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Development of High-Performance Concrete for Civil Engineering Structures Using Variable Proportions of Sharp Sand and Soft Sand as Fine Aggregates

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ABSTRACT

This study explores the properties of high-performance concrete intended for structural applications. It specifically examines the compressive strength of concrete specimens and evaluates workability through slump tests and compacting factor measurements. The concrete mix used follows a 1:2:3 ratio (cement:fine aggregate:coarse aggregate) with a water-to-cement ratio of 0.40. To assess the effect of fine aggregate composition, soft sand and sharp sand were blended in varying proportions, with soft sand content increased in 25% increments. The findings indicate that the highest compressive strength of 40.17 N/mm² was achieved with a mix containing 25% soft sand and 75% sharp sand. However, as the proportion of soft sand increased, the compressive strength declined. This reduction is attributed to the higher water absorption capacity of soft sand, which reduced the amount of free water available for complete cement hydration. Conversely, the mix with 100% sharp sand also yielded low compressive strength due to excessive free water, as sharp sand absorbs minimal water. In conclusion, combining soft and sharp sand in specific proportions—particularly around 25% soft sand—enhances the performance characteristics of concrete, making it suitable for use in civil engineering structure

Keywords: Development, High-Performance Concrete, Civil Engineering Structures, Variable Proportions of Sharp Sand, Soft Sand, Fine Aggregates

1. INTRODUCTION

High-performance concrete (HPC) is produced using carefully selected, high-quality materials and well-designed mix proportions. The processes of batching, mixing, placing, compacting, and curing are all carried out according to the highest industry standards. HPC typically exhibits greater strength than conventional concrete (Salau, 2003). However, strength is not always the most critical attribute.

For instance, a normal-strength concrete with superior durability and extremely low permeability may also be classified as high-performance due to its enhanced functional properties. It is defined as concrete that possesses strength and durability characteristics significantly above those of standard concrete. Although its production involves higher material costs, HPC is considered cost-effective for structural elements such as columns in high-rise buildings, as it allows for a reduction in steel reinforcement requirements.

Several studies have explored the use of locally available alternatives to river sand as fine aggregate in conventional concrete (e.g., Adepegba, 1975; Lasisi and Osunade, 1985; Salau, 2003; Jayawardena and Dissanayake, 2006). In recent times, the Nigerian construction industry and neighboring regions have seen a growing use of locally sourced sand—often referred to as "sharp-sharp sand"—from borrow pits for block molding and concrete applications. In some cases, this sharp sand is combined with softer sand.

Despite its widespread use, there is a lack of reliable data on the structural integrity of concrete made with these sand combinations, which is concerning given the increasing incidents of building collapses in major cities. Earlier research on laterized concrete has not fully addressed these concerns, mainly due to variations in physical properties such as particle size distribution and generally low compressive strength values. Visual inspection and preliminary particle size analysis suggest that the lateritic sand currently in use has a much sharper grain profile than those studied previously. This indicates potential suitability for structural concrete production, as aggregate size distribution significantly influences concrete strength.

In a related context, considerable deposits of sharp sand have been identified in riverbeds in Esako West Local Government Area of Edo State. Compressive strength is arguably the most commonly evaluated property in concrete because the material is naturally strong in compression but weak in tension. The combination of soft and sharp sand could contribute to achieving desired strength levels while also reducing construction costs.

This study aims to document the characteristics of these local materials comprehensively to support their inclusion in design standards and construction practices. Sharp sand, commonly sourced from rivers, is frequently used as fine aggregate in concrete. However, continuous sand mining has led to the depletion of river sand resources, making it scarce and raising several environmental concerns—including riverbed degradation and falling surface water levels. Understanding the structural behavior and performance of concrete made with these local materials is essential for the accurate design of building and bridge components. A key aspect of sustainable national development involves leveraging locally available natural resources to promote economic growth.

