INVESTIGATION ON THE EFFECTS OF COARSE AGGREGATE SIZE ON COMPRESSIVE STRENGTH OF CONCRETE

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ABSTRACT

Concrete being versatile, durable and cost-effective material is seeing as one of the most widely used construction materials in the world. Its compressive strength is considered as the most crucial mechanical property determining its performance and suitability for various applications. Despite the widespread use of natural gravel (bush gravel) as a low-cost aggregate in concrete production across rural and developing regions, the effects of its varying particle sizes on the compressive strength of concrete remain in adequately understood and poorly documented leading to inconsistent structural performance and reliability. This study investigated the influence of aggregate size on fresh and harden properties of concrete. The research examined different maximum aggregate sizes of; 12mm, 20mm, 25mm, and 30mm while maintaining consistent water-cement ratio, and mixing proportions. Specimens were tested for compressive strength at 3, 7, and 28 days of curing ages and slump tests. The experimental results demonstrated that concrete mixtures with maximum aggregate sizes of 20mm exhibited optimal compressive strength values, while smaller and larger aggregate sizes showed a slight decrease in strength. Hence, it is observed that 20 mm maximum size aggregate displayed the maximum strength and therefore recommended as the optimal size to achieve desired strength under same conditions.

Keywords: Compressive strength, Concrete, Aggregate, Slump

1 INTRODUCTION

Concrete is one of the most widely used construction materials in the world due to its versatility, durability, and cost-effectiveness. Its mechanical properties, particularly compressive strength, play a crucial role in determining its performance and suitability for various applications. The compressive strength of concrete is influenced by various factors, including the quality and proportions of its constituent materials, mixing process, curing condition, and the size of the aggregates used. Aggregates, which comprise approximately 60-80% of the concrete volume, have a significant impact on the compressive strength and other properties of concrete [1]. Aggregates can be classified based on their size, with coarse aggregates typically ranging from 4.75 mm to 37.5 mm and fine aggregates ranging from 0.075 mm to 4.75 mm [2]. The size and gradation of the aggregates used in concrete can influence various aspects, including workability, density, and strength. The effect of aggregate size on compressive strength has been a subject of extensive research and debate in the field of concrete technology. While some studies suggest that using smaller aggregate sizes can enhance compressive strength [1, 3], others indicate that larger aggregate sizes may be more beneficial [4, 5]. These conflicting findings highlight the complexity of the relationship between aggregate size and compressive strength. Understanding the effects of aggregate size on compressive strength is crucial for optimizing concrete mix designs and ensuring the desired performance of concrete structures. However, all the reviewed literature focused on crushed stone gravels (processed aggregates) and leave the natural coarse aggregate untouched. This research work investigated the effect of maximum size of natural coarse aggregate (bush gravel) on compressive strength of concrete. In many low-income regions, particularly in sub-Saharan Africa, there is a growing need for cost-effective and locally available materials for construction. One of such material that has gained attention is bush gravel, an unprocessed or minimally processed form of natural gravel sourced directly from bushlands, borrow pits, or streambeds. This material is often used as an alternative to conventional crushed stone aggregates, especially in rural or peri-urban infrastructure projects such as housing construction, rural roads, and foundations.

2 THEORIES AND MECHANISMS GOVERNING AGGREGATE SIZE AND COMPRESSIVE STRENGTH

The relationship between aggregate size and compressive strength of concrete is governed by several theories and underlying mechanisms such as particle packing theory and aggregate-paste interaction.

2.1 Particle Packing Theory

The particle packing theory, also known as the densification theory, suggests that the compressive strength of concrete is influenced by the packing density of the aggregates and the effective use of the cement paste [6]. According to this theory, the use of smaller aggregate sizes can lead to a denser packing arrangement, resulting in a higher compressive strength due to the more efficient utilization of the cement paste. The particle packing theory is based on the concept that aggregates of different sizes can fill the voids between larger particles, leading to a denser and more compact concrete matrix. By optimizing the aggregate gradation and incorporating smaller aggregate sizes, the void spaces can be minimized, resulting in a higher packing density and improved compressive strength [6, 7]. However, it is important to note that the particle packing theory alone may not fully explain the relationship between aggregate size and compressive strength, as other factors such as the interfacial transition zone and aggregate-paste interactions can also play significant roles.

