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Effect of Water Cement Ratio Variation and Coarse Aggregate Gradation on the Compressive Strength of Cement Concrete

D. B. Eme[1], C. Nwaobakata[2]
[1, 2]Department of Civil and Environmental Engineering, University of Port Harcourt, Port Harcourt, Nigeria
Email of corresponding author: dennis.eme@uniport.edu.ng

Abstract—*The importance of gradation of coarse aggregate has often been neglected in the rigid pavement construction process resulting to pavement failures even before the design life of the pavements. This paper therefore aimed at investigating the effect of gradation and water cement ratio variation on selected properties of cement concrete such as workability and compressive strength. Three different grades of coarse aggregate (5mm, 13.2mm and 19mm) were sourced from the same location and combined in equal proportions before the commencement of laboratory studies. The mixed coarse aggregate was sieved and separated into four categories; well graded (all sizes present) category, gap 1 graded (minus 5mm) category, gap 2 graded (minus 13.2mm) category and gap 3 (minus 19mm) graded category. A constant design mix of 1:2:4 with variable water cement ratios of 0.45, 0.50 and 0.55 was adopted and used for experimental purposes. The workability of fresh concrete was determined through the slump test procedure and the compressive strength was also determined for 7, 14 and 28 days hardened concrete specimens. Results of this study revealed that the workability of fresh concrete increases with increment in water cement ratio irrespective of the gradation status of coarse aggregate. However, this increment is small in well graded coarse aggregate concrete in comparison to the gap graded counterparts. The compressive strength of concrete was reduced as the water cement ratio increased with the strength reduction been uniform and steady for the well graded coarse aggregate concrete. From the ageing effect analysis, the well graded coarse aggregate concrete proved to be more durable as the strength increment remained positive. Thus, well graded coarse aggregate should be used in preference to gap graded coarse aggregate in cement concrete production*.

Keywords— *Gradation, water-cement ratio, compressive strength, workability*.

I. INTRODUCTION

The civilization of a nation is largely evaluated on visible infrastructures. Concrete is the basis of much of civilization's infrastructure and much of its physical development. It is a fundamental building material to municipal infrastructure, transportation infrastructure, office buildings, and homes. Concrete is a material comprising a binder such as cement, aggregates and water. Aggregates on the other hand, are of two categories: fine and coarse aggregates.

The importance of concrete in Civil engineering and the modern society at large cannot be overstated as it helps make modern life possible and is the foundation for the massive expansion of urban areas. Lately, the usage of concrete is increasing from time to time due to the rapid development of construction industries in the world. Concrete is the most extensively used construction material and according to [1], the annual world consumption of concrete has reached a value such that if concrete were edible, every person on earth would have 2000kg per year to "eat". This trend indicate that the supremacy of cement concrete as a construction material will continue for many decades to come. This is because of continuous improvement in the performance of concrete as a structural material due to scientific research and understanding of its properties [2]. According to [3], concrete is the only major building material in the world that can be delivered to the job site in a plastic state. This quality makes concrete desirable as a building material because it can be moulded and shaped to formwork with high compressive strength. Concrete has been developed and improved upon to enhance its quality and properties for various uses in Civil engineering works. Compressive strength is the primary property of concrete (others are generally derived from it), and it is the one most used in design. It is one of the fundamental properties used for quality control for concrete. It is found by measuring the highest compression stress that a test cylinder or cube will support. The 'concrete cube test' is the most familiar test and is used as the standard method of measuring the compressive strength of concrete for quality control purposes [4].

Concrete comprises of a very large proportion of inert rock fragments or gravel called aggregate and hence it forms very important consideration in concrete properties. Cement and water forms paste which combines with aggregate by developing mechanical bond to form hard mass called concrete. The aggregate imparts greater volumetric stability to concrete mass by offering greater resistance to deformations caused by shrinkage of cement paste. The sizes, shapes and gradation patterns of coarse aggregates play very important role on the resultant strength of concrete derived from such coarse aggregates. The grading of aggregate plays an important role in the mixing of concrete which in turn affects its strength. There have been series of studies on the effect of aggregate sizes and shapes on the compressive strength of concrete.

