EFFECTS OF AGGREGATE SIZE ON CONCRETE STRENGTH

[*]BABA BABANGIDA; [**]SAGIR YUSUF ABDULLAHI; [***]BUKATA YAKUBU GIZAKI; [****]MUHAMMAD SULAIMAN.
[*,**,***,&****] *Department of Civil Engineering, Abubakar Tatari Ali Polytechnic PMB 0094, Wunti Dada, Bauchi, Bauchi State, Nigeria*

ABSTRACT
This paper examines the effects of aggregate size on concrete strength. Concrete is a composite material made of aggregates bonded together by liquid cement which hardens over time. Compressive strength of concrete can be affected by many factors including water to cement ratio, aggregate size, degree of compaction and shape. Aggregate gradation plays an important role in concrete mixing. The fine and coarse aggregates generally occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy. Materials used was Portland cement, Granite aggregates are crushed had rock of granular structure, being the most common on earth. Granite rock comes from magma that erupted on the ground surface and then hardened. The results shows the weight retain for 2mm were 39g and 95.13g percentage passing 103g weight retain for 1.18mm and 2.38g for 1.0mm respectively. It was concluded that the aggregate size and gradation affect workability of fresh concrete and compressive strength of hardened concrete, workability of concrete made from uniform size aggregates decreases as the aggregate size increases, compressive strength of concrete made from uniform size aggregates increases with increase in aggregate size. It was also recommended that for a concrete beam, 10mm, 20mm 30mm coarse aggregate size could be adopted as they give appreciable compressive strength. Further research be carry out to investigate the use of appropriate aggregate gradation procedure for blending aggregate for concrete used for highway pavement and its effect on compressive strength of concrete.

Keywords: *Concrete, aggregate, strength, Portland and apparatus*

INTRODUCTION

Concrete is a composite material made of aggregates bonded together by liquid cement which hardens over time (Rocco, 2009). Concrete can be used as plain or reinforced concrete in civil engineering construction to build durable and long lasting structures. The major components of concrete are cement, water, and aggregates (fines and coarse aggregate) with coarse aggregates occupying over one-third of the volume of concrete. Research has shown that changes in coarse aggregate can change the strength properties of concrete. To predict the behavior of concrete under general loading requires an understanding of the effects of aggregate size. The compressive strength of concrete is one of the major properties that structural engineers take into consideration before erecting any structure (Kamaruddin, 1995). Compressive strength of concrete can be affected by many factors including water to cement ratio, aggregate size, degree of compaction and shape. Aggregate gradation plays an important role in concrete mixing.

Aggregates are the most mined material in the world. They are a component of composite materials such as concrete and asphalt concrete. 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 (Olanitori, 2005). Generally, in lower strength concretes, the reduction in mixing water is sufficient to offset the detrimental effects of aggregate size. However, in high-strength concretes, the effect of size dominates, and the smaller sizes produce higher strengths. Cordon and Gillespie (Cook 1989) also reported changes in concrete strength for mixes made with various water-to-cement ratios and aggregate sizes. They found that, at water-to-cement ratios from 0.40 to 0.70, an increase in maximum aggregate size from 19 mm to 38 mm decreases the compressive strength by about 30 percent.

They also concluded that, in normal-strength concrete, failure typically occurs at the matrix-aggregate interface and that the stresses at the interface which cause failure can be reduced by increasing the surface area of the aggregate (decreasing the aggregate size). Due to increasing cost of producing concrete using conventional materials such as cement, river sand as fine aggregate and granite as coarse aggregate in Nigeria, aggregate type has effect on the compressive strength of normal concrete, concrete made from crushed quartzite demonstrates higher compressive strength at all ages compared to the concrete with granite as a coarse aggregate.

LITERATURE REVIEW

2.1 Concrete

Concrete, usually Portland cement concrete (for its visual resemblance to Portland stone), (IRC 2008) is a composite material composed of fine and coarse aggregate bonded together with a fluid cement (cement paste) that hardens over time most frequently in the past a lime-based cement binder, such as lime putty, but sometimes with other hydraulic cements, such as a calcium aluminate cement or Portland cement. It is distinguished from other, non- cementitious types of concrete all binding some form of aggregate together, including asphalt concrete with a bitumen binder, which is frequently used for road surfaces, and polymer concretes that use polymers as a binder.