2. LITERATURE REVIEW

Concrete is a composite material made by binding coarse aggregates together with fluid cement, which hardens over time. The most commonly used concretes are lime-based, such as Portland cement concrete or those made with other hydraulic cements (Yeh, 2006). When dry Portland cement is mixed with water and aggregate, it forms a fluid mixture that can be molded into various shapes. The cement undergoes a chemical reaction with the water and other ingredients to create a hard matrix that holds the materials together, resulting in a durable, stone-like substance with a wide range of applications. Additives, like pozzolans or superplasticizers, are often added to improve the properties of the wet mix or the final product.

Concrete is typically reinforced with materials like rebar to enhance tensile strength, producing reinforced concrete (Omotola and Idowu, 2011). Sand constitutes about 35% of the volume of concrete used in the construction industry. Natural sand is mostly extracted from riverbeds, but it often contains high amounts of inorganic materials, chlorides, sulphates, silt, and clay, all of which can negatively affect the strength and durability of the concrete and its reinforcing steel, ultimately shortening the lifespan of the structure. To achieve optimal results, fine particles under 600 microns should comprise 30% to 50% of the mixture, but river sand often lacks sufficient quantities of these fine particles. Excessive sand extraction from riverbeds also has environmental consequences, such as lowering groundwater levels and causing erosion of nearby land. Therefore, alternative materials are necessary to meet the fine aggregate requirements (Pedersen and Smelpass, 2013).

Crushed sand, produced by crushing larger quarry stones to a specific size, has become a widely used and beneficial alternative to natural sand. The physical and chemical properties of crushed sand—such as its color, size, shape, and surface texture—depend on the type of stone and its source (Neelam, 2009). As a substitute for natural sand, crushed sand is essential for meeting technical, commercial, and environmental needs. Proper quality control when using crushed sand can yield better results. Various studies have examined the impact of crushed sand on concrete properties. Hadassa and Amnon (2009) explored the effects of fine materials in crushed sand, noting that fine fillers (mesh 0.075mm) can improve concrete properties. However, fine particles smaller than 5 microns, often used in plastering, may negatively impact concrete.

Their research also examined the influence of water-reducing agents on concrete mixes with crushed sand, noting that modern admixtures can enhance concrete properties. Concrete failure occurs when it can no longer support the required load. This failure can range from mild issues, such as visible cracks and deflections, to severe cases that cause partial or total collapse, either during construction or after completion. In Nigeria, particularly in major cities like Lagos, Port Harcourt, and Abuja, there have been numerous instances of structural failure linked to poor concrete practices.

2.1 The Production and Management of Concrete

Modern construction projects have become increasingly complex and costly, making it crucial to ensure quality. Quality can be defined as the entirety of features and characteristics of a product or service that affect its ability to meet the specified needs and its fitness for the intended purpose. To ensure safe construction, certain standards for materials and practices are established. Quality measurement is a key component of overall management, which determines and implements the quality policy set by a company (Emmitt et al., 2005). It involves guaranteeing quality through the application of management functions, which assess, utilize, and handle approved materials, human resources, and operational techniques to achieve the project goals within the given time and budget.

In the construction industry, the goal of all professionals is to deliver a product or service that meets the required standards, is properly constructed, performs satisfactorily, and offers value for money. Across the globe, many countries now emphasize product and service quality through the use of established standards. For example, in the UK, quality assurance standards such as BS5750, Part 2 (1987), ISO9002, and EN29002 (1987) are commonly used. In Nigeria, the Standard Organization of Nigeria (SON) and the Nigerian International Standards (NIS) were established by the government to ensure the quality of materials and finished goods produced within the country. Achieving quality, in all its aspects, begins at the conception stage of a project and continues through to its completion.

This means that every member of the construction team has a "duty of care" to the building's users. One critical question that often arises from disputes related to building failures is whether the application of current knowledge at the time of construction could have prevented the failure (Taylor, 2005). Taylor suggests that material failures result from improper manufacturing, selection, or incorporation into the building. If materials fail, it indicates they were either not produced correctly or used inappropriately for their intended purpose. Thus, material failures often point to issues within the design or construction process. This study, therefore, focuses on examining all the materials used in concrete production.

