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An Experimental Analysis of Coarse Aggregate Size Influence on Concrete Strength

Pankaj Singh [1], Devesh Ojha[2]

[1,2] Department of Civil Engineering, Amity University Uttar Pradesh, Lucknow Campus, India
[1]beerpankaj1@gamil.com, [2]deveshojha.ojha18@gmail.com

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Abstract

Concrete is one of the most used construction materials, with its mechanical proper-ties, especially compressive strength, significantly affected by the size of coarse aggregates. This research explores the impact of varying coarse aggregate sizes on concrete's com-pressive strength. Controlled experiments were conducted on concrete samples contain-ing different aggregate sizes, demonstrating a clear relationship between aggregate size and compressive strength. The study offers valuable insights for optimizing aggregate selection to enhance concrete performance in construction. The primary objective is to assess how coarse aggregate size influences concrete strength. The concrete mix utilizes cement, fine aggregates, coarse aggregates, and water as key com-ponents. Workability was measured using the slump test, and compressive strength was determined through cube tests, adhering to IS 456-2000 standards for fresh and hardened concrete. M20 grade concrete (1:1.5:3 mix ratio) specimens with dimensions of 150 mm x 150 mm x 150 mm were prepared and cured for 7, 14, and 28 days. The findings revealed that concrete with aggregate sizes between 20 and 25 mm achieved higher compressive strength after 28 days compared to concrete with smaller aggregate sizes of 12 to 19 mm and 4.75 to 10 mm.

Keywords

Aggregate size, Concrete strength, compressive strength, Mix ratio, Slump test

1. Introduction

Concrete, a composite material made from cement, water, fine aggregates, and coarse aggregates, exhibits varying properties based on the characteristics and proportions of its components. Coarse aggregates, defined as particles larger than 4.75 mm, play a vital role in determining concrete's mechanical performance. This study examines the effect of coarse aggregate size on the compressive strength of concrete, a critical property for structural applications. Previous research highlights the influence of aggregate type and size on strength. Abdullahi [2] found that concrete with crushed quartzite provided superior compressive strength at all curing stages compared to granite-based concrete. Similarly, Aginam et al. [3] noted that granite aggregates yielded stronger concrete than washed and unwashed gravel mixtures. Muhit et al. [4] reported that "vertically shafted" aggregates led to higher slump values, while reducing the water-to-cement ratio improved the compressive strength of concrete with "impact crushed" aggregates. Jimoh and Awe [5] observed a 34% strength increase using 20 mm granite and quarry dust versus 28 mm sand and gravel, concluding that compressive strength generally declines with increasing aggregate size, particularly with quarry dust. Xie et al. [6] confirmed this inverse relationship between aggregate size and strength, while Bhiskshma and Florence [7] demonstrated that a maximum aggregate size of 12.5 mm produced the highest strength in fly ash-enhanced high-grade concrete. Laterite, a cost-effective, environmentally friendly material prevalent in tropical regions, has seen growing use. Osadebe and Nwakonobi [8] noted its widespread application in Nigerian construction despite limited use in large-scale projects due to insufficient design data. Joseph et al. [9] found that replacing river sand with a mix of lateritic sand and quarry dust produced compressive strengths between 17 and 34.2 N/mm², supporting the use of laterized concrete with up to 50% laterite for structural purposes. Olubisi [10] revealed that laterite as a partial aggregate replacement increased strength under magnesium sulfate exposure but decreased it under cyclic wetting and drying. Optimal strength (12.9 N/mm²) was achieved with a 20% laterite ratio at 100°C. Despite extensive research on laterized concrete, few studies explore the impact of varying coarse aggregate sizes on its workability and strength. This study aims to fill that gap by investigating the influence of different coarse aggregate sizes on laterized concrete, given their common use in construction.

2. Objectives

a) To evaluate the effect of varying coarse aggregate sizes on the compressive strength of concrete.
b) To determine the optimal coarse aggregate size that maximizes compressive strength while preserving workability.

3. Materials and Methods

3.1. Materials

a) **Cement:** Ordinary Portland Cement (OPC) was used for the preparation of the concrete mix.
b) **Fine Aggregate:** Natural sand conforming to ASTM C33 specifications was employed as the fine aggregate.
c) **Coarse Aggregates:** Three different sizes of coarse aggregates were selected for the study:
Small (10 mm), Medium (20 mm), Large (25 mm)
d) **Water:** Clean, potable water was utilized for the mixing process.