[5] Studied the effects of coarse aggregate size on the properties of normal-strength concrete. Their work demonstrated that an increase in aggregate size from 10mm to 64 mm (3/8 to 2 ½ inch.) resulted in a decrease in the compressive strength of concrete, by as much as 10 percent. More recent studies seemed to disagree with this trend. [6] Showed that compressive strength increases with increase in

coarse aggregate size. [7] from their study revealed that larger coarse aggregate sizes in concrete mixtures improved the aggregate interlock between adjacent concrete slabs and therefore increased the strength. [8] investigated compressive strength of concrete made from 9.5mm, 13.2mm and 19.0mm aggregates. Their Result indicated that compressive strength of concrete increased with increase in aggregate size.

According to [9], aggregate particle size and shape can affect concrete compressive strength in a couple of different ways. First, particle size and shape can affect the cement-aggregate bond strength, and therefore, the strength of the concrete. Equi-dimensional particles are generally preferred to flat or elongated particles for use as concrete aggregates because they present less surface area per unit volume and generally produce tighter packing when consolidated.

One other important parameter that determines the strength of concrete is the water cement ratio. There have been various researches on the effect of water cement ratio on the workability and compressive strength of concrete. Workability is a fresh concrete property defined as "the amount of mechanical work, or energy, required to produce full compaction of the concrete without segregation [10]. [11] showed that due to reduction of water-cement ratio from 0.33 to 0.50, the compressive strength improved by 34.4% and 35.2%, respectively, while [12], was able to achieve a maximum strength of 23.71N/mm² with mix proportion of 1:2:4 and water-cement ratio of 0.5 at 28 days hydration. Tests by [13] indicate that by using an appropriate amount of mixing water, penetration of main corrosion causing agents like chloride ions and atmospheric carbon dioxide could be significantly reduced.

From the foregoing, it can be deduced that much work have not been done on the gradation status of coarse aggregate and how it affects concrete properties, hence this study. This study seeks to throw more light on the effect of water cement ratio variation and coarse aggregate gradation and take an in-depth look on their effects on workability and compressive strength of concrete through comprehensive durability studies.

II. Materials and Methods

2.1 Materials

The materials used in this research study were sourced locally from the Port Harcourt City Environment.

2.1.1. Fine aggregate

A well graded, zone II sand sourced from a construction site in Port Harcourt was used for experimental purposes in this study.

2.1.2. Coarse aggregate

Three different granite grades of 5mm, 13.2mm and 19mm coarse aggregates were used in this study. These coarse aggregate grades were sourced from a construction site in Port Harcourt metropolis.

2.1.3. Cement

The Dangote 3x cement brand which meets the requirements of BS 12 [14] was used in this study and obtained from a retail shop in Port Harcourt.

2.1.4. Water

The water used in this study was sourced from a tap in the structural laboratory of the University of Port Harcourt with a pH value of 6.9.

2.1.5. Equipment

The equipment used in this study were;

i. Universal concrete strength testing machine (Model 4207D, Chandler Eng. USA) which meets the requirements of BS 1881: 115 [15].
ii. Slump cone (Model HM-40, Gilson Company, USA) which meets the requirements of BS1881-102 [16].
iii. 150mm x 150mm x 150mm steel moulds
iv. Other apparatus include; curing tank, shovel, trowel, compacting rod and metallic ruler.

2.2 Methods

2.2.1 Experimental design

This research study was an experimental investigation involving three different grades of coarse aggregates (5mm, 13.2mm and 19mm) with three replicates per experimental run. Equal portions of the three grades of aggregates were measured and mixed together for the purpose of experiments. The mixed coarse aggregate was subjected to sieve analysis and separated into four different categories. Category A was tagged Well graded (all grades properly represented), Category B was tagged Gap 1 graded (with 5mm missing), Category C was tagged Gap 2 graded (with 13.2mm missing) and Category D tagged Gap 3 graded (with 19mm missing). A design mix of 1: 2: 4 with variable water cement ratio of 0.45, 0.50 and 0.55 was used for preparation of specimens. Workability test in form of slump test was carried out on fresh concrete specimens and compressive strength test was carried out on the hardened concrete specimens.

2.2.2. Concrete batching, mixing and curing

The batching by weight procedure was adopted in this study. Mixing of concrete components was done manually with the aid of a shovel and a trowel on a clean concrete covered surface to avoid incorporation of unwanted materials and absorption of moisture by the surface. After mixture of concrete components, the workability test was conducted using the slump height method and the concrete paste were poured into the concrete moulds. The fresh concrete specimens were allowed to set for 24 hours before they were demoulded and taken to a curing tank. The hardened concrete specimens were cured by complete immersion in water for 7, 14 and 28 days respectively before the compressive strength test was administered on the hardened concrete.

