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Comparative Analysis on Concrete Strength Using Various Sizes of Aggregates and Combined Gradation

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Abstract

This research delves into the effect of using various single coarse aggregate sizes and combinations of such by specific proportions. A thorough examination involving control specimens of 12mm, 20mm, and 25mm aggregates sizes, with combining proportions in the ratios – 5/8:3/8, 1/2:1/2, 3/8:5/8 have been conducted, shedding light on critical patterns that dictate concrete performance. The fine aggregate was properly zoned from the preliminary test. The design mix was calculated for a characteristic strength of 15N/mm2. The concrete mixes were in batches, each containing a single coarse aggregate size or a blend of two different coarse aggregate sizes. Crushed aggregate (Granite) was used in this experiment. The study reveals a consistent trend wherein mixes with larger single-sized coarse aggregates demonstrate superior compressive strengths, aligning with established principles of concrete technology. However, improvements were observed upon the use of an optimization ratio to combine different coarse aggregate sizes into a blend. Two standout mixes, E (12mm: 20mm - 5/8:3/8) with compressive strength of 21.4N/mm2 and 26.6N/mm2 and K (20mm: 25mm - 5/8:3/8) with compressive strength of 29.1N/mm2 and 33.3N/mm2, consistently exhibited remarkable strengths at 7 and 28 days respectively. The success of these mixes underscores the pivotal role of specific aggregate sizes and proportions in optimizing concrete performance. The findings offer practical recommendations, emphasizing the importance of carefully tailoring aggregate gradation, exploring effective ratios such as 5/8:3/8, and systematically monitoring strength development over time. This research not only contributes valuable insights for concrete mix design but also provides engineers with a nuanced understanding of how aggregate gradation influences compressive strength.

Keywords: compressive strength, combined gradation, crushed aggregate, preliminary test, aggregate gradation, design mix, optimizing concrete.

INTRODUCTION

Concrete, as one of the most widely used construction materials, plays a pivotal role in modern infrastructure development [1]. Its versatility, durability, and cost-effectiveness have made it indispensable for various applications, from residential buildings to massive industrial complexes.

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At the heart of concrete's performance lies the composition and characteristics of its components, with aggregates standing out as a crucial constituent. Among these components, aggregates, comprising granular materials like sand, gravel, and crushed stone, play a pivotal role in shaping the physical and mechanical properties of concrete [2].

The aggregate phase forms a substantial portion of the concrete mixture by volume, often accounting for up to 70-80% of the total volume (Mehta et al., 2013). This underscores their significance in influencing the properties of fresh and hardened concrete. The selection of appropriate aggregate types, sizes, and gradation greatly influences the workability, strength, and durability of the final concrete product. Aggregate characteristics interact intricately with cement paste, affecting the distribution of forces within the material and thus dictating its performance under varying loads and conditions [3].

Aggregate size distribution, an essential factor in concrete mix design, holds a key role in determining the workability and strength of concrete.

Coarser aggregates, such as granite, impart mechanical strength to the mixture through interlocking and load transfer mechanisms. Finer aggregates, like sand, fill the interstitial spaces, aiding in achieving better cohesion. These size-dependent effects significantly influence the void structure, porosity, and packing density of the concrete matrix.

However, the complex interplay of aggregate size and gradation with concrete strength is not fully understood, and further investigation is warranted. While previous studies have delved into the impact of individual aggregate sizes or specific gradations, a comprehensive comparative analysis encompassing a range of aggregate sizes and combined gradations is notably lacking.

As engineering demands diversify and construction practices evolve, there is an increasing need to tailor concrete mixtures to specific requirements. Achieving optimal concrete performance entails a thorough understanding of how different aggregate sizes and combined gradations affect properties such as workability, strength, and durability. Such knowledge is invaluable for engineers striving to design structures that not only withstand loads but also contribute to sustainable development.

The concept of "combined gradation" takes a holistic approach to aggregate mix design. By carefully balancing the proportions of various aggregate sizes, this technique aims to achieve a dense packing arrangement that minimizes voids and maximizes particle interlocking. The outcome is a concrete mixture with enhanced mechanical properties and improved resistance to external forces and environmental factors. Understanding the nuances of combined gradation and its synergy with different aggregate sizes is crucial for optimizing concrete mixtures for diverse applications.