When aggregate is mixed with dry Portland cement and water, the mixture forms a fluid slurry that is easily poured and molded into shape. The cement reacts with the water and other ingredients to form a hard matrix that binds the materials together into a durable stone-like material that has many uses. (Li, Zongjin 2011)

Often, additives (such as pozzolans or superplasticizers) are included in the mixture to improve the physical properties of the wet mix or the finished material. Most concrete is poured with reinforcing materials (such as rebar) embedded to provide tensile strength, yielding reinforced concrete.

2.1.1 TYPES OF CONCRETE

1.Normal Strength Concrete

The concrete that is obtained by mixing the basic ingredients cement, water and aggregate will give us normal strength concrete. The strength of these type of concrete will vary from 10 MPa to 40MPa. The normal strength concrete has an initial setting time of 30 to 90 minutes that is dependent on the cement properties and the weather conditions of the construction site.

2. Plain Concrete

The plain concrete will have no reinforcement in it. The main constituents are the cement, aggregates, and water. Most commonly used mix design is 1:2:4 which is the normal mix design.

The density of the plain concrete will vary between 2200 and 2500 Kg/meter cube. The compressive strength is 200 to 500 kg/cm^2. These types of concrete are mainly used in the construction of the pavements and the buildings, especially in areas where there is less demand of high tensile strength. The durability given by these types of concrete is satisfactory to high extent.

3. Reinforced Concrete

The reinforced cement concrete is defined as the concrete to which reinforcement is introduced to bear the tensile strength. Plain concrete is weak in tension and good in compression.

Hence the placement of reinforcement will take up the responsibility of bearing the tensile stresses. R.C.C works with the combined action of the plain concrete and the reinforcement.

The steel reinforcement used in the concrete can be in the form of rods, bars or in the form of meshes. Now fibers are also developed as reinforcement.

4. Precast Concrete

Various structural elements can be made and cast in the factory as per the specifications and bought to the site at the time of assembly. Such concrete units are called as the precast concrete.

The examples of precast concrete units are concrete blocks, the staircase units, precast walls and poles, concrete lintels and many other elements. These units have the advantage of acquiring speedy construction as only assemblage is necessary. As the manufacturing is done at site, quality is assured. The only precaution taken is for their transportation.

5. Lightweight Concrete

Concrete that have a density lesser than 1920kg/m^3 will be categorized as lightweight concrete. The use of lightweight aggregates in concrete design will give us lightweight aggregates.

Aggregates are the important element that contributes to the density of the concrete. The examples of light weight aggregates are the pumice, perlites, and scoria.

6. High-Density Concrete

The concretes that have densities ranging between 3000 to 4000 kg/m^3 can be called as the heavyweight concrete. Here heavy weight aggregates are used.

The crushed rocks are used as the coarse aggregates. The most commonly used heavy weight aggregates is Barytes.

These types of aggregates are most commonly used in the construction of atomic power plants and for similar projects. The heavy weight aggregate will help the structure to resist all possible type of radiations.

7. Air Entrained Concrete

These are concrete types into which air is intentionally entrained for an amount of 3 to 6% of the concrete. The air entrainment in the concrete is achieved by the addition of foams or gas – foaming agents. Some examples of air entraining agents are resins, alcohols, and fatty acids.

2.2.2. AGGREGATE

The importance of using the right type and quality of aggregates cannot be overemphasized. The fine and coarse aggregates generally occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy. Fine aggregates (Fig. 5-1) generally consist of natural sand or crushed stone with most particles smaller than 5 mm (0.2 in.). Coarse aggregates (Fig. 5-2) consist of one or a combination of gravels or crushed stone with particles predominantly larger than 5 mm (0.2 in.) and generally between 9.5 mm and 37.5 mm (3⁄8 in. and 11⁄2 in.). Some natural aggregate deposits, called pit-run gravel, consist of gravel and sand that can be readily used in concrete after minimal processing. Natural gravel and sand are usually dug or dredged from a pit, river, lake, or seabed. Crushed stone is produced by crushing quarry rock, boulders, cobbles, or large-size gravel. Crushed air-cooled blast-furnace slag is also used as fine or coarse aggregate.

