The Effects of Superplasticizer and Coarse Aggregate Sizes on The Mechanical Properties of Concrete and Its Drying Shrinkage

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ABSTRACT

This study presents the effects of superplasticizer and varying aggregate size on the mechanical properties of concrete. Six concrete sample groups were prepared using a prescribed mix ratio of 1:1½:3, with three aggregate sizes of 12.5 mm, 16 mm, and 19 mm, with and without a superplasticizer (Conplast 430). The compressive strength was determined on cubes of 150 x 150 x 150 mm, with samples cured for 7, 21, and 28 days, while the flexural strength was determined on unreinforced beams of 150 x 150 x 750 mm, with samples cured for 28 and 56 days. To evaluate drying shrinkage, 100 x 100 x 500 mm short concrete columns were cast and investigated for 90 days. The compressive strength results showed that samples made with 12.5 mm coarse aggregate and superplasticizer developed a maximum compressive strength (34.85 N/mm²) at 28 days. The concrete samples made with 12.5 mm, when compared with 16 mm and 19 mm, showed average strength increases of 6.5% and 9.7%, respectively. The flexural strength results showed that samples made with 12.5 mm coarse aggregate and superplasticizer developed a maximum flexural strength of 4.72 N/mm² at 56 days of curing. The drying shrinkage results showed that the shrinkage strain of concrete made with a smaller-size coarse aggregate (12.5 mm) without superplasticizer increased by 14.5% and 20.3% for 16 mm and 19 mm coarse aggregate sizes, respectively, whereas for concrete made with superplasticizer, the 12.5 mm coarse aggregate showed 7.77% and 13.04% increases when compared with 16 mm and 19 mm coarse aggregate sizes, respectively.

***Keywords*:** Coarse aggregate; compressive strength; flexural strength; drying shrinkage; superplasticizer.

1. Introduction

Concrete is the most employed construction material around the globe due to its ease of use, high compressive strength, high stiffness, durability, relatively low cost, and its ability to be formed in any shape and be used even underwater. To obtain high-strength and good-quality concrete, the proportion of the concrete is very important; different grades of concrete can carry different loads and have different proportions [1].

When building concrete structures, superplasticizers are frequently employed to increase concrete workability. Although superplasticizers and water reducers are similar, superplasticizers will substantially reduce the amount of water needed for concrete mixing [2]. Superplasticizers can lower the water-to-cement ratio while improving the concrete's flow characteristics, and the rate of carbonation slows down. High paste concentrations and comparatively low water-to-cement ratios (w/c) are typical characteristics of contemporary high-strength concretes [3]. Superplasticizer improves the production of denser concrete, which improves compressive strength in cured concrete. By retaining the concrete fluidity for an extended period of time, the risk of drying shrinkage will be decreased [2].

The ready-mixed concrete industry currently produces over 95% of the world's in-situ concrete. Retarding and superplasticizing (SP) admixtures, which are widely accessible from different manufacturers, are used by producers of ready-mixed concrete [4]. Sulfonated melamine formaldehyde condensates, sulfonated naphthalene formaldehyde condensates, modified lignosulfonates, and other substances (such as sulfonic acids and carbohydrate esters) are the four primary types of superplasticizers. Concrete with extremely high workability and/or strength is clearly one of the desired results of a superplasticizer. By imparting a strong negative charge to the cement particles, the superplasticizer causes them to reject one another because of their shared electrostatic charge. More fluid is available for mixing concrete by dispersing the cement particles [5].

Several studies have shown that the size of the coarse aggregate can affect the properties of concrete. Chen and Liu. [6] investigated the settlement of coarse aggregate in fresh concrete under vibration. They found that the larger the coarse aggregate size, the more significant the settlement issue. The effect of aggregate size on the compressive strength of concrete was investigated using three aggregate sizes (9.5 mm, 13.2 mm, and 19.0 mm) and the control. A constant mix of 1: 2: 4 with a water/cement ratio of 0.5 was used throughout the experiment. It was reported that concrete workability was directly proportional to aggregate size. The mean concrete compressive strength increased with increasing aggregate size [7]. Concretes with the same mix proportions and four distinct types of coarse aggregate were compared by Ezeldin *et al.* [8]. They came to the conclusion that whereas coarse aggregate strength has minimal bearing on compressive strength in normal-strength concretes, greater strength coarse aggregates generally result in higher compressive strengths in high-strength concretes. Neville [9] looked into how the amount of aggregate in concrete affected the ratio of concrete shrinkage to neat cement paste shrinkage. The findings demonstrated that the shrinkage value dropped as aggregate content increased; for instance, shrinkage decreased by 20% when aggregate content was increased from 71 to 74%. He came to the conclusion that using chemical admixtures and greater coarse aggregate sizes could result in an increase in aggregate content.

The application of a gravel-coarse-aggregate, sensible-heat-storage-assisted single-slope solar still was studied by Dhivagar *et al.* [10]. They discovered that adding superplasticizers greatly increased the concrete's compressive strength. Zhu *et al.* [11] studied the influence of a polycarboxylate-ether-based superplasticizer on the microstructure of cement paste during the setting process. The results reveal that cement hydration is not a steady process, and the manner of development for the hydration product region changes with cement particle size. In this approach, multiple hydration products may congregate around small cement particles and subsequently adsorb other unhydrated particles, resulting in the continuous region. Similarly, Pereira *et al.* [12] investigated the impact of superplasticizers on the workability and compressive strength of concrete formed from fine recycled concrete particles. Concrete containing recycled aggregates was shown to have lower relative performance. Concrete containing recycled aggregates and superplasticizers performed better mechanically than reference concrete with no admixtures or conventional concrete with lower-performance superplasticizers. Ahmad *et al.* [13] evaluated the effect of two superplasticizers, Rheobuild 1100 and Rheobuild 561M, on concrete workability, water reduction percentage, and cement savings. They discovered that the inclusion of superplasticizers (0.8% weight of cement) reduced the amount of water needed to make grade 25N/mm2 concrete. They concluded that both superplasticizer samples increased the qualities of the analyzed concrete; however, concrete samples containing Rheobuild 561M performed better in all properties tested.

