# EFFECT OF MAXIMUM PARTICLE SIZE OF COARSE AGGREGATES ON THE COMPRESSIVE STRENGTH OF NORMAL CONCRETE

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***ABSTRACT:*** *This research work presents the investigation on the effect of maximum size of aggregates on the compressive strength of concrete. Nominal mix ratios of 1:$1\frac{1}{2}$:3, 1:2:4 and 1:3:6 were prepared using two different water/cement ratios, that is 0.5 and 0.6. Five different sizes of coarse aggregates, that is, 5mm, 12mm, 20mm, 25mm, and 38mm were used. The concrete cubes cast were cured for the period of 14 and 28 days before testing for compressive strength. The research revealed that water absorption of the coarse aggregates increases with the decrease in aggregate size, consequently, the water demand in the concrete mix. It was also found that of the coarse aggregates, size 20mm produced concrete with highest compressive strength in all the mixes irrespective of water/cement ratio and curing age. Concrete's compressive strength increases with increase in curing age and with richer mixes. Based on the findings of the research, it was concluded that 20mm aggregate is the most suitable for the production of normal strength concrete.*

Key words: Coarse Aggregate Size, Compressive Strength Mix Ratio water/cement ratio
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## INTRODUCTION

Concrete is the most widely used construction material worldwide. It is the most commonly used structural materials alongside steel (Neville, 1981). The understanding of the properties of concrete makes possible the selection of a more suitable economic mix, bearing in mind that the strength of the concrete is one of the vital properties of the concrete to be considered (Aginam, Chidolue, & Nwakire, 2013). Concrete constitutes of coarse aggregates, fine aggregates, and cement as a binder mixed thoroughly with water. Sometimes it includes admixtures and/or pozzolanas to influence certain properties of the concrete. Cement is the most expensive amongst the constituents and in most cases it is responsible for cracking, creep and shrinkage in concrete. Therefore, by reducing the cement content in the concrete as much as possible while concurrently improving its engineering properties will produce a more cost-effective mix (Nilson, Darwin, & Dolan, 2004). Aggregates play a vital role in filling as much volume of concrete as possible while maintaining or improving the engineering properties of concrete. Particles with diameters greater than 3/16 in. or 5 mm (retained on the No. 4 sieve) are usually categorized as coarse aggregate, while smaller particles are called fine aggregate (McNally, 1998). Coarse aggregates may be artificial or natural; the artificial coarse aggregates are normally crushed in a quarry or manually to a suitable size while the natural one can be a by-product of natural weathering of rocks. For the natural coarse aggregates, the sizes might be assorted and the shape may be rough or smooth depending on the nature of weathering, transportation and deposition it undergoes. Fine aggregates may be river sand found by the river bank or dredged from the river bed. Aggregates are important constituents in making concrete. They give body to the concrete, reduce shrinkage and may affect economy. Aggregates may be chemically inert materials, which account for 60 to 80 per cent by volume and 70 to 85 per cent by weight of concrete (Aginam, Chidolue, & Nwakire, 2013) and about 25 to 45% of the total aggregates in the concrete are fine aggregates (Ioannides & Mills, 2006). Smaller sizes of aggregates have more surface area and require more cement paste to bind them together and in turn require more water for the mix. Consequently, increase in water/cement ratio leads to decrease in compressive strength of the concrete because more water than what is required for hydration would produce some pore spaces in the concrete after drying, that is, makes it less compact. However, the smaller size aggregates give a stronger aggregate interface bonding which leads to strong concrete in terms of compressive strength. While the larger aggregate sizes have a smaller surface area and in turn require little quantity of cement paste for binding the aggregates. Consequently, it needs lower water/cement ratio, which leads to higher compressive strength of the concrete. However, interface bonding of larger aggregates is weaker than that of smaller aggregates. Moreover, in the reinforced concrete structures, where congestion of reinforcement is encountered, the larger sizes of aggregates do clog the passage of other coarse aggregates and thereby causing segregation of the coarse aggregates from the cement paste. That is, if no or little compaction of the concrete is applied, voids might form, while over compaction might lead to separation of coarse aggregates from the cement paste.

