International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Effect of Coarse Aggregate Gradation on Workability and Flexural Strength of Cement Concrete

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

Abstract— *The construction of rigid pavements and other concrete structures in Nigeria without consideration of the gradation status of the coarse aggregate used served as a prerequisite for this study. This project thus investigated the effect of gradation of coarse aggregate on the workability and flexural strength of cement concrete. Coarse aggregates of nominal size of 5mm, 13mm and 19mm were sourced, mixed together and subjected to sieve analysis. The coarse aggregate were then grouped into well graded (consisting of all three aggregate sizes), gap 1 graded (minus 5 mm), gap 2 graded (minus 13mm) and gap 3 graded (minus 19mm) coarse aggregates. Fresh concrete test in form of workability tests was carried out on all concrete specimens and flexural strength test was performed for all hardened concrete specimens. The concrete specimens were cured for 7, 14, 21 and 28 days. From results of experiments, the workability of fresh concrete specimens increases with poor gradation pattern. The workability of well graded aggregate concrete was small in comparison to the other gradation patterns (gap 1, gap 2 and gap 3) and for the gap graded aggregates, the workability increased with removal of the larger aggregate size. For the flexural strength, the gap 1 graded aggregate concrete recorded the highest early strength due to presence of larger aggregate sizes. As the concrete ages, the percentage strength increment was noticed to be higher for the well graded aggregate concrete. That is, the well graded aggregates, gained more strength increase as the concrete ages. This indicates that the well graded aggregates will produce a more durable concrete in comparison to the gap graded aggregate concrete. The use of well graded aggregates in cement concrete construction should be encouraged as less binder content will be required and a more durable concrete produced.*

Keywords— *Flexural strength, workability, coarse aggregate, gradation.*

I. Introduction

Concrete as a construction material, is a composite mixture of aggregates and water bonded by a cementitious material. The quality of any concrete construction is indicated by the quality of the components of the concrete. Concrete has found major application in the construction industry such as the building industry and road industry. In the road industry, concrete is used in the construction of rigid pavement, otherwise called concrete pavement, where the major load bearing component is the concrete slab. The quality of concrete produced in any process is usually reflected by the concrete properties such as workability and flexural strength.

One important parameter for computing deflection in reinforced concrete structures is the flexural strength [1]. According to [2], the flexural strength (modulus of rupture) of concrete is the theoretical maximum tensile stress reached in the bottom fibre of a test beam during a flexural strength test. Another important property of fresh concrete is its workability. 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 [3].

One constituent of concrete that determines its strength is coarse aggregate which according to [4], takes about 50 and 60 percent of the concrete volume depending on the mix proportion adopted. There have been many researches on the effect of aggregate shape, type and size on the strength properties of concrete. [5] Studied the effects of coarse aggregate size on the properties of normal-strength concrete. Their work demonstrates that an increase in aggregate size from 10mm to 64mm results in a decrease in the compressive strength of concrete by as much as 10 percent; however, aggregate size seems to have negligible effects on flexural strength. More recent studies revealed otherwise. According to [6], the compressive strength increases with increase in coarse aggregate size. Studies by [7] investigated compressive strength of concrete made from 9.5mm, 13.2mm and 19.0mm aggregates. Their Results indicated that compressive strength of concrete increased with increase in aggregate size. [8] 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. Results from the studies of [9], on the effect of Aggregate type, size and content on concrete strength and fracture energy, revealed that the compressive strength of both normal and high strength concrete is little affected by aggregate size.

Gradation specification of aggregate must be met before usage as pavement materials [10]. [11] Studied the flexural strength and water absorption of concrete made from uniform size and graded coarse aggregate combined in varying proportions. Their results revealed that the flexural strength of concrete increased with increase in aggregate size and that the flexural strength of concrete made from uniform aggregate is higher in comparison to graded aggregate concrete. The virtually accepted usage of uniform and graded aggregates in rigid pavement construction without consideration of the gradation pattern, necessitated this study. This study thus aimed at investigating the effect of gradation as it affects the flexural strength and workability of cement concrete.

II. Materials and Methods

2.1. Materials

All materials used in this research were locally available within the Port Harcourt city environment

D. B. Eme and C. Nwaobakata, “Effect of coarse aggregate gradation on workability and flexural strength of cement concrete,” *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 1, pp. 128-132, 2019.