Researchers and engineers have been focusing during the past decades on enhancing the concrete properties, especially its compressive strength, workability, and resistance to cracking. Similar to other porous materials, concrete undergoes volume change known as concrete shrinkage or concrete swelling; concrete shrinkage leads to cracking that undermines the serviceability and durability of the material. Water movement and moisture losses within the concrete mixtures are the major factors causing shrinkage. Chemical reactions induce water movements within the concrete elements, leading to chemical and autogenous shrinkage; however, water movement outside the concrete elements, which is water loss, causes drying shrinkage [14]. It should be noted that there are different types of shrinkage: chemical shrinkage, autogenous shrinkage, plastic shrinkage, drying shrinkage, carbonation shrinkage, and thermal shrinkage [15]. Drying shrinkage is another important factor that influences the durability of concrete. Al-Attar [16] studied the effect of coarse aggregate characteristics on the drying shrinkage of concrete. Using saturated coarse aggregate in the mix always yields higher shrinkage strain than dry aggregate. He reported about 10% increase in drying shrinkage for most mixes in the study, and that the increased percentage was affected by the water absorption capacity of the aggregate. Arthur *et al.* [17] investigated the effect of water content on drying shrinkage in concrete. They reported that adding water increases drying shrinkage, with ultimate shrinkage ranging from 4×10^{-4} to 8×10^{-4} for conventional concrete, depending on the initial water content, ambient temperature, humidity, and aggregate type.

While many researchers [18, 19] have studied the strength characteristics of concrete made with different aggregate materials and cement brands, several other studies have looked into the individual impact of coarse aggregate sizes and superplasticizers on concrete properties. However, there is a gap in the literature regarding the combined effect of coarse aggregate sizes and superplasticizers on concrete properties, specifically compressive strength, flexural strength, and drying shrinkage, as well as the monitoring of concrete behaviour in response to temperature and relative humidity over time. As a result, the purpose of this study is to look into the effects of superplasticizer and coarse aggregate sizes on concrete's strength index and drying shrinkage. The result provides engineers and other stakeholders with logical relationships to project concrete behaviour and prevent field failures like excessive cracking or low strength, which will lower maintenance costs and extend the life of structures.

2. Materials and Methods

2.1 Materials

Coarse Aggregate

The coarse aggregate used was crushed granite from Bluestone Quarry, Akija village, Abeokuta, Ogun state, Nigeria. Through sieve analysis, single-size aggregates of 12.5 mm, 16 mm, and 19 mm were used for this study. The coarse aggregates conformed to BS 822 [20].

Fine Aggregate

The river sand aggregate used was obtained from the Ogun River, Ogun State. Sieve analysis conducted placed the aggregate in Zone 2 of maximum size 4.75mm.

Cement

Limestone Portland Cement (LPC) manufactured by Lafarge Cement Company, Nigeria, was used. The physical properties, such as initial and final setting time, were confirmed to BS 12 [21].

Water

Potable water was used.

Formwork

As shown in Fig. 1, Steel moulds of 150mm x 150mm x 150mm were used for casting concrete cubes. Wooden moulds of 100mm x 100mm x 500mm were used for the short concrete columns, and steel moulds of 150mm x 150mm x 750mm were used for the concrete beams. The moulds were properly cleaned before use.

Fig. 1 Moulds for casting concrete cubes and short columns

Superplasticizer

High-performance superplasticizer (Conplast SP430) from Purechem Manufacturing Limited, Isolo, Lagos, was used in this study. This admixture was used according to the manufacturer's instructions. A single dosage of superplasticizer was used throughout the study, and the water-cement ratio was reduced for concrete made with the addition of Conplast SP430 superplasticizer.

2.2 Methods

2.2.1 Preliminary Tests

Sampling of Fine Aggregates: The sampling of the fine aggregate was done before the sieve analysis. The riffler is a box with many parallel divisions that is used for sampling aggregates.

Sieve Analysis: Sieve analysis test was conducted for all the aggregates (sand and granite) used in this study. The weight of each sieve, as well as the bottom pan to be used in the analysis, was measured and recorded. It was ensured that all the sieves were clean, and they were assembled in the ascending order of sieve numbers (#4 sieve at top and #200 sieve at bottom). The pan was placed below the #200 sieve. The weight of the given dry aggregate sample was also recorded, and the aggregate sample was then carefully poured into the top sieve, and the cap was placed over it. The set of sieves was then shaken manually for 10 minutes. The weight of each sieve with its retained aggregate was then measured and recorded. The weight of the bottom pan with its retained fine aggregate was also recorded.

Specific Gravity: Apparent specific gravity is the ratio of the weight of a volume of the substance to the weight of an equal volume of the reference substance. The specific gravity of a soil is often used to describe the relationship between the weight of soil and its volume.

Aggregate Impact Value: The test specimen is compacted, in a standardized manner, into an open steel cup. The specimen is then subjected to several standard impacts from a dropping weight. This action breaks the aggregate to a degree that depends on the material's impact resistance. This degree is assessed by a sieving test on the impacted specimen and is taken as the aggregate impact value (AIV). This test was carried out in accordance with BS 812-112 [22].

Aggregate Crushing Value: The Aggregate crushing value provides a relative measure of an aggregate's resistance to crushing under a gradually applied compressive load. It is the percentage by weight of the crushed (or finer) material obtained when the test aggregates are subjected to a specified load under standardized conditions. This test was carried out in accordance with BS 812-110 [23].

