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Utilisation of Waste Shea Nutshell Fine-Grained Particles to Enhance Strength and Durability Behaviour of Concrete

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ABSTRACT
Shea nutshells possess properties that stabilise soil enough to resist water penetration. It is a waste material and incorporating it as an additive material in concrete will be a means by which it can be recycled. With this projection, the study incorporated shea nutshell particles (SSP) as fine aggregates in concrete. The aim was to determine their influence on strength and durability properties. Fine aggregates were partially replaced with 0%, 10%, 20%, 30%, and 40% SSP based on the weight of the aggregate, and labelled as A0, S10, S20, S30 and S40 respectively. Concrete cubes of size 150 mm and cylinders of diameter 150 mm and height of 300 mm were prepared and cured for 7, 14, 28, and 90 days. The concrete was tested for density, compressive strength, split tensile strength, water absorption, and sulphate attack. The inclusion of the SSP did not improve the compressive and split tensile strengths. However, water absorption and sulphate attack decreased with further addition. Though, strength properties did not appreciate, values at 10%, 20% and 30% additions in 28 and 90 days satisfied the 28 days minimum requirement of 25 N/mm2. Hence, the study recommends the use of SSP in concrete production up to 30%.
Keywords: Shea nutshell, compressive strength, split tensile strength, water absorption, sulphate attack.

1 INTRODUCTION

Provision of adequate and suitable housing for human habitation has been a problem for the human race since creation. Initially, the solution to this problem was found by primitive man in the form of natural shelters such as caves. Later in history, both natural and man-made materials were used to provide man-made housing for human habitation (Al-Sakaf, 2009). Presently, with the advent of technology, modern materials and products such as concrete, sandcrete blocks, clay bricks, timber, steel, plastics and aluminium are used for housing construction (Al-Sakaf, 2009; Yalley & Badu, 2018). Essentially, concrete is a composite product that consists of cement, aggregates, water and admixture(s). From literature it has been established that concrete is the most commonly used construction material, and is second to water as the most consumed substance with an annual estimated consumption rate of over 6 billion cubic metres (Amankwah, Bediako, & Kankam, 2015). This massive use of concrete largely affect the overall cost of housing provision, and also lead to environmental problems as a result of aggregate extraction (Amankwah, Bediako, & Kankam, 2015; Botchway & Masoperh, 2019). Aggregates form the bulk of concrete constituting of about 75–80% of the total volume (Sankh et al., 2014). Traditionally, aggregates have been readily available at economic prices and of qualities to suit concrete and mortar production. But the continued extensive extraction and use of aggregates from natural sources has been questioned, because of the depletion of quality primary aggregates and greater awareness of environmental protection (Rao et al., 2015). The excessive quarrying, mining and winning of aggregates for concrete production leads to the depletion of natural resources and directly causes negative impacts on the ecological environment, such as landscape/eco-system destruction and pollution (Blankendaal, Schuur, & Voordijk, 2014). Furthermore, the eminent shortage of conventional aggregates for construction purposes has also been realised globally. For instance, it has been reported that India (Sankh et al., 2014) and other countries around the world (Bhange, Awchat, & Goswami, 2019) are facing shortage of good quality aggregates, because the deposits are being used up thereby causing serious threat to the construction industry and the environment. It has also been reported that fine aggregate is becoming a very costly material in modern times, because of its demand for concrete and mortar formulation in the construction industry (Sankh et al., 2014).

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Similar concerns of the shortage of conventional aggregates, and its negative extraction impact on the environment have also been raised in Africa, especially in Nigeria (Ibrahim et al., 2021; Olowu et al., 2021). The Ghana Mineral Income Investment Report also indicates that Ghana risks importing aggregates if the rapid encroachment on quarry lands and sand deposits, and damages caused to arable lands through the extraction of conventional aggregates is not stopped (Ghana Mineral Income Report, 2022).