In light of these considerations, this study embarks on a journey of in-depth exploration. It seeks to bridge the gap in existing research by conducting an extensive comparative analysis of concrete strength, unraveling the intricate relationships between different granite aggregate sizes, combined gradations, and compressive strength. By systematically evaluating the effects of these variables, the study aims to contribute valuable insights to the field of concrete technology, offering guidance for efficient mix design and paving the way for more sustainable and resilient construction practices.

MATERIALS AND METHODS

Materials

Cement

The research utilized Dangote 3X cement, specifically grade 42.5 Portland cement, complying with ASTM C150 (2005) standards. This particular type of cement was sourced from reputable dealers located at AGIP Junction, Port Harcourt, Nigeria, ensuring authenticity and adherence to quality specifications.

Fine Aggregates

In this research, locally obtained natural river sand from Choba River, Port Harcourt, served as the fine aggregates.

Coarse Aggregates

For this experimental study, locally sourced granites for specific sizes and bags were obtained from a retailer.

Water

The water utilized in the study was sourced from potable tap water, ensuring it was devoid of impurities, odors, colors, or taste alterations. Its quality adhered to the standards outlined in BS EN1008, meeting the specified criteria set for such applications.

Methods

Sieve Analysis

The sieve analysis test for both fine and coarse aggregates adhered to BS EN 933 standards. To conduct this test, a 300g sample of fine aggregate was carefully weighed and then evenly distributed across various BS sieves with aperture sizes ranging from 5mm down to 150 µm, as well as a pan to collect the finest particles. The sieves were then vigorously shaken using a mechanical sieve shaker to separate the particles based on size. The weight of the sample retained on each sieve was meticulously recorded.

Subsequently, the gradation of the fine aggregates was determined by plotting a graph of the percentage passing against the different sieve sizes. This graph provided a clear visualization of how the aggregates were distributed across the various particle sizes.

Slump Test

The test was carried out for each of the samples of fresh concrete to determine workability. The slump mold was filled in three layers, and each layer underwent compaction using a steel rod with 25 blows before the subsequent layer was added. After filling the slump cone, the surface was leveled and left undisturbed for about 2 minutes. Subsequently, the slump cone was carefully lifted off the concrete, allowing the unsupported concrete pile to collapse naturally. The variance between the initial and final height of the concrete was then measured and recorded as the slump readings.

Mixing, Casting, and Curing

The proportions of cement to aggregates, as well as the water-cement ratio, are precisely determined to achieve the desired consistency and strength without compromising on workability. A design mix was calculated for a characteristic strength of 15N/mm^2, proportioning of coarse aggregate was specific to three ratios (5/8:3/8, 3/8:5/8, ½:½). The mixing was done following BS 5328-1, and BS 1881. The water/cement ratio was limited to 0.6 hence, ensuring its consistency. The size of the cube mold used for this experimental study was 150mm*150mm*150mm, which conformed to BS EN 12390.

Twenty-four hours after casting, the concrete specimen was de-molded, labelled, and then immersed in water for a period of 7 and 28 days. The curing water conformed to BS EN 1008.

Compressive Strength Test

The compressive tests were taken at 7 days and 28 days. 12 batches for each of the curing days. The batches comprised the control specimens for the 3 various granite aggregate sizes, and then the combination of the sizes according to the specified combining ratios (5/8:3/8, 3/8:5/8, ½:½). The test was following BS EN 12390-3:2002.

The cubes were removed from the curing tank, weighed, and tested at 7 and 28 days with the Universal Testing Machine. The value of the load at which the test cube failed was recorded and used to calculate the compressive strength at each curing age.

RESULTS AND DISCUSSIONS

Sieve Analysis

The equations employed are as follows:

$$C_U = D_{60}/D_{10}$$

$$C_C = {D_{30}}^2 / D_{60} \times D_{10}$$

Where:

- D60 particle size corresponding to 60% finer particles
- D30 particle size corresponding to 30% finer particles
- D10 particle size corresponding to 10% finer particles 3

From particle distribution curve in Figure 1. Since Cu is less than 6 and Cc is above 1 the sand is uniformly/well graded. From gradation, the fine aggregate is classified under zone I sand.

