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EXPERIMENTAL INVESTIGATION ON THE COMPRESSIVE STRENGTH OF CONCRETE WITH DIFFERENT SIZES OF COARSE AGGREGATE

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ABSTRACT

The grading of aggregates is an important factor in the preparation of concrete and its compression strength. This experimental investigation was conducted to find the impact of different aggregate sizes on the compressive strength of the concrete. The aggregates used in this experiment was 8 mm and 11.2 mm size. The concrete of M 25 grade and the water-cement ratio of 0.4 was used for this experiment. Tests were done on the concrete making materials, on the fresh concrete and hardened concrete. The fresh batches of concrete prepared from each of the coarse aggregate sizes were collected, and the slump test for the collected batches was conducted to determine the workability. In total, 24 concrete cubes of size 150 mm × 150 mm were cast and cured for 28 days. The cubes, after 28 days of curing, were tested in compression testing machine to determine the compression strength of the concrete. The results showed that the workability of the concrete was directly proportional to the aggregate size. And also, the compressive strength increased with an increase in aggregate sizes.

Key words: Compressive strength, slump test, water – cement ratio, workability

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1. INTRODUCTION

The compressive strength of the concrete, along with other factors, is dependent on the coarse aggregate. Over the past years, this subject is under study, a common knowledge of the effects of the behaviour of aggregate has gained importance because of the necessity of the High strength concrete. In high strength concrete, the coarse aggregate plays a vital role in increasing the strength of the concrete. In the normal strength concrete, the failure because of compression is due to debonding of the cement paste from the aggregates. In contrary, in high-strength concrete, the aggregate particles, as well as the aggregate interface, go through failure, undoubtedly affecting its overall strength. As the strength of the cement paste component in the concrete improves, there is more excellent compatibility of the stiffness and the strength between the normally harder, stronger coarse aggregate and the mortar surrounding it. Thus, microcracks tend to propagate through the aggregate particles since, not only is the matrix -aggregate bond more solid than in concretes of lower strength, but the stresses due to a mismatch in elastic properties are decreased. Thus, aggregate strength becomes an essential factor in high-strength concrete. This investigation describes the work that is intended to improve the understanding of the role of aggregates in concrete.

2. RELATED WORKS

Abdullahi, M. [1] has done an experimental investigation on the concrete with crushed quartzite, granite, and river gravel aggregates of size 12mm. The normal mix (1:2:4) was taken for this experiment, and by absolute volume method, the mix compositions were calculated. For each type of the coarse aggregate, 75 cubes (150mm × 150mm × 150mm) were cast and was cured for 3, 7, 14, 21, and 28 days, before conducting the test for determining the compressive strength. The results showed that the concrete with river gravel has the highest workability, followed by the crushed quartzite and crushed granite aggregates. Similarly, for the compressive strength, the concrete with quartzite has the highest followed by the river gravel and granite aggregates.

Table 1 Results of Compressive strength of aggregates

Types of aggregates	Compressive strength
Quartzite	High
Gravel	Medium
Granite	Low

Jimoh, A.A. and Awe, S.S. [2] found the effect of the aggregate type and its size on the compressive strength of concrete. The sample with a mix proportion of 1:2:4 was cast with sand, quarry dust, granite, and gravel of size 20 and 28 mm as coarse aggregates. The results demonstrated that the concrete prepared with quarry dust and 20 mm granite has more compressive strength. It was concluded that an increase in the size of coarse aggregate would lead to a decrease in compressive strength.

Nallathambi, P., Karihaloo, B. L. and Heaton, B. S. [3] performed a series of experiments to study the impact of dimension of the specimen, depth of the notch, size of the aggregate (10 mm, 15 mm, 20 mm) and w/c ratio on the facture behaviour of the concrete on the mortar and concrete beams of normal strength. They concluded that with 23% reduction in w/c ratio the fracture toughness increases to about 38% similar to that of compressive strength and elastic modulus. And also found that the increase in the maximum size of coarse aggregate increased the fracture toughness of the concrete. Further, it was observed that the energy is required during the process of crack distribution for microcracking and debonding of matrix – aggregate. And with the increase in the size of the aggregate, the crack area increases resulting in an increasing amount of consumption of energy requirement for the development of the crack.