2.3 Experimental Programme

Batching was done by weight, and the mixing sequence was as follows: dry materials (cement + fine aggregate + coarse aggregate) for 2 minutes, followed by water and Conplast SP430 (where applicable, pre-diluted in mixing water) for 3 minutes to achieve complete dispersion as well as uniform consistency. This study used single-size coarse aggregates measuring 12.5 mm, 16 mm, and 19 mm. A mix ratio of $1:1\frac{1}{2}:3$ and water-cement ratios of 0.55 and 0.4 were used for samples with and without superplasticizer respectively. Table 1 shows the composition of materials present in the different concrete samples.

Table 1: Composition of materials for different study concrete samples.

Sample designation	Material composition
1A	Limestone Portland cement, River sand, Granite (12.5 mm), and water (w/c 0.55).
IB	Limestone Portland cement, River sand, Granite (12.5 mm), water (w/c 0.4), and Conplast SP430 (dosage 500ml per 100kg of cement).
2A	Limestone Portland cement, River sand, Granite (16 mm), and water (w/c 0.55).

2B	Limestone Portland cement, River sand, Granite (16 mm), water (w/c 0.4), and Conplast SP430 (dosage 500ml per 100kg of cement).
3A	Limestone Portland cement, River sand, Granite (19 mm), and water (w/c 0.55).
3B	Limestone Portland cement, River sand, Granite (19 mm), water (w/c 0.4), and Conplast SP430 (dosage 500ml per 100kg of cement).

2.4 Compressive Strength Test

Compressive strength test was carried out at 7, 21, and 28 days of curing, respectively. A total of 6 mix combinations were prepared. 9 specimens per mix were cast at the 3 different curing ages, resulting in a total of 54 cubes. The specimen was removed from the curing tank after it had been cured for the proper length of time in the water. It was then placed in the machine and slowly brought the blocks to bear on the specimen without stopping until failure occurred. The machine was operated at a constant rate within the range of 0.140 to 0.350 MPa per second. The maximum load at failure was recorded and thus used in calculating the compressive strength for each concrete cube tested, as presented in Equation (1)

$$\text{Compressive strength (N/mm}^2\text{)} = \frac{\textit{Maximum load at failure } (N)}{\textit{Cross sectional area of specimen } (mm^2)} \qquad (1)$$

2.5 Flexural Strength Test

Flexural strength tests were conducted at 28 and 56 days of curing on a total of 36 beams. The third-point loading method was used, in which the beam was placed on ideal supports (a roller and a hinge support) and subjected to loads applied at the third points of the beam span, with the gauge's lever arm used to apply the loads, as shown in Fig. 2.

Fig. 2 Flexural strength test

Keen attention was paid to the beam's response to loading to identify the load that caused "sudden" failure, which is the rupture load. The Flexural Strength, or modulus of rupture (f_b), is given by Equation (2).

$$\text{Flexural strength } (f_b) = \frac{pl}{bd^2} \qquad (2)$$

Where:

f_b = Flexural strength in N/mm²

P = maximum applied load indicated by the testing machine, kN

l = span length in mm

b = average width of specimen at fracture, in mm

d = average depth of specimen, at fracture, in mm

2.6 Drying Shrinkage Test

A total of 18 short columns of 100 x 100 x 500 mm were cast as depicted in Fig. 3. The short column specimens were removed from the curing tank after they had been cured for 7 days. The short columns were then hung on the shrinkage test rig, which consists of a simple steel frame with an adjustable height beam, to hold the measuring gauge, calibrated to the nearest 0.01 mm, as shown in Fig. 4. This arrangement was placed centrally on top of the 100 mm x 100 mm rectangular prism. Daily measurements of the shrinkage deformation, temperature, and relative humidity commenced immediately after the curing and ran for 90 days.

Fig. 3 Casting short column concrete

Fig. 4 Set up for drying shrinkage test

3. Results And Discussion

3.1 Preliminary Test on Aggregates

3.1.1 Setting Time of Cement: The result of the setting time of cement shows that the initial setting time for the cement used in the study was 105 minutes, while the final setting time was 220 minutes. It was observed that the initial and final setting times are approximately related to the report of Zhang *et al.* [24] that Final setting time (min) = 90+1.2 × initial setting time (mins)

3.1.2 Sieve Analysis: The coefficient of uniformity (C_u) for the fine aggregate sample was 2.82, and the coefficient of curvature (C_c) was 0.93, thus indicating that the fine aggregate sample analyzed for particle size distribution is poorly graded according to Unified Soil Classification since Cu < 6 and Cc < 1, and it is designated as SP; according to the system. The coefficient of uniformity for the coarse aggregate sample obtained above was 1.89, and the coefficient of curvature was 1.92. Thus, according to the Unified Soil Classification System, the coarse aggregate sample was poorly graded since Cu < 4 and Cc > 1, it is designated as GP: according to the system.

3.1.3 Aggregate Crushing Value

The results obtained and calculations are presented in Table 2.

Weight of mould + base plate = W_1

Weight of mould + base plate sample = W_2

Weight of sample = $W_2 - W_1 = W_3$

After crushing (applying a force of 400kN), and sieving through a 2.36mm sieve

Weight of sample passing 2.36mm sieve after crushing = W_4

Table 2: Weight of samples for aggregate crushing value determination

Sample designation	Mass (kg)
W_1	14.7
W_2	20.5735
W_3	5.8735
W_4	1.0626

Aggregate crushing value (ACV) = $\frac{W4}{W3}\ x100$

$= \frac{1.0626}{5.8735}\ x100$

= 18.1%

3.1.4 Aggregate Impact Value

The results obtained and calculations are presented in Table 3.