2.2.3. Workability (Slump) test

The workability test method carried out in this project was the slump test. This test was carried out in accordance with [16].The internal surface of the slump cone was lubricated. The slump cone was placed on a smooth horizontal non-porous base plate. The slump cone was filled with prepared concrete mix in three approximately equal layers. Each layer was tampered 35 times with the rounded end of the tamping rod in a uniform manner over the cross section of the mould. For the subsequent layers, the tamping rod penetrated into the underlying layers. The excess concrete was removed and the

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surface levelled with a trowel. The slump cone with the pile of concrete was left standing for 2 minutes. The slump cone was then lifted off the fresh concrete allowing the unsupported pile of concrete to slump. The slump height was measured as the difference between the height of the slump cone and the recorded height of the unsupported concrete specimen being tested.

2.2.4 Compressive strength test

The concrete cubes were removed from the curing tank and tested at 7, 14 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 of concrete.

The compressive strength was calculated using Equation (1):

$$F_c = \frac{P}{A} \left(\text{N/mm}^2 \right) \quad (1)$$

Where;
P = Failure load in N
A = Cross sectional area of test cube in mm^2.

III. Results and Discussions

3.1. Effect of Water - Cement Ratio and Gradation on Workability of Fresh Concrete

Results in Figure 1 showed that the slump for well graded, gap 1 graded, gap 2 graded and gap 3 graded were 27mm, 27mm, 26mm and 28mm in that order for 0.45 w/c ratio. The slump for well graded, gap 1 graded, gap 2 graded and gap 3 graded were 28.5mm, 29mm, 28mm and 30mm in that order for 0.50 w/c ratio. The slump for well graded, gap 1 graded, gap 2 graded and gap 3 graded were 29.5mm, 31mm, 29mm and 32mm for 0.55 w/c ratio.

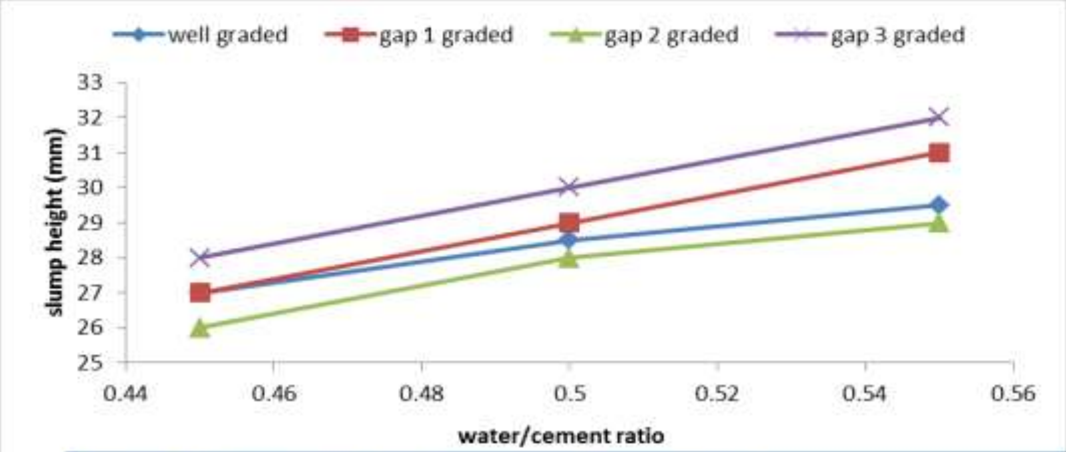

FIGURE 1. SLUMP HEIGHT AGAINST WATER CEMENT RATIO

The results indicated that as the water–cement ratio was increased workability of fresh concrete also increased. This incremental trend was noticed irrespective of the gradation pattern. That is for a given gradation pattern, the concrete slump was directly proportional to the water-cement ratio. This occurs due to the increment in water-cement ratio resulting in higher flow property of the fresh concrete mix. The result also revealed that the gradation status of coarse aggregate also affect the workability of the concrete mix. The well graded aggregate concrete produced a concrete of lower workability in comparison to the gap graded aggregate concrete (except gap 2) irrespective of the water-cement ratio. That is, the poorer the gradation, the higher the workability. This may be attributed to the fact that other gradation patterns have void spaces which the water occupies leading to a more workable concrete but for the well graded concrete, the particles were well distributed leaving less void spaces.

