showed a positive trend in terms of strengths development and durability indexes as per increase in the modulus of elasticity, strengths, enhanced chloride penetration resistance and carbonation [3,5,11,12]. In another research carried out by Khatib et al. [25] on concrete samples containing varying per cent of WFS partially replaced with natural fine aggregate. The authors concluded that at a mix proportion above 60% of WFS, a gradual decrease in compressive strength and increase in water absorption was observed. Martins et al. [4] affirmed the positive effect of waste foundry exhaust sand (WFES) on mechanical properties of concrete such as compressive and splitting tensile strengths, modulus of elasticity as well as water absorption. Siddique et al. [12] evaluated the influence of WFS on compressive and splitting tensile strengths as well as modulus of elasticity, ultrasonic pulse velocity (UPS) and chloride permeability on concrete grades M20 and M30. The outcomes of their investigations showed a marginal increase in strengths and durability features of two different concrete grades as the influence of WFS is more pronounced in M20 concrete grade. It is also worthy of note that as the percent of WFS used as partial replacement of fine aggregate increases so does the permeability reduces and hence, it improves the durability [5,11]. WFS had been used as a partial replacement of clay in the manufacturing of tiles; 0, 10, 15, 20, 40 and 60% of WFS was used as a partial replacement of clay soil. The results of the experiment showed a positive effect on shrinkage of tile samples, weight loss, and porosity, bending strengths, better resistance to acidic and alkaline solutions [27]. According to Torres et al. [28], the partial replacement of WFS with fine aggregate up to 30% of WFS does not affect compressive, splitting tensile and flexural strengths as well as modulus of elasticity in any way.

According to Siddique et al. [15], incorporation of 20% of WFS as partial replacement of fine aggregate improved mechanical properties in terms of compressive strength, flexural strength, modulus of elasticity and durability of green concrete well above the control concrete samples. Siddique et al. [12] had suggested an optimum partial replacement level of 15% while Manoharan et al. [7] suggested 20% partial replacement of fine aggregate as an optimal replacement of aggregate with WFS and Bilal et al. [22] suggested 30% of WFS as an optimal replacement for fine aggregate.

On the contrary, the results from Khatib et al. [29] showed that compressive strength and ultrasonic pulse velocity (UPV) decline with an increase in partial replacement of fine aggregate with WFS but with the likelihood of attaining required or adequate strength. Sua-Iam and Makul [30] used automobile engine parts foundry sand waste (ASW) as a partial replacement of ordinary Portland cement. The outcomes of the research indicated that the addition of ASW as partial replacement of cement results in a reduction in unit weight, compressive strength, splitting tensile strength, modulus of elasticity, slump loss (i.e. higher water requirement), setting time as well as resistance to sulfuric acid attack. The linear expansion of concrete samples with ASW as partial replacement of cement decline with an increase in ASW content. The outcomes of research by Sua-Iam and Makul [30] is very much similar to the research carried out by Makul and Sokrai [31]. WFS as a partial replacement for fine aggregate had also found positive applications in the development of high strength concrete (HSC), ready-mixed concrete (RMC), high-performance concrete (HPC), self-compacting concrete (SCC), geopolymer concretes (GPC) and alkali-activated slag concretes (AASC), geopolymer bricks [26,32–36]. WFS along with Fly ash and coal-combustion bottom ash had also been applied to manufacture bricks, wet-cast concrete bricks, ceramic bricks, masonry blocks, paving blocks and paving stones [8,37–39].

Additions of more WFS in concrete mixtures automatically lowered the workability, which in turn results in high water demand [10] but on contrary, report of researches carried out by Rashid and Nazir [14] and Etxeberria et al. [9] showed an increase in workability of concrete samples containing more WFS.

Therefore, the aim of this research was to investigate the influence of locally-sourced waste foundry sand (WFS) partially replaced with fine aggregate on compressive strength, hardened densities and the workability of fresh concrete samples. The utilization of WFS in concrete production will help in the safe disposal of WFS and sustainable re-utilization of WFS as construction material.

Although numerous studies have evaluated applications of WFS in different parts of the world, locally generated WFS as a construction material in Nigeria has not been investigated.

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3. METHODS AND MATERIALS

3.1 Materials

Materials used for this research include; Ordinary Portland cement (CEM I), Waste Foundry Sand (WFS), Fine aggregate (FA) and, Coarse aggregate (CA).