Weight of mould = W_1

Weight of mould + sample = W_2

Weight of sample = $W_2 - W_1 = W_3$

Weight of sample passing 2.36mm sieve = W_4

Table 3: Weight of samples for aggregate impact value determination

Sample designation	Mass (kg)
W_1	4.7
W_2	5.6235
W_3	0.9235
W_4	0.1426

Aggregate impact value (AIV) = $\frac{W4}{W3}\ x100$

$= \frac{0.1426}{0.9235}\ x100$

= 15.25%

Both the Aggregate Impact Value (AIV) and the Aggregate Crushing Value (ACV) are important parameters when choosing the aggregate to be used. The tougher a material is, the more resistance it has against wear. The lower the impact value, the stronger the aggregate, and as a result, aggregates with a lower AIV are preferred. The granite used for this research work has an AIV of 15.25% and an ACV of 18.1%

3.1.5 Slump test

According to BS EN 12350-2 [25], five classes of slump have been designated. Sample groups IA, 2A, and 3A correspond to slump class S3, as their slump values lie in the range of 100-150 mm. Sample groups 1B, 2B, and 3B correspond to slump class S4, as their slump value lies in the range of 160-250. True slump signifies that the mixture is quite workable; generally, slump values typically range from 25-200 mm, while collapse slump serves as an indication to modify the water-cement ratio of the concrete mix and consider the proportion of the other ingredients. Table 4 shows the degree of workability of the six sample designations of concrete made with different coarse aggregate sizes and superplasticizer.

Table 4: Workability of study concrete samples

Sample designation	Slump Value (mm)	Type of slump	Degree of workability
1A	108	True slump	High
IB	210	Collapse	Very high
2A	118	True slump	High
2B	215	Collapse	Very high
3A	128	True slump	High
3B	223	Collapse	Very high

It was observed that workability improved with larger aggregate sizes and the addition of superplasticizer. These findings can be attributed to a reduction in aggregate surface area in concrete and the ability of superplasticizer to deflocculate fines (cement and sand matrix) in concrete, reducing the amount of water required for mixing [26]. This explains why the same water-cement ratio was not employed in the study. A similar trend was reported by Mamaru [27]

3.2 Tests on Hardened Concrete

3.2.1 Compressive Strength

The percentage increase in compressive strength at 28 days curing for the different categories of sample mixes was 52.72%, 48.85%, and 50.6% for Sample 1A vs. Sample 1B; Sample 2A vs. Sample 2B, and Sample 3A vs. Sample 3B, respectively, as presented in Fig. 5.

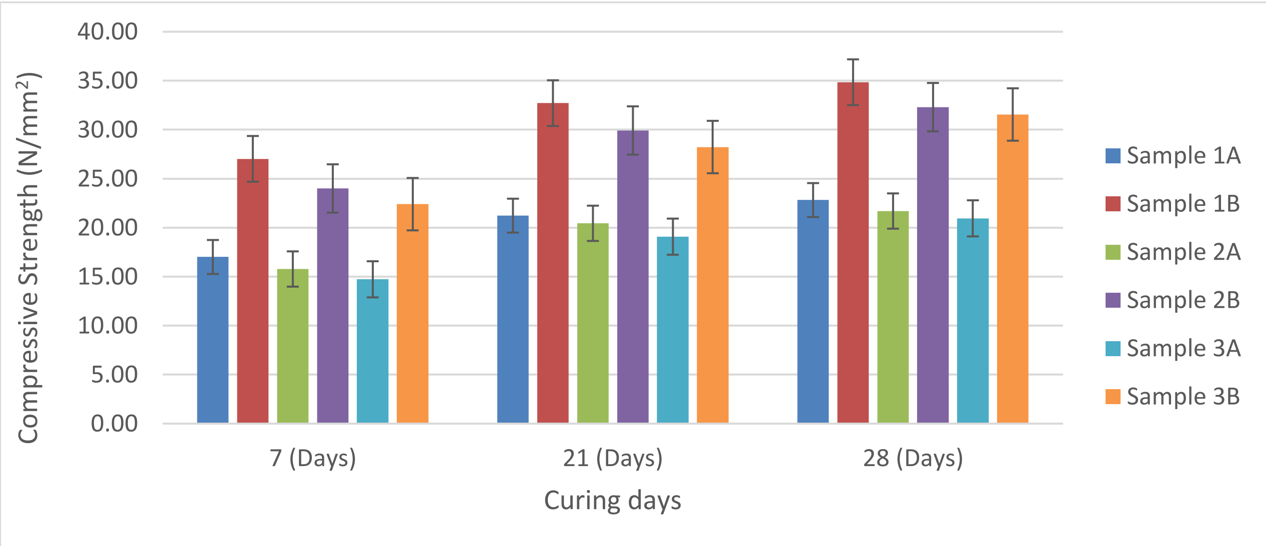

Fig. 5 Compressive strength of study samples

With and without the addition of superplasticizer, concrete samples made with 19 mm coarse aggregate size exhibited lower compressive strength when compared to concrete made with 12 .5 mm coarse aggregate size. This may be a result of the smaller size aggregate providing higher surface area for the development of gel bonds, which is responsible for the higher strength development. Similarly, Albarway *et al.* [28] carried out an experiment to investigate the effect of coarse aggregate size on the compressive strength of concrete. The test results showed that the compressive strength decreases with increasing coarse aggregate sizes. A smaller aggregate size causes a greater homogeneity in the concrete, which provides a uniform distribution of load when stressed. This can be explained by the coarse aggregate with bigger particle sizes having a weaker ITZ [29].

