RESEARCH ARTICLE OPEN ACCESS

Effect of Coarse Aggregate Size on the Compressive Strength and the Flexural Strength of Concrete Beam

S.O. Ajamu[1] and J.A. Ige[2]
[1,2]Department of Civil Engineering, Ladoke Akintola University of Technology, PMB 4000 Ogbomoso, Oyo State Nigeria

ABSTRACT
Concrete structures deflect, crack, and loose stiffness when subjected to external load. Loss of flexural strength of concrete is largely responsible for cracks in structure. In reinforced concrete structures, the mix proportions of the materials of the concrete and aggregate type determine the compressive strength while the composite action of concrete and steel reinforcement supplies the flexural strength. In occasion of loss of stiffness, steel reinforcement no longer supports flexural stresses; concrete in turn is subjected to flexure. The compressive strength and flexural strength therefore play a crucial role. Effect of varying coarse aggregate size on the flexural and compressive strengths of concrete beam was investigated.
Concrete cubes and beams were produced in accordance with BS 1881-108 (1983) and ASTM C293 with varying aggregate sizes 9.0mm, 13.2mm, 19mm, 25.0mm and 37.5mm, using a standard mould of internal dimension 150x150x150 for the concrete cubes and a mould of internal dimension of 150 x 150 x 750mm for the reinforced concrete beam. The water cement ratio was kept at 0.65 with a mix proportion of 1:2:4. The specimen produced were all subjected to curing in water for 28days and were all tested to determine the compressive strength and flexural strength using Universal Testing Machine.
Compressive strength of cubes is 21.26N/mm^2, 23.41N/mm^2, 23.66N/mm^2, and 24.31N/mm^2 for coarse aggregate sizes 13.2mm, 19mm, 25.0mm and 37.5mm respectively. That of flexural strength of test beams is 4.93N/mm^2, 4.78N/mm^2, 4.53N/mm^2, 4.49N/mm^2, 4.40N/mm^2 respectively.
In conclusion, concrete to be used mostly to resist flexural stresses should be made of finer coarse aggregates.
Key words: Flexural strength, compressive strength, stiffness, aggregate size.

I. Introduction

Flexural strength is a measure of the tensile strength of concrete; it is a measure of an unreinforced concrete beam or slab to resist failure resulting from bending stresses. Reinforcements are provided to enhance the tensile strength of concrete. The ability of concrete to induce tensile stresses to reinforcement depends mostly on the bonding force between the two materials and also on the size of aggregates. Inability of concrete to adequately induce tensile stresses to the reinforcement results in cracking at the bottom fibre; cracks will open up bond that exist between the two materials (concrete and steel). This eventually reduces the stiffness of the whole composite, and reinforcement will be exposed to corrosion agents (water, chloride, air etc.). This study therefore focused on the effect of coarse aggregate size on the flexural strength of concrete.

To evaluate the flexural strength (the theoretical maximum tensile stress reached in the bottom fibre of a test beam during a flexural strength test) of concrete implies subjecting concrete to loading on flexural testing machine in order to measure it's resistance to tensile stresses.

The constituents of concrete are cement, water, aggregates (fine and coarse aggregates), aggregates take about three-quarter of the volume of concrete with the coarse aggregates taking between 50 and 60% of the concrete mix depending on the mix proportion used (Waziri *et. al.*, 2011). The larger percentage of coarse aggregate in concrete mix makes it to contribute a lot to the strength of concrete. Its properties like toughness, hardness, shape, size, soundness, density, and specific gravity also affect the strength of concrete.

Many researchers (Wu *et. al.*, (1997), Zhang *et. al.* (2010), Waziri *et. al.* (2011), Abdullahi (2012), and Joseph *et. al.* (2012)) have carried out studies on the strength characteristics of concrete produced using different aggregate materials and using different brands of cement but little or no attention have been focused on the flexural bond stress (which is the stress in structural concrete members between the concrete and the reinforcing element that results from the application of external loads) between reinforcement and concrete. Use of poorly graded coarse aggregate in concrete matrix also has it share in the causes of structural failure due to the development of horny comb in the concrete. This also results in a cohesionless composite of concrete and steel with poor flexural bond. In such a case concrete will not be able to effectively transmit the induced external (flexural) load to the reinforcement, thus resulting in structural failure as the concrete will be subjected to tensile stresses than it can accommodate. Therefore it is imperative to determine the effect of coarse aggregate size on the flexural bond strength of concrete.

