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The Effect of Aggregate Size on the Compressive Strength of Concrete

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Abstrsct

Aggregate grading is an important element in concrete mixing and the resultant compression strength. An experiment was conducted to determine the effect of aggregate size on the compressive strength of concrete. The experiment had three treatments, which were the 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. Tests that were conducted included the slump and compressive strength tests. Fresh concrete batches were formulated from each of the coarse aggregate sizes and the slump test was conducted to test for workability. Three cubes (150 mm × 150 mm) were cast from each batch and the compressive strength was determined using a concrete load testing machine (Pro-Ikon cube press) after 7 days curing. The results reflected that workability (slump) increased with increasing aggregate size. The concrete made from the 9.5 mm, 13.2 mm and 19.0 mm aggregate sizes had workability (slumps) of 10 mm, 13.5 mm and 20 mm, respectively. The mean compressive strength for the 9.5 mm, 13.2 mm, and 19 mm were 15.34 N/mm^2, 18.61 N/mm^2 and 19.48 N/mm^2, respectively. The 9.5 mm and 19.0 mm aggregates had compressive strengths that were significantly different ($P<0.05$; 0.034), while the 13.2 mm and 19.0 mm aggregate sizes had compressive strengths that were not significantly different ($P>0.05$; 0.585). It was concluded that concrete workability (slump) was directly proportional to aggregate size. The mean concrete compressive strength increased with increasing aggregates size.

Keywords

Aggregate Size, Concrete, Compressive Strength

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1. Introduction

Concrete is a composite material made of aggregate bonded together by liquid cement which hardens over time (Woodford, 2016). The major components of concrete are cement, water, and aggregates (fines and coarse aggregate) with aggregates taking about 50 to 60% of the total volume, depending on the mix proportion. The amount of concrete used worldwide is twice that of steel, wood, plastics, and aluminum combined (Rajith, and Amritha, 2015). Moreover, according to Yaqub and Bukhari (2006) concrete's use in the modern world is exceeded only by that of naturally occurring water.

Concrete can be used either singular or reinforced with steel in order to achieve the required strength. Concrete builds durable, long lasting structures that will not rust, rot, or burn. It is widely used for making architectural structures, foundations, brick walls, bridges and many other civil engineering works. Concrete is used in large quantities almost everywhere mankind has a need for infrastructure because of its high compressive strength and durability (Ajamu and Ige, 2015).

The compressive strength of concrete is one of its major properties that structural engineers take into consideration

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before erecting any structure (Hollaway, 2010). This property can be affected by many factors including water to cement ratio, degree of compaction, aggregate size and shape to name a few. Aggregate gradation plays an important role in concrete mixing. Unsatisfactory gradation of aggregates leads to segregation of mortar from the coarse aggregates, internal bleeding, need for chemical admixtures to restore workability, excessive water use and increased cement use (Loannides and Mills, 2006).

Aggregates constitute about 50 to 60% of the concrete mix depending on the mix proportion used. The larger the aggregate percentage in concrete mix makes it to contribute a lot to its strength (Waziri *et. al.*, 2011). Aggregates are the most mined material in the world. They are a component of composite materials such as concrete and asphalt concrete. The aggregates are responsible for the unit weight, elastic modulus and dimensional stability of concrete because these properties depend on the physical characteristics (strength and bulk density) of the aggregate (Anonymous, 2012).

Cement is generally an agent that is used to bond materials together, which happens as a result of a chemical reaction known as hydration. The concrete needs to be cured by immersing concrete cubes in water (i.e. ponding) for this process. Curing is designed primarily to keep the concrete moist by preventing loss of moisture from it during the period in which it is gaining strength. Curing can be achieved by keeping the concrete element completely saturated or as much saturated as possible until the water-filled spaces are substantially reduced by hydration products. According to Hassan and Mohammed (2014) curing concrete increase strength by up to 50% and also improve durability, making it more water tight and improve its appearance. If the concrete is not cured and is allowed to dry in air, it will gain only 50% of the strength of continuously cured concrete (Raheem, 2013).