3.2. Acceptability Criteria for Testing Hardened Concrete

a) **Strength Test:** Strength tests were conducted to evaluate the potential strength of the concrete after curing. These tests followed standard procedures to ensure proper control over the batching and mixing processes, confirming that the concrete met the specified requirements.
b) **Laboratory Testing:** Laboratory tests were performed on both retarder and Ordinary Portland Cement (OPC) to characterize their properties and determine the resulting strength when mixed with other components. These tests included compressive strength assessments and slump tests.
c) **Curing of Cubes:** Concrete cubes measuring 15 cm x 15 cm were cast for compressive strength testing. The cubes were cured and tested at 7, 14, and 28 days to assess their strength development over time.

3.3. Preparation of cubes for checking compressive strength of concrete

Proper preparation of concrete cubes is essential for obtaining reliable compressive strength test results. The process begins with a 15 cm × 15 cm cube mold, a concrete mix prepared according to specified ratios, and a suitable compaction method, such as a vibrator or tamping rod. The mixed concrete is poured into the molds in three layers, with each layer thoroughly compacted to remove air pockets and ensure uniform density and strength. A tamping rod or vibrating table is commonly used for this purpose. After compaction, the surface is leveled to create a smooth, even finish. To prevent moisture loss during curing, the molds are covered with plastic sheeting or damp burlap. Initial curing takes place for 24 to 48 hours in a controlled environment at room temperature. Once this period is complete, the cubes are carefully demolded and transferred to a curing tank filled with water or another humid environment to maintain hydration. The curing process continues for specified durations of 7, 14, and 28 days, ensuring the concrete develops its full-strength potential. After the final curing period, the cubes are ready for compressive strength testing.

3.4. The slump and compressive tests

Slump Test: The slump test is a simple and widely used method for evaluating the workability and consistency of fresh concrete. In this test, concrete is placed into a conical mold in three layers, with each layer compacted using a tamping rod. Once the mold is carefully lifted, the concrete settles into a shape known as a "slump." The vertical distance the concrete sinks is measured to determine their workability. A higher slump indicates greater workability, meaning the concrete is more fluid and easier to place and handle. This test ensures that the mix has adequate workability for proper placement without segregation, contributing to consistent quality and durability in construction.

Compressive Strength Test: The compressive strength test assesses the hardened concrete's ability to resist axial loads. Concrete cubes or cylinders are cast and allowed to cure for specified durations—typically 7, 14, and 28 days. After curing, the specimens are placed in a compression testing machine, where an axial load is applied until failure. The maximum load recorded is divided by the cross-sectional area of the specimen to calculate the compressive strength. This test provides critical information about the concrete's load-bearing capacity, a key factor in ensuring structural safety. When combined with the slump test, it helps verify that the concrete mix meets both workability and strength requirements for construction applications.

3.5. Sieve Analysis

Sieve analysis is a laboratory method used to determine the particle size distribution of granular materials, such as the aggregates used in concrete. In this procedure, a sample of the material is passed through a series of standardized sieves with progressively smaller openings. The amount of material retained on each sieve is weighed to calculate the percentage of total weight corresponding to each particle size fraction. The data obtained from the sieve analysis is used to construct a particle size distribution curve, which helps assess whether the aggregates are suitable for specific construction purposes. Well-graded aggregates, as determined by sieve analysis, are easier to work with and result in concrete with fewer voids, enhancing their strength and durability. An important component of sieve analysis is the calculation of the **fineness modulus (FM)**, which provides a single value representing the average particle size in the aggregate sample. The fineness modulus is calculated using the following formula:

$$\mathrm{FM} = \frac{\sum(\text{cumulative percent retained on each sieve})}{100}$$

Typically, the percentages of material retained are collected from a defined series of sieves. The fineness modulus (FM) is particularly useful in concrete mix design, as it assists in determining the appropriate proportions of fine and coarse aggregates required to achieve the desired properties in the final concrete product. By understanding the fineness modulus, engineers can optimize the aggregate composition to enhance the workability, strength, and durability of the concrete mix.

4. Results and Discussion

The study involved conducting sieve analysis, compressive strength testing, and slump testing. The outcomes of the sieve analysis, detailing the sizes of both fine and coarse aggregates, are presented below.

Table 1. Results of sieve analysis test for fine aggregate.

