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GAP GRADING OF AGGREGATES & ITS EFFECT ON THE INHERENT PROPERTIES OF CONCRETE

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Abstract - Aggregate are the important constituent in concrete. They give body to concrete, reduce shrinkage and affect economy. Earlier, aggregates were considered chemically inert but now it has been recognized that some of the aggregate are chemically active and also certain aggregates exhibit chemical bond at the interface of aggregate and paste. The mere fact that they occupy 70-80% of volume of concrete, their impact on various characteristics of concrete is undoubtedly considerable along with its gradation. The depth of range of studies that are required to be made in respect of aggregate to understand their widely varying effect and influence on properties of concrete such as compressive strength, durability, workability, shrinkage, density etc. cannot be underrated. The emphasis is given on the gradation and type of aggregate which influence the properties effectively. The grading curves are studied in detail to know the behavior of coarse as well fine aggregate as properties of concrete. In this work, emphasis has been given to Gap grading which is a relatively new term as far as traditional methods of combining aggregates are concerned. Three different batches were cast, using Well graded, Uniformly graded & Gap graded aggregate sample in consecutive batch for M20 grade of concrete. Various tests were carried out to evaluate the effect of grading of aggregate on the inherent properties of fresh and hardened concrete.

Keywords: *Gap Grading, Plain Concrete, Grading of aggregate, Types of Grading, Gap graded Concrete*

I. INTRODUCTION

Aggregate occupies 70% to 75% of the volume of conventional normal strength Portland cement concrete and therefore the properties of aggregates have a dominant effect on the overall performance of concrete in its fresh and hardened state. Among the various characteristics of aggregates that have a significant influence on properties of concrete, the size distribution of aggregate particles or otherwise known as *aggregate gradation* plays an important role in achieving the desired properties of concrete. Aggregate gradation determines the void content within the structure of aggregate and consequently the amount of cement paste that is required to fill the void space between the aggregate and ensure a workable concrete. As Portland cement is the most expensive and high carbon footprint ingredient in concrete, it is desirable to optimize the aggregate gradation to minimize the void content in the aggregate and therefore the volume of cement paste required to achieve a workable, economical and an environmentally sound concrete for a given application.

The need to optimize aggregate gradation also arises from the desire to improve rheological, mechanical and durability properties of concrete. Proper aggregate gradation is not only important to ensure a workable concrete mixture that can be compacted easily, but also to minimize problems associated with plastic concrete such as potential for segregation, bleeding and loss of entrained air and potential for plastic shrinkage cracking. Furthermore, most concrete that is used in construction of transportation infrastructure is often vibrated to achieve good compaction in concrete. Concrete containing aggregate with poor gradation can be particularly vulnerable to problems such as segregation in plastic state under vibration. Aggregate is often considerably stronger, harder and stiffer than the hydrated cement paste. As a result, an optimized aggregate gradation in concrete can minimize the requirement of cement paste and maximize the compressive strength, increase the abrasion resistance of concrete and modulus of elasticity of concrete. However, these durability problems have historically been minimal to non-existent in South Carolina and therefore will not be dealt with in this research investigation.

The main objective of this research project was to understand the effects of aggregate properties and aggregate gradation in pervious concrete mixtures. The following is an outline of the specific objectives of this research:

- To understand the concept behind Gap grading of aggregates and how it affects the properties of concrete in fresh & hardened state.
- To determine the effects of aggregate type, size, and content on the compressive strength, workability, durability and other properties of fresh as well as hardened concrete,
- To determine the relationships between these three measures of materials performance.