A number of concrete structures around the globe cracks and lose stiffness when subjected to external load. Having premature deterioration of concrete is an international problem, the building industry needs to increase the load carrying capacity of structures by using concrete of high strength. In concrete structures, the mix proportion of the different components together with the aggregate type and size determine the compressive strength of hard concrete. According to Adiseshu and Ganapati (2011), larger aggregates demand lower water on its mix thus reducing the workability and increasing the compressive strength of concrete, hence this study.

Objective

To investigate the effects of aggregate size on the compressive strength of concrete, with particular reference;

i. To determine the workability of concrete made from different sized coarse aggregates.

ii. To assess the compressive strength of different coarse aggregate sizes on concrete.

2. Methodology

2.1. Research Design

The research was an experiment with three treatments including the control and three replications per treatment. Concrete mixtures of different aggregate sizes were used as treatments. The first, second and third treatments utilized the coarse aggregate sizes of 9.5 mm, 13.2 mm and 19 mm (control), respectively. The constituents that were used to formulate the concrete mixes were, Portland cement, river sand as fines and crush stone as coarse aggregates. A constant mix proportion of 1:2:4 and a constant water to cement (w/c) ratio of 0.5 were used throughout the experiment.

2.2. Materials and Methods

The equipment and materials that were used in the study were; metal cube mould (150 mm × 150 mm × 150 mm), spade, compacting rod, slump test cone, concrete load testing machine (cube press; Pro-Ikon), crush stone, river sand, Afrisam Portland cement, trowel and a scale rule. The crush stone was sourced from a quarry site (Nkwalini quarry), already graded and in the desired sizes.

2.2.1. Concrete Moulding

The concrete was mixed manually on a clean concrete covered surface to avoid incorporation of debris and absorption of moisture by the surface. Since coarse aggregates were sourced already graded from the quarry site, only the fine aggregates were sieved using a 5 mm test sieve to remove debris and attain homogeneity of the particles. The sand and cement were mixed on a non-absorbent surface using a spade and the mixing was done until the mixture was thoroughly blended and was of uniform colour. Then the coarse aggregates were added and mixed with the cement and sand made earlier until they were thoroughly distributed on the batch. A mound was opened from the top of the prepared mixture (cement, sand and coarse aggregates) and water was added using a water to cement ratio of 0.5. A spade was used to thoroughly mix the concrete constituents by working from the sides towards the center until the desired mix was achieved.

i. Slump Test

Fresh concrete was cast into a slump test cone in small amounts that were compacted per batch to determine its workability before being cast into the concrete cube moulds. The cube moulds were filled piece meal and the concrete was compacted to reduce air voids in the mix and trowelled level at the top of the mould to maintain its size. The cubes were coded according to the aggregate sizes for ease of identification.

ii. Curing

Concrete curing was done by covering the specimen with a plastic sheet under shade, while in the concrete moulds for the first 24 hours after moulding. The cube moulds were then carefully removed and the cubes were then immersed in clean water for a period of 6 days. This added up to 7 days of concrete curing.

2.2.2. Compressive Strength Test

The concrete cubes were weighed using a beam balance prior to testing and the mass were recorded against the cube reference code. All the concrete cubes were tested on the same day using a Pro-Ikon cube concrete load testing machine. The compressive strength was calculated using equation 1.

$$\sigma_c = \frac{F}{A} \tag{1}$$

Where:

σ_c - Compressive strength (N/mm^2)

F - Failure load (N)

A - Area of bed-face (mm^2)

3. Results and Discussion

3.1. Concrete (Fresh) Workability (Slump) Results

The results in Table 1 reflected that the workability (slump) for the 9.5 mm, 13.2 mm and 19 mm coarse aggregate sizes were 10 mm, 13.5 mm and 20 mm, respectively. It is worth noting that as the slump increases, so does the workability. However, this occurs while the compressive strength is reduced, a condition driven by the water cement ratio (w/c).

Table 1. Concrete slump test for coarse aggregates.