3.2. Effect of Water- Cement Ratio on Compressive Strength of Concrete

The compressive strength test result is presented in Figure 2 (a-c) for 7, 14 and 28 days. The results revealed that for 7th day, 0.45 w/c ratio concrete, the mean compressive strength were 16.23N/mm^2, 14.66Nmm^2, 11.95 N/mm^2 and 12.8N/mm^2 for well graded, gap 1 graded, gap 2 graded and gap 3 graded concrete in that order (Figure 2a). For 0.5 w/c ratio, the recorded compressive strength were 14.31N/mm^2, 14.44N/mm^2, 8.16N/mm^2 and 11.06N/mm^2 for the different graded aggregate concrete (Figure 2a). Mean compressive strengths of 12.81N/mm^2, 12.15N/mm^2, 13.38 N/mm^2 and 11.05 N/mm^2 were recorded for the well graded, gap 1 graded, gap 2 graded and gap 3 graded in that order for 7th day, 0.55 w/c ratio concrete (Figure 2a).

The results also revealed that for 14th day, 0.45 w/c ratio concrete, the mean compressive strength were 16.44N/mm^2, 15.40N/mm^2, 19.96 N/mm^2 and 18.83N/mm^2 for well graded, gap 1 graded, gap 2 graded and gap 3 graded concrete in that order (Figure 2b). For 0.5 w/c ratio, the recorded compressive strength were 14.37N/mm^2, 15.67N/mm^2, 16.63N/mm^2 and 16.60 N/mm^2 for the different graded aggregate concrete (Figure 2b). Mean compressive strengths of 13.82N/mm^2, 14.34N/mm^2, 17.49 N/mm^2 and 13.38 N/mm^2 were recorded for the well graded, gap 1 graded, gap 2 graded and gap 3 graded in that order for 14th day, 0.55 w/c ratio concrete (Figure 2b).