2.1.1. Portand cement

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

2.1.2. Water

Clean tap water sourced from the structural laboratory of the University of Port Harcourt with a pH value of 6.9 was used for all experimental procedures.

2.1.3. Fine aggregate

Fine river sand sourced from a construction site in Port Harcourt was used for experimental purposes in this study. From the gradation studies, the sand was discovered to be a well graded, zone II sand.

2.1.4. Coarse aggregate

The granite grades used in this study are; 5mm, 13mm and 19mm aggregates. These coarse aggregate grades were sourced from a construction site in Port Harcourt.

2.1.5. Equipment

The following equipment were used in this study:

i. Slump cone (Model HM-40, Gilson Company, USA) which meets the requirements of BS1881-102 [13].
ii. 150mm x 150mm x 150mm steel moulds
iii. Universal concrete strength testing machine (Model 4207D, Chandler Eng. USA).
iv. Other apparatus include; shovel, trowel, curing tank compacting rod and metallic ruler.

2.2 Methods

2.2.1 Experimental program

This study involved experimental investigation using three different grades of coarse aggregates; 5mm, 13mm and 19mm coarse aggregate grades. These grades of coarse aggregate were mixed together in equal proportions and subjected to particle size distribution analysis. The coarse aggregates were then categorized into well graded (all three sizes properly represented), gap 1 graded (5mm missing), gap 2 graded (13mm missing) and gap 3 graded (19mm missing) coarse aggregates. A constant design mix of 1: 2: 4 with a water-cement ratio of 0.5 was adopted. The workability of fresh concrete produced was determined using the slump cone method and the flexural strength of hardened concrete determined after 7, 14, 21 and 28 days of curing.

2.2.2 Batching, mixing and curing of concrete composites

The batching by weight method was adopted. The mixing of concrete constituents was done manually with the aid of a shovel and trowel, with a design mix of 1: 2: 4 and water cement ratio of 0.5. Curing of concrete specimen was done by complete immersion in water in a curing tank. The concrete specimens were left for 7 days, 14 days, 21 days and 28 days in the curing tank, after which, they were taken for flexural strength test in the laboratory.

2.2.3 Slump cone test

The slump test is the method adopted in this study to determine the workability of fresh concrete. This test was carried out in accordance with [13]. The apparatus used for the essence of this experiment were; slump cone, compacting rod, level surface (which is a tray), trowel, and metallic ruler. The slump cone was placed on the level surface. Fresh concrete was poured into the slump cone with the aid of the trowel and compacted in three layers, with the aid of the compacting rod giving it 35 blows uniformly across the entire surface. The fresh concrete specimen after filling the cone was then leveled and left to stand for 2 minutes. The slump cone was pulled from the fresh concrete leaving the pile of concrete unsupported. The difference in height between the initial specimen (height of cone) and the pile of unsupported specimen was taken as the slump height.

2.2.4 Flexural strength test

The universal strength testing machine was used in determining the flexural strength of concrete specimen. The equipment/apparatus used for this experiment were; 100mm x 100 mm x 500mm beam moulds, Universal strength testing machine, compacting rod, trowel and shovel. The centre point load test was used in determining the flexural strength of hardened concrete specimens. The flexural strength is measured in terms of the modulus of rupture computed using Equation (1).

$$\mathrm{MR} = \frac{3PL}{2bd^2} \quad (1)$$

Where: MR= Modulus of rupture in N/mm^2
P = Load at fracture in N
L = span length in mm
b = average width of the specimen at the fracture in mm
d = average depth of the specimen at the fracture in mm

III. RESULTS AND DISCUSSIONS

3.1. Effect of Gradation on Workability of Concrete

The result of slump test which is adopted here, as a representation of workability of fresh concrete is presented in Figure 1. The result in figure 1 revealed that the slump height for well graded, gap 1 graded, gap 2 graded and gap 3 graded were 28.50mm, 29mm, 30mm and 31mm in that order.

From the bar chart of slump height versus gradation pattern (Figure 1), the workability of fresh concrete is smaller in well graded coarse aggregate concrete in comparison to the other graded aggregate concretes. On close observation of figure 1, the larger the size of aggregate removed, the higher the workability. This may be attributed to the fact that bigger pore spaces were left open when these sizes were removed, allowing water to occupy more void spaces. The low workability value observed for the well graded aggregate fresh concrete may be attributed to the fact that less void spaces were created on the concrete mix as the aggregate sizes were well distributed.