Aggregate (mm)	Slump (mm)	Slump type
9.5	10.0	True slump
13.2	13.5	True slump
19.0	20.0	True slump

* w/c ratio was 0.5 and mix ratio was 1:2:4.

The results indicated that the concrete workability (slump) was directly proportional to aggregate size, meaning that they both increased simultaneously. When all other factors (i.e. w/c ratio and mix proportion) remain constant an increase in coarse aggregate size led to an increase in workability. This occurs due to the increase in aggregate size, which results in smaller surface area to be wetted. However, there are other constraints on the maximum aggregate size. It should also be considered that as the maximum aggregate size increases, the size and toughness of the mixers, and other equipment needed to make and place the concrete also increase.

3.2. Compressive Strength Results

The mean compressive strength results in Table 2 for hardened concrete after seven days of curing reflected an increase of compressive strength with increasing aggregate size. This trend ranged from 15.21 N/mm^2 for the 9.5 mm aggregate size to 23.02 N/mm^2 for the 19 mm aggregate size.

Table 2. Concrete compressive strength test results after 7 days of curing.

Aggregate Size (mm)	Compressive Strength (N/mm^2)
9.5	15.56
9.5	15.26
9.5	15.21
Mean	15.34
13.2	18.62
13.2	17.80
13.2	19.40
Mean	18.61
19.0	19.48
19.0	19.47
19.0	19.49
Mean	19.48

The mean compressive strengths for the 9.5 mm, 13.2 mm and 19.0 mm aggregate size varied and were found to be 15.34 N/mm^2, 18.61 N/mm^2 and 19.48 N/mm^2, respectively. Given the fact that aggregates were extracted from the same site, therefore have the same mineralogy; the reason behind the variation of compressive strengths could be attributed to the differences in wetted surface areas in the respective concrete batches. Concrete batches of smaller aggregates have a larger wetted area than larger aggregates. When wetted area dries up during the curing process, it leaves pores where micro cracks start. This is the reason attributed to the low compressive strength associated with smaller sized aggregates compared to large sized aggregates.

The results in Table 3 indicated that the 9.5 mm and 19.0 mm aggregate sizes, had a mean difference of 4.14, which was significantly different ($P < 0.05$; 0.034). The mean compressive strength for the 19.0 mm was higher (19.48 mm) than the 9.5 mm (15.34 mm) coarse aggregates.

Table 3. Concrete compressive strength analysis of variance.

Aggregate Size (mm)	Aggregate Size (mm)	Mean Difference	Standard Error	Sig. (P-value)
9.5	13.2	-3.26333	1.51190	0.074
	19.0	-4.13667	1.51190	0.034*
13.2	9.5	3.26333	1.51190	0.074
	19.0	-0.87333	1.51190	0.585
19.0	9.5	4.13667	1.51190	0.034*
	13.2	0.87333	1.51190	0.585

* The mean difference is significant at 0.05

The 13.2 mm and 19.0 mm aggregate sizes, had a mean difference of 0.87333, which was not significantly different (P >0.05; 0.585). The results indicated that larger sized coarse aggregates yielded higher compressive strength than smaller sized aggregates.

4. Conclusions

Given a constant water to cement ratio (0.5) and mix (1:2:4), a change in coarse aggregate size affected the workability (slump) of concrete. The workability (slump) was directly proportional to the aggregate size. It increased from 10.0 mm, 13.5 mm to 20.0 mm for the 9.5 mm, 13.2 mm and 19.0 mm, respectively. As the slump increased, the concrete became more workable.

The mean compressive strength of the concrete aggregates was assessed and found to increase with increasing aggregates size. The aggregate sizes 9.5 mm, 13.2 mm and 19.0 mm had mean compressive strengths of 15.34 N/mm^2, 18.61 N/mm^2 and 19.48 N/mm^2, respectively. The 9.5 mm and 19.0 mm course aggregate sizes were significantly different ($P < 0.05$; 0.034), while the 13.2 mm and 19.0 mm aggregate sizes had compressive strength that was not significantly different (P>0.05; 0.585).

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