3.2.2 Flexural Strength

The percentage increase in flexural strength at 56 days curing for the different aggregate sizes was 26.88%, 25.62%, and 26.76% for Sample 1A vs. Sample 1B; Sample 2A vs. Sample 2B, and Sample 3A vs. Sample 3B, respectively. According to the relationship, concrete samples with 19 mm coarse aggregate size had a lower flexural strength than concrete samples with 12.5 mm aggregate size, for both concrete, with and without superplasticizer. This trend is similar to what was recorded under the compressive strength in this study. While Sridhar *et al.* [30] found that smaller coarse aggregate sizes produced a better flexural fatigue than bigger coarse aggregate sizes, Jhatial *et al.* [31] found that superplasticizer increased flexural strength. It can be concluded that for each aggregate size, and for the same curing day, the flexural strength with superplasticizer (Conplast SP430) outperforms that without the chemical admixtures, as shown in Fig. 6.

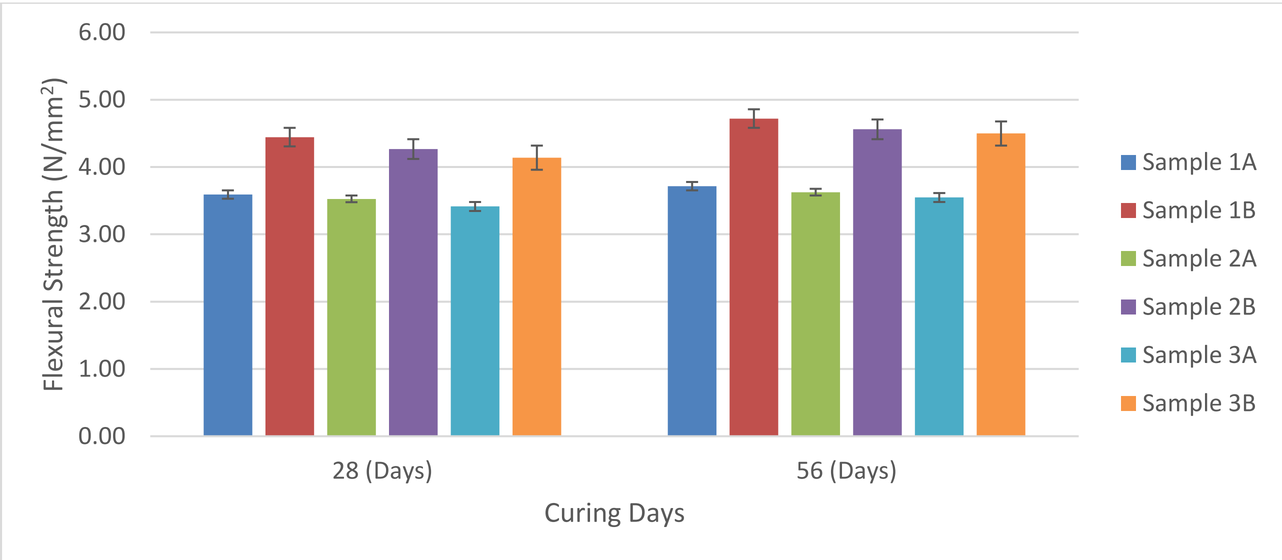

Fig. 6 Flexural strength of study samples

3.2.3 Failure pattern of concrete beams

Failure during the application of load on the concrete beams was sudden, which is the expected failure mechanism for an unreinforced concrete element subjected to bending. The failure plane for most of the test samples was within the middle-third and at the centre of the beam, as can be seen in Fig. 7.

Fig. 7 Failure pattern of test samples

3.2.4 Drying Shrinkage of Concrete Columns

The percentage increase in shrinkage strain over 90 days for the different aggregate sizes was 12.35%, 5.60%, and 5.60% for Sample 1A vs. Sample 1B; Sample 2A vs. Sample 2B, and Sample 3A vs. Sample 3B, respectively.

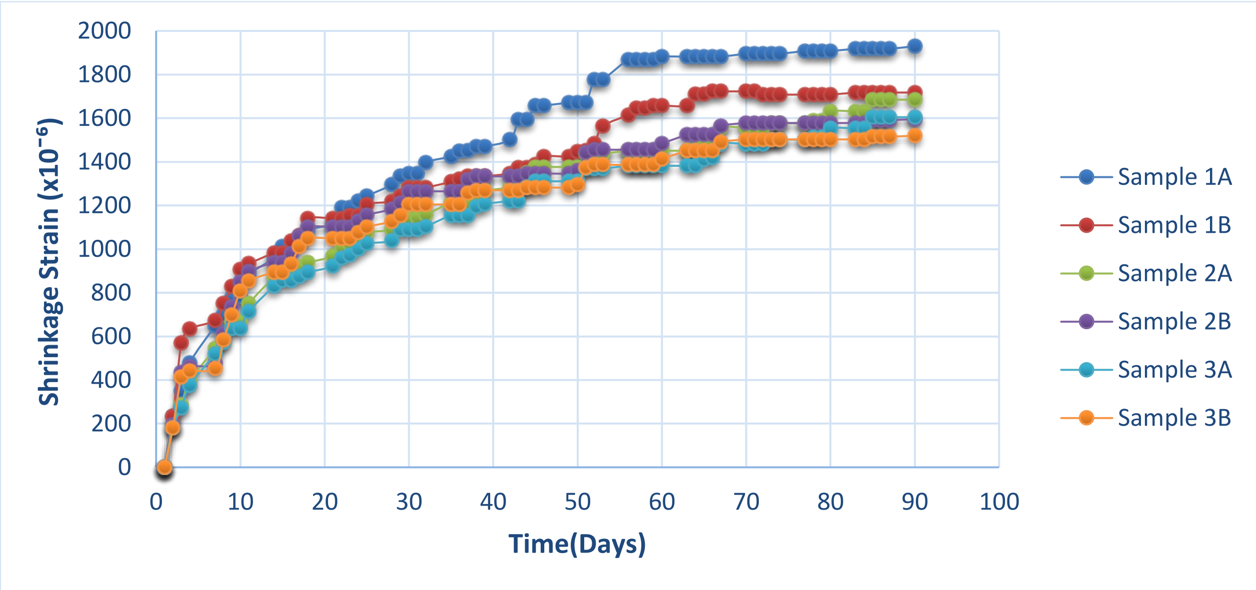

Fig. 8 Combined effect of Shrinkage strain (E) Vs Time (Days) for all study samples