Sieve sizes (mm)	Weight Retained (kg)	Percentage Retained	Cumulative percentage Retained	Cumulative Percentage Passing
4.75 mm	0.0354	3.54	3.54	96.46
2.36 mm	0.0324	3.24	6.78	93.22
1.18 mm	0.143	14.3	21.08	78.92
600 microns	0.254	25.4	46.48	53.52
300 microns	0.347	34.7	81.18	18.82
150 microns	0.162	16.2	97.38	2.62
Pan	0.0151	1.51	-	-
Finess Modulus			2.41	

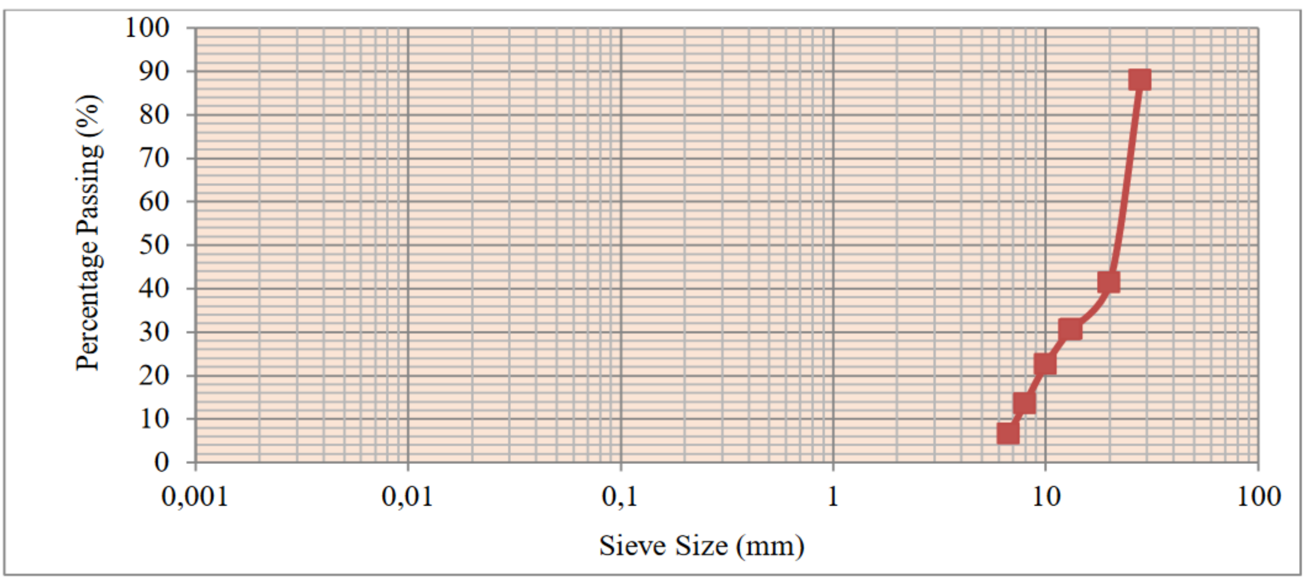

Figure 2. Particle size distribution for fine aggregate

Table 2. Results of sieve analysis test for coarse aggregate.

Sieve sizes (mm)	Weight Retained (kg)	Percentage Retained	Cumulative percentage Retained	Cumulative Percentage Passing
80 mm	0	0	0	100
40 mm	0	0	0	100
20 mm	1.618	1.618	26.96	73.04
10 mm	4.247	5.865	97.75	2.25
4.75 mm	0.135	6.000	100	0
Pan	0	0	-	-
Finess Modulus			7.30	

