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An Experimental Investigation on Aggregate Gradation and W/C ratio on Strength and Cost Effectiveness of Concrete

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Abstract
The selection and mixing of the aggregates has a dominating influence on the quality and price of the concrete. The aim of aggregate selection and combination is to make concrete mix with lowest void content, which in turn will lead to the lower cement consumption, porosity and shrinkage, and thus the concrete with the higher performance and the lower price. In addition to gradation of aggregates, the water/ cement (W/C) ratio also plays a major role in determining the strength of concrete. This paper presents the results of an experimental investigation to evaluate the effect of aggregate gradation and W/C ratio on strength parameters and possible reduction in cost of the concrete. Gap graded and continuously graded aggregate has been used to prepare concrete with different W/C ratio to study the strength parameters. Intermediate graded aggregate was blended with gap-graded aggregate using an iterative process to obtain well-graded or continuously graded aggregate. The compressive strength and shrinkage specimens were prepared from the gap graded and well graded concrete, and tested in accordance with the ASTM test procedures. The study showed relatively high compressive strength and less shrinkage for specimens prepared from well graded concrete compared to the specimens prepared from gap-graded aggregate. Slump test and German drop test were conducted immediately upon mixing concrete and it was found that the slump and the number of drops of the concrete with well–graded aggregates is greater than that of gap graded aggregates – an indicator of workability of concrete. A well graded aggregate played a dominant role in concrete workability and influenced the minimum cement content needed in concrete and thus a reduction in price of the concrete mix. The study concluded that the use of dense graded aggregate in the preparation of concrete can reduce the cement requirement by approximately 17% in the mixture proportion, and hence a reduction in cost without compromising the strength of the concrete.

Keywords
Concrete, Aggregate Gradation, Water-cement Ratio (W/C), Compressive Strength, Workability, Shrinkage.

1. Introduction

The material characteristics of concrete constituents have large impact on the strength and cost of the concrete (Goltermann, Johansen & Palbol, 1997). The optimization of the concrete mixture involves the utilization of available resources to meet the engineering criteria, construction operations and economic needs. For the purpose of mix design aggregates are selected and combined based on certain grading .the

quality and price of the concrete is highly influenced by the selection and combination of the aggregates (Goltermann, Johansen & Palbol, 1997). The size and gradation of aggregate, water-cement (W/C) ratio and other parameters determine the strength, workability and durability of concrete. The early age cracking of concrete arises from the rapid, complex and time dependent volumetric deformations due to shrinkage, creep and thermal characteristics (Altoubat & Lange, 2001). During the initial hydration process, when strength is relatively low, the above-mentioned volumetric deformations cause tensile stresses in concrete. The crack generation initiates when the stress in concrete exceeds the strength. The stress at which the crack develops depends largely on the strength characteristics of the coarse aggregate and the mechanical bond between aggregate and cement paste (Neville, 1998). The grading or the size distribution of the aggregate is an important characteristic because it influences the paste requirement for workable concrete (Neville, 1998).

Generally a low W/C ratio results in increased compressive and flexural strengths, better bonding between the concrete and the reinforcing steel, reduced shrinkage cracking, low permeability and better resistance to wear and weather. On the other hand an increase in the cement content increases the concrete strength as well as the shrinkage, which increases the cracking tendency (Neville, 1998). The role of cement paste is to fill the voids between the aggregates, to give certain workability and to bind the aggregates together. A reduction in the cement paste could be possible through a reduction of the void volume between the aggregates. To achieve this, a better packing of the aggregate mix is required. Altering the aggregate grading in order to achieve the desired strength characteristics and workability of the concrete could vary the aggregate volume concentration in concrete mix. Aggregate grading that provides maximum density and maximum particle interlock is highly desirable for the concrete mixtures (Abdel-Jawad & Abdullah, 2002).

This study investigates the effect of aggregate gradation and W/C ratio on strength properties and cost effectiveness of concrete. This study investigates the advantage of dense graded aggregate over gap-graded aggregate with respect to the strength and workability of concrete with different W/C ratios.