All samples without superplasticizer (1A, 2A, and 3A) gave higher shrinkage strain values of 1929.8, 1684.8 and 1604.5 ($x10^{-6}$) respectively when compared to samples with superplasticizer (1B, 2B, and 3B) with shrinkage strain values of 1717.6, 1595.4 and 1519.4 ($x10^{-6}$) respectively over 90 days. This shows that the presence of Conplast SP430 superplasticizer in concrete indirectly reduces shrinkage strain due to the lower water-cement ratio required for the mix. The drying shrinkage of concrete actually combines the autogenous shrinkage of concrete and the desiccation deformation caused by moisture evaporation together. High temperature will accelerate the hydration reaction of cement, and change the composition and internal structure of concrete [32]. Results in Fig. 8 were obtained at an average humidity of 80±10% and temperature of 28ºC±2. The drying shrinkage of concrete in sample 1A presents a distinct change of shrinkage, 14.54% increase to sample 2A, and 20.27% to sample 3A. It is observed that with an increase in the age of the concrete, the shrinkage strain increases due to moisture loss to the surrounding caused mainly by climatic factors such as temperature and relative humidity. The greater internal restraint provided by the larger coarse aggregate size also directly reduces the shrinkage of the cement paste [33].

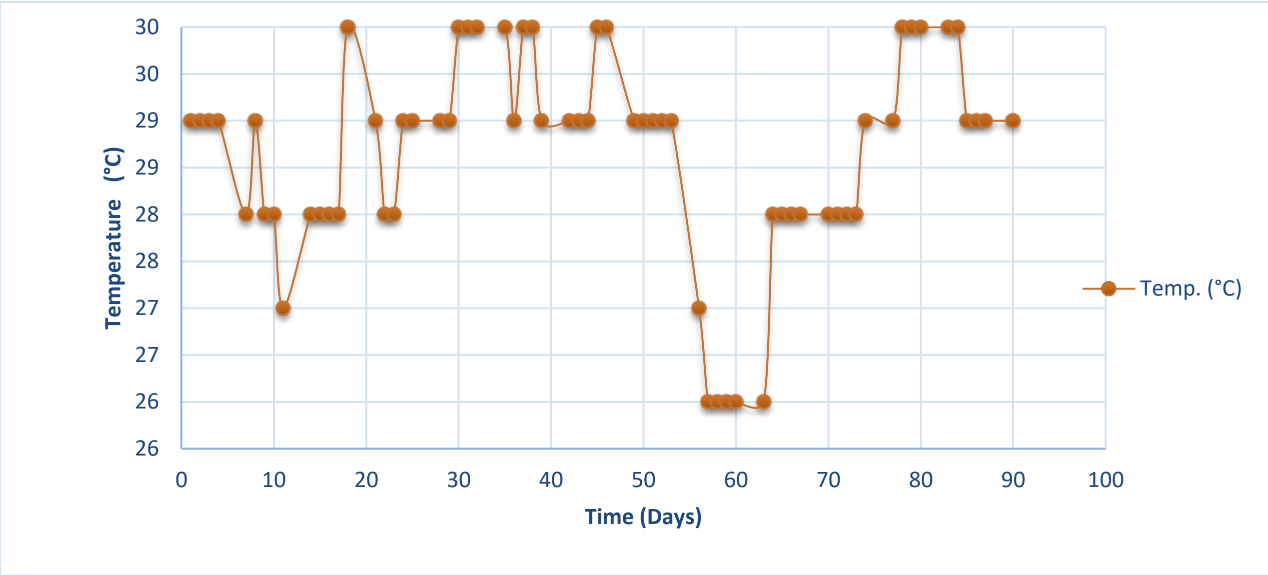

Fig. 9 Variation in temperature over 90-days

As shown in Figs. 9 and 10, the temperature and humidity values vary throughout the experiment. There was significant drying and increased shrinkage when temperatures were high above 28^{o}±2 and relative humidity (60 - 90) on samples. Conversely, low temperatures and high relative humidity slow down the drying process, which reduces shrinkage over a longer period.