The high demand of aggregates from natural sources due to rapid urbanisation, and the disposal problem of agricultural wastes in developed countries have created opportunities for use of agro-wastes in the construction industry. The prospective shortage of natural aggregates and the environmental impact due to their extraction are some of the driving forces promoting the use of agricultural waste particles as aggregates for lightweight concrete and mortar formulation (Ibrahim et al., 2021). Research findings have shown that 75% of natural aggregates can be replaced by using sustainable materials derived from agricultural nutshells (Sankh et al., 2014; Dewanshu & Kalurkar, 2013). Agricultural-based nutshells are already being used in concrete production as alternatives for aggregates (Prusty, Patro, & Basarkar, 2016; He, Kawasaki, & Achal, 2020). For instance, research findings have showed that oyster shell particles can replace up to 5% fine aggregate in concrete production with improved strength properties over the control sample (Yang, Yi, & Leem, 2005; Kuo et al., 2013). In contrast, some studies also found that oyster nutshell particles used as partial replacement for fine aggregate decreased strength properties with further addition compared to the control sample (Rao et al., 2015). Again, both decrease and increase in strength properties with further addition of sugarcane bagasse particles as partial replacement for fine aggregates over the control concrete samples have also been reported (Modani & Vyawahare, 2013; Shafana & Verkatasubramani, 2014). Some recent studies reported a decrease in water absorption percentages from 1.2% to 0.73% over the control concrete sample for walnutshell particles used as partial replacement for fine aggregates (Kamal et al., 2017). Similarly, a decrease of water absorption percentages from 2.67% to 2.24% over the control concrete samples for groundnutshell particles used as partial replacement for fine aggregates were also reported (Buari et al., 2019).

The potential use of shea nutshells for concrete and bricks production has been investigated and documented. For instance, one study has demonstrated that shea nutshell ash could be used as cementitious material for concrete production owing to its pozzolanic reactive properties (Zievie, Yalley, & Saan, 2016; Tsado et al., 2014). Again, shea nutshell fine-grained particles had also been used as stabiliser for the production of fired clay bricks (Adazabra, Viruthagiri, & Kannan, 2017). However, the use of the shea nut fine-grained particles as fine aggregates substitutes in concrete production has not been explored or investigated. This study, for the purpose of concrete cost reduction and environmental sustainability evaluates the influence of shea nutshell fine-grained particles as partial replacement for fine aggregates on the workability, density, compressive strength, split tensile strength, water absorption, and sulphate attack behaviour of concrete.

Reports from literature showed that Ghana is the fourth leading producer of shea nut worldwide, at about 200,000 metric tons annually, and processes 15,000 tons of the nuts into butter for the international market while 70,000 metric tons are processed for the local market (SNV Netherland Development Organization, 2011). Shea trees occupy about 77,670 km2 of land area in the northern and middle belt of Ghana and produces over 300,000 metric tons of the nutshells as wastes (Adazabra, Viruthagiri, & Kannan, 2017; Naamgmenyele et al., 2023). With the abundance of shea trees and high annual processing of shea nut into butter and nutshell waste generation, it is obvious that the shea nutshells will be in abundance, and as such, cost savings in their use as lightweight aggregate in concrete production will be achieved.

2 MATERIALS AND METHODS

2.1 Materials

The materials used in the production of the concrete specimens in this study were cement, water, shea nutshell particles (SSP), fine aggregates and granite stones.

2.1.1 Cement

Ordinary Portland cement grade 32N conforming to BS EN 197-1, 2011 specifications (BS EN 197 – 1, 2011), produced locally by Ghana Cement Company Limited (GHACEM), was used.

2.1.2 Water

Clean tap water free from chemicals and impurities, supplied to the laboratory by the Ghana Water Company Limited was used to mix the constituent materials.

2.1.3 Shea Nutshells Particles (SSP)

The shea nutshells were sourced from a local shea butter extraction waste dumping site in Dokpong, Wa Municipality, Ghana, that conformed to BS EN 12620, 2019 requirements (BS EN 12620, 2019) were used.

2.1.4 Aggregates

Good quality river sand and crushed granite stones with an average size of 10 mm, conforming to BS EN 12620, 2019 (BS EN 12620, 2019), were used.

2.2 Testing Methods and Procedures

2.2.1 Shea Nutshell Preparation

Shea nutshells (Figure 1) were preconditioned by washing to remove all dirt and loose materials. They were then air-dried in the laboratory for three days before they were broken into pieces and manually ground into small pieces using a hammer and a local grinding stone, and then sieved through a 4.750 mm BS sieve. The shea nutshell fine-grained particles (SSP) that passed through the 4.750 mm sieve (Figure 2) were then tested for specific gravity, water absorption, and fineness.

Figure 1: Shea nutshells

Figure 2: Shea nutshell particles (SSP)

2.2.2 Aggregates Suitability Assessment

The aggregates were tested in accordance with the BS EN 12620, 2019 specifications (BS EN 12620, 2019) for the following properties: organic impurities, specific gravity, water absorption, fineness modulus, grain size distribution, abrasion strength, flakiness, and elongation indices.