2. Research Significance

Grading of coarse aggregates and the proportions used have an important effect on concrete. A well-graded aggregate will have a continuous distribution of particle sizes producing a minimum void content and will require a minimum amount of cement paste to fill the voids. This will result in most economical use of cement and will provide maximum strength with minimum volume change and drying shrinkage. A reduction in the cement paste and the concrete mix price will be possible through a reduction of the void between the aggregates. To achieve this, a better packing of the aggregate mix is required. The effect of W/C ratio will also affect the rate of gain of strength of concrete. Also dense graded mixes with low W/C ratio will gain strength more rapidly than mixes with higher W/C. Therefore it is important to analyze:

- The advantage of dense graded aggregate over gap-graded aggregate relative to the strength.
- The effect of aggregate gradation and W/C ratio on shrinkage of concrete.
- The reduction in cement quantity and concrete cost effectiveness due to the change in gradation of aggregates

3. Experimental Program

Aggregate properties were determined based on the standard ASTM test methods. These test results were used to design gap graded and dense graded concrete mixes with two water-cement ratios (0.42 and 0.45) and two cement factors (5 and 6). Concrete prepared with W/C 0.5 and cement factor 5 is also used to study the effect of gradation on cost of concrete. ASTM C192/C concrete mixing procedure was followed to make the concrete specimens. The slump of each batch of concrete was tested immediately after mixing in

accordance with ASTM C 143 test method. Workability was tested using the drop test (DIN 1048), which is a Germen test standard used to measure the mobility of concrete mixture with a slump less than 50mm to serve as an indicator of whether workability is sufficient during placement of the concrete. In this test program, the drop test was also used to evaluate the workability of concrete with the slump less than 50 mm. Twelve cylindrical concrete specimens were prepared from each batch of gap graded and well-graded concrete prepared and 1, 3, 7, and 28 day compressive strength were determined using the ASTM C 39 test procedure. Early age shrinkage of concrete was also determined in accordance with ASTM C 157 test method.

4. Experimental Results and Discussions

4.1 Concrete workability

The slump test and drop test (DIN1048) were conducted immediately after mixing the concrete to describe the slump and number of drops as a measure of consistency, mobility and workability of the concrete. The measured slump and the number of drops for gap graded and dense graded concrete with W/C ratio 0.42 and 0.45 are given in Table 1. The comparative study shows that the slump and number of drops of the concrete mixed with dense graded aggregate is greater than that of gap graded for both cases of W/C ratio. The number of drops for concrete mixed with dense graded aggregate is greater compared to gap graded shows the greater resistance of the concrete mix to lateral movements and a consistent flow of the concrete mix. The higher adhesion between aggregates and cement mortar due to the dense gradation resisted the concrete from bulging laterally outward. The slump for concrete mixed with gap-graded aggregate and W/C ratio 0.45 is greater than 50mm with smaller number of drops compared to concrete with dense graded aggregate shows less mobility of concrete mix. This is an indication of lack of cohesion in the concrete mix due to the change in grading of aggregate such as a deficiency of intermediate aggregates of one or more sizes.

Table 1: Slump and Drop test results

Type	W/C = 0.42		W/C= 0.45	
	Slump (mm)	Number of Drops	Slump (mm)	Number of Drops
Gap Gradation	45	4	65	3
Dense gradation	30	8	50	5

4.2 Effect of aggregate grading on compressive strength

The effect of aggregate gradation on compressive strength of concrete is analyzed by testing the compressive strength specimens made from concrete mix prepared using gap graded and well graded aggregate. Concrete specimens are prepared for water-cement ratios 0.42 and 0.45. Compressive strength test results are used to access the quality control of concrete proportioning, mixing and placing operations. The cylindrical specimens were tested for four different ages to find the compressive strength of the concrete using standard ASTM procedure. Experimental data for two W/C ratios have also been plotted on figures 1(a) and 1(b) for gap graded and dense graded concrete to show the influence of aggregate gradation.

The study shows that by reducing the gap between the coarse aggregate sizes in a concrete mix can increase the compressive strength of the concrete. As the gap between coarse aggregate sizes increases the need of intermediate size aggregate or the sand to fill the voids increases. It is known that the presence of voids in

concrete greatly reduces the strength of concrete. In order to obtain a dense concrete it is necessary to have maximum particle interlock. This can be achieved by optimizing the mixture proportioning with the help of proper aggregate selection and combination through aggregate grading. It is observed from the study that the gradation of aggregates greatly affects the compressive strength of the concrete mix. Therefore, the aggregate fraction in the cement concrete must be adjusted to properly fill voids to get mobility needed and maximize the strength. The experimental result shows that compressive strength of the concrete can be increased by the optimization of aggregate gradation in mixture proportioning.