Gradation of aggregates -

The particle size distribution of an aggregate as determined by sieve analysis is termed as grading of the aggregates. If all the particles of an aggregate are of uniform size, the compacted mass will contain more voids whereas aggregate comprising particles of various sizes will give a mass with lesser voids. The particle size distribution of a mass of aggregate should be such that the smaller particles fill the voids between the larger particles. The proper grading of an aggregate produces dended concrete and needs less quantity of fine aggregate and cement waste, therefore, it is essential that coarse and fine aggregates be well graded to produce quality concrete. The grading of aggregates is represented in the form of a curve or an S CURVE. The curve showing the cumulative percentages of the material passing the sieves represented on the ordinate with the sieve openings to the logarithmic scale represented on the abscissa is termed as Grading Curve. The grading curve for a particular sample indicates whether the grading of a given sample conforms to that specified, or it is too coarse or too fine, or deficient in a particular size.

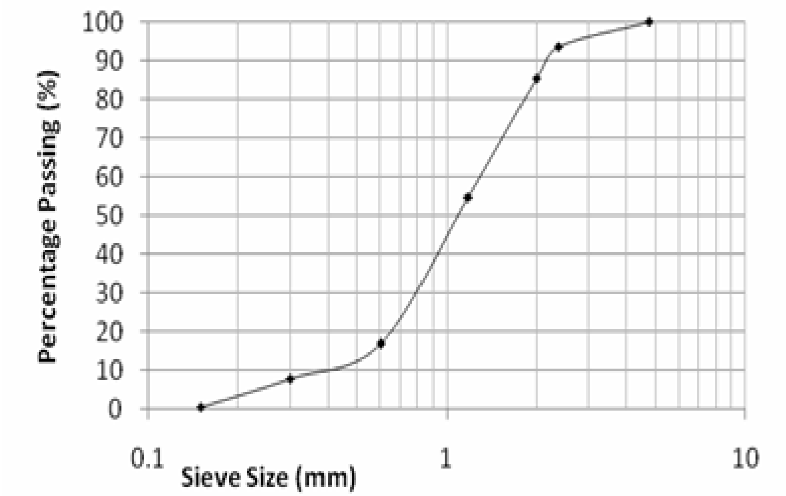

Fig. 1 - Grading Curve for an aggregate sample

Types of Grading of Aggregates -

Aggregate comprises about 55% of volume of mortar and about 85% volume of mass concrete. Mortar contains aggregate size of 4.75mm and concrete contains aggregate up to a maximum size of 150mm. Since, the strength of concrete is dependent upon the water/cement ratio provided the concrete is workable, the qualifying clause provided the concrete is workable assumes full importance. One of the most important factors for producing workable concrete is good gradation of aggregates. Good grading implies that a sample of aggregates contains all standard fractions of aggregates in required proportions such that the sample contains the minimum voids.

According to the size distribution of particles an aggregate can be classified as:

- Uniformly Graded -
  Also known as narrow gradation, a uniform gradation is a sample that has aggregate of approximately the same size. The curve on the gradation graph is very steep, and occupies a small range of the aggregate. It refers to a gradation that contains most of the particles in a very narrow size range. In essence, all the particles are the same size. The curve is steep and only occupies the narrow size range specified.

- Open Graded -
  An open gradation refers an aggregate sample with very little fine aggregate particles. This results in many air voids, because there are no fine particles to fill them. On the gradation graph, it appears as a curve that is horizontal in the small size range. It refers to a gradation that contains only a small percentage of aggregate particles in the small range. This results in more air voids because there are not enough small particles to fill in the voids between the larger particles. The curve is near vertical in the mid-size range, and flat and near-zero in the small-size range.

- Gap Graded -
  A gap gradation refers to a sample with very little aggregate in the medium size range. This results in only coarse and fine aggregate. The curve is horizontal in the medium size range on the gradation graph. It refers to a gradation that contains only a small percentage of aggregate particles in the mid-size range. The curve is flat in the mid-size range. Some PCC mix designs use gap graded aggregate to provide a more economical mix since less sand can be used for a given workability. HMA gap graded mixes can be prone to segregation during placement.

- Dense Graded -
  A dense gradation refers to a sample that is approximately of equal amounts of various sizes of aggregate. By having a dense gradation, most of the air voids between the materials are filled with particles. A dense gradation will result in an even curve on the gradation graph.