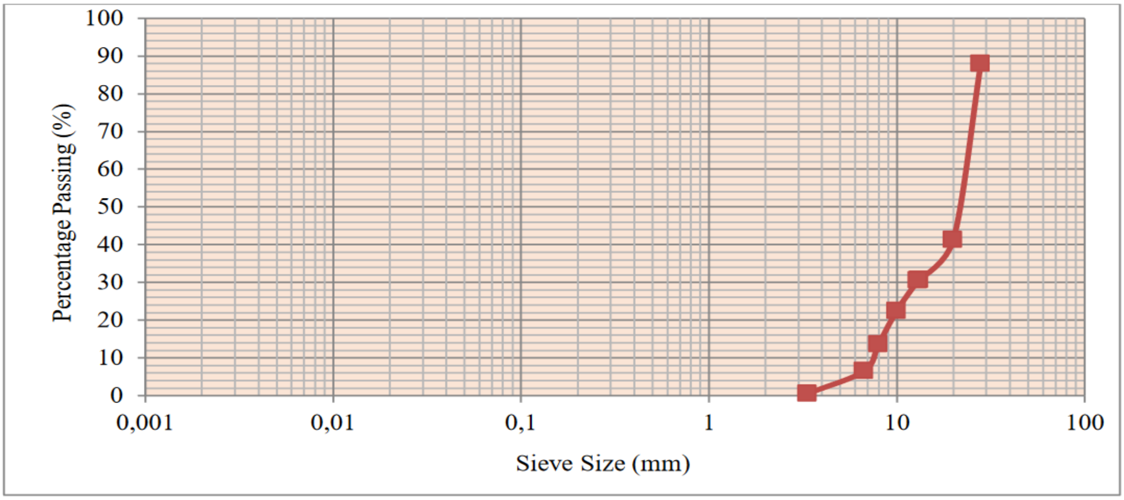

Figure 3. Particle size distribution for coarse aggregate

The results from the compressive strength test for various coarse aggregate sizes (4.75mm–10mm, 12mm–19mm, and 20mm–25mm) are presented below.

Table 3. Results of compressive strength for 4.75mm-10mm coarse aggregate.

AGGREGATE SIZES = 4.75mm-10mm; AREA OF CUBE = 22500mm					
Age (Days)	Cube Description	Weight Before Curing (Kg)	Weight After Curing (Kg)	Load (KN)	Compressive Strength (N/mm^2)
7	AA	7.64	7.94	500	21.11
	AB	8.09	8.25	495	
	AC	8.04	8.13	525	
14	BB	7.84	7.92	536	23.82
	BC	7.68	7.89	500	
	BD	7.89	8.21	525	
28	CC	7.74	8.02	600	26.67
	CD	8.15	8.35	598	
	CE	8.11	8.223	581	

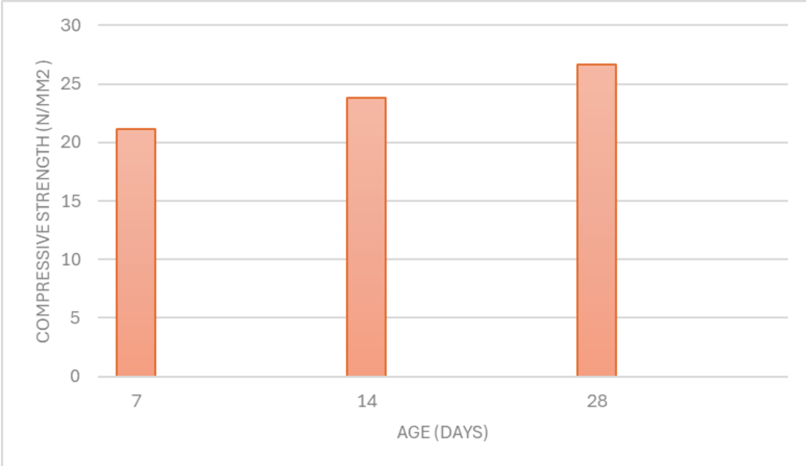

Figure 4. Compressive strength of 4.75mm-10mm coarse aggregate

Table 4. Results of compressive strength for 12mm-19mm coarse aggregate

AGGREGATE SIZES = 12 mm-10mm; AREA OF CUBE = 22500mm					
Age (Days)	Cube Descrip-tion	Weight Before Curing (Kg)	Weight After Curing (Kg)	Load (KN)	Compressive Strength (N/mm^2)
7	DD	8.44	8.75	565	26.21
	DE	9.19	9.25	545	
	DF	9.02	9.23	586	
14	EE	8.94	8.96	621	28.42
	EF	8.61	8.79	613	
	EG	8.81	8.91	652	
28	FF	8.84	9.02	667	32.15
	FG	9.05	9.35	673	
	FH	9.07	9.22	669	