CEM I: Locally produced ordinary Portland cement of strength grade 42.5Mpa was used for this research. CEM I used for this research was purchased from local vendor at Ilorin and it is usually called *Dangote 42.5R*. Chemical composition of cement sample was carried out at the department of chemical and petroleum engineering Afe Babalola University, Ado-Ekiti, Ekiti State, Nigeria using X-ray fluorescence spectrometer Shimadzu EDXRF-702HS. Table 1 shows the physical and mechanical properties of CEM I.

Table 1: Physical and mechanical properties of CEM I

Strength grade	42.5Mpa
Fineness	7.50%
Specific gravity	2.9
Initial setting time	30mins
Final setting time	600mins
Consistency	30%

WFS: Already used and discarded waste foundry sand sourced from local iron pot maker located at Oluode area of Osogbo, Osun State, Nigeria was collected in bags. To determine the chemical composition, a sample of WFS was taken to the department of chemical and petroleum engineering at Afe Babalola University, Ado-Ekiti, Ekiti State, Nigeria for XRF analysis using X-ray fluorescence spectrometer Shimadzu EDXRF-702HS. WFS is primarily silica oxides in the form of quartz crystalline [4,31,37]. Lumps of WFS were broken with hands into smaller and finer particles. By visual inspection, the collected WFS is dark brown. The chemical composition of CEM I and WFS are as shown in Table 2.

Table 2: Chemical composition of CEM I & WFS

Parameter	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	TiO_2	MnO	Cl	LOI
*CEM I	61.76	20.62	5.35	3.07	1.93	1.52	1.03	0.2	0.12	0.04	0.13	3.47
WFS	2.42	73.55	8.07	2.52	1.48	0.3	2.89	0.79	<0.01	0.06	-	2.38

*Salman et al. [40]

Fine Aggregate (FA): The sharp sand used as FA was purchased from a local vendor. The FA was probably sourced from Busamu River in Moro local government area of Kwara State where sharp sand is mined. FA was taken to the Institute of Technology, cleaned and sundried for days in order to remove any deleterious materials and water from it. The physical properties of the FA are presented in Table 3.

Coarse Aggregate (CA): Granite used for this research was purchased from a local vendor and taken to the Institute of Technology, Ilorin where it was clean and sundried for days in order to remove any unwanted dirties and water. Table 3 presents the physical properties of CA.

Table 3: Physical properties of aggregates and WFS

	FA	CA	WFS
Specific gravity	2.66	2.6	2.42*
Fineness Modulus	3.41	3.41	2.46

*Siddique and Kadri [41]

3.2 Methods

Compressive strength test

The compressive test is the most commonly used and most acceptable concrete strength assessment test by concrete technologists and concrete design engineers because of its desirability to estimate the characteristic compressive strength of the concrete, upon which engineers based their design of concrete structures [40]. WFS partially replaced sharp sand (FA) at the incremental rate of 10% from 0 - 30% and batching by weight method was employed for the mix proportioning as shown in Table 4. A water-cement ratio of 0.5 was used for all the concrete mixtures as shown in Table 4. 150mm cubes of concrete samples were prepared in three layers of approximately 50mm each and each layer receiving 25 evenly distributed strokes as laid out in BS 1881 -116 [42]. The freshly prepared concrete samples for each mix were demoulded after 24hrs of casting and water cured for the 7th, 21st and 28th-days. The concrete samples were cured at normal room temperature at the Institute of Technology's concrete laboratory, Ilorin, Kwara State.

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Table 4: Concrete mix design in kg/m^3

Mix code	% replacement	CEM1	FA	CA	Water	WFS	w/c
WFS-1	0%	596	525	981	298	0.00	0.5
WFS-2	10%	596	472.5	981	298	52.5	0.5
WFS-3	20%	596	420.0	981	298	105.0	0.5
WFS-4	30%	596	367.5	981	298	157.5	0.5

Workability test

The workability of fresh concrete is evaluated through methods such as slump cone test, compacting factor test, flow test, K-slump tester, Vee Bee consistometer test and Kelly ball test. The slump cone test is the most commonly employed test method used in measuring the fresh property of concrete samples owing to its wide applicability both on-site and off-site or at the laboratory. "Consistency of freshly prepared concrete" and "workability" are two terms interchangeably used to refer to fresh properties of concrete. Slump cone test was carried out on each concrete mix sample with 0, 10, 20 and 30% of WFS partially replaced with sharp sand as per BS1881- 102 [43]. The mix proportion for the concrete samples is shown in Table 4.