1.1 Materials and Methods

The materials used for this work are coarse aggregate, fine aggregate, cement, beam mould (750mm x 150mm x 150 mm), cube mould (150mm x 150mm x 150 mm), water, shovel, weighing balance, set of sieve, UTM (Universal Testing Machine). The coarse aggregate used was sourced from a single quarry site (Igbo Ile Quarry Site, Ogbomoso) to ensure uniformity of results. Dangote brand of Ordinary Portland Cement (OPC) was used; clean water fit for drinking was used throughout for the research work.

1.1.1 Sieve Analysis

The fine and coarse aggregate was sieved to various sizes in accordance with BS 812:103 as shown in Figure 1 (A, B, C, D and E).

(A) Aggregate size 9mm

(B) Aggregate size 13.2mm

(C) Aggregate size 19mm

(D) Aggregate size 25mm

(E) Aggregate size 37.5mm

Figure 1: Coarse aggregate sizes used

1.1.2 Mix Proportion

The proportion of each constituent material (i.e. cement, fine aggregate, coarse aggregate and water) was estimated with the following procedure:

(i) The total volume of concrete required to cast three samples of test beams and three samples of test cubes per specimen of coarse aggregate size was estimated.

(ii) The total weight of concrete required per mix was gotten by multiplying the total volume required per mix by the unit weight of concrete ($24kN/m^3$).

(iii) The weight of cement, fine aggregate and coarse aggregate required per mix was calculated using a mix ratio of 1:2:4.

(iv) The weight of water required per mix was gotten by multiplying the weight of cement required per mix by a constant water cement ratio (0.65).

(v) The weight required per mix of cement, fine aggregate, coarse aggregate and water was weighed on the weighing balance.

1.1.3 Slump Test

Slump test (test for workability of fresh concrete mix) was carried out per mix (Figure 2) in accordance with the procedure outlined in BS 1881-102 (1983).

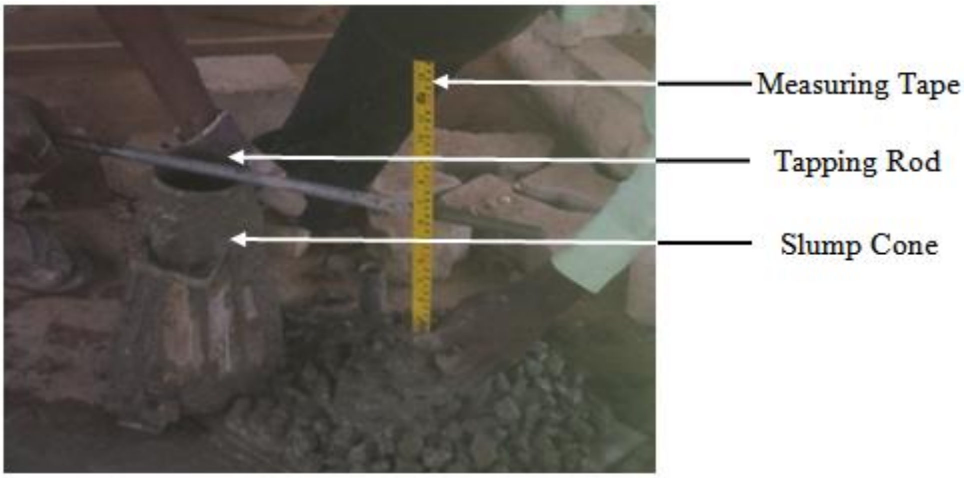


Figure 2: Slump Test Apparatus

II. Curing of Test Specimen

The specimen prepared for testing, concrete cubes and the beams were cured in curing tank for 28 days bore carrying out the compressive and flexural strength tests (Figure 3).

Figure 3: Curing Tank with the Concrete Specimen

2.1 Compressive Strength and Flexural Strength Tests

The compressive strength and the flexural strength tests were carried out on Universal Testing Machine – UTM (Figures 4a, 4b and 4c) in accordance with the procedures outlined in BS1881-116: (1983) and BS 1881-118: (1983) respectively. The formulae used to calculate the compressive strength and flexural strength are respectively given by equation (1) and equation (2).