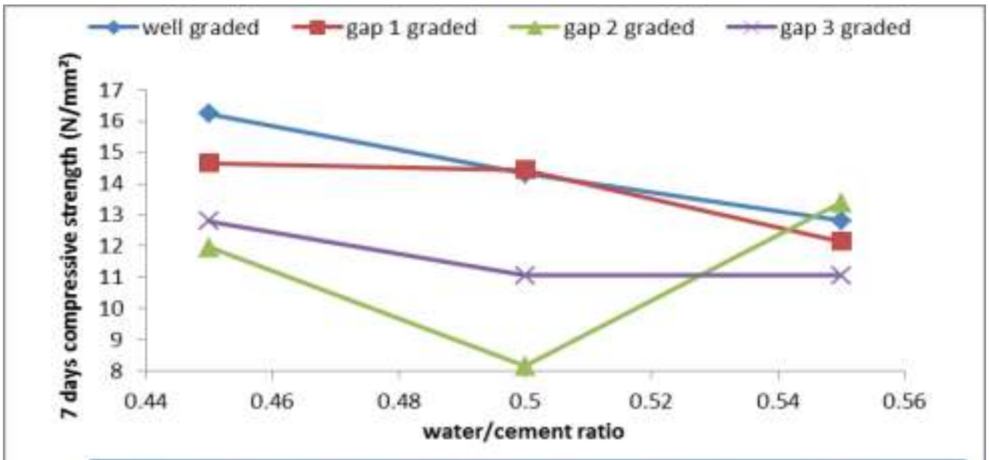

Figure 2a. 7 DAYS COMPRESSIVE STRENGTH VS WATER/CEMENT RATIO

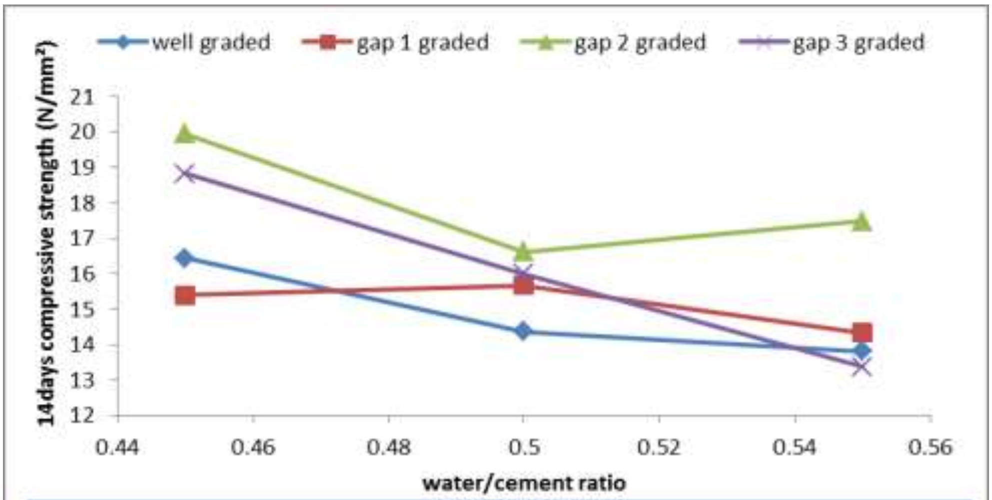

FIGURE 2b. 14 DAYS COMPRESSIVE STRENGTH VS WATER/CEMENT RATIO

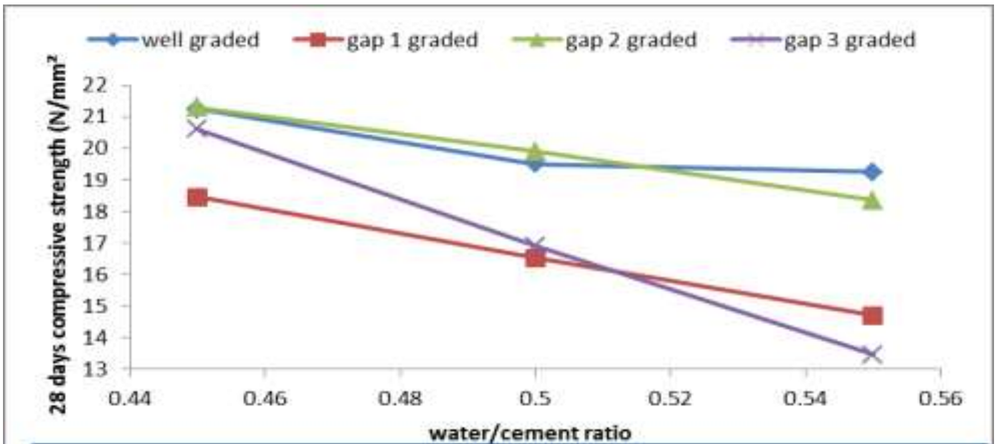

FIGURE 2c. 28 DAYS COMPRESSIVE STRENGTH VS WATER/CEMENT RATIO

For 28th day, 0.45 w/c ratio concrete, the mean compressive strength were 21.25N/mm2, 18.45N/mm^2, 21.30 N/mm^2 and 20.60N/mm^2 for well graded, gap 1 graded, gap 2 graded and gap 3 graded concrete in that order (Figure 2c).

For 0.5 w/c ratio, the recorded compressive strength were 19.50N/mm^2, 16.52N/mm^2, 19.90N/mm^2 and 16.90 N/mm^2 for the different graded aggregate concrete (Figure 2c). Mean compressive strengths of 19.25 N/mm^2, 14.70 N/mm^2, 18.35 N/mm^2 and 13.45 N/mm^2 were recorded for the well graded, gap 1 graded, gap 2 graded and gap 3 graded in that order for 28th day, 0.55 w/c ratio concrete (Figure 2c).

The results indicated that the compressive strength of concrete generally decreased as the water-cement ratio was increased irrespective of the gradation status of the coarse aggregate and the age of the concrete. For the well graded coarse aggregate concretes, the decrements in the compressive strength were relatively steady in comparison to the gap graded coarse aggregate concretes.

3.3. Effect of Coarse Aggregate Gradation on Compressive Strength of Concrete

The results displayed in Figure 3(a-c), showed how the compressive strength of concretes for different ages were been affected by gradation pattern of coarse aggregate.