When deciding on the strength of normal concrete, mostly aggregates are several times stronger than the other constituents and therefore not a factor in the strength of normal strength concrete. Lightweight aggregate concrete may be more affected by the compressive strength of the aggregates (Neville, 1981). However, for the high strength concrete, the strength of the aggregates is of utmost importance as it may be weaker than the concrete's targeted strength and thereby fail well below the targeted compressive strength of the concrete when subjected to expected compressive stress. Aginam, Chidolue, and Nwakire, (2013) asserted that, when stress is applied to a mass concrete, failure may initiate within the aggregates, the matrix, or at the aggregate-matrix interface. The aggregate-matrix interface is an important factor in determining the strength of concrete. Stanton and Bloem, (1960) discovered that there was always a decrease in concrete strength as the maximum size of aggregate increased at the same water/cement ratio. They further revealed that presence of foreign materials such as clay, silt, crush dust and all forms of over coating were all tagged as materials that deter the development of aggregate-cement bonds; as a result, the strength of concrete reduces. Any form of coating on the surface of aggregates that may reduce cement paste-aggregate binding should be avoided. Aginam, Chidolue, & Nwakire, (2013) have pointed out that, as the compressive strength of concrete increases, its other properties such as, durability, flexural strength and the like usually improve. Tests for compressive strength are easily performed; concrete compressive strength is commonly used in the construction industry for the purpose of specification and quality control. They further asserted that, the Engineer knows his targeted flexural strength and expresses it in terms of compressive strength. There are many factors that affect the compressive strength of concrete; the nature of aggregates (fine and coarse), cement type and content, curing methods and duration, water/cement ratio and the like. The coarse aggregates which constitute about 60 – 70% of the constituents of the concrete, need to be seriously taken into consideration as it certainly play a vital role in the strength improvement of the concrete. It is not uncommon in Nigeria that strong arguments will be holding between a contractor and a consultant/client on the influence of the size of aggregates on the compressive strength of concrete. The consultant might be clamouring for the aggregates of certain size while the contractor would like to go for the cheapest, irrespective of the implication on the strength of the concrete. Without strict supervision, the contractor would not like to go for the size specified in the technical specification if it is more expensive than the other sizes. He/she may likely choose the one that will earn him more profit. This piece of work tries to address the issue of the influence of the size of coarse aggregates on the strength of concrete. Therefore, the research looks into the effect of maximum particle size of coarse aggregates on the compressive strength of concrete.

## MATERIALS AND METHODS

Ashaka brand of Ordinary Portland cement was used for the work. The fine aggregates used are the locally available river sand from Damaturu Local government area of Yobe state. The coarse aggregates used are the crushed stones of sizes: 5mm, 12mm, 20mm, 25mm and 38mm. The gravel samples were washed to remove any clay, dust and other deleterious substances on the surfaces of the coarse aggregates as pointed out by Stanton & Bloem, (1960). The coarse aggregates (gravels) of different sizes were prepared by using sieve aperture, that is, by separation of one size from others. Absorption test was carried out for each of the separated sizes. All the materials used were tested for specific gravity. The procedure adopted for casting of the test specimens is in accordance with BS 1881 (1983).The batching of the concrete was by weight and the mix ratios of $1:1\frac{1}{2}:3$, 1:2:4 and, 1:3:6 were adopted for the work. The water/cement ratio of 0.5 and 0.6 were used for the research. For each mix ratio sixty (60) cubes were cast; thirty (30) for each of the water/cement ratio. A total of 180 cubes were cast altogether. Three cubes for each of the mix ratio and water/cement ratio were cured for 14 and 28 days before crushing. An automatic concrete compressive testing was used for the compressive strength of various cubes after the stipulated maturity age of curing at the Civil Engineering Laboratory from the Federal Polytechnic Damaturu. The cubes were weighed before crushing using digital weighing balance.