Figure 4a: Compressive Strength Test Using concrete cube specimen

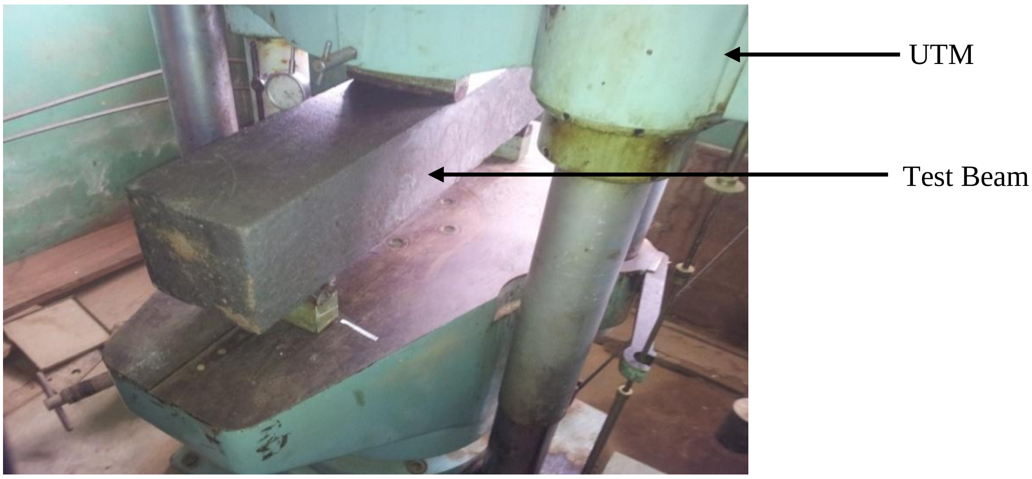


Figure 4b: Flexural Strength Test Using Concrete Beam Specimen
(UTM: Avery-Denison EN76066 7113DCJ; Capacity of 600kN)

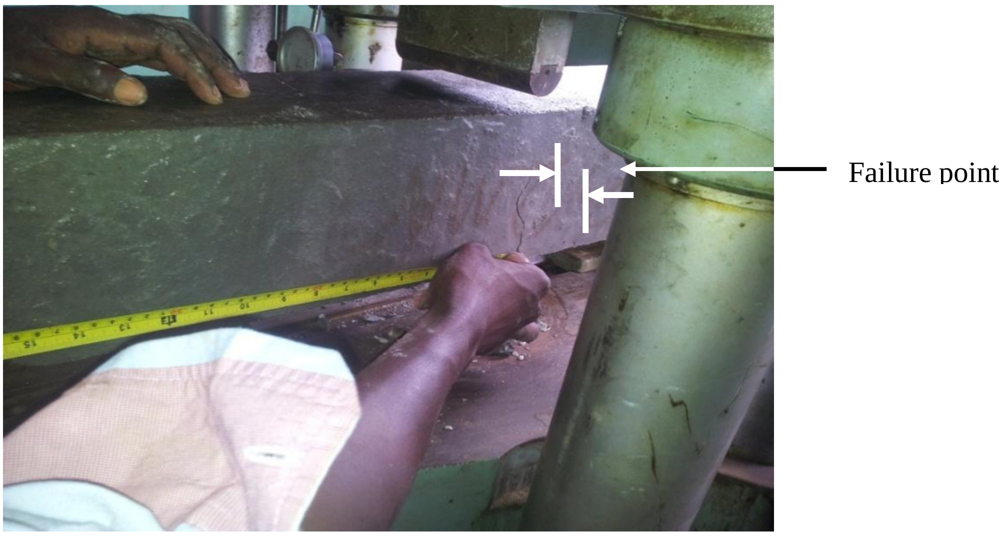


Figure 4c: Concrete Beam Specimen after Failure

2.1.1 Concrete Cube Strength Calculation

The formula used to calculate the compressive strength of each of the concrete cube specimen is given by equation (1):

$$Cube\ Strength = \frac{F}{A} \quad (1)$$

Where:

F = Load at failure or crushing load (N)
A = Load Bearing area of the cube (mm^2)

2.1.2 Flexural Strength Calculation

Flexural Strength is the theoretical maximum tensile stress reached in the bottom fibre of a test beam during a flexural strength test. The formula used to calculate the flexural strength of each of the beam specimen using the results of the three point flexural test is given by equation (2) for a rectangular cross-section:

$$Flexural\ Strength, R = \frac{3PL}{2bd^2} \quad (2)$$

Where:
R = modulus of rupture or flexural strength (N/mm^2)
P = Load at failure (kN)
L = span length (mm)
b = average width (mm)
d = average depth (mm)

III. Result and Discussion

3.1.1 Workability of Fresh Concrete: This test was carried out in order to determine the effect of the variation of coarse aggregate size with constant water-cement ratio on the workability of fresh concrete. The results gotten are presented in Table 1 and plotted in Figure 5.