2.2.3 Mix Design

The fine aggregate was replaced with shea nutshell fine-grained particles by weight of fine aggregate and denoted as A0 for the control sample and Sy for samples with y% of shea nutshell fine-grained particles. Concrete properties improvement depends on the durability of the aggregates. Previous researched works have shown that up to 75% of natural aggregate can be replaced by agro-based waste nutshell particles for lightweight concrete production. In this study, the fine aggregate content was replaced with up to 40% shea nutshell particles because of their lower unit weight due to lower specific gravity (2.47) compared to that of the fine aggregate used. Based on trial mixes and with a targeted cube strength of 25 N/mm2 a binder-to-aggregate ratio of 1:2:4/0.55 (binder: sand: stones/water/binder ratio) was used to prepare the specimens (See Figure 1). Concrete materials were mixed using a concrete mixer. The fine aggregates and cement were first mixed in a dry state to form a uniform mixture before the granite stones were added. Drinkable water was added in two phases and mixed with a uniform colour and consistency. Twelve cubes of size 150 mm for density, compressive strength, water absorption and sulphate attack and twelve cylinders of size 150 mm and height of 300 mm were produced for each substitution level. In all 60 number cubes and 15 number cylinders were cast for the study.

Table 1: Mix design for strength and durability tests.

Sample	Cement (%)	Stones (%)	Sand (%)	Shea nutshell (%)	W/C ratio
A_0	100	100	100	0	0.55
S_{10}	100	100	90	10	0.55
S_{20}	100	100	80	20	0.55
S_{30}	100	100	70	30	0.55
S_{40}	100	100	60	40	0.50

2.2.5 Test Procedures

The slump method, using the conical mould was used to measure the concrete mix workability in line with BS EN 12350-2, 2019 (BS EN 12350-2, 2019). This method was employed because of its suitability for the measurement of medium to high workability (25 – 125 mm slump) using stones of up to 30 mm nominal maximum size.

For the strength and durability properties tests, the test specimens were cast and cured in water for 7, 14, 28, and 90 days. The strength properties tested were density, compressive strength, and split tensile strengths, and the durability properties evaluated were water absorption and sulphate attack. The compressive strength test was performed by steady application of load on the cubes until failure using a compression testing machine (Figure 3).

Again, the split tensile strength test was performed by applying a gradual load using a universal compression testing machine (Figure 3). For the water absorption test, the cured cubes were dried to constant weight (M1) and then immersed in water for 24 hours. The cubes were removed and, cleaned, and their weights were measured again (M2). The differences in weight before and after immersion were determined, and the percentage of water absorption was calculated. The sulphate attack test was also performed after the cubes were cured in clean water for 28 days and dried to constant weights (M1). The cubes were cured again in a water tank containing 5% magnesium sulphate (MgSO4) solution. The cubes were weighed again after removal from the immersed solution (M2), and the degree of sulphate attack was measured by the percentage loss of weight at 7, 14, 28, and 90 days of immersion.

The data obtained from the various experimental studies were analysed based on descriptive statistics using the Statistical Package for Social Sciences Version 16.0. Tables and graphs displaying the values and means for the shea nutshell fine-grained content specimens and curing durations are used to explain the results of the analysis.

Figure 3: Cube and cylinder being crushed.

3 RESULTS AND DISCUSSIONS

3.1 Materials Properties

The physical properties of the shea nutshell fine-grained particles (SSP) and aggregates used are presented in Table 2. The grading of the shea nutshell fine-grained particles is good for concrete production, as 35.4% of its particles size pass through the 0.600mm sieve. The shea nutshell particles recorded a bulk specific gravity value of 2.47 and a lower water absorption percentage value of 1.4%. The aggregate properties were also within the established BS EN 12620, 2019 (BS EN 12620, 2019) suitability limits.

The shea nutshell fine-grained particle acid properties are also presented in Table 3. From the mean percentage values, the shea nutshell fine-grained particles possessed mild acid properties. According to studies, this mild acid content of the shea nutshell particles mixes easily with damped soil and stabilises it enough to resist water penetration in shea nutshell dumping grounds (Adazabra, Viruthagiri, & Kannan, 2017).

Table 2: Summary of materials properties

Property	Shea nutshell	Sand	Stones	BS EN Ref
Bulk s. g.	2.47	2.60	2.56	2.38 – 2.75
Apparent s. g.	--	--	2.65	2.38 – 2.75
Water absorption	1.41	14%	2.3%	≤ 20%
Fineness modulus	3.0	3.2	6.60	2.0 – 8.0
Abrasion strength	--	--	26%	≤ 40%
Flakiness index	--	--	12.7%	≥ 15%
Elongation index	--	--	9.7%	≥ 10%

Table 3: Acid composition of crude shea and fine-grained shell particles

Fatty acid	Palmite	Stearic	Oleic	Linoleic
Mean value (%)	3.6	44.4	42.4	5.9

3.2 Workability

From the results shown in Table 4 and Figure 4, concrete mixes with shea nutshell fine-grained particle (SSP) content exhibited a steady increase in slump up to 147 mm at the 40% SSP (S_{40}) replacement level, more than the 114 mm recorded by the normal mix. This outcome is consistent with findings of a previous study where the slump values of cashew nutshell fine-grained particle concrete mix increased from 30 mm to 70 mm as the substitution of fine aggregate increased from 0% to 20% (Oyebisi, Igba, & Oniyide, 2019).