2.2 Concrete, a Sustainable Resource

Sustainability involves balancing economic, social, and environmental factors, not only during the initial stages but also throughout the lifecycle of use. From an economic perspective, while cement is expensive to produce both financially and in terms of embodied energy, it makes up only about 10% of the raw materials in concrete. Additionally, the combined embodied impact of cement, aggregates, water, and admixtures in concrete contributes to just 10% of the environmental impact during the operational phase of conventional buildings. Over the long term, concrete's durability, low maintenance requirements, and potential for reuse, along with various other environmental benefits, result in significant positive effects both economically and environmentally. In the construction industry, achieving this balance is crucial not only during the construction phase but also during the design process.

Selecting the right materials and construction methods is essential to ensuring long-term sustainability. A freely available model from www.cnci.org accounts for the “cradle-to-grave” emissions of common raw materials used in concrete, including transport, and provides average emission data in kg CO2 per ton of material produced. Using this information, designers can experiment with different material combinations to minimize environmental impact while evaluating the cost-effectiveness of concrete per cubic meter. For further details on concrete's cost-efficiency, energy efficiency, thermal mass, light reflectance, fire resistance, low maintenance, acoustic properties, pollution reduction, water conservation, construction flexibility, retrofitting, recycling, and reuse, refer to the C&CI's series of booklets on Sustainable Concrete.

2.3 Factors Affecting Workability

Workability is affected by water content, actual proportioning of raw materials, aggregate and cement types and characteristics, admixtures, time elapsed after mixing, and ambient and concrete temperatures.

Water content

In an average concrete mix using 19mm stone, total water content of about 210litres/m3 gives as lump of 75mm. In a well-proportioned mix, an increase in water content will make the concrete more mobile or foldable.

Cement content and type

Generally, mixes with low cement contents are less workable and more difficult to finish; mixes with high cement contents, typically above 500kg/m^3, tend to be sticky and lose workability quickly. Using cements containing Fly Ash (FA) gives concrete improved workability.

Sand
If the sand content is too low, the concrete will be harsh. The sand content needs to be sufficiently high and contain about 30 to 40% material finer than 300µm. Coarse sands are often blended with fine sands to overcome this deficiency.

Aggregate characteristics
The use of water-reducing admixtures allows for increased workability without increasing the water content of the concrete. In some instances, considerable reductions in water content can be achieved while maintaining workability.

2.4 Bleeding
Bleeding is a form of segregation in which some water migrates to the surface as the solid particles settle. This may result in a layer of clear, greenish water forming on the surface of the concrete. This will continue until the concrete has stiffened sufficiently to prevent further settlement. The use of high extender contents and retarding admixtures will prolong the setting time and thus increase the time during which bleeding may occur.

3. MATERIALS AND METHOD

3.1 Preparations of Concrete Materials
The concrete materials used in this research were cement, aggregate (fine and coarse) and water.

3.1.1 Choice of Cement to BS 12:1989
The cement used in this work is from the Bua brand, which is produced in compliance with the BS12:1989 standards.

3.1.2 Preparation of Coarse Aggregate (Granite to BS 812: Part 1. 1995)
Particle size distribution analysis was conducted on the coarse aggregate as part of this study, following the guidelines outlined in BS 812: Part 1, 1995. The coarse aggregate used was crushed rock.

3.1.3 Preparation of Fine Aggregates. (Sharp sand and soft sand) To BS: 812: Part 1:1995
Fine aggregates are often considered as inert material. The sharp sand used in was obtained from river Iyora, and the soft sand was obtained from Auchi, Edo state. The aggregates were thoroughly washed (to remove unwanted materials) and dried.

3.2 Concrete Mix Design
The concrete mix is designed to achieve the specified strength while minimizing costs. These costs are influenced by the value of materials, as well as the labor needed for batching, mixing, transporting, placing, compacting, and finishing, along with the curing method used.

3.2.1 Batching
In this study, the various components of the concrete were measured by weight to ensure greater accuracy. A weighing machine was utilized for this purpose. The required net weight of each constituent, based on the specified mix ratio, was strictly followed before mechanically mixing them.
Batching refers to the process of measuring concrete ingredients either by volume or by weight. Batching by volume is less precise than by weight. While batching by volume is traditionally used, most specifications require batching by weight.