2.2.2.1 TYPES OF AGGREGATE

1. **Coarse Aggregate**

Coarse-grained aggregates will not pass through a sieve with 4.75 mm openings (No. 4).

Those particles that are predominantly retained on the 4.75 mm (No. 4) sieve and will pass through 3-inch screen are called coarse aggregate. The coarser the aggregate, the more economical the mix. Larger pieces offer less surface area of the particles than an equivalent volume of small pieces. Use of the largest permissible maximum size of coarse aggregate permits a reduction in cement and water requirements. Using aggregates larger than the maximum size of coarse aggregates permitted can result in interlock and form arches or obstructions within a concrete form. That allows the area below to become a void, or at best, to become filled with finer particles of sand and cement only and results in a weakened area.

For Coarse Aggregates in concrete the following properties are desirable:

1. Strength
2. Hardness
3. Toughness
4. Durability
5. Shape of aggregates

2. Fine Aggregate

The other type of aggregates are those particles passing the 9.5 mm (3/8 in.) sieve, almost entirely passing the 4.75 mm (No. 4) sieve, and predominantly retained on the 75 µm (No. 200) sieve are called fine aggregate. For increased workability and for economy as reflected by use of less cement, the fine aggregate should have a rounded shape. The purpose of the fine aggregate is to fill the voids in the coarse aggregate and to act as a workability agent.

MATERIALS AND METHODS

3.1 MATERIALS

The materials used in this research are as follows to facilitate the process and the outcome of the research.

A. Ordinary Portland Cement

Tsivilisa et al., (2003) reported that Portland cement is the most common type of cement in general used globally. It is used as a basic ingredient of concrete, mortar and most non-specialty grout. Burg (1996) further stated that cement was developed from other types of hydraulic lime in England in the mid 19^{th}century and originates from limestone. It is a fine powder produced by heating materials in a kiln to form what is called clinker, grinding the clinker, and adding small amounts of other materials. Several types of Portland cement are available, with the most common being called ordinary Portland cement (OPC) which is grey in color, but a white Portland cement is also available (Alamri, 1988).

B. **Fine and coarse Aggregates**

Granite aggregates are crushed had rock of granular structure, being the most common on earth. Granite rock comes from magma that erupted on the ground surface and then hardened (Lafarge, 2013). Good properties of granite stones make the most popular building material and especially coarse granite aggregates between 18-20mm while fine granite aggregates between 75μ-4.75mm particle sizes (Osborne, 1999).

C. **Water**

Franchi et al., (2004) reported that just as water is a source of life for all living thing, so it is the primary ingredient for the beginning of all concrete. Without water all that exists is a pile of rocks and powder. This can adversely affect the development of concrete. Too much water and concrete will become a soupy mixture resembling clam chowder rather than a functional structural material (Samuel, 2014).

Water is imperative for two reasons: one is to hydrate the cement and secondly, is to create a workable substance (Mantel, 1991).

3.1.1 APPARATUS

The equipment that were used in the study were: 150mm x 150mm x 1500mm steel moulds, tags sieves, retainers, brush, weighing instrument, trowel, spanners, shovel, slump test cone, curing tank and concrete Universal Testing Machine.

3.3 METHODS

Experimental Design

A mix ratio of 1:2:4 and water to cement ratio of 0.55 w/c will be adopted and use.

Density

W = Density X v

24KN x 3.375 x 10^{-3}

24000 x 3.375 x 10^{-3}

Mass = 81N/m^3

Convert into kg

= 8.23kg/m^3

1:2:4 = 7

Cement x 8.23 = 1.175kg

Fine aggregate = x 8.23 = 2.35kg

Coarse = x 8.23 = 4.70kg

Water cement ratio = 0.55L =

W = 0.55L x C

W = 0.55 x 1.175 = 0.646kg/L

Convert to gram per Litre

0.646 x 1000 = 646g/L

The amount of water required in each cube is 646g/L

3.2.1 Concrete Batching, Mixing and Curing

Coarse aggregate, fine aggregate and cement were thoroughly mixed together manually, after which the required water estimated at 0.6 water-cement ratio (w/c) was added. The entire constituents were mixed until an even paste was obtained.