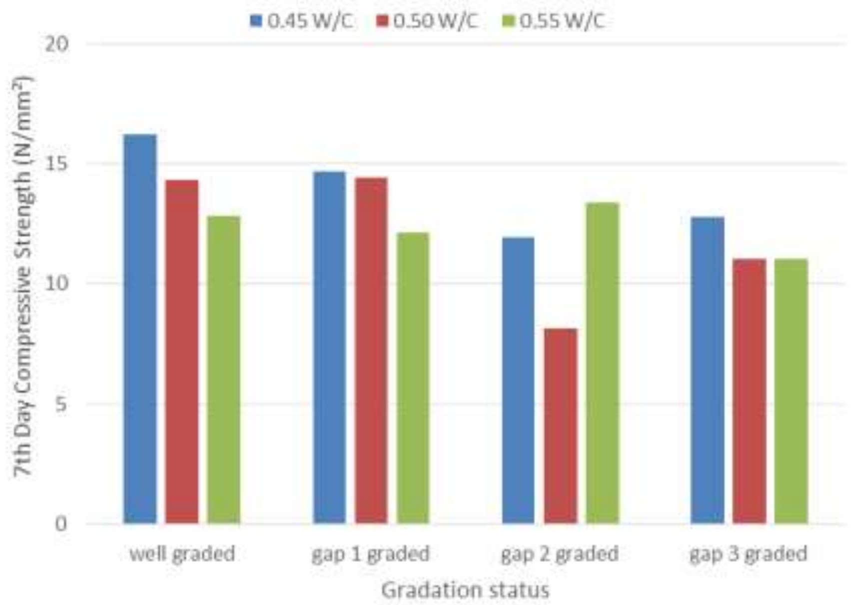

Figure 3a. 7th Day Compressive Strength Against Gradation Pattern

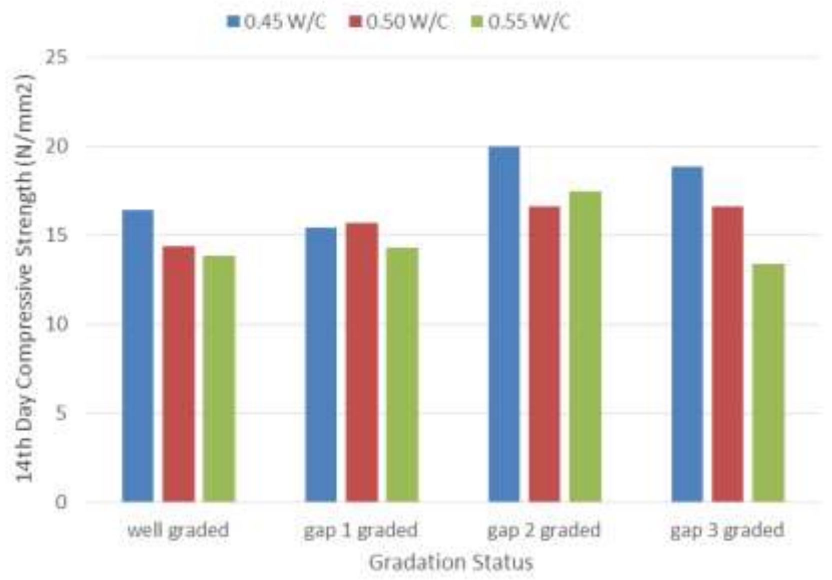

Figure 3b. 14th Day Compressive Strength Against Gradation Pattern

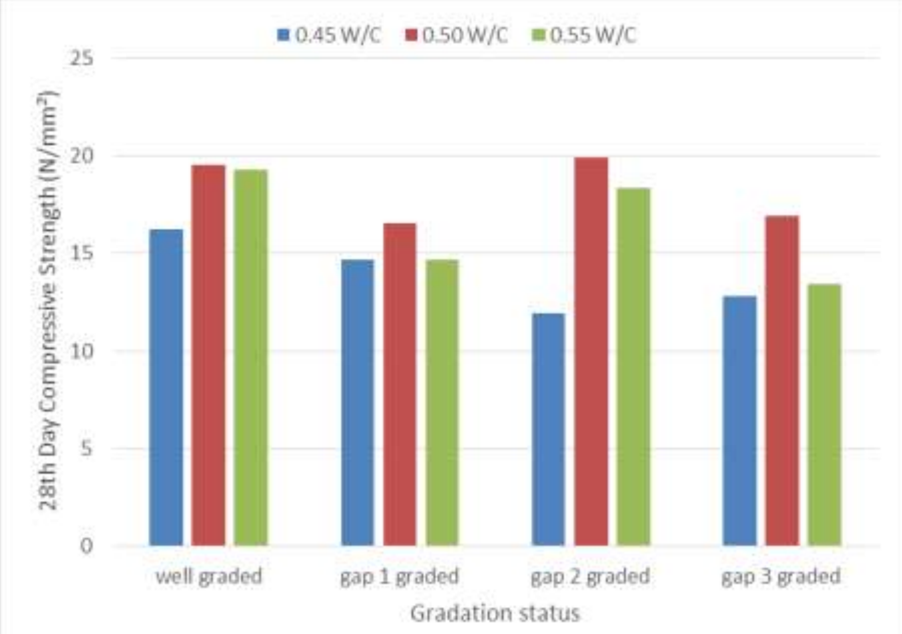

Figure 3c. 28th Day Compressive Strength Against Gradation Pattern

A close examination of the results displayed in Figure 3(a-c) revealed that for the early age concrete specimens (7 days), the well graded and gap 1 graded coarse aggregate concrete on the average produced a better strength concrete in comparison to the other graded aggregate concrete. This may be attributed to the presence of larger coarse aggregate sizes present in the gap 1(19mm and 13.2mm) and well graded coarse aggregate concretes. They were followed by the gap 2 (without 13.2mm) and lastly by the gap 3 (without 19mm) coarse aggregate