D. B. Eme and C. Nwaobakata, “Effect of coarse aggregate gradation on workability and flexural strength of cement concrete,” *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 1, pp. 128-132, 2019.

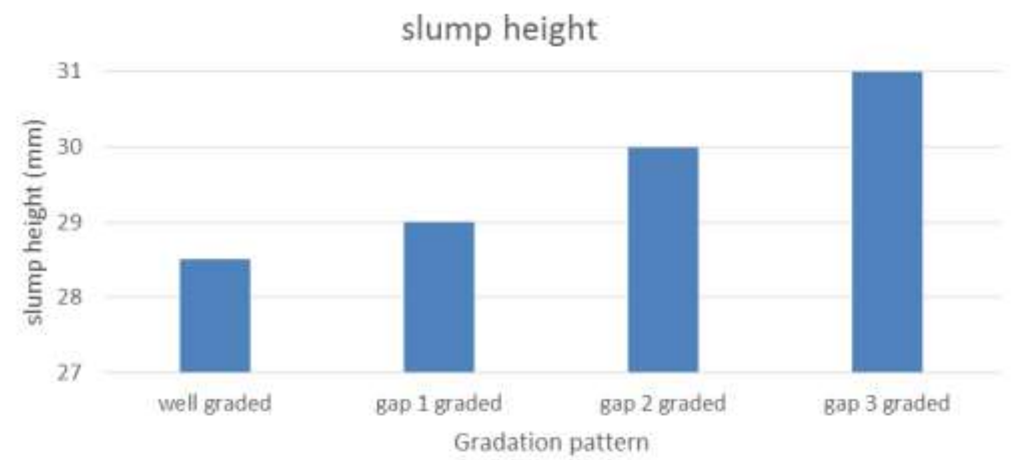

Figure 1. Slump height variation with gradation pattern

3.2. Effect of Gradation on Flexural Strength of Concrete

The flexural strength result for the different concrete ages is presented in figure 2. The result in figure 2 revealed that the flexural strength of well graded coarse aggregate concrete is 3.56N/mm^2, gap 1 graded coarse aggregate concrete is 3.57N/mm^2, gap 2 graded coarse aggregate concrete is 2.96N/mm^2 and gap 3 graded coarse aggregate concrete is 3.13N/mm^2 for the 7 days old concrete. For the 14 days concrete, values of 3.58N/mm^2, 3.72N/mm^2, 3.83N/mm^2 and 3.81N/mm2 were recorded for flexural strength of well, gap 1, gap 2 and gap 3 graded coarse aggregate concretes in that order. 3.65N/mm^2, 3.78N/mm^2, 3.90N/mm^2 and 3.81N/mm^2 were recorded as flexural strength values for well graded, gap 1 graded, gap 2 graded and gap 3 graded concrete for the 21 days old concrete. The flexural strength values for the 28 days old concrete were 4.15N/mm^2, 3.82N/mm^2, 4.19N/mm^2 and 3.86N/mm^2 in that order for the well, gap 1, gap 2 and gap 3 graded coarse aggregate concretes.