4.3 Effect of W/C ratio on compressive strength

To demonstrate the effect of water/ cement ratio on compressive strength of the concrete, the test results for the gap graded and dense graded concrete are plotted (Figure 2). It shows that the cylindrical specimens made from concrete prepared using dense graded aggregate yielded high compressive strength values for both water/ cement ratios compared to specimens prepared from gap graded aggregate. Also it is noted that the lower W/C ratio yielded higher compressive strength in both cases of concrete mixes. These results support the general believe that a lower W/C ratio allows for increased compressive strength and flexural strength.

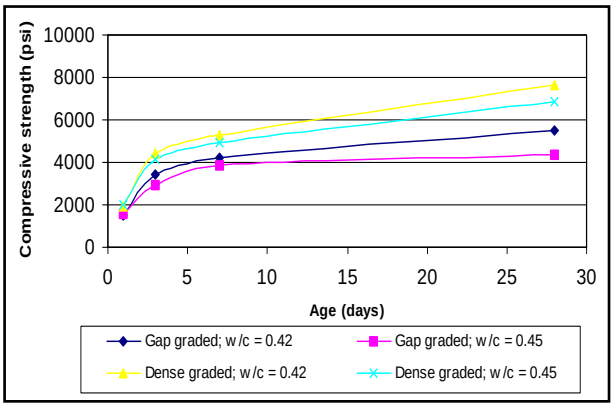

Figure 2: Effect of W/C ratio on compressive strength of concrete

4.4 The effect of aggregate grading and w/c ratio on shrinkage

The grading of aggregates and W/C ratio are two important factors that affect the shrinkage of the concrete. Shrinkage specimens made from concrete prepared using gap and dense graded aggregates were tested to study the effect of grading and w/c ratio on shrinkage. The measurement of length change facilitates the

assessment of the potential for the volumetric change of cement concrete. Experimental data obtained from tests have been used to calculate the shrinkage strain in concrete prepared from gap graded and dense graded aggregates for w/c ratios 0.42 and 0.45 and cement factor CF 6. Figures 3(a) and 3(b) clearly illustrates that the shrinkage strain of concrete prepared using dense graded aggregate is relatively less compared to the shrinkage strain of concrete prepared using gap graded aggregate. Also it is observed that the shrinkage strain of concrete prepared using dense graded aggregate with W/C ratio 0.42 is considerably less than that of concrete prepared using dense graded aggregate with W/C ratio 0.45. It clearly indicates that a dense graded concrete with continuous distribution of particle sizes can provide maximum strength with minimum volume change and shrinkage. Thus the selection and combination of the coarse aggregates plays a dominant role in the strength and workability of the concrete. The study revealed that concrete prepared from a well-graded aggregate has the highest strength and lowest shrinkage compared to concrete prepared from gap-graded aggregate.