concrete. This was due to the absence of 19mm aggregate sizes in the gap 3 graded coarse aggregate concrete. At later ages of the concrete life, the well graded aggregate continued to develop greater strength on the average as the concrete age increases in comparison to other graded concretes. This may be attributed to increase in the bonding of the aggregate particles whereas the bonding in the gap graded concretes becomes weak due to the presence of the void spaces created.

3.4. Rate of compressive strength development (Effect of Ageing)

The result for the investigation of percentage increment in strength against the age of concrete is presented in Figure 4(a-c).

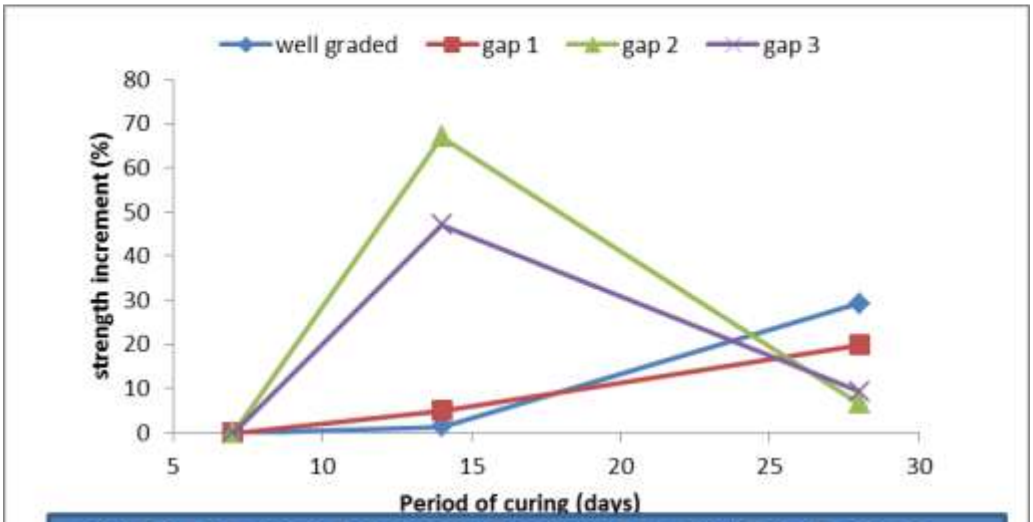

FIGURE 4a PERCENTAGE STRENGTH INCREMENT FOR W/C RATIO OF 0.45

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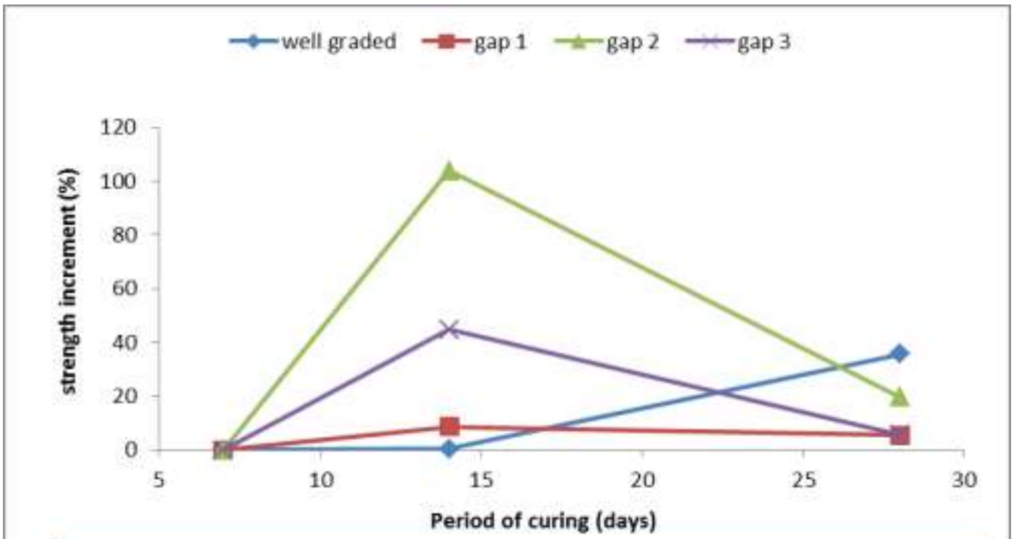