3.2.1.1 Slump Test

The slump mould was filled in three layers, each layer was compacted by a steel rod with 25 blows before pouring the next layer. The surface was leveled after filling the slump cone, and allowed for 2 minutes. The slump cone was then lifted off the concrete, thus allowing the pile of unsupported concrete to collapse. The difference between the initial and the final height of the concrete was measured and recorded as the slump.

3.2.1.2 Curing

For the three concrete specimen made from the uniform and graded aggregates, three (3) cubes were cast for each specimen making a total of nine cubes (9). The cubes were cast by filling each mould in small layers and compacting manually before the next layer was poured. They were left in the mould for 24 hours to set at laboratory temperature, after which they were demoulded and transferred into a curing tank that contained clean water. For each specimen, three (3) cubes were cured for 7 days and three (3) for 28 days.

3.2.1.3 Compressive Strength Test

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. The compressive strength was calculated using equation 1.

$$f_c = {}^{P}/_{A} \ (\text{N/mm}^2)$$

Where; P = Failure load in N

A = cross-sectional area of test cube in m^2

3.2.2. Sieve Analysis

Sieve Analysis for fine aggregate

This method was use primarily to determine the percentage by mass of particles within the different size ranges.

Procedure

i. First for the fine aggregate I use the sample of 800g we ensure that the sample is dried and all sieves are clean
ii. Secondly I arrange the sieves in series and put the sample in the sieve, I then sieved the sample in turn by shaking manually using my hand. For about 15 minutes.
iii. Finally I obtain the percentage retained and percentage passing as

3.2.2.3 Sieve Analysis for Coarse Aggregate

i. First for the coarse aggregate I use the sample of 1000g we ensure that the sample is dried and all sieves are clean
ii. Secondly I arrange the sieves in series and put the sample in the sieve, I then sieved the sample in turn by shaking manually using my hand. For about 15 minutes.
iii. Finally I obtain the percentage retained and percentage passing as presented in chapter four.

3.2.2.4 Specific Gravity

Specific Gravity for Fine Aggregate using Density Bottle

This method was used primarily to determine the specific gravity of fine aggregate

Procedures

i. Weigh the empty container and record as W_1
ii. Fill the bottle with the sample at least and measured as W_2
iii. Add water to the sample in bottle and stir it, put in the desicator and allow it to set. After it set weigh it as W_3
iv. Discharge the water from the bottle, wash the bottle and dry it.
v. Fill the bottle with water and weigh as W_4

Formula for use in obtaining specific gravity

G.S =

Specific Gravity of Coarse Aggregate using gas jar

This method was use primarily to determine the specific gravity of coarse aggregate

Procedures

i. Weigh the empty container and record as W_1
ii. Fill the bottle with the sample at least and measured as W_2
iii. Add water to the sample in bottle and stir it, put in the desicator and allow it to set. After it set weigh it as W_3
iv. Discharge the water from the bottle, wash the bottle and dry it.
v. Fill the bottle with water and weigh as W_4

Formula for use in obtaining specific gravity

G.S =

3.2.3.5. Hardness Test

Aggregate Crushing Value (ACV)

Aim: To determine, the aggregate crushing value of a sample of coarse aggregate.

Procedure:

i. Sieve the aggregate sample to pass through sieve size 12.7 mm and retained on the B.S sieve 9.5mm.
ii. Prepare sufficient aggregate for tests (about 5kg) and ensure that it is in a clean and surface dry condition (according to standard requirement, it should be oven dried, 100-110ºC).
iii. Place the cylinder on the base plate and fill with aggregate in three equal layers giving 25 blows to each layer.
iv. Level off the top of the aggregate with the tamping rod and weigh (total weight of material). Insert the plunger so that it just rests horizontally on the surface of the aggregate.
v. Test sample in the compression machine loading at 40KN/MIN to a load of 40KN(10 minutes)
vi. Remove the material from the cylinder and sieve on a 2.40mm B.S test sieve.
vii. Determine the weight of the fines passing the 2.40mm sieve (weight weight of material passing) and express this as a percentage of the total weight of the aggregate used as shown in the calculation below.