The granite aggregate was already prepared in specific sizes and bagged according to request.

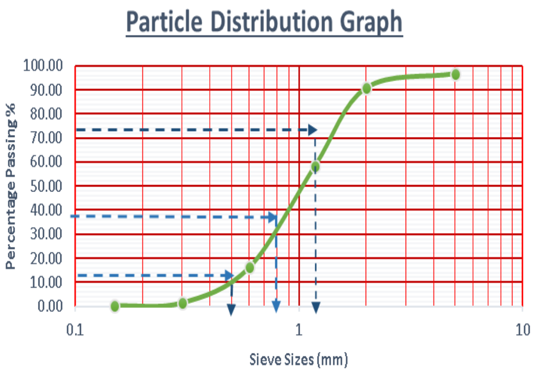

Figure 1. Particle size distribution of fine aggregates.

Slump Test

The slump values which show the degree of workability across the concrete specimens have been presented in Figure 2. The average value of the trials for the various batches based on mixed proportions of aggregates has been labeled from Tag A to Tag L as represented in Figure 3. It can be deduced that mixes with combinations of granite aggregate sizes proved more workable. The average increase in workability due to the combined granite aggregate sizes was at least 30%.

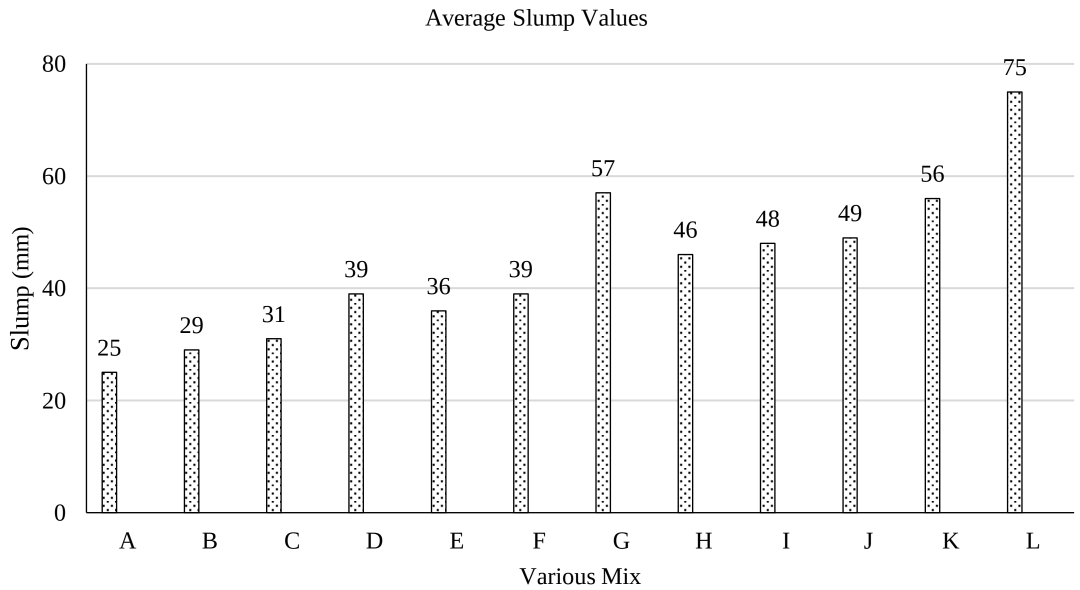

Figure 2. Average slump values for all mixes

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Tags	Material Identification
A	12 mm-CTRL
B	20 mm-CTRL
C	25 mm-CTRL
D	12mm:20mm-(1/2:1/2)
E	12mm:20mm-(5/8:3/8)
F	12mm:25mm-(3/8:5/8)
G	12mm:25mm-(1/2:1/2)
H	12mm:25mm-(5/8:3/8)
I	12mm:25mm-(3/8:5/8)
J	20mm:25mm-(1/2:1/2)
K	20mm:25mm-(5/8:3/8)
L	20mm:25mm-(3/8:5/8)

Figure 3. Various mixes and their identification.