4. RESULTS AND DISCUSSION

4.1 Compressive Strength

Table 5 presents the compressive and normalized compressive strength of concrete samples with WFS incorporated as partial replacement of fine aggregate as compared to control concrete samples (WFS-1). At the 7th-day curing age, control samples (WFS-1) had a compressive strength of 28.30Mpa (100%) whereas concrete samples with 10% of WFS (WFS-2), 20% of WFS (WFS-3) and 30% of WFS (WFS-4) had a compressive strength of 30.37Mpa (or 107% of WFS-1), 30.89Mpa (or 109% of WFS-2) and 32.00Mpa (or 113% of WFS-1) respectively. At the 21st-day curing age, WFS-1 achieved a compressive strength of 29.85Mpa while WFS-2, WFS-3 and WFS-4 achieved a compressive strength of 31.60Mpa (or 106% of WFS-1), 33.56Mpa (or 112% of WFS-1) and 34.00Mpa (or 114% of WFS-1) respectively. At the 28th-day curing age, WFS-1, WFS-2, WFS-3 and WFS-4 achieved a compressive strength of 38.52, 39.11 (or 102% of WFS-1), 40.1 (or 104% of WFS-1) and 40.78Mpa (or 106% of WFS-1) respectively. As can be seen above, compressive strengths across all curing ages rise with an increase in the percent replacement of fine aggregate with WFS. The increments in the compressive strengths of concrete samples containing 10 - 30% of WFS as a partial replacement for fine aggregate indicate that WFS could be successfully used in the production of concrete. An increase in compressive strength of concrete samples containing WFS could be attributed to the fact that WFS contain finer soil particles than the sharp sand and thus, help to create a denser concrete matrix and closing up the voids [3,11]. Result obtained here is similar to results reported by researchers such as Bilal et al. [22], Martins et al. [4], Torres et al. [28], Gurumoorthy and Arunachalam [24], Singh and Siddique [11], Siddique et al. [3] wherein partial replacement of sharp sand with WFS results in increase in compressive strength of concrete samples.

Table 5: Compressive strength in Mpa - ***normalized compressive strength in %***

Mix code	7th-day	21st-day	28th-day
WFS-1	28.30 - ***100%***	29.85 - ***100%***	38.52 - ***100%***
WFS-2	30.37 - ***107%***	31.60 - ***106%***	39.11 - ***102%***
WFS-3	30.89 - ***109%***	33.56 - ***112%***	40.19 - ***104%***
WFS-4	32.00 - ***113%***	34.00 - ***114%***	40.78 - ***106%***

The relationship between the compressive strengths and percent replacement of sharp sand with WFS is as shown in Figure 1. As can be seen in Figure 1, a linear correlation was developed for the relationship between compressive strengths and percent replacement of sharp sand with WFS at different curing ages. Very strong coefficient of determinations, R^2 were obtained for different curing ages; $R^2 = 0.9363$ for 7th-day, $R^2 = 0.9472$ for 21st-day and $R^2 = 0.9847$ for 28th-day curing age respectively. These demonstrate that there existed strong relationships between compressive strengths and percent replacement of sharp sand with WFS for all curing ages. It also implies that an increase in the percent of WFS will most likely be responsible for the increase in compressive strengths of concrete samples with WFS as a partial replacement of sharp sand.

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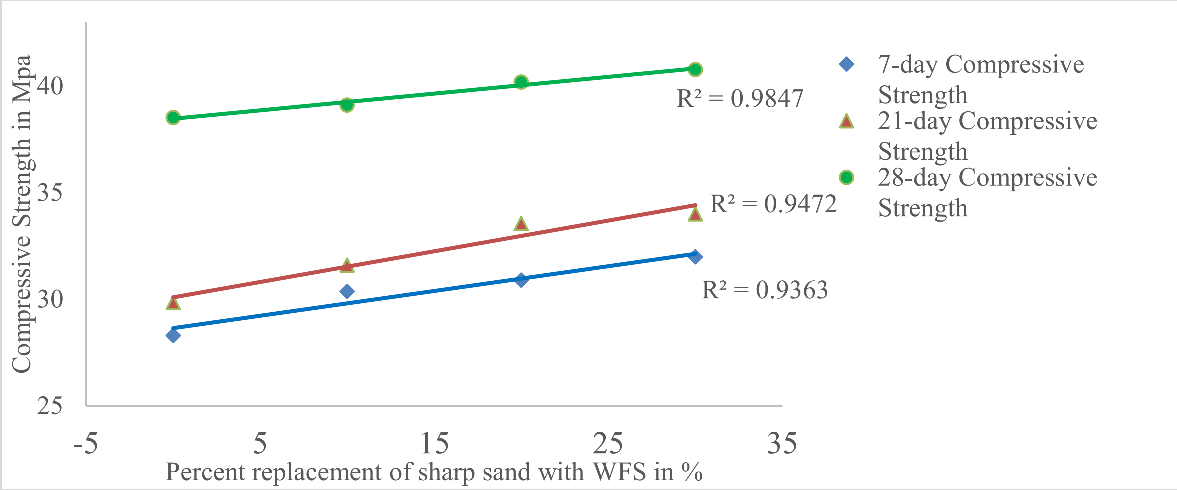