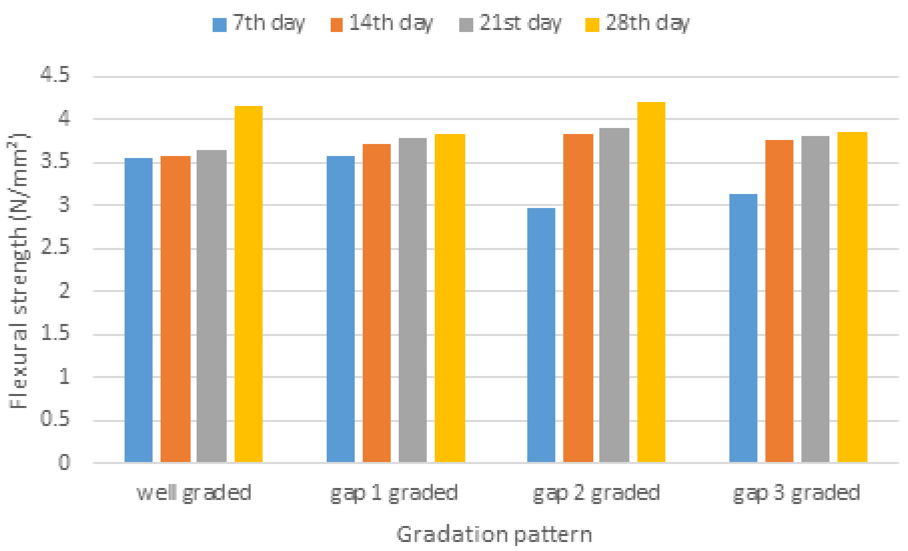

Figure 2. Flexural strength variation with gradation pattern

As observed from figure 2, the flexural strength of concrete was increased as the age increased for any particular gradation pattern. The flexural strength increased marginally during the early stages but increased abruptly at 28 days for the well graded aggregate concrete. For gap 1 to gap 3 aggregates, the concrete increased more at its early ages. On a close observation of figure 2, the early flexural strength for gap 1 (minus 5mm) aggregate is higher due to the presence of

D. B. Eme and C. Nwaobakata, “Effect of coarse aggregate gradation on workability and flexural strength of cement concrete,” *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 1, pp. 128-132, 2019.

more bigger aggregate sizes (13mm and19mm) in comparison to the other graded coarse aggregate concrete. Thus, establishing that the bigger the sizes of coarse aggregate present in a concrete mix, the higher the early flexural strength. As the concrete ages, the well graded aggregate concrete gained more strength than other graded aggregate concretes. At 28 days, the flexural strength of well graded coarse aggregate concrete was higher than the others. This may be attributed to increase in the bonding of the aggregate particles whereas the bonding in the gap graded concretes became weak due to the presence of the void spaces created.

3.3. Effect of Gradation on Durability of Concrete

Figure 3 presents the results of the durability studies of gradation effect on flexural strength of concrete with respect to percentage increment in strength of concrete as the concrete ages.

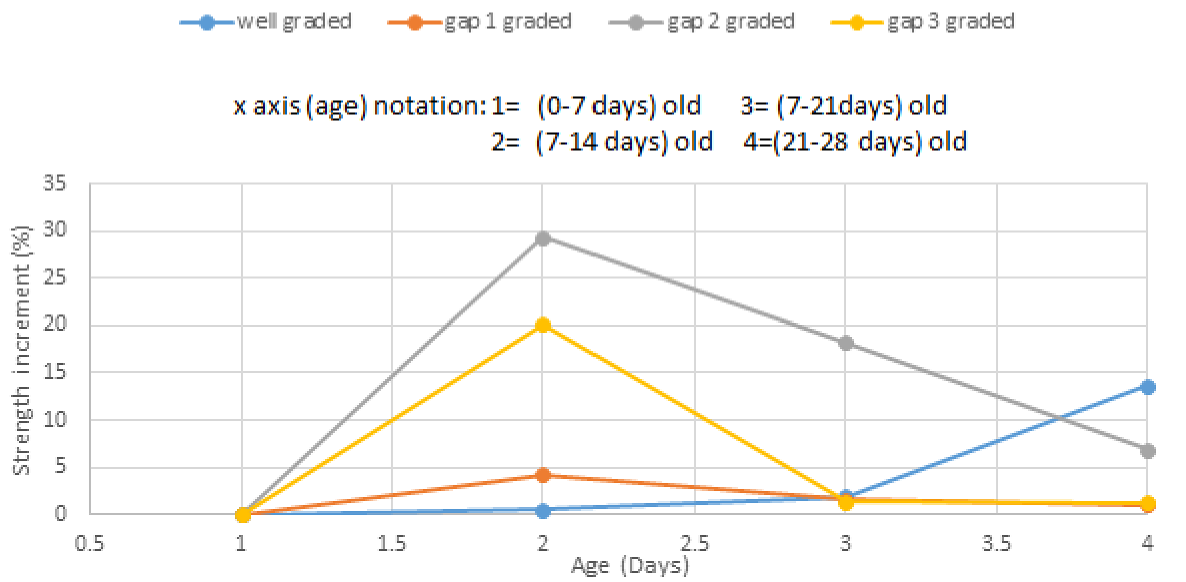

Figure 3. Strength increment variation with Age of concrete

Based on the results shown in figure 3, the flexural strength increased with increase in the concrete age. The percentage increase in flexural strength increases with age of concrete for the well graded aggregate. For the case of the gap graded aggregates, this increment is only noticed at the early ages (0-7 days). The percentage increment in strength reduces as the concrete ages for the gap graded aggregate concretes. The percentage increment in flexural strength for the well graded aggregate might be attributed to the development of bonding strength between aggregate particles. For the gap graded aggregates, the bond weakness starts becoming evident as the concrete ages, signifying that the well graded aggregate concrete is more durable than its gap graded counterparts.