## RESULTS AND DISCUSSION

Table 1 shows the result of water absorption of the coarse aggregates of different sizes used. The water absorption of the aggregates reduces as the size of the aggregates increases. This entails that in order to achieve the same water/cement ratio for the concrete produced using these aggregates, the smaller the aggregate size, the higher the quantity of water required and the larger the aggregate size, the lower the quantity of water required.

Table 1: Water Absorption for the Coarse Aggregates of Different Sizes

| S/No. | ID No. | Aggregate Sizes (mm) | Water Absorption (%) |
|---|---|---|---|
| 1 | P1 | 5 | 2 |
| 2 | P2 | 12 | 1.8 |
| 3 | P3 | 20 | 1.3 |
| 4 | P4 | 25 | 0.7 |
| 5 | P5 | 38 | 0.5 |

Figures 1 through 4 show the graphs of average compressive strength against the aggregate sizes. In all the results and the maximum compressive strength was found to be in the concrete cast with 20mm aggregates as the coarse aggregates while the strength reduces with the increment or reduction in aggregate size. For the water/cement ratio of 0.5 and a mix ratio of $1{:}1\frac{1}{2}{:}3$, with curing ages of 14 and 28 days, aggregate size 20mm was found to have the highest compressive strength. The difference in strength between aggregate size 20mm and 12mm at 14 days curing age is 3.26 $N/mm^2$ which is representing about 17% increment in strength. However, at the curing age of 28 days, the difference is about 1.24 $N/mm^2$. This implies that gain in strength for the 20mm aggregates initially was more rapid compared to 12mm aggregates. It was observed that apart from size 20mm aggregate, for a mix ratio of $1{:}1\frac{1}{2}{:}3$, the smallest size of coarse aggregate gave a stronger concrete. This might be due to the fact that, the cement paste has started becoming sufficient for the relatively larger surface area of the aggregates. A similar result was found by Yaqub & Bukhari, (2006) when they compared the strengths of high performance concrete using five different sizes of aggregates, they found that the combination with smallest aggregate sizes yielded the strongest concrete.

Likewise, all other combinations of water/cement ratios and mix ratios, aggregate size 20mm showed a better result in terms of compressive strength of the concrete. This might well be explained that, in the smaller sized aggregates, the cement paste was not strong enough to resist the stress applied on it, so the concrete failed as a result of insufficient paste to produce a good bonding. However, in the larger aggregates, even though the cement paste might be adequate to coat the aggregates and produce a stronger bonds but the interface bonding of the larger aggregates is weaker. This might be due to the fact that the sizes of the aggregates might be heavier and producing some sort of segregations in the concrete. However, it might create a large proportion of voids that could not be properly filled by the cement paste without using smaller coarse aggregates to fill in the gaps, as asserted by Ioannides & Mills, (2006).So the optimum size of aggregates to be used for aggregates of normal strength concrete might be size 20mm.

However, it was observed from the results obtained that the compressive strengths of the concrete increases with increase in curing age, this is in accordance with finding of many researchers such as James, Malachi, Gadzama, & Anametemfiok, (2011); Joseph, Maurice, & Godwin, (2012) & Aginam, Chidolue, & Nwakire, (2013).