Table 4: Effect of shea nutshell particles (SSP) on slump

Mix	Cement (%)	Stones (%)	Sand (%)	Nutshell (%)	w/b ratio	Slump height (mm)	Collapsed height (mm)	Degree of workability
A_0	100	100	100	0	0.55	114	186	High
S_{10}	100	100	90	10	0.55	119	181	High
S_{20}	100	100	80	20	0.55	123	177	High
S_{30}	100	100	70	30	0.55	131	169	High
S_{40}	100	100	60	40	0.55	147	153	High

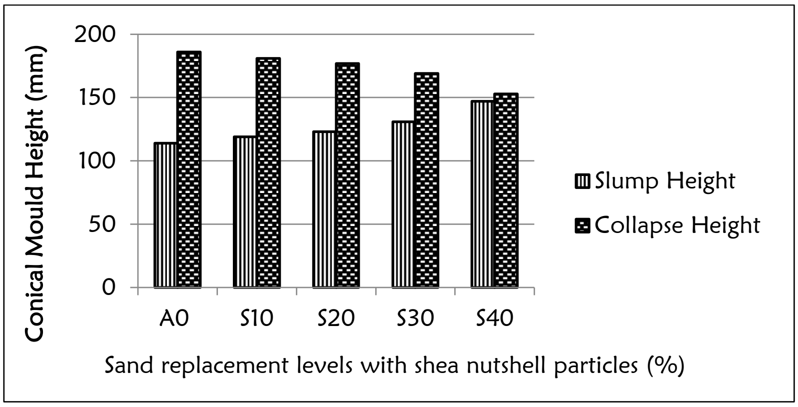

Figure 4: Slump behaviour of shea nutshell particles concrete mix.

3.3 Density

The result of the density test for the cubes is presented in Figure 5. It is observed that density decreased with further replacement of fine aggregate with shea nutshell fine-grained particles. In 7 days the control cubes obtained the highest density of 2100kg/m^3 and decreased to 1995kg/m^3 for the 40% substitution level. In 90 days, the control cube density rose to 2266kg/m^3 representing 7.9% increase whereas experimental cubes with 40% SSP obtained a density of 2190kg/m^3 representing 9.8% increase. The marginal reduction trend of density for the experimental cubes compared to the control and increase with longer curing days implies that the inclusion of the shea nutshell particles will not have a high significant effect on density. The reduction of density was expected because the shea nutshell fine-grained particles displayed lower unit weight due to lower specific gravity (2.47) compared to that of the fine aggregate (2.60), and the formation of voids due to the particle size and shape. In a similar study using walnutshell fine-grained particles, a steady and marginally reduction of density from 2050kg/m^3 for the control to 1850kg/m^3 at the 25% replacement level was observed (Cheng, Liu, & Chen, 2017). The decrease of density was attributed to the formation of more voids in the mixture through the irregular shape of the walnutshell fine-grained particles.