2.2 Aggregate-Paste Interactions

The interactions between the aggregates and the cement paste can have a significant influence on the compressive strength of concrete. These interactions are governed by factors such as the surface texture and shape of the aggregates, as well as the bond strength between the aggregates and the cement paste. Rougher surface textures and irregular aggregate shapes can enhance the mechanical interlocking between the aggregates and the cement paste, potentially leading to improved bond strength and higher compressive strength [8]. On the other hand, smooth and rounded aggregates may provide weaker bonds, potentially reducing the compressive strength. The size of the aggregates can also impact the aggregate-paste interactions. Smaller aggregate sizes generally have a higher surface area-to-volume ratio, which can lead to increased bond strength and improved stress transfer between the aggregates and the cement paste [9].

3 MATERIALS AND METHOD

3.1 Materials

The materials used in this research work includes Dangote Portland cement, Fine aggregate (sharp river sand), Coarse aggregate (known as natural coarse aggregate or bush gravel), and water.

3.2 Methods

The experimental design consisted of preparing and testing concrete mixes with different coarse aggregate sizes while keeping other factors, such as water-cement ratio, cement content constant. The experimental variables and their levels are presented in Table 1. A total of four concrete mixes were prepared, each with a different maximum coarse aggregate size. The mix proportions were designed in accordance for normal-weight concrete with a target compressive strength of 30MPa at 28 days. The concrete mix proportions were determined based on the DOE method; the mix proportion for the concrete mixes was 1: 1.10: 2.23.

Table 1. Experimental variables and levels

Variable	Levels
Coarse Aggregate Size (mm)	12, 20, 25 and 30
Water-Cement Ratio	0.45
Cement Content (kg/m³)	413

3.2.1 Mixing Procedure

The concrete mixes were prepared using mechanical mixer in accordance with procedure laid by [11]. First, fine and coarse aggregates were mixed dry for approximately 1 minute. Then, cement was added and mixed with the aggregates for an additional 2 minutes. lastly, water was added, and the mixing continued for 3 more minutes until a homogeneous concrete mixture was achieved.

3.2.2 Casting and Curing

Methods laid down by [11] was used in making and curing the concrete. After mixing, Slump test was performed to assess the workability of the concrete with different aggregate sizes. The fresh concrete was cast into square moulds with dimensions of 150mm×150mm×150mm. The moulds were filled in three layers, with each layer being compacted using a tamping rod to ensure proper consolidation and removal of entrapped air voids. After casting, the specimens were left undisturbed for 24 hours. Then, demoulded and transferred to a curing tank filled with clean tap water until the desired testing age.

3.2.3 Compressive Strength Test

The compressive strength of the concrete specimens was determined at the age of 3, 7, and 28days as outlined by [12]. Nine replicate specimens from each mix were tested to ensure the reliability and accuracy of the results. The compressive strength test was conducted using a hydraulic compression testing machine of 2000 kN capacity, at constant loading rate of 0.25 ± 0.05 MPa/s until failure occurred. The strength of each specimen was calculated and presented in Table 2.

4 RESULT AND DISCUSSION

4.1 Slump Test Results

Slump test was performed to assess the workability of the concrete for each mix having different aggregate sizes. Table 3 presents the slump test results for each mixture. The results show a clear trend of increasing slump as the maximum aggregate size increases. This can be attributed to the increased lower surface area as larger aggregates have less total surface area per unit volume than smaller ones, reduced water demand and improved concrete flow. This resulted in increased workability. This contradicted the findings [10]. The contradiction may be attributed to the type of coarse aggregates used.