Figure 1: Relationship between compressive strength and percent replacement of sharp sand with WFS

Figure 2 shows the normalized compressive strength of concrete samples. The compressive strengths of the concrete samples containing 10, 20 and 30% of WFS (i.e. WFS-2, WFS-3 and WFS-4) were normalized against the control samples (WFS-1). As shown in Table 5 and Figure 2, WFS-2 have normalized compressive strengths of 107, 106, 102% at the 7th-day, 21st-day and 28th-day curing ages respectively while WFS-3 achieved normalized compressive strengths of 109, 112, 104% at the 7th-day, 21st-day and 28th-day curing ages respectively and also WFS-4 attained normalized compressive strengths of 113, 114, 106% at the 7th-day, 21st-day and 28th-day curing ages respectively. These demonstrate that strength gained by WFS-2, WFS-3 and WFS-4 rise with curing age and reached its peak at 21st-day curing age (except WFS-2 that has its peak of strength gained at 7th-day; there is no much difference between 107% and 106%). At the 28th-day curing age, it is obvious that strength gained had slow down across all concrete samples containing WFS. This could be because there has been a lower strength contribution from WFS owing to the existence of finer particles on the 28th-day but the compressive strengths from WFS-2 (10% WFS), WFS-3 (20% WFS) and WFS-4 (30%WFS) were still found to be higher than that of control samples. This observation agrees with what was reported by Martins et al. [4], Torres et al. [28], and Siddique et al. [3] wherein a marginal increase in compressive strength properties of concrete samples due to the replacement of fine aggregate with WFS was observed.

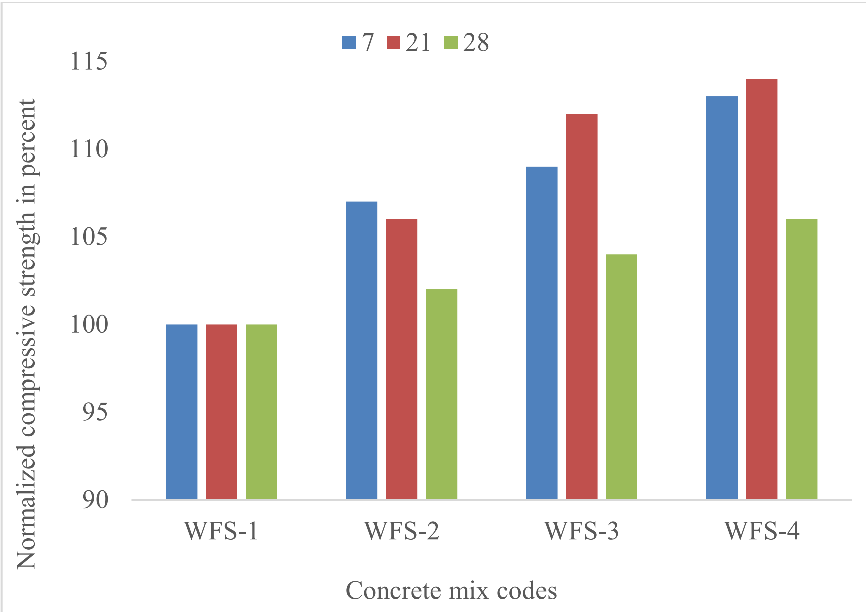

Figure 2: Normalized compressive strength in percent

4.2 Workability

The slump cone test method was used to evaluate the workability or consistency of fresh concrete samples as mostly used in construction sites. Table 6 shows slump values for fresh concrete samples as prepared based on the concrete mix design shown in Table 4. As can be seen in Table 6, an increase in the percent replacement of sharp sand with WFS in the mix design leads to an increase in slump values of fresh concrete samples. However, anomalous decrement in the slump value of

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the fresh concrete samples was noticed as per concrete sample containing 30% of WFS. This increment could best be regarded as an outlier and may be attributed to random experimental error.