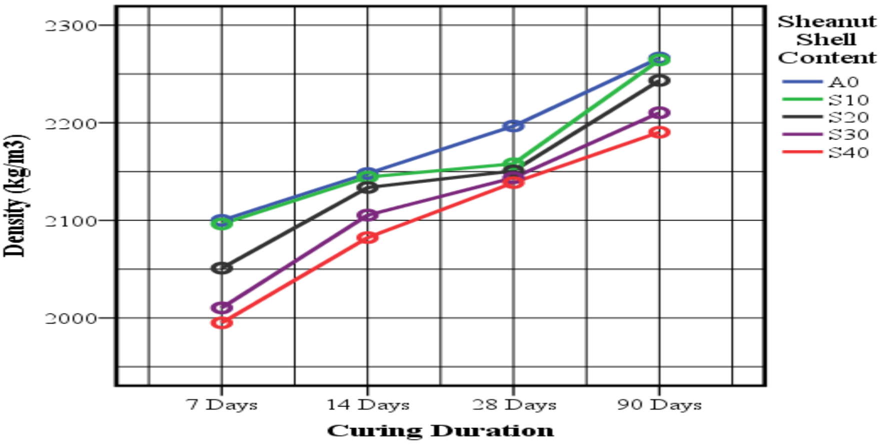

Figure 5: Variation of density with SSP content and curing duration

3.4 Compressive Strength

The compressive strength declined steadily with further addition of the shea nutshell fine-grained particles (SSP) in all curing durations for the experimental cubes, as shown in Figure 6. However, it exhibited a steady increase as the curing duration was extended. For example, in 7 days the cubes without shea nutshell particles recorded a compressive strength value of 16.38 N/mm^2 and this dropped to 14.17 N/mm^2 at the 40% shea nutshell fine-grained particle content. In 90 days, the cubes without shea nutshell particles compressive strength increased to 32.62 N/mm^2 whereas the 40% shea nutshell particles content cubes compressive strength also increased to 27.50 N/mm^2. This reduction of compressive strength with increased shea nutshell particles content and appreciation with extended curing age can be attributed to the smaller unit weight of the shea nutshell particles owing to the lower specific gravity (2.47) compared to that of the fine aggregate (2.60) coupled with the development of more pores owing to the particle shape. Again, more particles (35.4%) passed through the 0.600 mm sieve, which is responsible for the substantial increase in strength as the curing period is prolonged.

This trend of the compressive strength result is in agreement with those of earlier studies. Fine aggregates were replaced with coconut shell and oyster shell particles of up to 20%. It was noticed that the control cube achieved the highest compressive strength, followed by a gradual decreased to the 20% replacement level (Rao et al., 2015; Yang, Yi, & Leem, 2005; Kuo et al., 2013) Notwithstanding, the marginal and steady reduction in compressive strength with further addition of the shea nutshell particles, the compressive strength values recorded at all substitution levels at 28 and 90 days satisfied the 28 days curing age minimum compressive strength of 25N/mm^2 recommended in the BS EN 12390-3 (2019) for normal concrete.

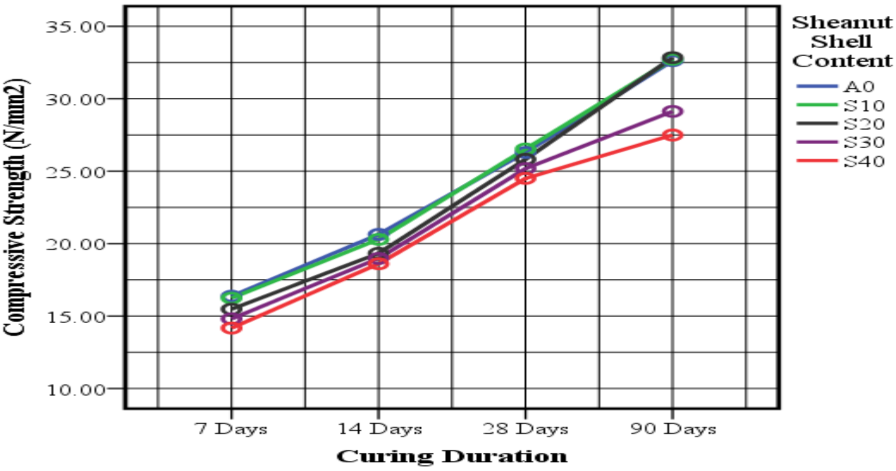

Figure 6: Variation of compressive strength with SSP content and curing duration

3.5 Split Tensile Strength

Figure 7 presents the results of the concrete cylinders split tensile strength crushing test carried out. The split tensile strength also exhibited a steady drop from the control cylinders to the experimental concrete cylinders as the shea nutshell fine-grained particle (SSP) content increased, and a consistent appreciation as the curing period was extended. Concrete cylinders without shea nutshell particles content recorded a split tensile strength of 2.59 N/mm^2 in 7 days and increased to 5.19 N/mm^2 after 90 days. In a similar trend, the 40% shea nutshell particles content concrete cylinders recorded a split tensile strength value of 2.26 N/mm^2 in 7 days and increased to 4.40 N/mm^2 in 90 days curing duration. This decrease of strength with increased shea nutshell fine-grained particles content and increase in split tensile strength with prolonged curing durations once again, is linked to the smaller unit weight of the shea nutshell particles due to the lower specific gravity (2.47) compared to that of the fine aggregate (2.60) coupled with the development of more pores due to the particle shape. Again, more particles (35.4%) passed through the 0.600 mm sieve, which is responsible for the substantial increase in strength as the curing duration is prolonged. This result is in agreement with those of earlier studies. Oyster shell and sugarcane bagasse waste fine-grained particles were used as partial replacement for fine aggregates (Yang, Yi, & Leem, 2005; Modani & Vyawahare, 2013; Shafana & Verkatasubramani, 2014). It was found that the split tensile strength of concrete cylinders dropped with further addition of the oyster shell and sugarcane bagasse waste particles as compared to the control concrete cylinders and increased as the curing age was extended, which fits perfectly well with the current result recorded.