Table 2. Slump Test Results

Mix ID	Maximum Aggregate Size (mm)	Slump (mm)
M1	12	58
M2	20	45
M3	25	50
M4	30	55

4.2 Compressive Strength Results

Compressive strength tests were conducted on concrete specimens at 3, 7, and 28 days of curing. Three cubes were tested for each of the aggregate size and curing period. Table 3 and 4 presents the detailed results, including the weight of each cube before crushing, the load at which the cube was crushed, and the calculated compressive strength. Figure 1 demonstrated that all mixtures exhibit a typical strength development pattern, with rapid initial strength gain followed by a more gradual increase as similarly reported by [4]. M2 (20mm max) consistently demonstrates higher strength values throughout the curing period, followed by M3 (25mm max), M1 (12mm max), and M4 (30mm max).

Table 3. Detailed Compressive Strength Results

Mix ID	Aggregate Size (mm)	Curing Days	Cube	Weight (kg)	Crushing Load (kN)	Compressive Strength (MPa)	
			1	8.189	337.54	15.00	
		3	2	8.058	299.51	13.31	14.17
			3	8.199	319.91	14.22	
			1	8.142	465.81	20.70	
M1	12	7	2	8.136	469.22	20.85	20.51
			3	8.135	449.34	19.97	
			1	8.165	685.66	30.47	
		28	2	8.186	655.91	29.15	29.18
			3	8.157	628.11	27.92	
			1	8.234	368.98	16.40	
		3	2	8.251	371.31	16.50	16.51
			3	8.286	374.64	16.65	
			1	8.818	489.13	21.74	
M2	20	7	2	8.187	452.52	20.11	20.89
			3	8.529	468.37	20.82	
			1	8.227	699.81	31.10	
		28	2	8.548	706.52	31.20	31.18
			3	8.399	702.76	31.23	
			1	8.301	353.90	15.73	
		3	2	8.219	342.57	15.23	16.21
			3	8.510	386.51	17.18	
			1	8.597	476.28	21.17	
M3	25	7	2	8.957	474.65	21.10	20.85
			3	8.989	456.21	20.28	
			1	8.512	600.77	29.70	
		28	2	8.369	574.11	29.52	29.52
			3	8.319	570.14	29.34	
			1	8.925	313.53	13.93	
		3	2	8.134	337.51	15.00	14.88
			3	8.925	353.63	15.72	
			1	8.531	459.76	20.43	
M4	30	7	2	8.925	456.98	20.31	20.31
			3	8.722	454.52	20.20	
			1	8.151	510.23	29.53	
		28	2	8.888	531.12	29.00	29.38
			3	8.590	550.12	29.60	