Bloem, D. L. and Gaynor, R. D. [4] examined the effects of the size and other properties of the coarse aggregate on the requirement of water and strength of the concrete. Their investigation revealed that with the increase in the maximum size of aggregate the total surface area of the aggregate gets reduced, hence reducing the requirement of water for mixing. But, unlike other researchers they found that even with reduction in water the concrete prepared with larger size aggregate has less compressive strengths compared to concrete prepared with smaller sized aggregates. Normally, the concrete of lower strengths, the decrease in the quantity of water is enough to balance the detrimental effects of the size of the aggregate. Yet, in concrete of high strengths, the effect of size of aggregates governs, and the smaller size aggregates gives higher strengths.

Walker, S. and Bloem, D. L. [5] prepared normal strength concrete and examined the effects of the coarse aggregates on its properties. They found that with an increase in the aggregate size from 10 mm to 64 mm showed a decrease in the compressive strength of the concrete to an extent of 10%, but aggregate sizes did not have big effect on the flexural strength of concrete. Their study also showed that the concrete of compressive strengths between 35 MPa and 46 MPa, had flexural strength to compressive strength ratio at approximately 12%.

Kaplan, M. F. [6] prepared high strength and normal strength concrete with thirteen coarse aggregates and studied the effects on its flexural and compressive strength. He found that at all ages of curing, the compressive strength of concrete prepared with basalt mix was high compared to the limestone mix but could not ascertain the difference in higher strength concrete. There was a 9 to 12% flexural to compressive strength ratios for concrete prepared with basalt and limestone aggregates. He also observed that concrete with 91-day strengths, contrary to most results, that concrete with compressive strengths greater than 69 MPa was generally greater than mortar of the same mix proportions which indicates that at very high strengths, the presence of coarse aggregate contributed to the ultimate compressive strength of concrete.

Pradeep Kumar, D. and Eswaramoorthi, P. [7] conducted a number of experiments with M30 grade of concrete and found that the coarse aggregate with size 20 mm demonstrated a compressive strength of 37.25 MPa.

3. MATERIALS AND METHODS

3.1. Materials

The following the materials are used in the research.

3.1.1. Cement

The cement is a pulverised material and when mixed with water will react and develop binding forces. These finely ground powders have the valuable property that when mixed water starts the chemical reaction (hydration). The hydration produces a strong and healthy binding medium for the fine and coarse aggregates.

3.1.2. Aggregate

The aggregates occupy large volume of the concrete which will be at least three quarters. The aggregates used in the experiment are brought from the Bule Hora town. Necessary precautions and measures like removing impurities, tests for grading and specific gravity were taken before going for mix proportioning.

3.1.3. Mixing water

The tap water was used for preparing the concrete mix. It was well ensured that it doesn't contain solid waste in it [8].

3.2. Methods

The following methods were used to find the properties of materials used in the concrete:

3.2.1. Tests on Materials

3.2.1.1. Sieve analysis

The sieve analysis which is well known as the gradation test is used to determine the gradation (i.e. the distribution of the aggregate by size within a given sample). This gradation is used to calculate the relationship between different aggregates or aggregate mixes, to know compliance with those mix, and to predict trends during production by plotting gradation curves graphically, to name just a few uses.

3.2.1.2. Specific gravity and water absorption

For the design of the concrete mix, information about the specific gravity and water absorption of the coarse aggregates are required. The specific gravity of aggregate provides valuable information on its quality and properties. When the specific gravity is above or below the value normally assigned to a particular type of aggregate; it may indicate that shape and grading of aggregate has altered. It is also important in the determination of moisture contact and in many concrete mix design calculations. It is also required for the calculation of volume yield of concrete.

3.2.1.3. Setting time of cement

When the water is added to the cement, its hydration starts leading to the formation of the cement paste. Due the nature of plasticity, the cement paste can be moulded to any shape. During this period, the cement continuously reacts with water and slowly starts losing its plasticity and gets hardened. This complete cycle is called setting time. The initial set is a phase where the cement paste starts to stiffen to such an extent that the Vicat needle will not be able to move down into the paste within 5 ± 0.5 mm measured from the bottom of the mould. To put in other words, it is the time the cement paste starts losing its plasticity. The time passed between the moment the water is added to the cement to the initial set is regarded as initial setting time of the cement. And, during this period any crack that may occur after the initial set may not reunite. Final setting time is a time when the cement paste becomes so hard that the annular attachment to the needle under the standard weight only makes an impression on the hardened cement paste.