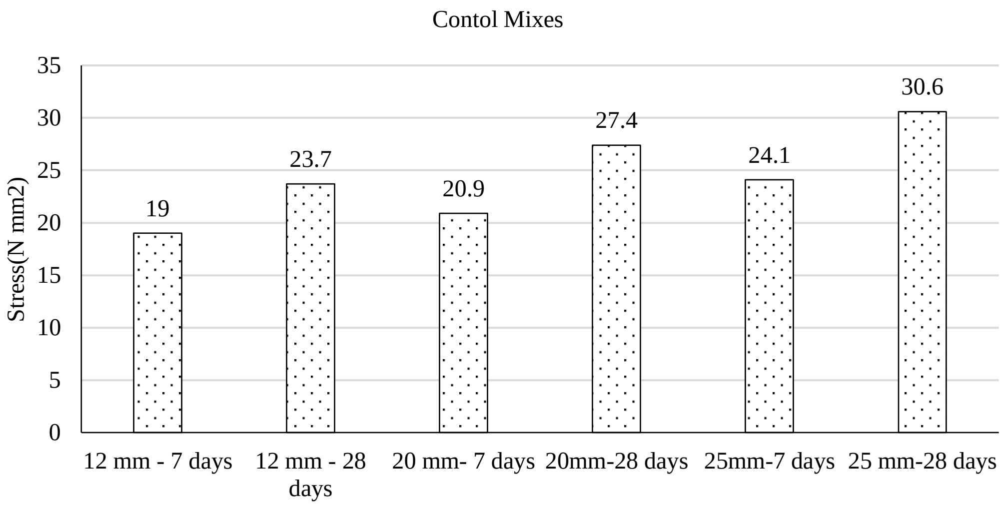

Figure 4. Compressive stress of control mixes for 7 days and 28 days.

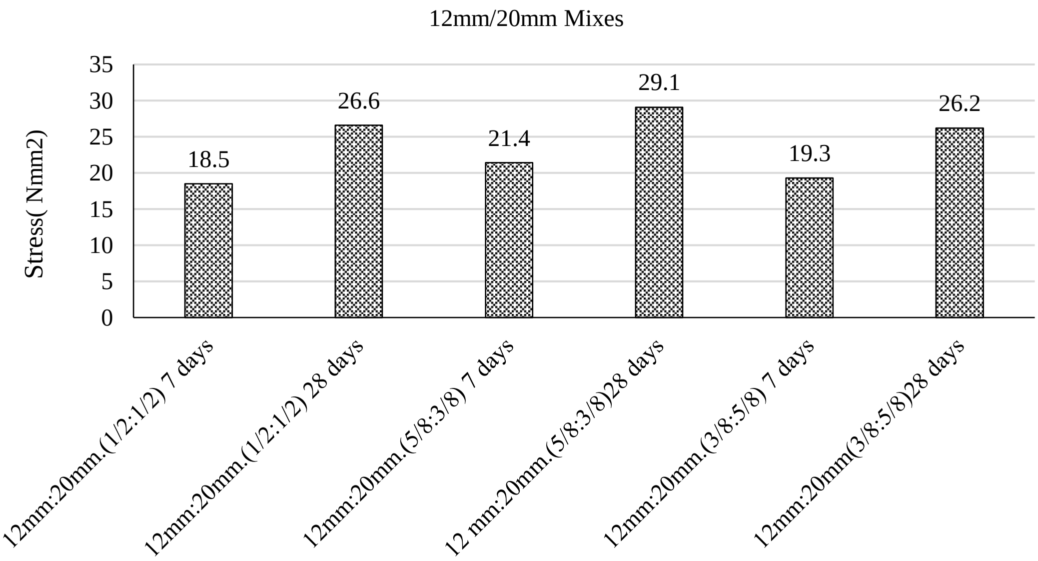

Figure 5. Compressive stress of 12mm/20mm mixes for 7 days and 28 days.