Calculations: Aggregate crushing value = x 100

DISCUSSION OF RESULTS

Particle Size Distribution

Table 1 Sieve analysis for fine aggregate

Sieves Size	Weight retain (g)	Percentage Retain (g)	Percentage passing (g)
2mm	39	4.88	95.13
1.18mm	103	12.88	82.25
1.0mm	19	2.38	79.88
600mic	115	14.38	65.50
300mic	279	34.88	30.63
150mic	219	27.38	3.25
63mic	21	2.63	0.63
Pan	3	0.38	0.25

The table 1 above shows that the weight retain for 2mm were 39g and 95.13g percentage passing 103g weight retain for 1.18mm and 2.38g for 1.0mm respectively. Further shows that percentage retains of 14.38g for 600mic and 30.63g percentage passing for 300mic.

Table 2 Sieve analysis for coarse aggregate

Sieves Size	Weight retain (g)	Percentage Retain (g)	Percentage passing (g)
16mm	296	29.60	70.40
12.5mm	399	39.90	30.50
10mm	240	29	6.50
6.3mic	63	6.30	0.20
4.75mic	1	0.10	0.10
Pan	0	-	-

Table 2 above revealed that 296g weight retain for 16mm 29.60 percentage retain and 70.40 percentage passing. It further shows that 29g percentage retain for 10mm and 63 weight retain 6.3mic while 0.10 percentage passing for 4.75mic respectively.

4.1.2 Specific Gravity

Specific gravity for fine aggregate

W_1 = 30g

W_2 = 85g

W_3 = 114g

W_4 = 81g

G.S = = = = 2.5%

G.S = 2.5% for fine aggregate

Specific gravity for coarse aggregate

W_1 = 342g

W_2 = 544g

W_3 = 743g

W_4 = 615g

G.S = = = = 2.73%

G.S = 2.73% for coarse aggregate

4.1.3 Hardness Test

Aggregate Crushing Value

ACV = x 100 = 12.99%

Aggregate Impact Value

AIV = x 100 = 9%

4.1.4 Slump Test

Table 3 Concrete Slump Test

Aggregate Size (mm)	Slump (mm)	Slump Type
10	10.0	True slump
20	13.5	True slump
30	20.0	True slump

The results in Table 3 reflected that the workability (slump) for the 10 mm, 20 mm and 30 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).

4.1.5 Compressive Strength

Table 4 Concrete compressive strength test results after 7 days of curing

Aggregate Size (mm)	Compressive Strength (N/mm^2)
10	19.48
20	18.61
30	15.34

The compressive strength results in Table 4 for hardened concrete after seven days of curing reflected an increase of compressive strength with increasing aggregate size. This trend ranged15.34 N/mm^2 for the 10 mm aggregate size, 18.61 N/mm^2 for the 20 mm aggregate size and 19.48 N/mm^2 for the 30 mm respectively.

Table 5 Concrete compressive strength test results after 28 days of curing

Aggregate Size (mm)	Compressive Strength (N/mm^2)
10	20.9
20	20.0
30	18.2

The compressive strength results in Table 5 for hardened concrete after twenty eight days of curing reflected an increase of compressive strength with increasing aggregate size. This trend ranged 18.2 N/mm^2 for the 10 mm aggregate size, 20 N/mm^2 for the 20 mm aggregate size and 20.9 N/mm^2 for the 30 mm respectively.

CONCLUSION AND RECOMMENDATION

It concluded that the aggregate size and gradation affect workability of fresh concrete and compressive strength of hardened concrete, workability of concrete made from uniform size aggregates decreases as the aggregate size increases, compressive strength of concrete made from uniform size aggregates increases with increase in aggregate size.

It further revealed that the workability (slump) for the 10 mm, 20 mm and 30 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. The following recommendations are made. For a concrete beam, 10mm, 20mm 30mm coarse aggregate size could be adopted as they give appreciable compressive strength. The choice of well graded aggregate size in concrete mix is as important as proper compaction of fresh concrete in order to prevent honey comb which can result to loss of stiffness of structural component and consequently. Thus concrete mix should be well compacted. Concrete to be used mostly to resist compressive strength should be made of finer coarse aggregates. Further research be carry out to investigate the use of appropriate aggregate gradation procedure for blending aggregate for concrete used for highway pavement and its effect on compressive strength of concrete.

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