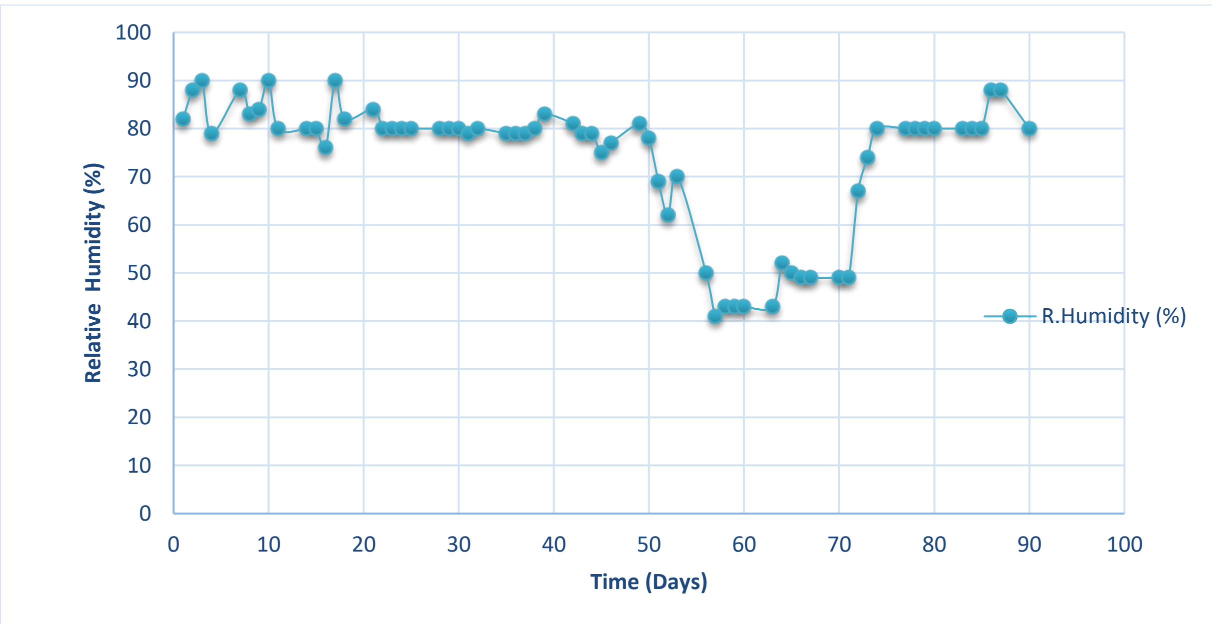

Fig. 10 Variation in relative humidity over 90-days

In both the compressive and flexural strength tests, Coarse aggregates with greater particle sizes have a weaker Interfacial Transition Zone (ITZ), owing to cement particles being significantly smaller than coarse aggregates. When constituents are mixed, bigger aggregates destabilize spatial packing, preventing cement grains from packing firmly at their surfaces and resulting in a looser, more porous structure [34]. The porous environment of the ITZ encourages the formation of massive, oriented calcium hydroxide crystals (portlandite) and ettringite. Unlike dense C-S-H gel, these massive, directed crystalline formations lack cohesive strength, resulting in weak zones at the boundary [35].

The addition of Conplast SP430, a high-range water-reducing superplasticizer based on sulphonated naphthalene polymer (SNF) in this study, significantly reduced the water added to the concrete mix and expedited the acquisition of early strength. Its primary impact on concrete hydration is an electrostatic dispersion that facilitates ettringite's early growth [36]. However, in terms of drying shrinkage, higher aggregate volume fractions and bigger maximum aggregate sizes produce a stiffer, more interconnected internal skeleton that provides better constraint and results in lower total drying shrinkage, as demonstrated by the findings of this study. A zone of transition emerges around each aggregate component, preventing the cement paste from shrinking. The degree of constraint is determined by the thickness of this shell and the size of the aggregate.

3.2.5 Statistical Analysis

Concrete's mechanical qualities (compressive and flexural strength) are influenced by a number of physical parameters, including the inclusion of a superplasticizer, days of curing, and variations in coarse aggregate sizes.

The ANOVA for the compressive strength of concrete with coarse aggregate of different sizes (with or without a superplasticizer) is shown in Table 5.

Table 5: ANOVA for compressive strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	636.255	212.085	314.89	0.000
Coarse aggregate	1	29.426	29.426	43.69	0.000
Days	1	164.496	164.496	244.23	0.000
Super Plasticizer	1	442.333	442.333	656.75	0.000
Error	14	9.429	0.674		
Total	17	645.684			

Model Summary

S	R-Sq	R-Sq(adj)	R-Sq(pred)
0.820684	98.54%	98.23%	97.44%

For the strength of the study concrete, every variable (days of curing, coarse aggregate sizes, and the presence or absence of superplasticizer) is statistically significant ($P < 0.05$). Superplasticizer had the biggest impact, followed by the curing days, according to the ANOVA's F-value; coarse aggregate size had the least impact. This can be confirmed from the Pareto plot.

The model summary demonstrates that the terms in the model are adequate to represent the compressive strength through the (R^2), and the model has a very predictive capability based on the (R^2adj). The model is significant according to the ANOVA, indicating that it can accurately predict the compressive strength with a high degree of confidence ($P < 0.05$).

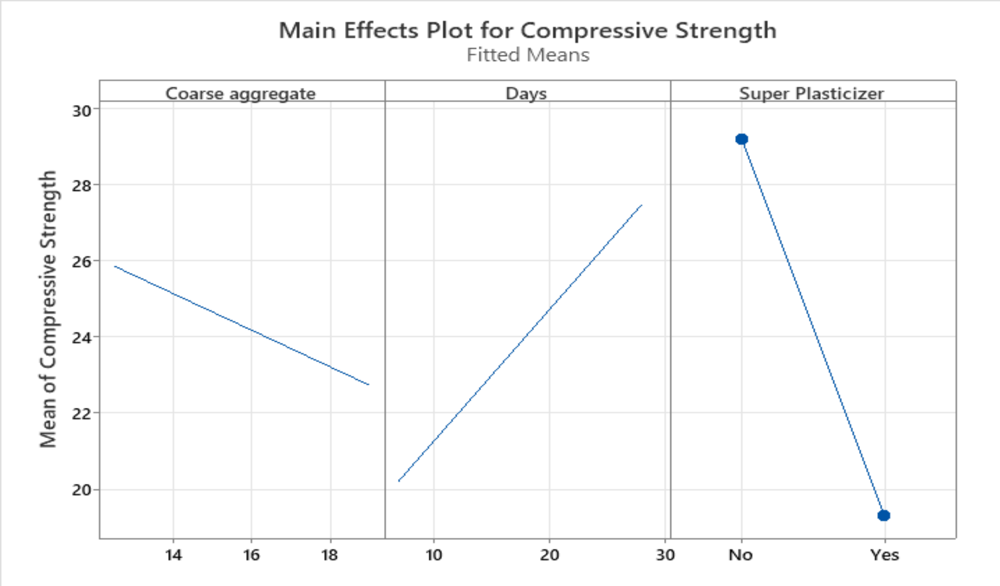

Fig. 11 Main effects plot for compressive strength.