Table 1: Slump Test Result for Different Aggregate Sizes with the Same Water Cement Ratio and Mix Proportion

Coarse Aggregate size (mm)	Slump (mm)
9.00	15
13.20	60
19.00	165
25.00	166
37.50	180

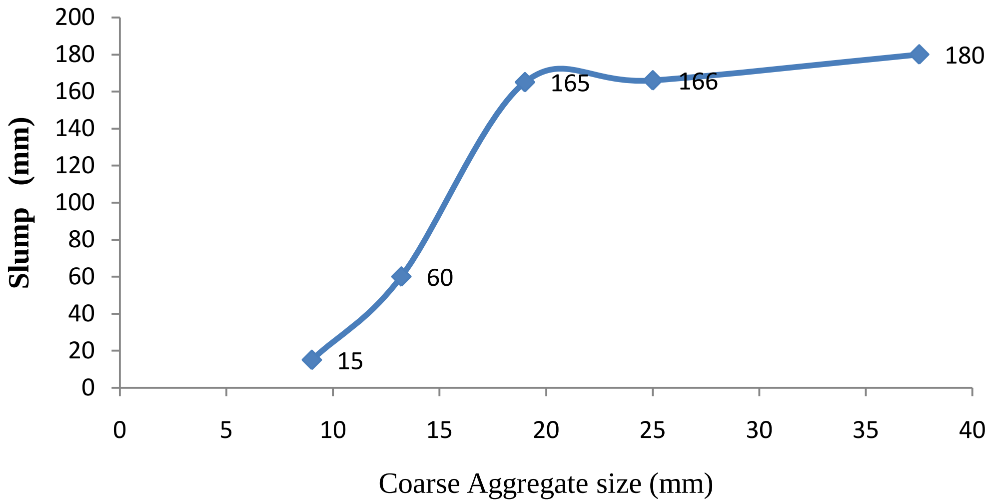


Figure 5: Variation of Slump with change in coarse aggregate size

3.1.2 Effect of Coarse Aggregate Size on Concrete Compressive Strength: The compressive test results are presented in the Table 2.

Table 2: Compressive Strength Result after 28 Days of Curing

Aggregate Size (mm)	Average Crushing Load (KN)	Average Compressive Strength (N/mm)
13.20	478	21.26
19.00	527	23.41
25.00	532	23.66
37.50	547	24.31