Table 6: Workability of fresh concrete samples

Mix code	% replacement	Slump (mm)
WFS-1	0%	80
WFS-2	10%	105
WFS-3	20%	115
WFS-4	30%	100

Ordinarily, fine particles are known to increase the cohesion and enhance the finish-ability of concrete samples owing to the filling up of voids but the existence of fine particles are also known to lower the workability of concrete samples. However, the reverse is the case here in this research, which may be ascribed to a decrease in bond strength between cement paste and aggregate. The loss of adhesion between cement paste and aggregate could be a result of excess fine particles, which are known to weaken bond strength and consequently results to an increase in workability of concrete samples [44]. Similar trends were reported by Rashid and Nazir [14] and Etxeberria et al. [9].

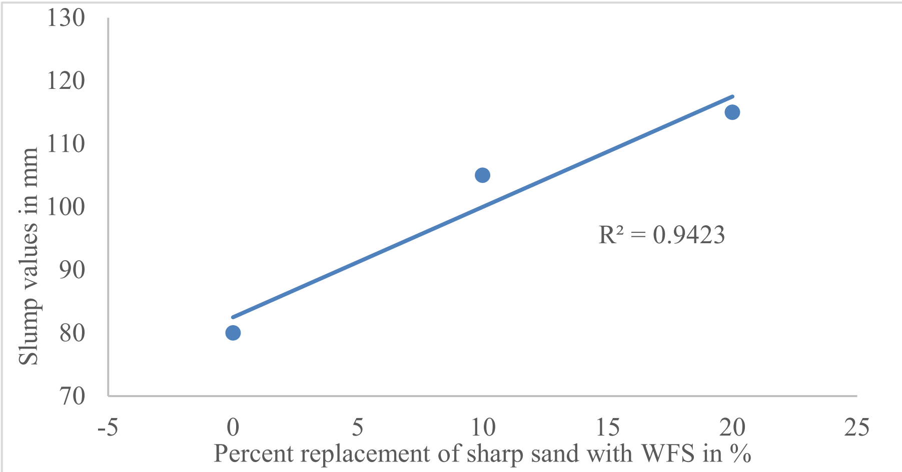

Figure 3: Relationship between slump values and percent replacement of sharp sand with WFS

Figure 3 shows a linear relationship between slump values and percent replacement of sharp sand with WFS (with exception of the outlier i.e. 30% and its correspondent slump value). A strong coefficient of determination, $R^2 = 0.9423$ was obtained for the relationship between slump values and percent replacement of sharp sand with WFS. Existed strong relationship between slump values and percent replacement of sharp sand with WFS is also an indicator that slump values will rise as more WFS is incorporated into concrete mix and vice-versa.

The relationship between slump values of fresh concrete samples containing 0-20% WFS and 28th-day compressive strength is shown in Figure 4. A linear correlation using Pearson's correlation method was used to develop a linear relationship between slump values and 28th-day compressive strength (with exception to 28th-day compressive strength and slump value for concrete containing 30% of WFS; 30%WFS been an outlier). A strong coefficient of determination, $R^2 = 0.8408$ was obtained from the correlation which indicates a strong relationship between the slump values and 28th-day compressive strengths. It can be understood from Figure 4 that as more WFS is incorporated, so thus the slump values increase (as explained under Figure 3) and an increase in slump values lead to an increase in 28th-day compressive strength and vice-versa. The above assertion also agreed with the explanation provided under Figure 1 which represents the relationship between percent of WFS and compressive strengths; a reduction in compressive strength is owing to a reduction in incorporated WFS and vice-versa. In similar research by Prabhu et al. [45], a coefficient of determination, $R^2 = 0.9143$ was obtained indicating a strong relationship between 28th-day compressive strengths and slump values.