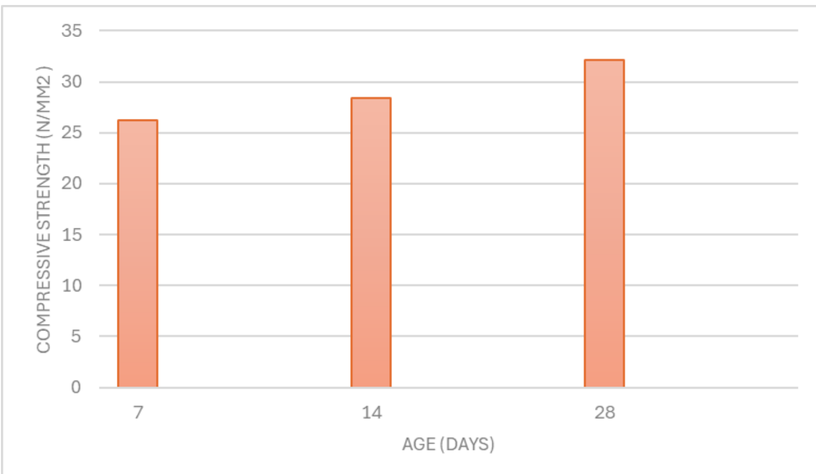

Figure 5. Compressive strength of 12mm-19mm coarse aggregate

Table 5. Results of compressive strength for 20mm-25mm coarse aggregate.

AGGREGATE SIZES = 12 mm-10mm; AREA OF CUBE = 22500mm					
Age (Days)	Cube Descrip-tion	Weight Before Curing (Kg)	Weight After Curing (Kg)	Load (KN)	Compressive Strength (N/mm^2)
7	GG	9.34	9.45	473	24.25
	GH	9.29	9.32	554	
	GI	9.43	9.48	565	
14	HH	9.64	9.66	634	26.36
	HI	9.61	9.69	609	
	HJ	9.41	9.54	642	
28	II	9.54	9.61	658	30.65
	IJ	9.35	9.47	662	
	IK	9.47	9.58	648	

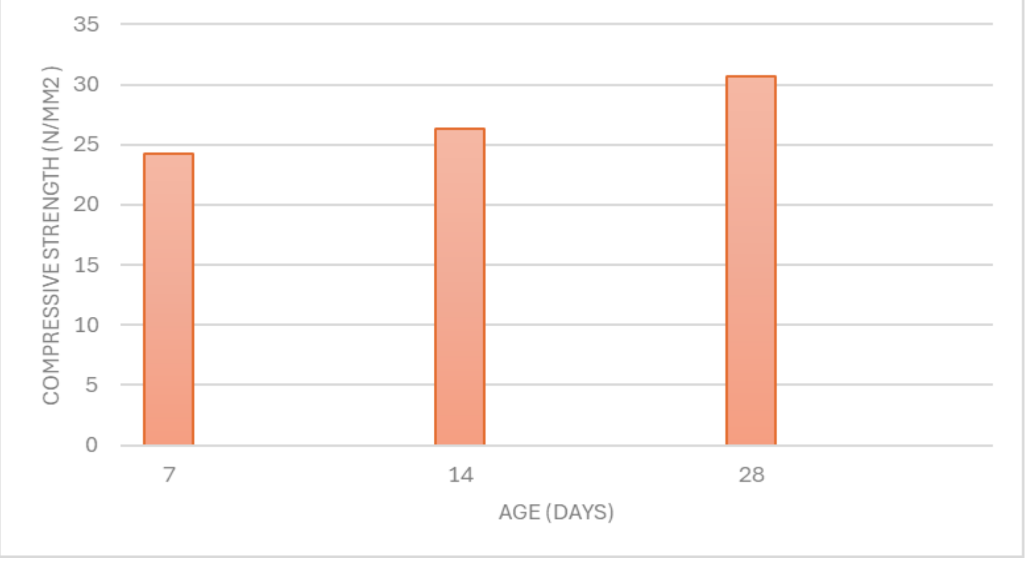

Figure 6. Compressive strength of 20mm-25mm coarse aggregate

Table 6. Summary of compressive strength for different coarse aggregate sizes.