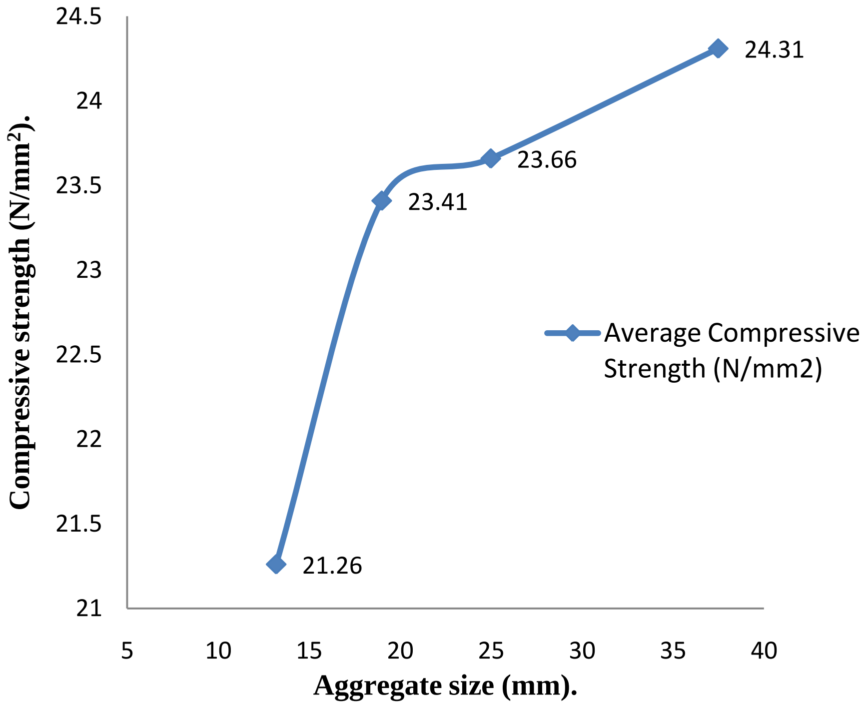


Figure 6: Variation of Compressive strength with change in coarse aggregate size

Figure 6 illustrates the effect of varying coarse aggregate size on compressive strength of the hardened concrete after 28-days of curing. It was observed that 28-days compressive strength of concrete increases relatively with increase in coarse aggregate size. With increase in coarse aggregate size from 13.2 mm to 19 mm aggregate size compressive strength was found to increase significantly. According to specification in BS1881-116 (1983), compressive strength for 1:2:4 mix at 28days should not be less than 20 N/mm^2.

3.1.3 Effect of Coarse Aggregate Size on Concrete Compressive Strength

Flexural Strength is the theoretical maximum tensile stress reached in the bottom fibre of a test beam during a flexural strength test. The flexural test measures the force required to bend a beam under single point loading conditions. The test was conducted to compare the flexural strength between the beam sizes 150 x 150 x 750mm casted with difference aggregate sizes. The test was conducted on 5 different difference coarse aggregate sizes, and the final results are as presented in Table 3 and Figure 7.

Table 3: Flexural Strength Result after 28 Days of Curing

Aggregate Size (mm)	Weight after curing (kg)	Deflection (mm)	Distance of failure point from Left Support (mm)	Crushing Load (kN)	Average Flexural Strength (N/mm^2)
9.00	39.60	1.50	203.00	30.00	
9.00	39.80	2.00	193.00	30.50	4.93
13.20	40.40	2.10	141.00	29.00	
13.20	40.30	1.70	166.00	29.00	
13.20	39.40	1.80	195.00	30.00	4.78
19.00	40.00	1.50	165.00	30.50	
19.00	40.10	1.20	196.00	28.00	
19.00	40.20	1.75	253.00	25.00	4.53
25.00	41.00	1.50	147.00	30.00	
25.00	41.40	1.30	185.00	26.00	
25.00	39.60	1.00	200.00	27.00	4.49
37.50	41.20	1.15	233.50	30.00	
37.50	39.80	1.55	135.00	23.00	
37.50	40.50	1.40	162.00	28.00	4.40