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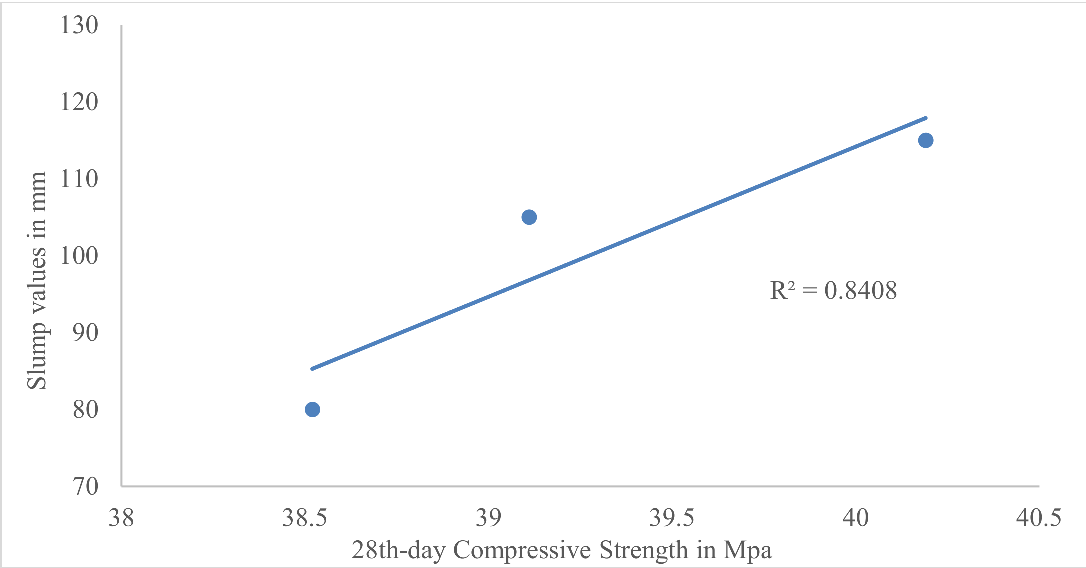

Figure 4: Relationship between Slump values and 28th-day compressive strength

4.3 Hardened Density

The densities of hardened concrete samples depend on the densities of aggregates and properties of other constituent materials of the concrete. The density of hardened concrete can have a profound effect on the self-weight of a structure. The density of concrete is also one of the important factors used in assessing the compressive strength of concrete [46].

Table 7: Hardened densities of concrete samples (kg/m^3)

Days	7days	21-days	28-days
WFS-1	2450	2450	2450
WFS-2	2290	2360	2490
WFS-3	2380	2370	2420
WFS-4	2440	2450	2450

Table 6 shows hardened densities for WFS-1, WFS-2, WFS-3 and WFS-4 at different curing ages (7th, 21st & 28th-day) to the nearest tens. WFS-1 has a hardened density of 2450kg/m^3 at 7th, 21st and 28th-day curing ages. WFS-2 have hardened densities of 2290kg/m^3, 2360kg/m^3, 2490kg/m^3 at curing ages of 7th, 21st and 28th-day respectively. WFS-3 attained a hardened density of 2380kg/m^3 at the 7th-day curing age, 2370kg/m^3 at the 21st-day curing age and 2420kg/m^3 at the 28th-day curing age respectively. WFS-4 achieved a hardened density of 2440, 2450 and 2450kg/m^3 at the 7th, 21st and at the 28th-day curing age respectively. It was expected that there would be a marginal increase in the densities of concrete samples as curing ages increase owing to activities related to hydration of un-hydrated cement paste [47]. As shown in Table 7, the reverse is the case especially for WFS-1, whose hardened densities remain the same for all the curing ages, this may due to poor/improper compaction during the placement of fresh concrete into the moulds. Poor/improper compaction results in a decrease in mass or weight of the concrete samples due to the formation of entrapped air voids [47]. Discrepancies in the hardened densities of concrete samples could have been a result of poor/improper compaction during concrete placement.

However, a close look at the densities of all the concrete samples across all curing ages shown that the densities of the concrete samples fall within the range of 2200 - 2600kg/m^3, which is considered as the density of a normal-weight concrete [31,47,48].

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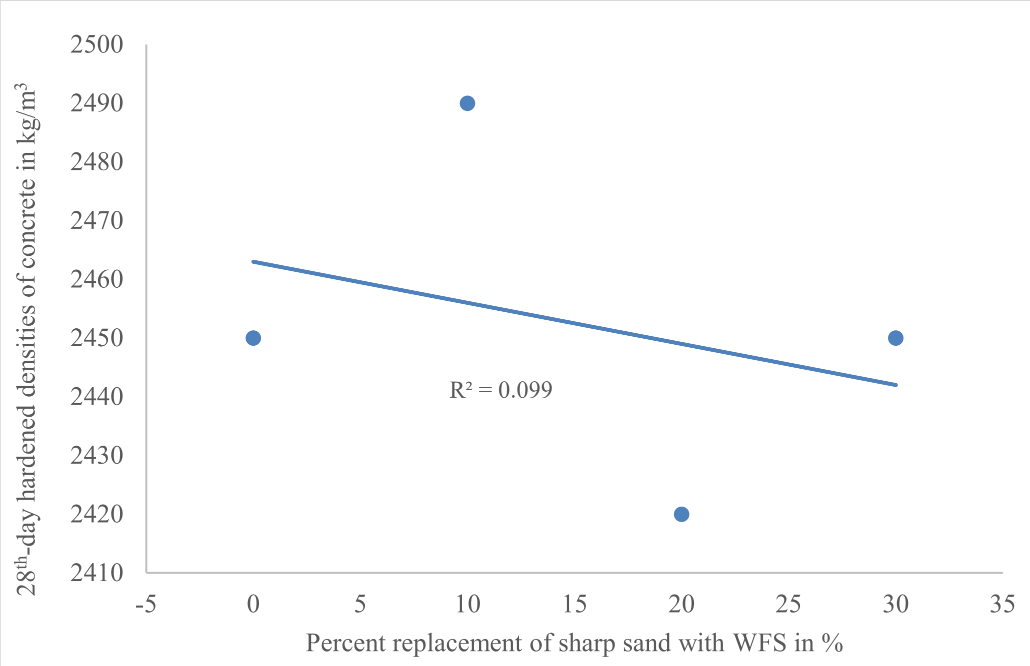