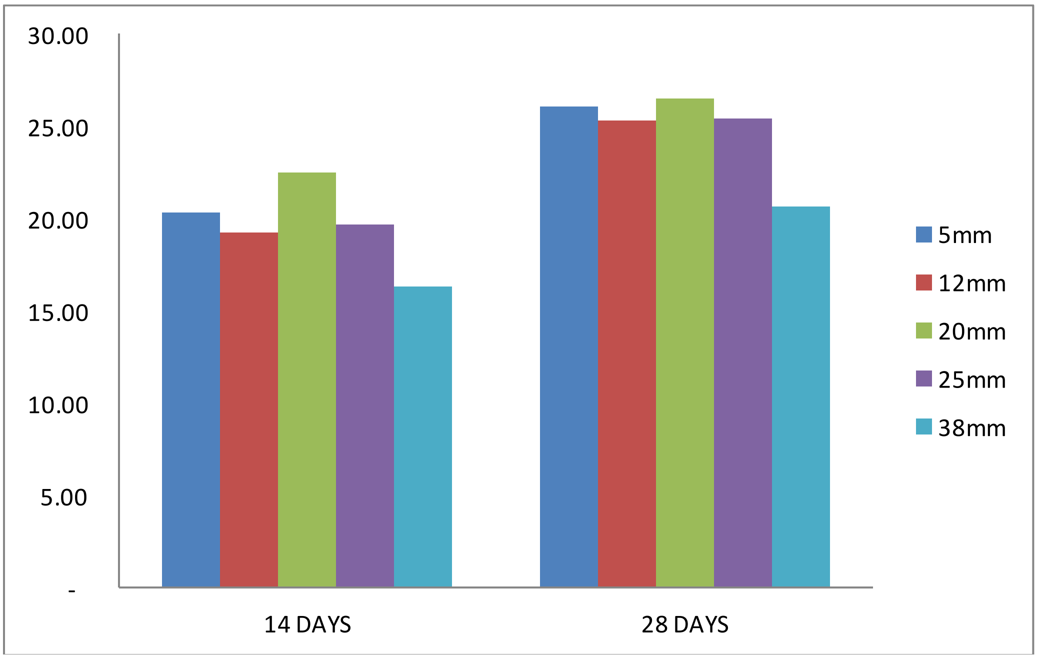


**Figure 1: Cubes Compressive Strengths for Different Aggregate Sizes with Mix Ratio of $1:1\frac{1}{2}:3$ and Water/Cement Ratio of 0.5**

**Table 2: Concrete Cubes for Different Aggregate Sizes with Mix Ratio of $1:1\frac{1}{2}:3$ and Water/Cement Ratio of 0.5**

| Aggreg / Age | 14 Days | 28 Days |
| --- | --- | --- |

| | Average Compressive strength (N/mm$^2$) | |
|---|---|---|
| 5mm | 18.22 | 22.79 |
| 12mm | 19.21 | 25.31 |
| 20mm | 22.47 | 26.55 |
| 25mm | 19.71 | 25.42 |
| 38mm | 16.29 | 20.69 |