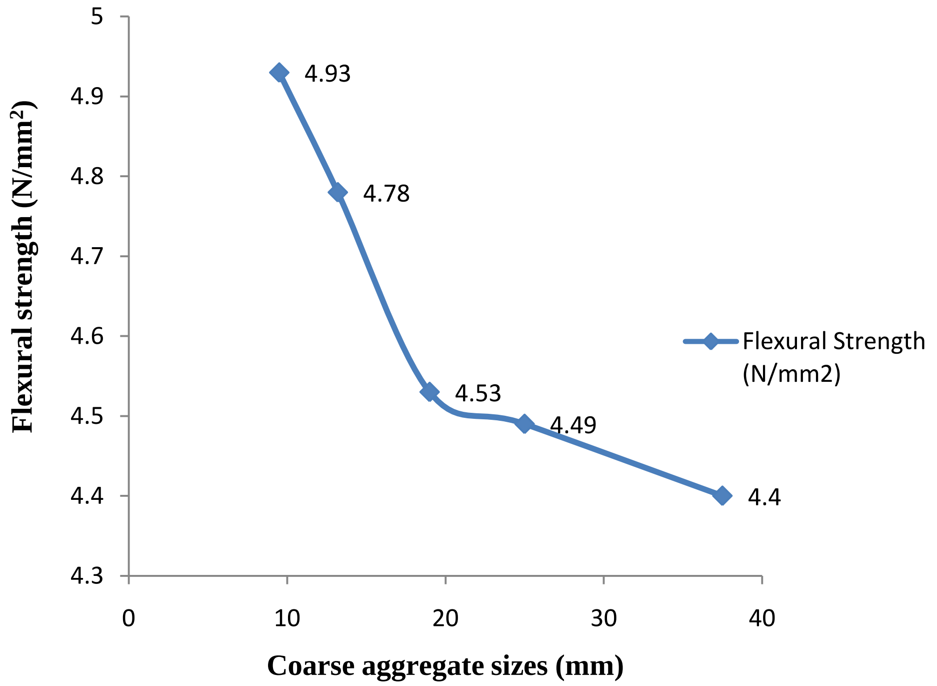
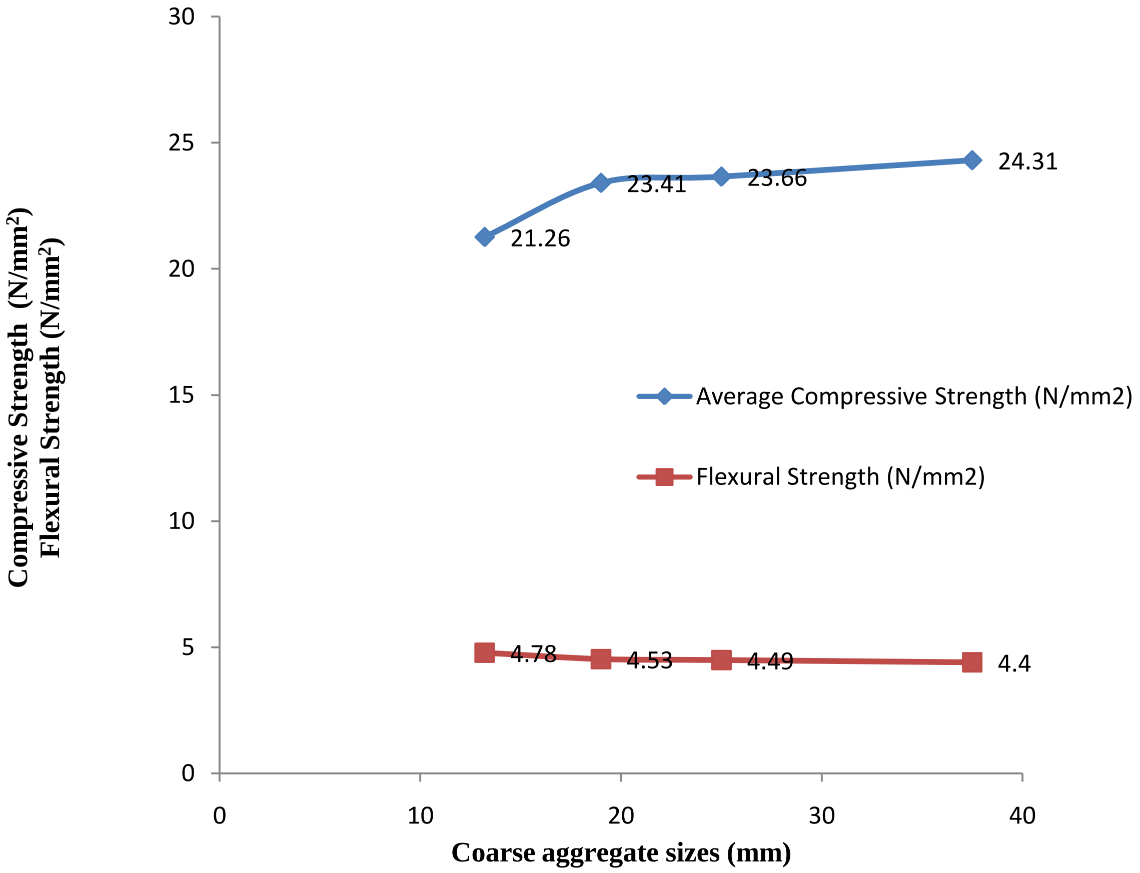


Figure 7: Variation of flexural strength with coarse aggregate sizes

Table 4 and Figure 7 show the summary of results of the compressive and flexural strength tests carried out

Table 4: Compressive Strength and Average Flexural Strength Test Results

Coarse aggregate Sizes (mm)	Average Compressive Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
13.2	21.26	4.78
19.0	23.41	4.53
25.0	23.66	4.49
37.5	24.31	4.40



It is found that with increase in coarse aggregate size the flexural strength and compressive strength of concrete of the same mix is inversely proportional.

IV. Conclusions and Recommendations

The effect of coarse aggregate size on the compressive and the flexural strength of concrete beam were explored in this research. The following are the conclusions and recommendations.