Proportioning aggregates by volume does not account for the amount of water they retain, which can impact the water-cement ratio of the mix. Wet sand, for example, occupies more volume than dry sand. To accurately proportion the materials for a desired concrete strength, aggregates are often sampled and dried to determine the amount of water they retain. This information is crucial for adjusting the water content in the mix, considering the water already present in the aggregate. Water can also be measured by either weight or volume, depending on the chosen batching method.

3.2.2 Mixing

The concrete components were carefully mixed to achieve a uniform mixture. Efforts were made to minimize material wastage, ensuring that the correct quantities of materials batched were fully utilized and present in the mix. This process was carried out in compliance with BS 1881-125: 1983.

3.2.3 Transportation, Placing and Compacting.

The fresh concrete were filled into steel cylindrical moulds (which had been cleaned, oiled and properly arranged closed to the mixing point with the aid of spade, trowel and tamping rod (16mm in diameter) for proper compaction.

3.2.4 Curing

After casting the compressive test specimens, the cylindrical moulds were left for 24 hours in the laboratory to adequately set before demoulding. The compressive strength specimens were then demoulded and transferred into a curing tank that contain clean water, where they were stored till the respective testing ages (7,14,21 and 28 days).

3.3 Determination of the workability of concrete Mix by Slump test to BS: 1881: part 102: 1983

The slump test, as per BS 1881: Part 102: 1983, was conducted to assess the uniformity and workability of the concrete mix.

The following procedure was followed:

1. Position the slump mould on a smooth, flat surface.
2. Moisten the inside of the mould and its base at the start of each test.
3. Fill the slump mould with fresh concrete in three layers, tamping each layer 25 times using a steel rod.
4. Strike off any excess concrete using a screed, ensuring the mould is held firmly against its base during this step.
5. Once the mould is filled to the top, slowly lift the cone, allowing the concrete to slump. The reduction in height from the centre of the mould is recorded as the slump.

3.4 Compacting Factor Test according to BS1881: part 103, 1983

This test assesses the compatibility of concrete, which refers to its ability to be compacted effectively to eliminate air or voids. Developed in the United Kingdom by Glanville et al. (1947), the test apparatus is inexpensive and easy to fabricate, as described in BS1881: Part 103: 1993. It consists of two truncated cone hoppers with trap doors at the bottom and a cylindrical container, as shown in Fig. 3.4 below. The fresh concrete sample is first placed in the top hopper and then released through the trap door into the second hopper. After opening the trap door of the second hopper, the concrete is deposited into the cylindrical container. To minimize friction, all internal surfaces of the apparatus are polished. Excess concrete above the top of the cylinder is then leveled off, and the weight of the concrete in the cylinder is measured using a weighing balance.

The compacting factor (C.F.) is determined by comparing this weight with the weight of an equal volume of fully compacted concrete from the same mix and batch. The latter is achieved by filling the cylinder in four layers, each tamped or vibrated to ensure full compaction. The compacting factor test (C.F.) provides an effective measure of workability, particularly for drier mixes with medium or low workability. A compacting factor of 0.85 indicates poor workability, 0.92 represents medium workability, and 0.95 corresponds to good workability. However, according to BS1881: Part 103 (1983), the test is unsuitable for concrete with compacting factors below 0.70 or above 0.98.

3.5 Preparation of the compressive strength Specimens

The concrete was batched by weighing the individual constituent materials according to the specified mix ratio of 1:2:3, with a water-cement ratio of 0.40. The fine aggregate portion of the mix was derived by blending soft and sharp sand in 25% increments (i.e., 0% soft: 100% sharp sand, 25% soft: 75% sharp sand, 50% soft: 50% sharp sand, 75% soft: 25% sharp sand, and 100% soft: 0% sharp sand). These sand portions were mixed together using a shovel, and the required amount of water was added once the mixture achieved a homogeneous consistency.

The mixture was then transferred to a head pan, and 150mm x 150mm cubes were cast to determine the average compressive strength of the concrete. Each mold was filled in three layers using a trowel, with each layer being compacted by tapping 25 times with a 20mm diameter tamping rod, as per BS 1881(15) standards. After demoulding, the specimens were placed in a curing tank with clean water, where they were stored for 7, 14, 21, and 28 days before compressive strength testing. In total, 45 concrete specimens were produced for this experiment, which was carried out in the concrete workshop at Auchi Polytechnic, Auchi.