4. EXPERIMENTAL INVESTIGATION

The fresh properties and mechanical properties of the concrete specimens prepared were tested.

4.1. Fresh properties

The properties of the fresh concrete were found using the slump cone and compaction factor tests to make sure that the workability meets the necessary requirements.

4.2. Mechanical properties

The mechanical properties of the hardened concrete were tested using compressive testing machine.

5. RESULTS AND DISCUSSIONS

5.1. Results

5.1.1. Fresh concrete properties

The slump of concrete prepared with coarse aggregate of 11.2 mm shows 13.5 cm while the slump of concrete prepared with aggregate of 8 mm showed 10 cm. The results showed that the concrete prepared with aggregate of 11.2 mm has workability and the concrete prepared with 8 mm coarse aggregate has medium workability.

The fresh concrete prepared with aggregate of size 11.2 mm when tested for compaction factor showed the value 0.93 while the concrete prepared with aggregate of size 8 mm showed 0.89. The results showed that the concrete prepared with 11.2 mm coarse aggregate has high workability and the concrete prepared with coarse aggregate of size 8 mm has medium workability.

Both the tests for the workability showed that the concrete prepared with 11.2 mm coarse aggregate has high workability and the concrete prepared with 8 mm coarse aggregate has medium workability.

5.1.2. Hardened concrete properties

The compressive strength of hardened concrete prepared with 8 mm and 11.2 mm coarse aggregate is tabulated below:

For aggregate size 11.2mm

(a) For 3 days strength:

Table 2 Compressive strength for aggregate size of 11.2mm for 3 days

Sl. No.	Mix Identity	Compressive Strength (MPa)
1	M1.1	3.03
2	M1.2	3.02
3	M1.3	3.04
Average		3.03

(b) For 7 days strength:

Table 3 Compressive strength for aggregate size of 11.2mm for 7 days

Sl. No.	Mix Identity	Compressive Strength (MPa)
1	M1.4	6.65
2	M1.5	6.33
3	M1.6	6.40
Average		6.46

(c) For 14 days strength

Table 4 Compressive strength for aggregate size of 11.2mm for 14 days

Sl. No.	Mix Identity	Compressive Strength (MPa)
1	M1.7	7.96
2	M1.8	7.80
3	M1.9	7.81
Average		7.86

(d) For 21 days of strength

Table 5 Compressive strength for aggregate size of 11.2mm for 21 days

Sl. No.	Mix Identity	Compressive Strength (MPa)
1	M1.10	8.96
2	M1.11	8.17
3	M1.12	8.04
Average		8.40

(e) For 28 days of strength

Table 6 Compressive strength for aggregate size of 11.2mm for 28 days

Sl. No.	Mix Identity	Compressive Strength (MPa)
1	M1.13	13.43
2	M1.14	13.21
3	M1.15	13.09
Average		13.24

For aggregate size 8mm

(a) For 3 days strength:

Table 7 Compressive strength for aggregate size of 8mm for 3 days

Sl. No.	Mix Identity	Compressive Strength (MPa)
1	M2.1	2.09
2	M2.2	2.14
3	M2.3	2.21
Average		2.15

(b) For 7 days strength:

Table 8 Compressive strength for aggregate of size 8mm for 7 days

Sl. No.	Mix Identity	Compressive Strength (MPa)
1	M2.4	3.42
2	M2.5	3.31
3	M2.6	3.36
Average		3.36

(c) For 14 days strength:

Table 9 Compressive strength for aggregate of size 8mm for 14 days

Sl. No.	Mix Identity	Compressive Strength (MPa)
1	M2.7	4.39
2	M2.8	4.35
3	M2.9	4.31
Average		4.35

(d) For 21 days of strength:

Table 10 Compressive strength for aggregate size of 8mm for 21 days

Sl. No.	Mix Identity	Compressive Strength (MPa)
1	M2.10	6.60
2	M2.11	5.80
3	M2.12	5.79
Average		6.06

(d) For 28 days of strength:

Table 11 Compressive strength for aggregate size of 8mm for 28 days

Sl. No.	Mix Identity	Compressive Strength (MPa)
1	M2.13	8.56
2	M2.14	8.44
3	M2.15	8.66
Average		8.52

5.2. Discussions

The results obtained from previous experiments were discussed and interpreted what their value indicates about their workability and strength.