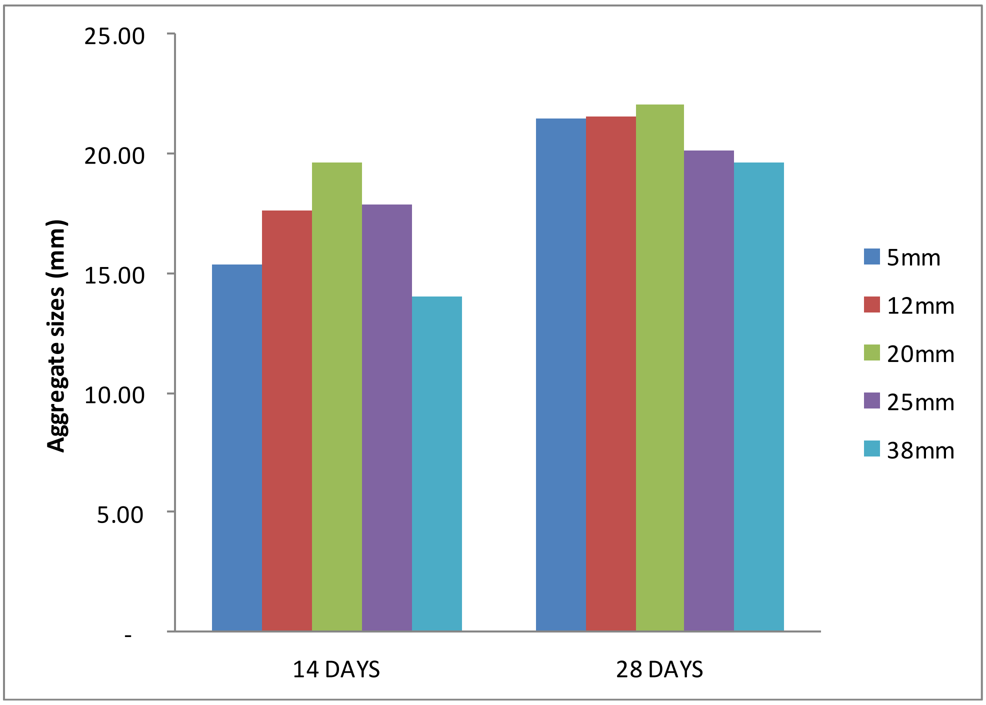


Figure 2: Cubes Compressive Strengths for Different Aggregate Sizes with Mix Ratio of 1:2:4 and Water/Cement Ratio of 0.5

Table 3: Concrete Cubes for Different Aggregate Sizes with Mix Ratio of 1:2:4 and Water/Cement Ratio of 0.5

| Aggregate size / Curing Age | 14 Days | 28 Days |
|---|---|---|

| | Average Compressive strength (N/mm$^2$) | |
|---|---|---|
| 5mm | 15.36 | 21.44 |
| 12mm | 17.60 | 21.56 |
| 20mm | 19.67 | 22.02 |
| 25mm | 17.87 | 20.16 |
| 38mm | 14.01 | 19.61 |

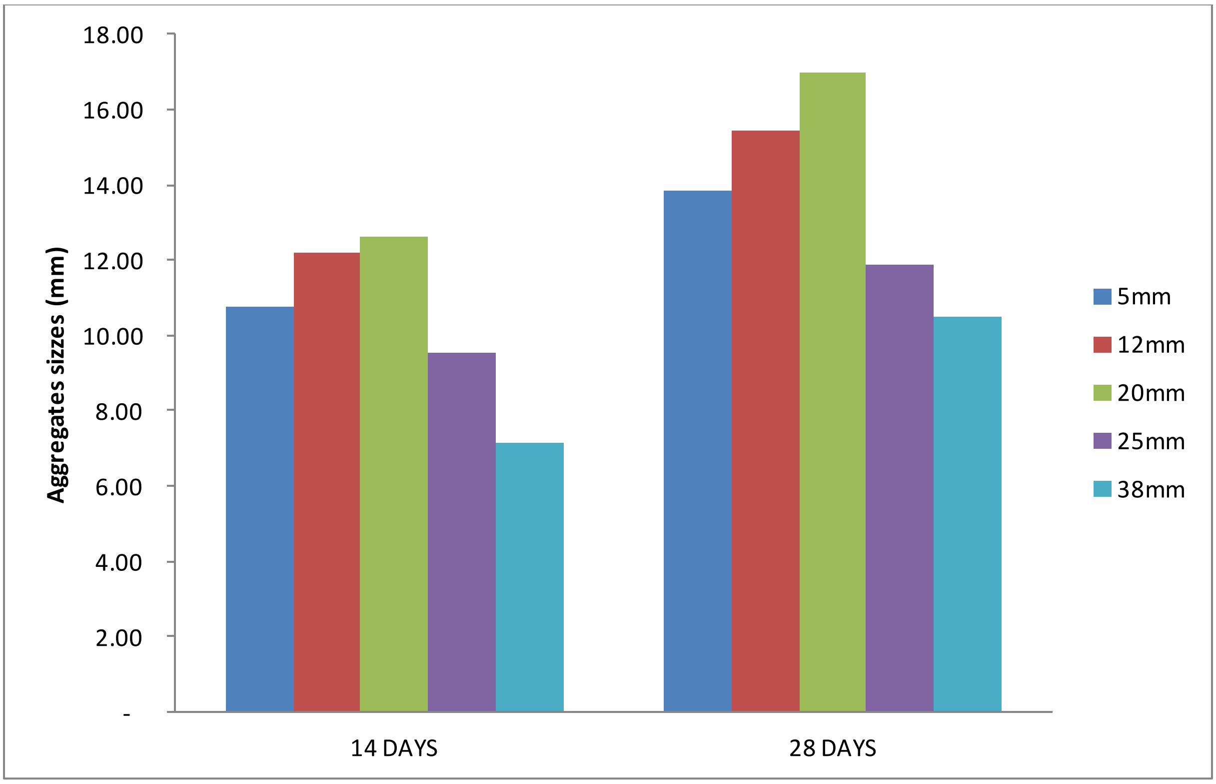


Figure 3: Cubes Compressive Strengths for Different Aggregate Sizes with Mix Ratio of 1:3:6 and Water/Cement Ratio of 0.5