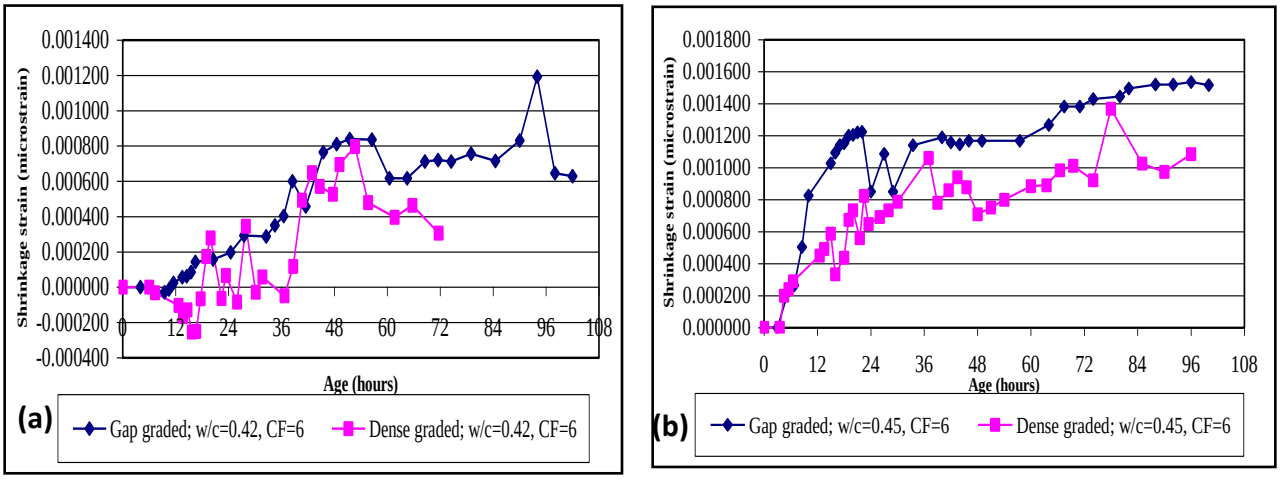

Figure 3: Effect of aggregate grading and W/C ratio on shrinkage; (a) with W/C=0.42, and (b) W/C=0.45

4.5 Effect of aggregate gradation on the cost of concrete

The grading or size distribution of aggregate is considered as an important characteristic because it determines the paste requirements of the concrete. The cost of the concrete is controlled by this paste requirement, as cement is the most expensive component of the concrete. It is therefore desirable to minimize the amount of cement content in the concrete while providing the required strength and durability. It has already been found that a dense graded aggregate often provides the best workable or flow-able concrete with relatively high strength by minimizing the void space. The cost analysis of the materials used in the preparation of concrete used in this study revealed that the dense graded concrete was highly cost effective than the gap graded concrete. It was observed that in comparison with the gap-graded concrete the dense graded concrete could provide, for the same w/c ratio, a 17% cement reduction without considerable reduction in compressive strength. Since the required amount of cement paste depends up on the void space that must be filled, the use of dense graded or continuously graded aggregate can lower the paste requirement and, thus, the price of the concrete mix. Table 2 shows the mixture proportions for one-meter cube of gap and dense graded concrete with W/C ratio 0.42. The cement factors used in this study to prepare gap graded and dense graded concrete are 6 and 5 respectively. The compressive strength results

of gap graded and dense graded concrete for W/C ratio 0.42 are shown in Table 3. This comparative study showed that the use of dense graded aggregate in the preparation of concrete can reduce the cement requirement in the mixture proportion and there by the cost of concrete without compromising the strength of concrete.

Table 2: Mixture proportion for the concrete with w/c = 0.42

Mixture components	Mixture Proportions per 1 m^3 (35.3 ft^3)	
	Gap Gradation (CF=6)	Dense Gradation (CF=5)
Water (lb)	309.7	258.1
Cement (lb)	**553.0**	**460.9**
Fly Ash (lb)	184.3	153.6
Coarse Aggregate (lb)	2423.8	1558.1
Intermediate aggregate (lb)	0.0	932.8
Fine Aggregate (lb)	1165.3	1332.8
Air-Entraining Mixture (ml)	236	I96

Table 3: Compressive strength of gap and *dense graded concrete with w/c = 0.42*

Age (Days)	Compressive Strength (psi)	
	Gap Gradation (CF = 6)	Dense Gradation (CF = 5)
1	1504	2445
3	3398	3583
7	4292	4563
28	5478	4890

5. Conclusions

An experimental study conducted to determine the effect of aggregate gradation and water-cement (W/C) ratio on strength parameters and cost effectiveness of concrete concluded as follows.

1. The results from the test indicated that the concrete prepared from dense graded aggregate could provide consistent and more workable mix in comparison with the concrete prepared from gap-graded aggregate.
2. The compressive strength of the concrete could be increased by the use of dense graded aggregate, irrespective of the w/c ratio, for the preparation of concrete.
3. The use of dense graded aggregate and a lower w/c ratio for the preparation of concrete can considerably reduce the shrinkage of concrete.
4. The use of dense graded aggregate in the preparation of concrete can reduce the cement requirement (by approximately 17%) in the mixture proportion and there by a reduction in cost with out compromising the strength of concrete.

6. References

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