5.2.1. Fresh Concrete Workability Results

a) Slump Cone Test

The results in Table 5.11 reflected that the workability (slump) for the 8 mm and 11.2 mm coarse aggregate sizes were 10cm and 13.5 cm, respectively. And it is worth noting that as the slump increases, so does the workability which is highly dependent on the water-cement ratio (w/c).

Table 12 Slump Cone Test Results

Aggregate size(mm)	Slump (cm)	Slump types
8mm	10	Shear slump
11.2mm	13.5	Shear slump

** w/c ratio was 0.4, and the mix ratio was 1:2:3.*

From the results, it is understood that the concrete workability (slump) was directly proportional to the size of the aggregate which means that both increased simultaneously. When all other factors (i.e., w/c ratio and mix proportion) were constant, an increase in the size of coarse aggregate increase its workability. The reason for this is attributed to the increase in aggregate size, leading to a smaller surface area to be wetted. However, there are other factors to be considered when using maximum aggregate sizes. Like, as the maximum aggregate size increases, the size and toughness of the mixers, and other equipment needed to prepare and place the concrete in the forms also increase.

b) Compaction Factor Test

In this experiment the compaction factor value increased from 0.89 to 0.93 for aggregate size of 8mm and 11.2mm respectively. It is very important to notice that as the value of compaction factor increase the workability also increase. The aggregate size is directly proportional to the workability of the concrete. Here method of compaction has a great effect on the ratio of compaction.

Table 13 Compaction factor test result

Aggregate size(mm)	Compaction factor	Workability
8mm	0.89	Medium
11.2mm	0.93	High

Results allows to conclude that aggregate size and workability of concrete by compaction factor method are directly proportional.

5.2.2. Hardened Concrete

a) Compressive Strength Results

The mean compressive strength results in Table 5.13 for hardened concrete after 28 days of curing reflected an increase in the compressive strength with the increasing size of aggregate. This increase ranged from 8.52 MPa for the 8 mm aggregate size to 13.24 MPa for the 11.2 mm aggregate size.

Table 14 Concrete compressive strength test results after 28 days of curing

Aggregate size (mm)	Compressive strength (MPa)
8mm	8.56
8mm	8.44
8mm	8.66
Mean	8.52
11.2mm	13.43
11.2mm	13.21
11.2mm	13.09
Mean	13.24

The mean compressive strengths for the 8 mm and 11.2 mm aggregate size varied and were found to be 8.52 MPa and 13.24 MPa, respectively. Considering that aggregates to be taken from one site, having uniform mineralogy, the reason for the difference in compressive strengths could be due to the differences in the wetted surface areas of the respective concrete batches. Obviously, the concrete prepared with small aggregates will have larger wetted area compared to the larger aggregates. During the curing phase, when the wetted area gets dried it will lead to the formation of microcracks. This microcracks will make the concrete prepared with small size aggregate to have lesser compressive strength compared to the concrete prepared with larger size aggregate.

Table 15 Aggregate size with corresponding compressive strength

Aggregate size	Compressive strength in (MPa)				
	3 days	7 days	14 days	21days	28 days
8mm	2.15	3.36	4.35	6.06	8.52
11.2mm	3.03	6.46	7.86	8.40	13.24

6. CONCLUSIONS

Given constant water to cement ratio (0.4) and mix (1:2:3), the change in the size of the coarse aggregate affected the workability (slump) of concrete. The workability (slump) was directly proportional to the size of the aggregate. It was found to increase from 10cm to 13.5cm for 8mm and 11.2mm aggregate, respectively. When the slump increased, the concrete became more workable. And the same goes to workability by compaction factor test that it increased as the aggregate size increased. The mean compressive strength of the concrete was calculated and found to increase with increasing size of the aggregate. The aggregate sizes 8mm and 11.2mm had mean compressive strengths of 8.52 N/mm^2 and 13.24 N/mm^2, respectively.

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