Table 4: Concrete Cubes for Different Aggregate Sizes with Mix Ratio of 1:3:6 and Water/Cement Ratio of 0.5

| Aggreg ate size / Age | 14 Days | 28 Days |
|---|---|---|

| | Average Compressive strength (N/mm$^2$) | |
|---|---|---|
| 5mm | 10.77 | 13.85 |
| 12mm | 12.20 | 15.46 |
| 20mm | 12.63 | 17.00 |
| 25mm | 9.51 | 11.87 |
| 38mm | 7.15 | 10.49 |

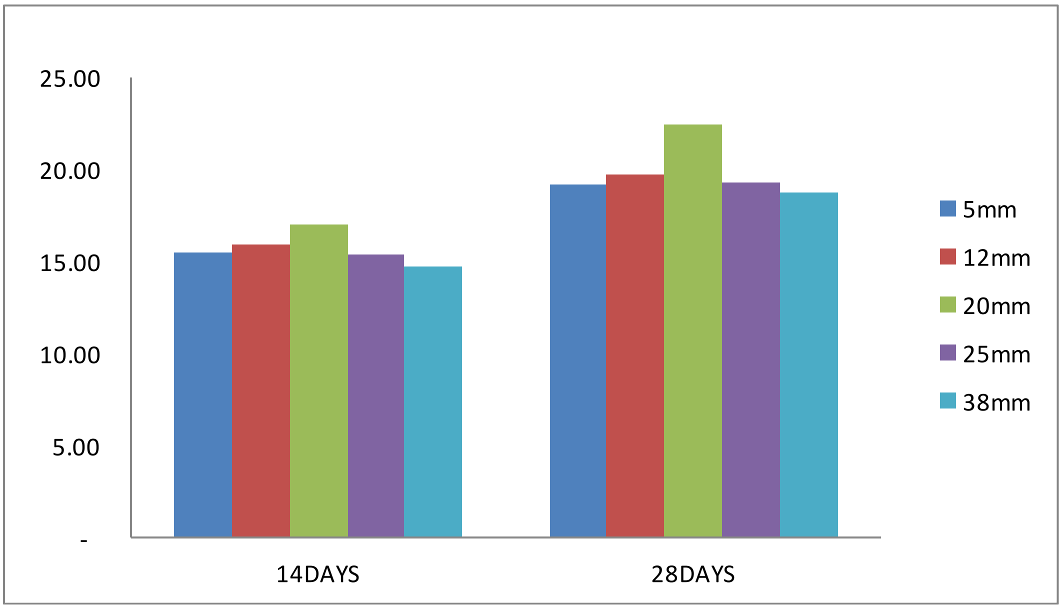


Figure 4: Cubes Compressive Strengths for Different Aggregate Sizes with Mix Ratio of $1{:}1\frac{1}{2}{:}3$ and Water/Cement Ratio of 0.6

Table 5: Concrete Cubes for Different Aggregate Sizes with Mix Ratio of 1:$1\frac{1}{2}$:3 and Water/Cement Ratio of 0.6

| Aggregate size \ Curing Age | 14 Days | 28 Days |
|---|---|---|
| | Average Compressive strength (N/mm$^2$) | |
| 5mm | 15.49 | 19.16 |
| 12mm | 15.88 | 19.70 |
| 20mm | 17.01 | 22.41 |
| 25mm | 15.36 | 19.20 |
| 38mm | 14.69 | 18.76 |