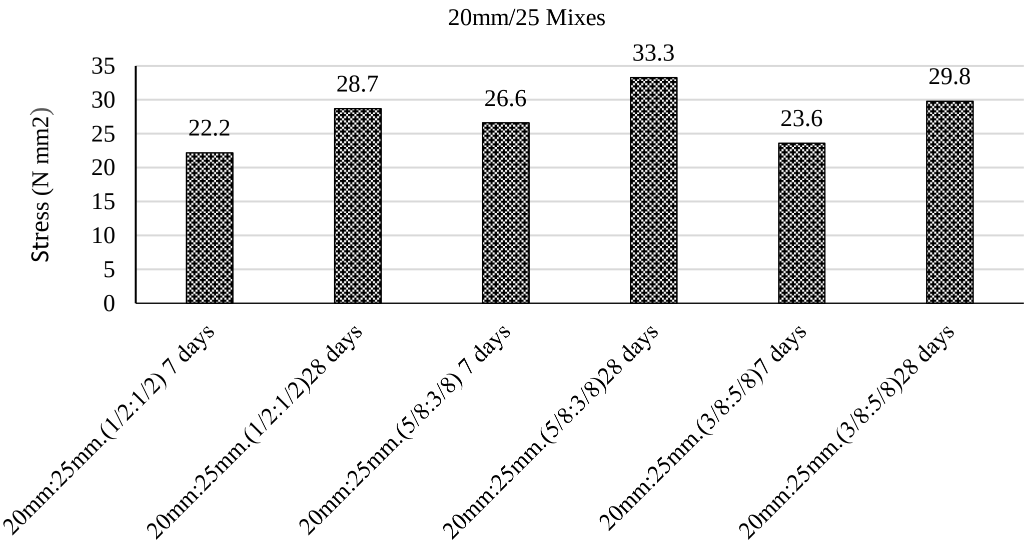

Figure 6. Compressive stress of 20mm/25mm mixes for 7 days and 28 days.

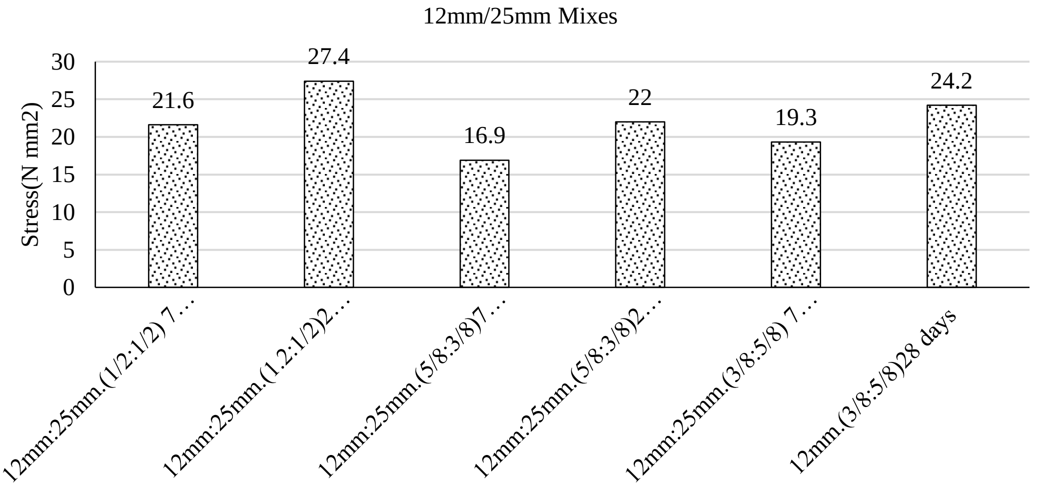

Figure 7. Compressive stress of 12mm/20mm mixes for 7 days and 28 days.