3.6 Testing Procedure

3.11.1 Determination of compressive strength test for concrete. To BS: 1881, part 108 and BS: 1881 part 116 1983

i. Fill the 150mm x 150mm iron mold in three layers with fresh concrete, vibrating each layer for a few minutes, depending on the water-to-cement ratio and the concrete grade.
ii. Smooth the surface of the concrete in the mold using a hand trowel, and allow it to harden overnight before removing from the mold.
iii. After demolding, place the concrete specimens in a curing tank filled with water, curing them for specified periods of 7, 14, 21, and 28 days.
iv. Using the universal testing machine, position the hardened concrete cubes on the fixed lower part, while the movable upper part is activated to make contact with the specimen. The specimen is then loaded until it fails, which is indicated when the two dial gauge indicators, which move clockwise during loading, show that one returns to zero and the other remains at the maximum reading reached. This maximum value is recorded. After failure, the upper part of the machine is moved upward, allowing space for removing, cleaning the failed specimen, and placing the next specimen for testing. Three concrete cubes from the same trial mix ratio are used to calculate the average compressive strength.

4. RESULTS AND DISCUSSIONS

Below is a detailed discussions on the results obtained. The analysis is presented in tables 4.1 to 4.5 and graphs 4.1

Table 4.1 slump tests result

Percentage of proportioning both soft and sharp sand	Slump value(mm)	Compacting factor ratio
0% soft: 100% sharp sand	5	0.8
25% soft: 75% sharp sand	7	0.83
50% soft: 50% sharp sand	19	0.85
75% soft: 25% sharp sand	12	0.81
100% soft: 0% quarry dust	20	0.87

Table 4.2 Rate of compressive strength development at 7 days

Percentage of proportioning both soft and sharp sand	Compressive strength(N/mm2)
0% soft sand: 100% sharp sand	16.54
25% soft sand: 75% sharp sand	21.34
50% soft sand: 50% sharp sand	16.91
75% soft sand: 25% sharp sand	15.13
100% soft sand: 0% sharp sand	12.86

Table 4.3 Rate of compressive strength development at 14 days

Percentage of proportioning both soft and sharp sand	Compressive strength(N/mm2)
0% soft sand: 100% sharp sand	20.16
25% soft sand: 75% sharp sand	30.38
50% soft sand: 50% sharp sand	26.87
75% soft: 25% sharp sand	21.80
100% soft sand: 0% sharp sand	20.90

Table 4.4 Rate of compressive strength development at 21 days

Percentage of proportioning both soft and sharp sand	Compressive strength(N/mm2)
0% soft sand: 100% sharp sand	28.70
25% soft sand: 75% sharp sand	35.23
50% soft sand: 50% sharp sand	29.80
75% soft sand: 25% sharp sand	27.9
100% soft sand: 0% sharp sand	28.0

Table 4.5 Rate of compressive strength development at 28 days

Percentage of proportioning both soft and sharp sand	Compressive strength(N/mm2)
0% soft sand: 100% sharp sand	31.6
25% soft sand: 75% sharp sand	40.17
50% soft sand: 50% sharp sand	38.77
75% soft sand: 25% sharp sand	35.6
100% soft: 0% sharp sand	32.0