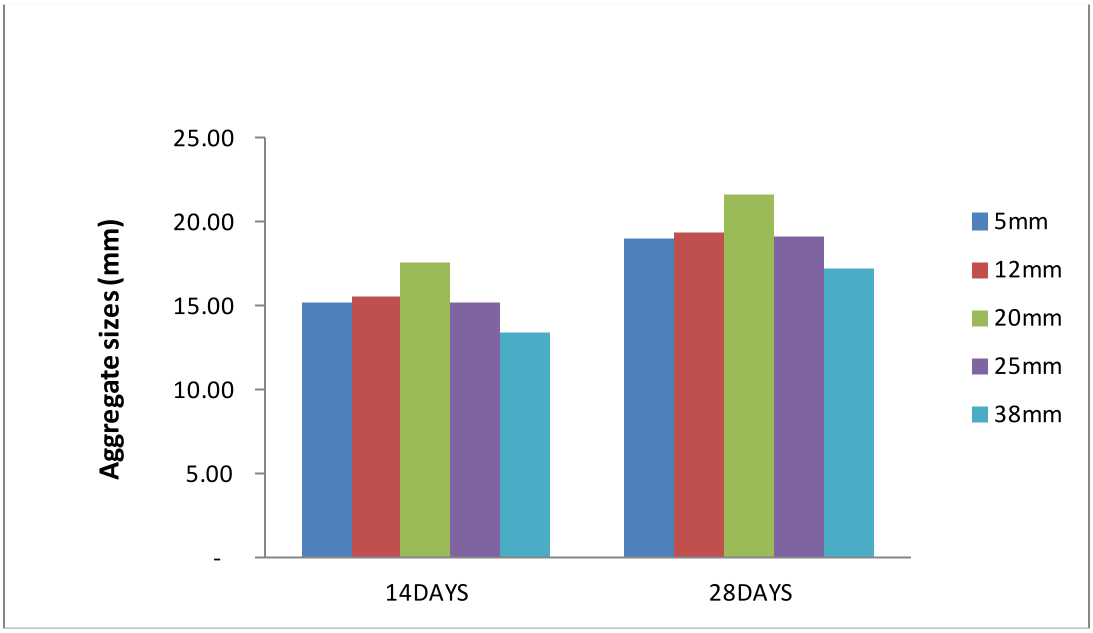


Figure 5: Cubes Compressive Strengths for Different Aggregate Sizes with Mix Ratio of 1:2:4 and Water/Cement Ratio of 0.6

Table 6: Concrete Cubes for Different Aggregate Sizes with Mix Ratio of 1:2:4 and Water/Cement Ratio of 0.6

| Aggregate size \ Curing Age | 14 Days | 28 Days |
|---|---|---|
| | Average Compressive strength (N/mm$^2$) | |
| 5mm | 15.17 | 19.05 |
| 12mm | 15.53 | 19.39 |
| 20mm | 17.58 | 21.61 |
| 25mm | 15.15 | 19.16 |
| 38mm | 13.43 | 17.21 |