Fig. 11 and Fig. 12 depict the main effects plots of the manufacturing parameters on the study concrete. According to the effects plots, increasing the coarse aggregate sizes reduces the mean strength properties (compressive strength and flexural strength), whereas increasing the curing days improves both the compressive and flexural strengths.

Table 6 shows the ANOVA for the flexural strength. A similar trend was observed as with the compressive strength. All the variables are statistically significant.

Table 6: ANOVA for flexural strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	2.48909	0.82970	197.51	0.000
Coarse aggregate	1	0.09493	0.09493	22.60	0.001
Days	1	0.14083	0.14083	33.53	0.000
Super Plasticizer	1	2.25333	2.25333	536.42	0.000
Error	8	0.03361	0.00420		
Total	11	2.52270			

Model Summary

S	R-Sq	R-Sq(adj)	R-Sq(pred)
0.0648127	98.67%	98.17%	96.93%

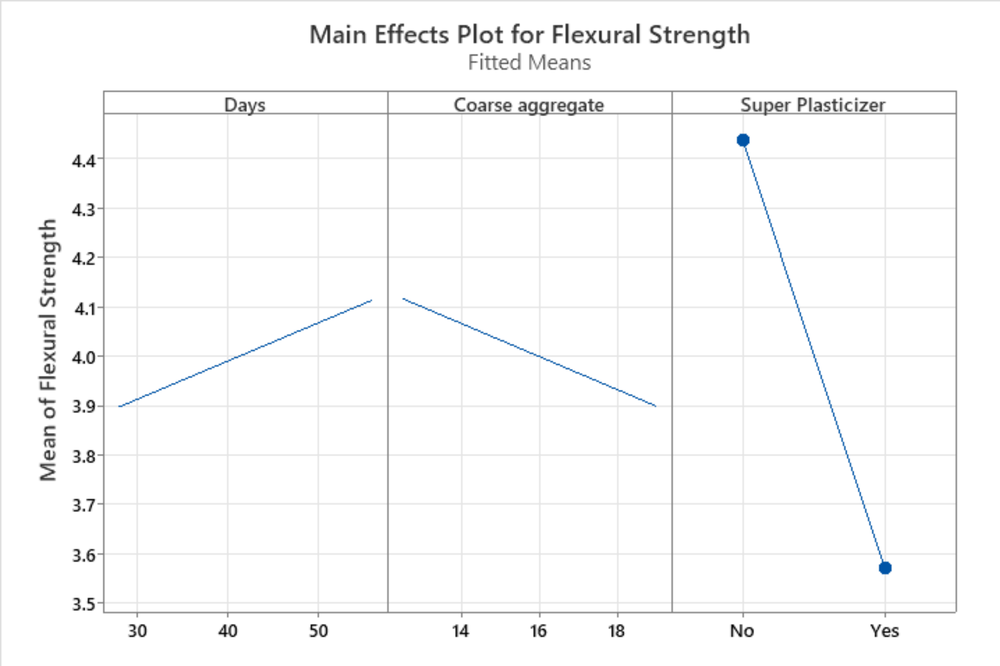

Fig. 12 Main effects plot for flexural strength.

4. Conclusion

The following conclusions were made from this study:

- Workability improved with larger aggregate sizes and the addition of superplasticizer.
- When a superplasticizer is applied, less water is needed to produce concrete, which reduces the amount of evaporable water in the mix and the voids it causes.
- Concrete with superplasticizer has a higher compressive strength than Concrete without superplasticizer, irrespective of the size of coarse aggregate used. The percentage increase in compressive strength of concrete samples with superplasticizer when compared to the samples without superplasticizer gave 52.72% increase for 12.5 mm aggregate size, 48.85% for 16mm aggregate size, and 50.6% for 19mm aggregate size.
- Concrete made with 12.5 mm coarse aggregate has higher flexural strength than that made with larger-size coarse aggregates (16 mm and 19 mm) of the same mix proportion, with and without superplasticizer. The concrete samples made with 12.5 mm compared to 16mm and 19mm gave an average of 3.1% and 4.85% increment in flexural strength.
- The concrete made with superplasticizer has a lower rate of moisture loss to the environment than concrete without superplasticizer, irrespective of the size of coarse aggregate used.
- An increase in the size of coarse aggregate in the concrete reduced the drying shrinkage of the concrete.
- The drying shrinkage results revealed that, in comparison to conventional concrete produced with 16 mm and 19 mm, respectively, the shrinkage strain of concrete manufactured with a smaller-size coarse aggregate (12.5 mm) without superplasticizer was higher by 14.5% and 20.3%. Concrete made with 12.5 mm coarse aggregate was higher than concrete with 16 mm and 19 mm coarse aggregate by 7.77% and 13.04%, respectively, when superplasticizer was applied.

- The model is significant according to the ANOVA, indicating that it can accurately predict the compressive strength with a high degree of confidence ($P < 0.05$).

5. Study Limitation

This study considered single-sized aggregates of 12.5 mm, 16 mm and 19 mm. Only Conplast SP430 superplasticizer at a single dosage was used. The results of this study were experimental, and no microstructural analysis was carried out.

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Author Contributions

*Conceptualization: [**Y.O.A., and A.A.F**]; Methodology: [**Y.O.A., and A.A.F.**]; Formal analysis and investigation: [**A.A.F., Y.O.A., and J.I.O.**]; Writing - original draft preparation: [**A.A.F.**]; Writing - review and editing: [**Y.O.A., and J.I.O**], ...; Resources: [**A.A.F., S.O.K. and Y.O.A.**]; Supervision: [**Y.O.A.]***

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics declaration

Not applicable

Consent to publish

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Consent to participate

Not applicable

Clinical trial declaration

Not Applicable

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

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