Age (Days)	**Compressive strength for difference coarse aggregate sizes**		
	20-25mm	**12-19mm**	**4.75 - 10mm**
7	24.25	26.21	21.11
14	26.36	28.42	23.82
28	30.65	32.15	26.67

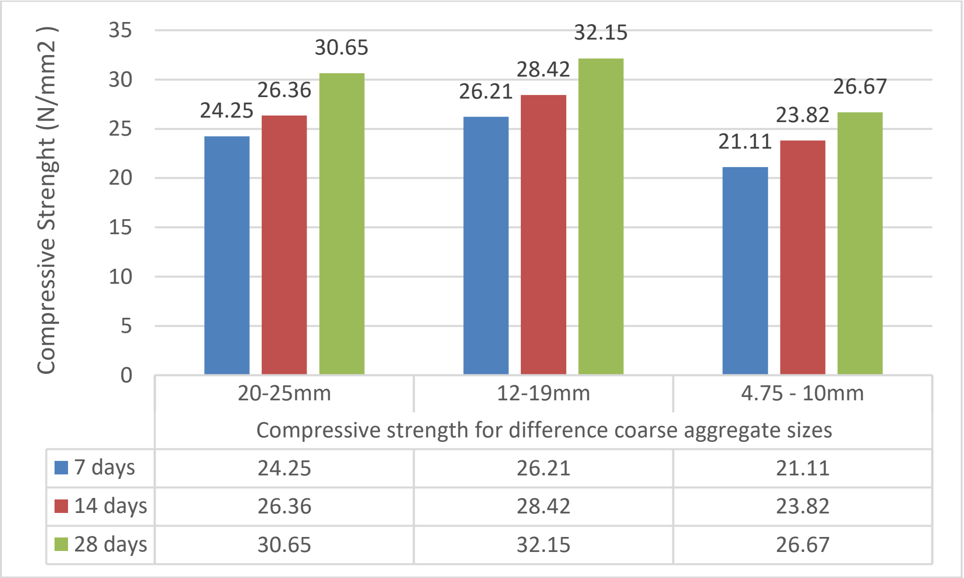

Figure 7. Compressive strength of different sizes of coarse aggregates

According to the results of the laboratory experiment, concrete made with coarse aggregates ranging from 20mm to 25mm (retained between the 20mm and 25mm sieves) displayed the highest compressive strength compared to the other aggregate size ranges. These results are shown graphically in Figure 7 and summarized in Table 6. In contrast, the smallest aggregate size range, 4.75mm to 10mm, resulted in the lowest compressive strength, with strength decreasing as the aggregate size increased from 12mm to 19mm.

Concrete made with larger aggregate sizes (20 mm to 25 mm and 12 mm to 19 mm) exhibited a slightly higher weight compared to concrete made with smaller aggregates (4.75 mm to 10 mm), both before and after curing. This increased weight indicates that the concrete is more robust and capable of withstanding greater loads, resulting in improved load-bearing capacity and enhanced pressure resistance. The data presented in Tables 3, 4, and 5 further support this observation, showing that concrete with larger coarse aggregates required higher crushing forces. Thus, it can be concluded that concrete with larger coarse particles tends to be stronger and more durable.

5. Conclusion

The experimental findings indicate a clear relationship between the size of coarse aggregates and the compressive strength of concrete, with larger aggregate sizes correlating with increased strength. Additionally, longer curing durations were shown to enhance the concrete's overall strength. It was observed that concrete cubes containing larger coarse aggregates had a greater weight compared to those made with smaller aggregates. Moreover, crushed stone was noted for its favorable surface roughness, which promotes a strong bond between the cement paste and the aggregates. Based on these insights, the following recommendations are proposed for selecting aggregate sizes to achieve optimal concrete strength:

a) **Utilize Larger Aggregate Sizes for Foundations**: For foundation construction, it is advisable to use larger aggregate sizes due to their demonstrated higher compressive strength, which contributes to overall structural integrity.

b) **Ensure Proper Compaction of Concrete**: Effective compaction of concrete cubes is critical, as it was found to enhance strength significantly during the experimentation process. Adequate compaction minimizes voids and ensures uniform density.

c) **Prioritize Workability in Concrete Mix Design**: The workability of the concrete mix is essential, as it directly influences compressive strength. The mix should be designed to ensure sufficient workability, facilitating proper placement and compaction while achieving the desired strength characteristics.

6. Recommendations

Further research is needed to explore the effects of different aggregate sizes on other important concrete properties, such as flexural strength and durability. These aspects are crucial for the long-term performance of concrete in various applications, especially in environments subject to harsh conditions. Additionally, investigating the combination of multiple aggregate sizes within a single mix could offer valuable insights into optimizing concrete performance. Such studies may reveal how to balance the benefits of different sizes to enhance overall strength, workability, and durability, leading to more efficient and sustainable concrete formulations.

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