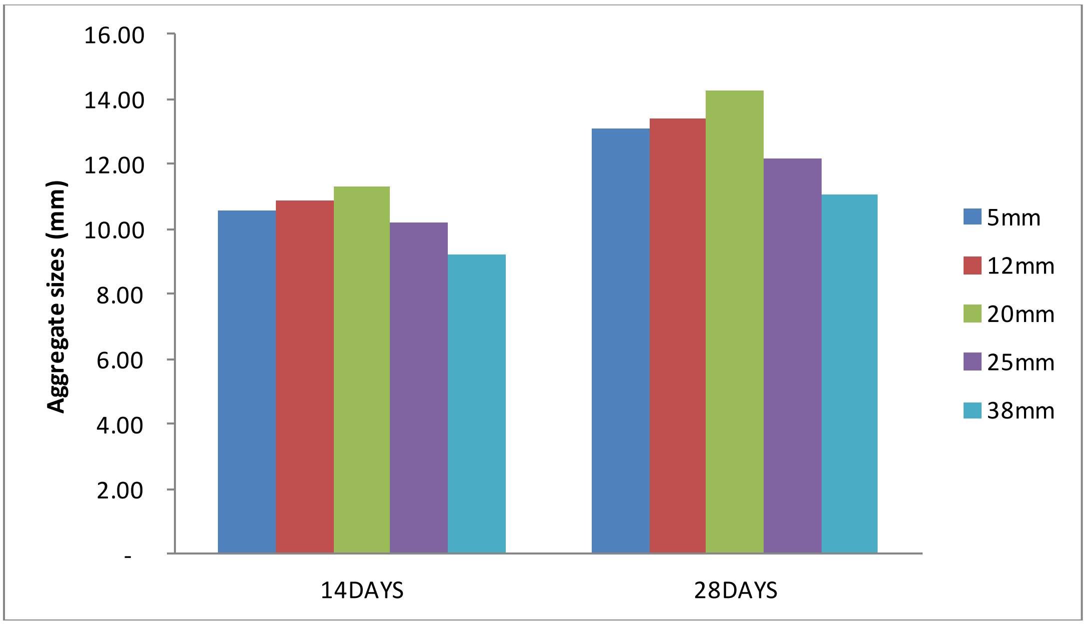


Figure 6: Cubes Compressive Strengths for Different Aggregate Sizes with Mix Ratio of 1:3:6 and Water/Cement Ratio of 0.6

**Table 7: Concrete Cubes for Different Aggregate Sizes with Mix Ratio of 1:3:6 and Water/Cement Ratio of 0.6**

| Aggregate size \ Curing Age | 14 Days | 28 Days |
|---|---|---|
| | Average Compressive strength (N/mm$^2$) | |
| **5mm** | 10.56 | 13.12 |
| **12mm** | 10.88 | 13.43 |
| **20mm** | 11.32 | 14.25 |
| **25mm** | 10.20 | 12.16 |
| **38mm** | 9.22 | 11.05 |

## CONCLUSION

Based on the results of this research work, the following conclusions could be drawn:

- Water/cement ratio has a vital role to play one the compressive strength of concrete
- The optimum size of aggregate suitable for the normal strength concrete might be size 20mm
- The strength of concrete increases with the richer mix in cement content
- The strength of smaller aggregates improves as the mix ratio of the concrete gets richer in cement content.

## REFERENCES

Aginam, C. H., Chidolue, C. A., & Nwakire, C. (2013, Jul. - Aug). Investigating the Effects of Coarse Aggregate Types on the Compressive Strength of Concrete. *International Journal of Engineering Research and Applications (IJERA), 3*(4), 1140 - 1144.

Ioannides, A. M., & Mills, J. C. (2006). *Effect of Larger Sized Coarse Aggregates on Mechanical Properties of Portland Cement Pavements and Structures.* Columbus, Ohio: Ohio Department of Transportation Research and Development.

James, T., Malachi, A., Gadzama, E. W., & Anametemfiok, V. (2011). Effects of Curing Methods on the Compressive Strength of Concrete. *Nigerian Journal of Technology, 30*(3), 14 - 20.

Joseph, O. U., Maurice, E. E., & Godwin, A. A. (2012). Compressive Strength of

Concrete Using Lateritic Sand and Quarry Dust as Fine Aggregate. *ARPN Journal of Engineering and Applied Sciences, 7*(1).

McNally, G. H. (1998). *Soil and Rock Cnstruction Materials* (1st ed.). New York: Routledge.

Neville, A. M. (1981). *Concrete Technology* (3rd ed.). London, UK: Longman Group Ltd.

Nilson, A. H., Darwin, D., & Dolan, C. W. (2004). *Design of Concrete Structures.* New York: McGraw-Hill.

Stanton, W., & Bloem, D. L. (1960). Effects of Aggregate Size on Properties of Concrete. *Journal of American Concrete Institute, 57,* 203 - 290.

Yaqub, M., & Bukhari, I. (2006). Effect of Size of Coarse Aggregates on Compressive Strength of High Strength Concrete. *31st Conference on Our World in Concrete & Structures.* Singapore: CI - Premier PTE Ltd.

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