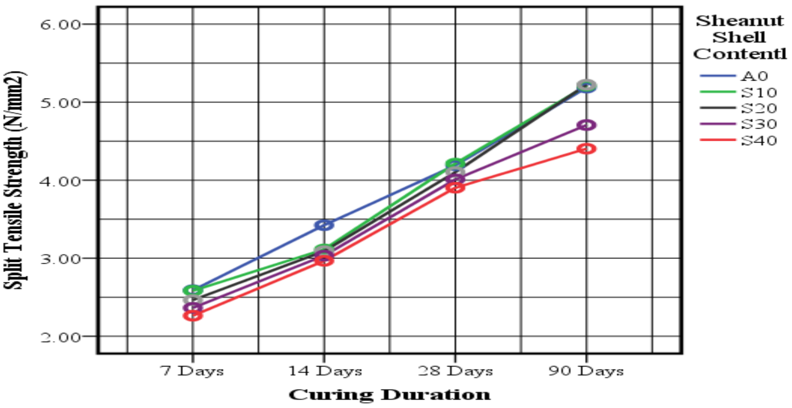

Figure 7: Variation of split tensile strength with SSP content and curing duration.

Analysis of variance (ANOVA) test results for the compressive strength values obtained are given in Table 5. The results showed a significant effect of the two factors on the compressive strength behaviour. P-values of 0.000 were generated for both factors, that is, curing duration, F(1,40) = 2032.774, $p < 0.05$, and shea nutshell particles, F(1,40) = 53.820, $p < 0.05$. It can be noticed that curing duration had more influence to the compressive strength development than the shea nutshell fine-grained particles. From earlier results on descriptive statistics, this was anticipated. It is also noticed that the coefficient of correlation, $R^2 = 0.994$ is higher than 0.95. Hence, it is presumed that the model is a statistical fit to predict the compressive strength data because 99.4% of the variability can be explained by the model. This implies that the equation was valid for up to 40% shea nutshell particles content after 90 days of curing. To evaluate the contribution levels of curing duration and shea nutshell fine-grained particles on the split tensile strength data of the concrete cylinders, an analysis of variance (ANOVA) test was also performed at a significance level of 0.05. The statistical test results presented in Table 6 produced P-values of 0.000 for both curing durations, F(1,40) = 997.723, $p < 0.05$, shea nutshell particles, F(1,40) = 24.478, $p < 0.05$. Because the variance ratio (F) value for curing duration is much greater (997.723) than that of the shea nutshell fine-grained particle (24.478), this indicates that the curing duration contributed heavily to the split tensile strength data than the shea nutshell particles content. Notwithstanding, the R-square statistic generated by the model indicates that 99.2% ($R^2 = 0.992$) of the variation in the split tensile strength behaviour can be linked to the curing duration and shea nutshell particles inclusion. With this high explanatory power of the model, the reliability of the data could be seen as excellent and valid up to the 40% shea nutshell fine-grained particle replacement level after 90 days of curing.

Table 5: ANOVA analysis of compressive strength data (N/mm^2)

Source	Sum of squares	df	Mean square	F-value	P-value
Model	2198.578^a	19	115.715	336.611	0.000
Intercept	31478.800	1	31478.800	91571.138	0.000
Duration	2096.379	3	698.793	2032.774	0.000
Shell	74.005	4	18.501	53.820	0.000
Duration & shell	28.193	12	2.349	6.835	0.000
Error	13.751	40	0.344		
Total	33691.128	60			
Corrected total	2212.328	59			

a. $R^2 = 0.994$ (Adjusted $R^2 = 0.991$)

Table 6: ANOVA analysis of split tensile strength data (N/mm^2)

Source	Sum of squares	df	Mean square	F-value	P-value
Model	56.132^a	19	2.954	164.815	0.000
Intercept	800.226	1	800.226	44643.026	0.000
Duration	53.653	3	17.884	997.723	0.000
Shell	1.755	4	0.439	24.478	0.000
Duration & shell	0.724	12	0.060	3.367	0.002
Error	0.717	40	0.018		
Total	857.075	60			
Corrected total	56.849	59			

a. $R^2 = 0.987$ (Adjusted $R^2 = 0.981$)

Again, a correlation analysis between the compressive strength and split tensile strength of concrete cubes and cylinders was conducted, and the results are given in Figure 8. It appears from the results that there is a very good correlation between the compressive strength and split tensile strength of the concrete cubes and cylinders, with a coefficient of determination (R^2) of 0.992. The two strength properties – compressive strength and split tensile strength, are positively influenced by the inclusion of shea nutshell particles (SSP) and curing duration.