FIGURE 4b PERCENTAGE STRENGTH INCREMENT FOR W/C RATIO OF 0.50

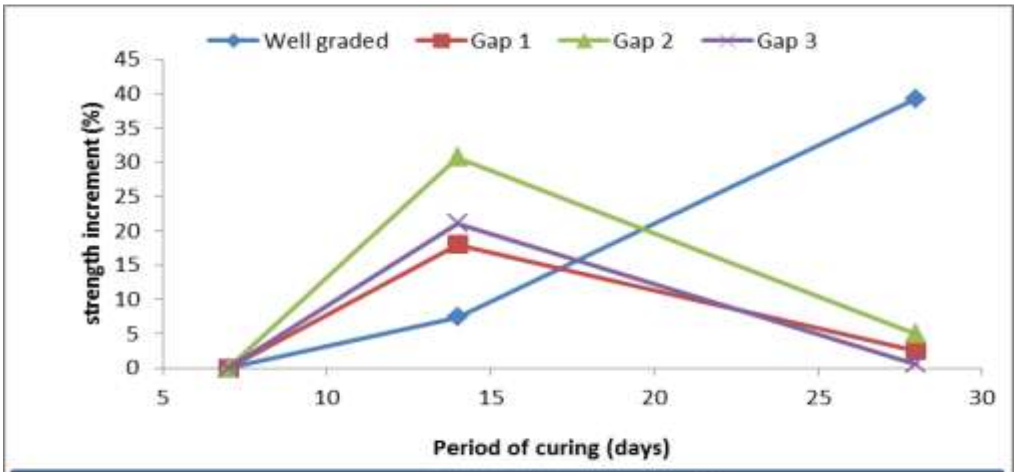

FIGURE 4c PERCENTAGE STRENGTH INCREMENT FOR W/C RATIO OF 0.55

Based on the results from the tests on the various aggregate pattern with the three water-cement ratios as shown in figures 4a to 4c, the compressive strength of different concrete increased with increase in the period of curing from 7 to 28 days as expected. It was observed that there was a steep increase in the percentage strength increment of the well graded concrete at early curing periods (7 to 14th day), while there was only a slight increase in the percentage strength increment of concrete at later curing period (28 day). Whereas, for the gap graded concrete (gap 1, gap 2 and gap 3), there is a spontaneous increase in strength at the early curing period (7 to 14th day) and a decrease in percentage strength increment at the 28th day. This indicated that the well graded concrete would produce a more durable concrete compared to the gap graded concretes.

IV. CONCLUSIONS

The workability of fresh concrete increases with increase in water-cement ratio irrespective of the gradation pattern. This finding is in agreement with earlier results by [17] whose study revealed that the water cement ratio is directly proportional to the workability of M-20 grade concrete. The gradation pattern also affects the workability of concrete as revealed by this study. The increment in workability of well graded aggregate is small in comparison to the other gradation patterns. This suggests that the better the gradation pattern, the lower the workability of fresh concrete.

The compressive strength generally reduces as the water-cement ratio increases irrespective of the age of the concrete. This finding is also in consonance with results from earlier studies ([11], [18]). With respect to the gradation pattern, the decrement in strength with water-cement ratio increase is uniform and steady for the well graded aggregate concrete in comparison to other gradation patterns.

The presence of larger aggregate sizes in the well graded and gap 1 graded aggregate concrete resulted in higher early strength of concrete. This suggests that the larger the sizes of coarse aggregate present in a concrete mix, the greater the compressive strength. This is in agreement with the findings of [8].

The durability studies of this research revealed that well graded aggregate concrete produces a more durable concrete in comparison to gap graded coarse aggregate concrete. The gap graded coarse aggregate might produce concrete of high early strength due to presence of larger particles. However, as the concrete ages, the weak bonding strength becomes more evident resulting in significant strength loss. Thus, well graded coarse aggregate is strongly recommended for usage instead of its gap graded counterparts.

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