IV. CONCLUSIONS

Based on the results of the study of the effect of gradation on flexural strength of cement concrete, the following conclusions are hereby made:

i. The workability of fresh concrete increases with poor gradation of the coarse aggregate. The workability of fresh concrete is higher for gap graded coarse aggregate concrete than for well graded coarse aggregate concrete. For the gap aggregates, the bigger the particle sizes removed, the higher the workability. That is, concrete with smaller size particles have higher workability in comparison to concrete with bigger size particles.
ii. The flexural strength of concrete generally increases with increase in the age of concrete. Gap graded aggregate with larger particle sizes, possess higher flexural strength at the early stage of concrete in comparison to the well graded counterpart. This signifies that, the larger the coarse aggregate sizes present in a concrete mix, the higher the flexural strength.
iii. From the result of the durability study, well graded aggregate concrete develops a positive strength increment trend as the concrete ages while the strength increment for the gap graded counterparts only increases at the early stages. Well graded aggregate concrete is therefore, considered more durable than gap graded aggregate concrete.

REFERENCES

[1] K. Anbivelan and K. Subramanian, "An empirical relationship between modulus of elasticity, modulus of rupture and compressive strength of M60 concrete containing metakaolin," *Res. J. Appl. Sci. Eng. Technol.*, vol. 8, issue 11, pp. 1294-1298, 2014.
[2] Ajamu, S.O and Ige, J.A., "Effect of coarse aggregate size on compressive strength and flexural strength of concrete beam," *Int. Journal of Engineering Research and Applications*, vol. 5, issue 1, pp. 67-75, 2015.

[3] Mindess S., Young, J.F., and Darwin, D., *Concrete*, 2nd ed. Prentice Hall, Upper Saddle River, New Jersey, 2003.
[4] Wu, K-R., Chen, B., Yao, W., and Zhang, D., "Effect of coarse aggregate type on mechanical properties of high performance concrete," *Cement and Concrete Research*, vol. 31, issue 10, pp. 1421-1425, 1997.
[5] Walker, S. and Bloem, D. L., "Effects of aggregate size on properties of concrete," *ACI Journal, Proceedings*, vol. 57, no. 3, pp. 283-298, 1960.
[6] Zhou, F. P., Barr, B.I. and Lydon, F.D., "Fracture properties of high strength concrete with varying silica fume content and aggregates," *Cement and Concrete Research*, vol. 25, no. 3, pp. 543-552, 1995.
[7] Vilane, B.R. and Sabelo, N., "The effect of aggregate size on the compressive strength of concrete," *Journal of Agricultural Science and Engineering*, vol. 2, issue 6, pp. 66-69, 2016.
[8] Chupanit, P. and Roesler, J.R., "Improvement of concrete cracking resistance and joint load transfer through coarse aggregate selection accepted for publication," *Transport Research Record*, *Journal of Transportation Research Board*, 2005.
[9] Rozalija, K and Darwin, David, Effect of Aggregate Type, Size and Content on Concrete Strength and Fracture, The Reinforced Concrete Research Council, Project 56, The U.S Department of Transportation, Federal Highway Administration, SM Report No. 43, 1997.
[10] Aggregate Gradation for Concrete Pavement Mixtures, CP Road Map, Map Brief, October 2014.
[11] Ekwulo E. O. and Eme D. B., "Flexural strength and water absorption of concrete made from uniform size and graded coarse aggregates," *American Journal of Engineering Research*, vol. 6, issue 10, pp. 172-177, 2017.
[12] British Standard Institution, Specification for Portland cement (BS 12), London: British Standard Institution, 1996.
[13] British Standards Institution, BS. 1881 Part 102: Method for determination of slump, London: British Standard Institution, 1983.

D. B. Eme and C. Nwaobakata, "Effect of coarse aggregate gradation on workability and flexural strength of cement concrete," *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 1, pp. 128-132, 2019.