Figure 5: Relationship between the 28th-day hardened densities of concrete and percent replacement of sharp sand with WFS

The relationship between 28th-day hardened densities and percent replacement of sharp sand with WFS is presented in Figure 5. As shown in Figure 5, though the coefficient of determination, $R^2 = 0.099$ shown a weak relationship between the 28th-day hardened densities of concrete sample and percent replacement of sharp sand with WFS. This indicated that there are still possibilities that as more WFS is incorporated into concrete, there will be a reduction in hardened densities of concrete and also lesser WFS in concrete indicated higher hardened density for concrete. The reduction in the hardened density of concrete may be due to the lower density contribution from WFS, so higher WFS incorporated into concrete signifies lower hardened density and vice-versa [11,36]. This agrees with several previous researchers which found lower hardened densities in concrete samples been a result of higher incorporated WFS [7,11,30,36,49].

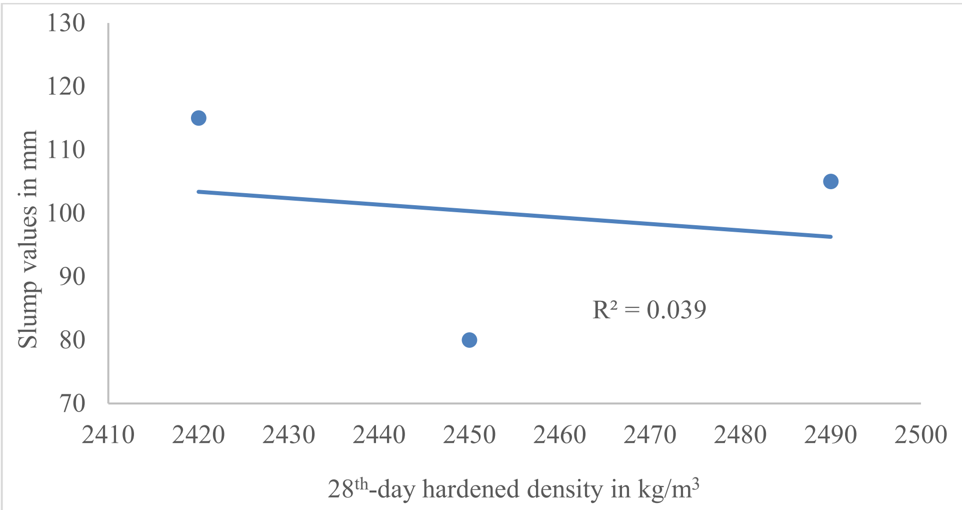

Figure 6: Relationship between Slump values and 28th-day hardened density of concrete samples

Figure 6 presents the relationship between slump values and 28th-day hardened densities (with exception to slump value and correspondent 28th-day hardened densities for concrete with 30% WFS; slump value for 30% of WFS been an outlier). As shown in Figure 6, a weak coefficient of determination, $R^2 = 0.039$ was obtained for correlation between slump values and 28th-day hardened densities as against strong correlation ($R^2 = 0.9959$) between slump loss and density of concrete obtained by Prabhu et al. [45]. Figure 6 shows that there is a tendency for an increase in slump values which is owing to a higher WFS content in concrete (as explained under Figure 3) could lead to a reduction in the 28th-day hardened densities of concrete samples and vice-versa [45]. Figure 5 also support the above assertion wherein a reduction in 28th-day hardened densities could be a result of a decrease in WFS been incorporated into the concrete mix and vice-versa.