4.1 Conclusions

The following conclusions are drawn from the output of this research and can be summarized as follows:

(1) Coarse aggregate size is directly proportional to the slump (workability) of a fresh concrete with constant water cement ratio.
(2) Compressive strength of a concrete increases with increase in coarse aggregate size. Coarse aggregate size 13.2 mm, 19 mm, 25 mm, and 37.5 mm gave average compressive strength of 21.26 N/mm^2, 23.41 N/mm^2, 23.66 N/mm^2 and 24.31N/mm^2 respectively.
(3) Flexural strength of concrete beam is inversely affected by the increase in coarse aggregate size
(4) Compressive strength of concrete is inversely proportional to flexural strength as coarse aggregate size increases when subjected to the same condition(s)

4.2 Recommendations

The following recommendations are made:
For a reinforced concrete beam, 19 mm and 25 mm coarse aggregate size could be adopted as they give appreciable flexural strength and compressive strength and it also appropriate for minimum bar spacing in beam.

(1) 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 result in flexural crack. Thus concrete mix should be well compacted.
(2) Concrete to be used mostly to resist flexural stresses should be made of finer coarse aggregates.

References

[1] Abdullahi, M. (2012): “*Effect of aggregates type on compressive strength of concrete*” International Journal of Civil Engineering and Structural Engineering, 2(3), pp.791

[2] ACI Committee (1998): “*Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete*”. American Concrete Institute Materials Journal, 95, (3), pp. 252.

[3] Aluko, O.S. (2005): "*Comparative Assessment of Concrete Curing Methods*," Unpublished Post Graduate Diploma Thesis, Federal University of Technology, Akure, Nigeria.

[4] BS 1881-102 (1983): "*Testing Concrete-Method for determination of slump*", British Standard Institution, London.

[5] BS 812-103 (1985): "*Method for determining sieve analysis*", British Standards Institution, London.

[6] BS 1881-108 (1983): "*Method for making test cubes from fresh concrete*", British Standards Institution, London.

[7] BS1881-116 (1983): "*Method for determining compressive strength*", British Standards Institution, London.

[8] BS 1881-118 (1983): "*Method for determining flexural strength*", British Standards Institution, London.

[9] Elayesh, S. M. (2009) "*Performance of laterite aggregate concrete*". Un-published, M. Eng. Thesis University Technology, Malaysia.

[10] Hudson, B. (1999): "*Modification to the Fine Aggregate Angularity Test*". Seventh Annual International Center for Aggregates Research Symposium, Austin, Texas.

[11] Joseph, O., Ukpata and Maurice, E. (2012): "*Flexural and Tensile Strength Properties of Concrete using Lateritic Sand and Quarry Dust as Fine Aggregate*". ARPN Journal of Engineering and Applied Sciences, 7(3).

[12] MacGinley, T. J. and Choo, B. S. (2003): "*Reinforced Concrete Design Theory and Examples*" (Second Edition). New York: Taylor & Francis Group.

[13] Mosley, W. H. and Bungey, J. H. (2006): "*Reinforced Concrete Design (Revised Edition)".* London: Macmillan Education Ltd.

[14] Mtallib, M.O.A. and Marke, A.I. (2010): "*Comparative evaluation of the flexural strength of concrete and colcrete*". Nigerian Journal of Technology, 29(1), 13-22.

[15] Oyenuga, V. O. (2005): "*Simplified Reinforced Concrete Design (Second Edition)*". Nigeria: ASROS Ltd.

[16] Pedro, N. Q. and Fowler W. F. (2003): "*The Effects of Aggregates Characteristics on the Performance of Portland Cement Concrete*". International Center for Aggregates research, 104-F.

[17] Waziri, B.S., Bukar, A.G and Gaji, Y.Z.A. (2011): "*Applicability of Quarry Sand as a Fine Aggregate in the Production of Medium Grade Concrete*". Continental J. Engineering Science, 6(2), 1-6.

[18] Webster L. F. (1997): "*The Wiley Dictionary of Civil Engineering and Construction (Revised Edition)".* New York: John Wiley and Sons, Inc.

[19] Wu, K-R., Chen, B., Yao, W., and Zhang, D., (1997): "*Effect of Coarse Aggregate Type on Mechanical Properties of High-Performance Concrete*". Cement and Concrete Research, 31(10), 1421-1425.

[20] Zhang, P., Li, Q. and Wei, H. (2010): "*Investigation of flexural properties of cement-stabilized macadam reinforced with polypropylene fiber*". Journal of Materials in Civil Engineering.American Society of Civil Engineers (ASCE).