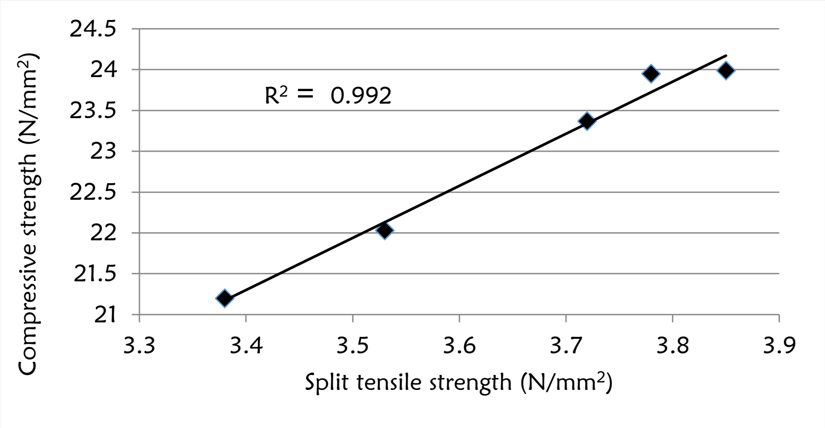

Figure 8: Relationship between compressive strength and tensile strength

3.6 Water Absorption

The results for water absorption by concrete cubes showed a steady and significant reduction percentage values by the experimental cubes, with further addition of the shea nutshell particles (SSP) as compared to the control cubes (Figure 9). The absorption of water also reduced as the curing period increased. This reduced water absorption trend might have been influenced by the mild acid properties of the shea nutshell particles which repel water penetration through the pores due to capillary action. Again, it can also be attributed to the fine grinding of the shea nutshell particle, which increased their filling capacity thereby reducing permeability as the SSP percentage inclusion and curing duration is increased. In 7 days, the control cube water absorption percentage was 12.11% and decreased to 8.9% for the 30% SSP content cubes, representing 36% decrease. The 40% SSP content cubes obtained an absorption percentage value of 8.22% representing 8% decreased from the 30% SSP content cubes. In 90 days the 30% SSP content cubes water absorption percentage was 7.10%, representing 25% decrease from the 7 days. The percentage drop beyond the 30% SSP content cubes to the 40% SSP content cubes is minimal. This result confirms the findings of earlier studies that used ago-based nutshell particles as a fine aggregate replacement. In a recent study using walnutshell and ground nutshell fine-grained particles as a fine aggregate replacement (Kamal et al., 2017; Buari et al., 2019), a decrease in water absorption percentage from 1.20% to 0.73%, and 2.67% to 2.24%, as the replacement level increase to 20% and 40% addition respectively was observed.

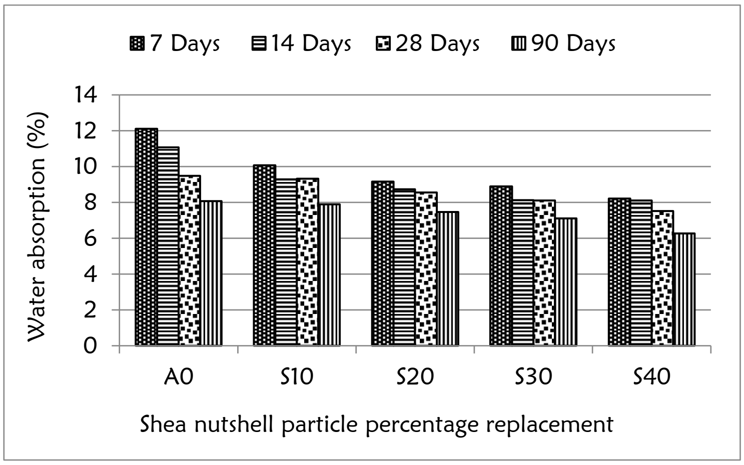

Figure 9: Variation of water absorption with SSP content and curing duration.

In addition to the descriptive statistics of water absorption percentage values, an analysis of variance (ANOVA) test was performed to determine the level of contribution of curing duration and shea nutshell fine-grained particle content to the water absorption behaviour. The test results as given in Table 9, generated a p-value of 0.000 for curing duration, $F(1,40) = 39.467$, $p < 0.05$ and a p-value of 0.000 for the shea nutshell particles content as well, F (1,40) = 34.680, $p < 0.05$. This implies that there is a statistically significant influence of both curing duration and shea nutshell particle content to the water absorption data. Again, the R-square value of ($R^2 = 0.875$) shows that 87.5% of the variation in the water absorption percentage data can be explained by the model. This suggests that the incorporation of the shea nutshell particles as partial replacement of fine aggregate resulted in a significant reduction in the water absorption percentage at all replacement levels in all curing durations.