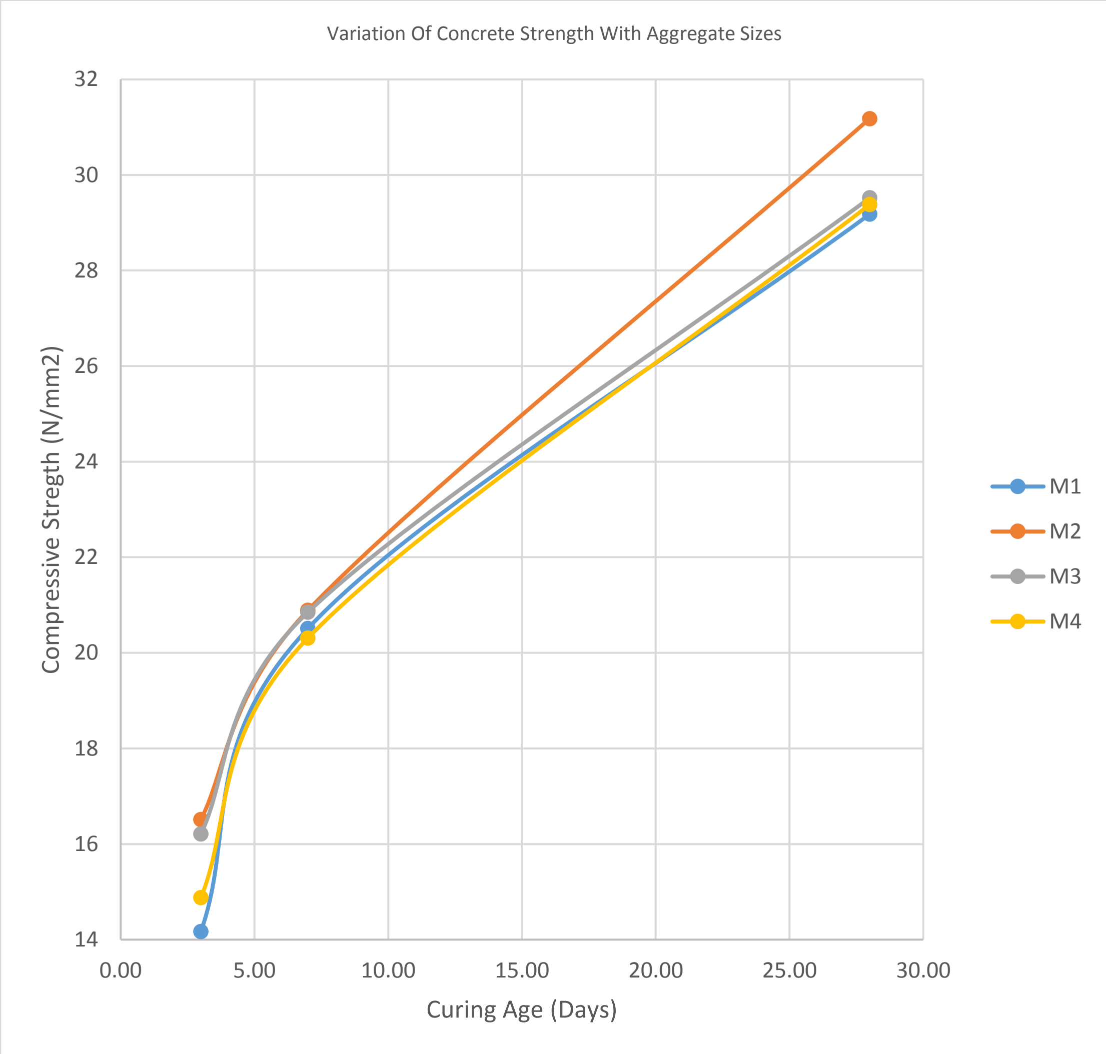

Figure. 1. Average Compressive Strength Results (MPa)

4.4 Effect of Aggregate Size on Early-Age Strength (3-day)

It can be observed from table 4 that at 3 days of curing, the compressive strengths of the concrete mixes are all above the 45% minimum set by standard, likewise at 7days curing all are above the 65% minimum this is likely due to denser packing arrangement as explained by [6]. But in the 28-day strength only M2 have above 100% which is the minimum set by standard.

Table 4. Strength Gain Percentages

Mix ID	Maximum Aggregate Size (mm)	3-day Strength (%)	7-day Strength (%)	28-day Strength (%)
M1	12	47.23	68.37	97.27
M2	20	55.03	69.63	103.93
M3	25	54.03	69.50	98.40
M4	30	49.60	68.70	97.93

5 CONCLUSIONS

This study confirms that aggregate size significantly influences the compressive strength of M30 concrete. Among the tested sizes, 20 mm maximum aggregate consistently yielded the highest compressive strength, likely due to optimal packing density, reduced voids, and an effective balance in crack resistance and stress distribution. Smaller aggregates, such as 12 mm, improved workability and slump, making them suitable for applications requiring high flowability; however, they did not achieve the highest strength, possibly due to their increased surface area demanding more cement paste. In contrast, larger aggregates (30 mm) consistently produced lower strength, suggesting that oversized particles may introduce stress concentrations that weaken the concrete matrix. Across all sizes, strength development followed a typical trend with consistent percentage gains over time, indicating that the influence of aggregate size is established early and persists throughout the curing process.

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