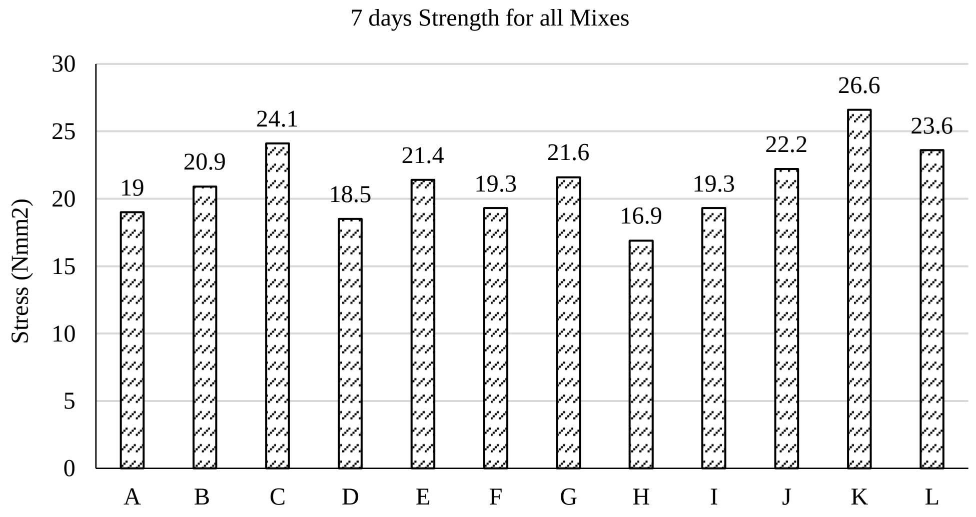

Figure 8. Compressive stress of all mixes for 7 days.

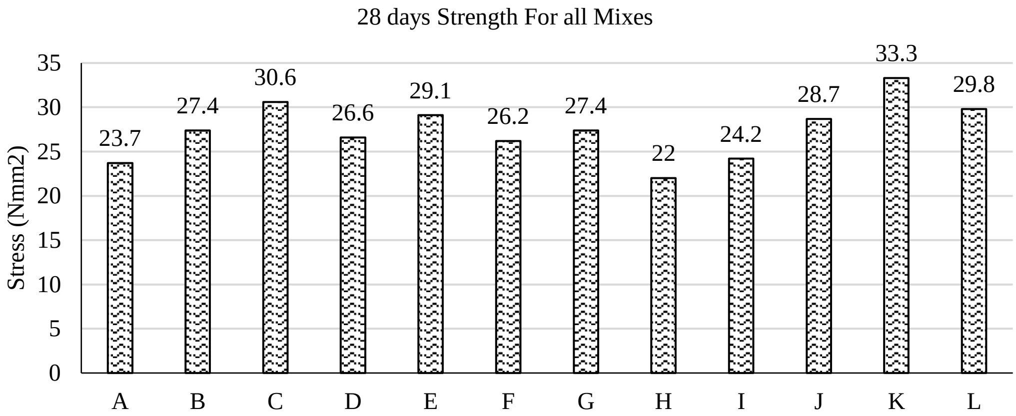

Figure 9. Compressive stress of all mixes for 28 days

Compressive Strength

Figure 4 shows the appreciation in concrete strength for 7 days and 28 days for the control mixes of singly sized 12mm, 20mm, and 25mm granite aggregate. Figures 5, 6, 7 show concrete strength for 12/20, 20/25, and 12/25 mixes respectively. Ultimately, the attribute of larger coarse aggregate size as well as the attribute of combined size gradation is clearly shown in Figure 8 and Figure 9. Larger aggregate sizes show higher load bearing while the combining ratio of closely gapped aggregate sizes showed improvement in concrete strength compared with the controls, especially the 5/8:3/8 proportion.

CONCLUSION

- The study reveals a consistent upward trajectory in compressive strength across diverse mixes, emphasizing the sustained development of concrete strength from 7 days to 28 days. At least 70 percent of 28 days strength was recorded at 7 days.
- The results of this work show that for an increase in single coarse aggregate size from 12mm up to 25mm at constant water content, the compressive strength increased by at least 10 percent.
- There were noteworthy performances with mixes E (12mm: 20mm - 5/8:3/8) and K (20mm: 25mm - 5/8:3/8) emerge as particularly effective, indicating that the combination of specific aggregate sizes and in specific proportions significantly optimizes compressive strength achieved.
- The trend of optimized and improved strength characteristics with the use of the 5/8:3/8 proportion failed with the mix H (12mm: 25mm). This can be accrued to the wide gap in gradation range. This suggest greater voids and lower packing density of concrete.

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