Table 9: ANOVA analysis of water absorption data (%)

Source	Sum of squares	df	Mean square	F-value	P-value
Model	103.530[a]	19	5.449	14.776	0.000
Intercept	4519.676	1	4519.676	12256.361	0.000
Duration	43.662	3	14.554	39.467	0.000
Shell	51.154	4	12.789	34.680	0.000
Duration & shell	8.715	12	0.726	1.969	0.054
Error	14.750	40	0.369		
Total	4637.957	60			
Corrected total	118.281	59			

a. $R^2 = 0.875$ (Adjusted $R^2 = 0.816$)

3.7 Sulphate Attack

Figure 10 shows the sulphate attack behaviour of the experimental concrete cubes, as a result of weight loss percentage. From the result, sulphate attack minimally increased with increasing shea nutshell fine-grained particle content and prolonged curing duration. It was evidenced that concrete cubes recorded lower weight losses in 7 and 14 days immersion periods. Weight loss then increased steadily with increasing shea nutshell particle content and immersion duration up to the 40% replacement level and in 90 days. This low weight loss trend as a result of sulphate attack was expected because the shea nutshell particles possessed some elements of mild acid properties. These properties initially slowed down the absorption rate of the cubes immersed in the magnesium sulphate solution in the 7 and 14 days up to 30% SSP replacement level. However, it is evidenced that sulphate attack as a result of weight loss was high in 28 and 90 days in all replacement levels because of longer immersion and released of acid elements within the SSP fine-grains in the cubes. This implies that, the more the addition of the SSP, and the longer the immersion of the cube in the solution, the higher the sulphate attack. This trend has also been observed by other researchers who used agricultural waste nutshell particles as fine aggregates. Studies found that oyster shell particles gradually increased weight loss in concrete cubes from an average of 1.17% to 4.82%, as the fine aggregate substitution and cube immersion duration in the solution increased (Kuo et al., 2013; Yang, Kim, Park, & Yi, 2010).

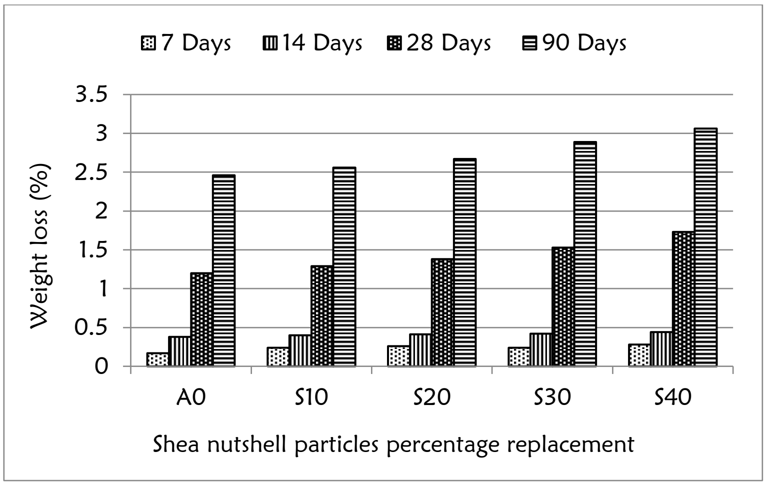

Figure 10: Variation of sulphate attack with SSP content and curing duration.

4 CONCLUSIONS

The effect of shea nutshell fine-grained particle (SSP) on concrete workability, density, compressive strength, split tensile strength and sulphate attack has been studied. Based on the results from the experimental investigation, the following conclusions and recommendations can be made:

1. Increasing content of shea nutshell fine-grained particle (SSP) progressively increased the workability of the mix, and because the values are less than 150 mm maximum prescribed by the standards, their use can be beneficial in situations where high workability is required.

2. Though, density, compressive strength, and split tensile strength of the experimental samples reduced with further addition of the shea nutshell fine-grained particle (SSP) compared to the control samples, values up to 30% addition met the minimum 28 days compressive strength of 25.0 N/mm^2 for normal concrete in the 28 and 90 days curing ages.
3. Shea nutshell fine-grained content of up to 30% significantly reduced water absorption in all curing durations, its use can be advantageous in damped and water-logged grounds.
4. The cubes exhibited less sulphate attack up to 30% SSP content in short-term immersion owing to low absorption. However, attack increased in long-term immersion because of greater absorption from the outside environment (sulphate solution) and released of the acid elements within the SSP content cubes. Hence, their use in damped related sulphate grounds will not be beneficial.

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