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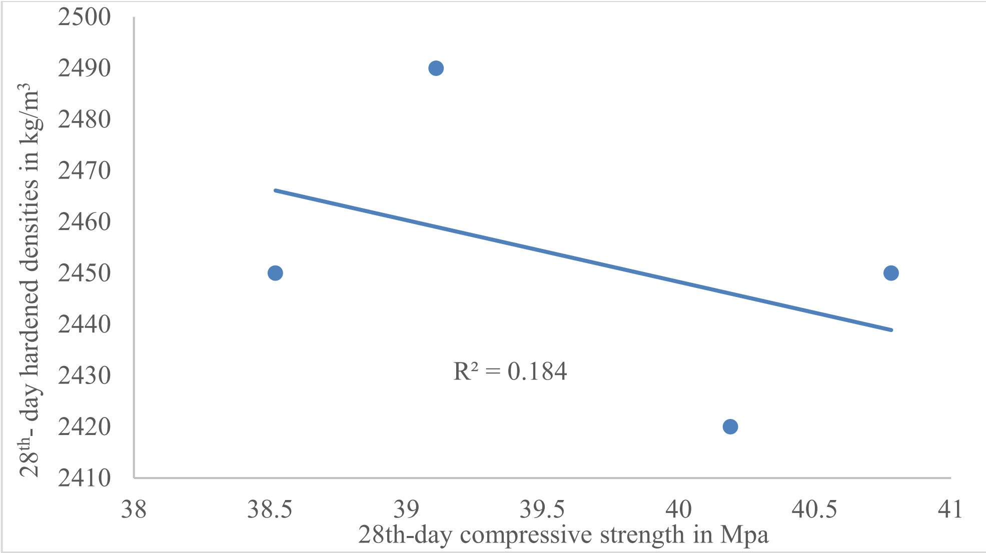

Figure 7: Relationship between 28th-day hardened densities and 28th-day compressive strengths.

Figure 7 represents the relationship between the 28th-day hardened densities and the 28th-day compressive strengths of concrete samples. A weak coefficient of determination, R^2 = 0.184 was obtained for the relationship between 28th-day hardened densities and 28th-day compressive strengths of concrete. Existed weak correlation (as shown in Figure 7) shows that there is a tendency that a reduction in 28th-day compressive strengths could be a result of an increase in hardened densities. Raheem et al. [50] also established a weak relationship between densities and compressive strengths while in contrast, Prabhu et al. [45] established a strong relationship between hardened densities and compressive strength. Higher hardened densities may be owing to lower WFS been incorporated into concrete mix and vice-versa (as explained under Figure 5) while lower compressive strengths could be a result of lower WFS been incorporated into concrete mix and vice-versa (as explained under Figure 1).

5. CONCLUSION

The following conclusions can be extracted from this empirical work;

Compressive strength of concrete samples rises with an increase in the amount of WFS incorporated into the concrete mix. The strength gained reached its peak at the 21st-day curing ages (with exception of the concrete sample containing 10%WFS i.e. WFS-2) for all concrete mixes containing WFS and only slight increment was noticed at the 28th-day curing age compared to the control. There existed a strong coefficient of determination, R^2 = 0.9847, 0.9472 and 0.9363 at 28th, 21st and 7th-day curing ages respectively.

Slump values for fresh concrete samples rise with an increase in the WFS incorporated into mix design with exception of the samples containing 30% of WFS whose slump value decrease slightly as compared to slump value for the fresh concrete sample containing 10% of WFS. Slump value for fresh concrete containing 30% of WFS was considered as an outlier and a random experimental error. There existed a strong correlation (R^2 = 0.9732) between slump values and percent replacement of fine aggregate with WFS (with exception of slump value for 30% WFS). A strong coefficient of determination, R^2 = 0.8408 was also obtained for the relationship between slump values and 28th-day compressive strengths (with exception of slump value for 30% WFS and its corresponding 28th-day compressive strength).

The dry hardened densities for concrete samples fall within the range of 2200 – 2600kg/m^3, which is considered as the density of a normal-weight concrete. There is a weak correlation between hardened density and percent replacement of fine aggregate with WFS. The relationship shows that there is a tendency for an increase in hardened density, which could be a result of lower WFS been incorporated into the concrete mix. The correlation between hardened densities and compressive strength also exhibits a weak relationship.

Up to 30%WFS could be used as a partial replacement for fine aggregate in plain concrete production without any adverse effect on the compressive strength.

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