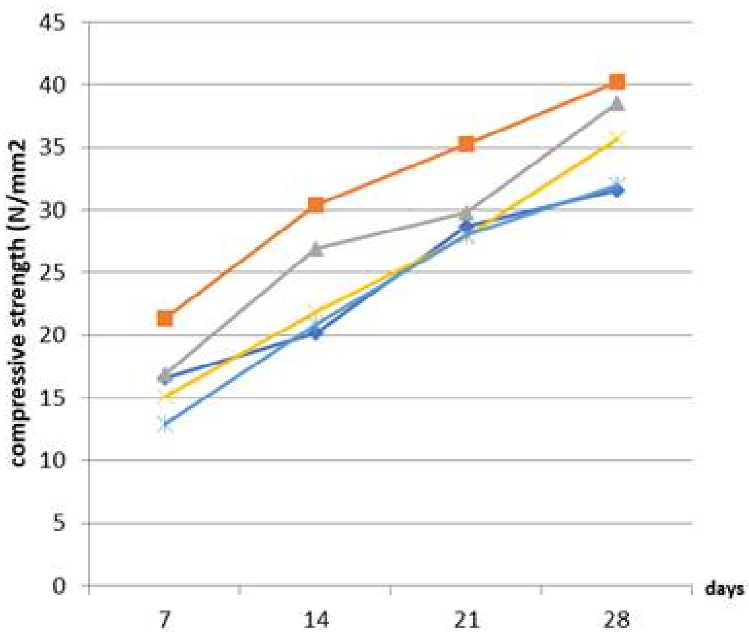

Fig. 4.1 Variation of compressive strength development with Age.

4.1 Discussions

Tables 4.1 to 4.5 present the variation in compressive strength development with age for different combinations of soft sand and sharp sand as fine aggregates. The compressive strength development for the mix ratio (1:2:3) with a water/cement ratio of 0.40 is illustrated in Figure 4.1. The highest compressive strength of 40.17 N/mm² was achieved at 28 days with a mix of 25% soft sand and 75% sharp sand. This strength was found to be inversely proportional to the water/cement ratio, as expected.

In general, the compressive strength for other combinations—50% soft sand: 50% sharp sand, 75% soft sand: 25% sharp sand, and 100% soft sand: 0% sharp sand—showed a decrease in strength as the percentage of soft sand in the mix increased. This reduction in strength may be due to the higher water absorption of soft sand, which leaves insufficient water for the complete hydration of the cement. Additionally, the compressive strength for the 100% quarry mix was lower, likely because excess water, beyond the optimum quantity required for cement hydration, was introduced into the concrete, as sharp sand has low water absorption capacity. Concrete mixes containing varying proportions of soft sand and sharp sand exhibited characteristics similar to concrete made with river sand as the fine aggregate.

From the experiment, it was observed that workability increased with a corresponding increase in the amount of soft sand up to 50%. This trend held true for the water/cement ratio considered in the study. However, beyond this point, further increases in soft sand led to a reduction in strength.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The investigation into the development of high-performance concrete (HPC) using varying proportions of sharp sand and soft sand as fine aggregates has led to several key conclusions:

i. The proportion of fine aggregate significantly influences the compressive strength, flexural strength, and workability of HPC. Mixes with a balanced ratio of sharp sand to soft sand (typically around 60:40 or 70:30) exhibited superior compressive strength and durability compared to mixes using either aggregate exclusively.
ii. An optimal mix design was identified where the inclusion of sharp sand improved strength due to its angularity and better interlocking characteristics, while soft sand contributed to improved workability and finishability. The synergy of both sands at appropriate proportions enhanced the overall performance of the concrete.
iii. Mixes with higher soft sand content exhibited better workability and surface finish but were prone to reduced strength and segregation issues. Sharp sand-dominant mixes showed higher strength but were less workable, requiring the use of admixtures to achieve desirable placement characteristics.
iv. Utilizing locally available soft and sharp sands in varying proportions offers a sustainable approach to HPC production, reducing reliance on imported or industrially processed fine aggregates without compromising structural performance.

5.2 Recommendations

Based on the findings of this study, the following recommendations are proposed:

i. For most civil engineering applications, a fine aggregate mix ratio of 60% sharp sand to 40% soft sand is recommended to achieve an optimal balance of strength, workability, and durability in high-performance concrete.
ii. When higher proportions of sharp sand are used, incorporating superplasticizers or water-reducing agents is advisable to improve workability and ensure proper compaction without increasing water content.
iii. It is recommended that standards or guidelines be developed for the use of mixed fine aggregates in HPC, including permissible ranges and required performance characteristics for different structural applications.
iv. Continuous monitoring of aggregate grading, cleanliness, and moisture content is essential to maintain consistency in concrete quality when using variable sand types.

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