- Rich Gradation -
  A rich gradation refers to a sample of aggregate with a high proportion of particles of small sizes.

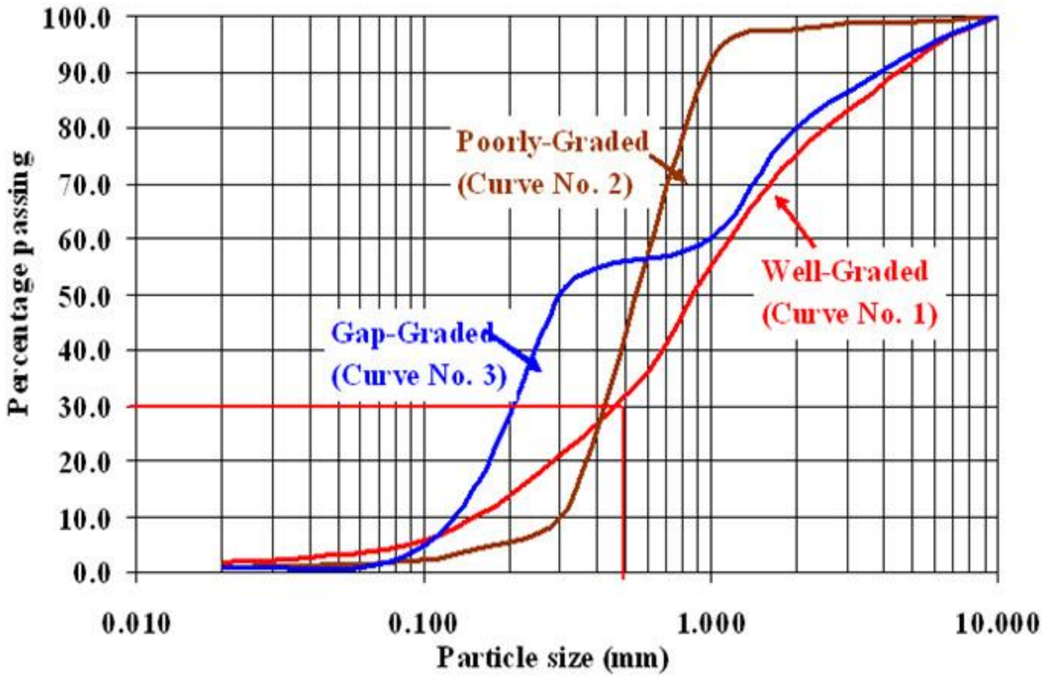

Fig. 2 - Curves Representing Different Grades of Aggregates

II. SAMPLE PREPARATION

For the tests to be conducted we need to prepare the samples of concrete constituting the different grades of aggregates i.e. Well Graded, Uniform Graded and Gap Graded. One batch of concrete from which three cubes could be casted, thus, prepared for each grade to perform the tests which determine the effect of gradation on properties of concrete.
Since the concrete of strength M-20 is to be analyzed the Mix Proportion 1 : 1.5 : 3 is used for Cement, Fine aggregate and Coarse aggregate respectively. The following Mix Proportion has been used for aggregates to be mixed in concrete as per IS Code recommendations.

WELL GRADED:

Table 1 - Mix proportion of aggregates in Well Graded

IS Sieve Designation	Percentage of particular size present(%)	Weight of aggregate of size used (in kg)
40 mm	5	1.175
20 mm	45	10.575
4.75 mm	20	4.7
600 microns	15	3.525
150 microns	15	3.525

UNIFORM GRADED:

Table 2 - Mix proportion of aggregates in Uniform Graded

IS Sieve Designation	Percentage of particular size present (%)	Weight of aggregate of size used (in kg)
40 mm	14	2.165
20 mm	81	12.530
10 mm	5	0.773

GAP GRADED:

Table 3 - Mix proportion of aggregates in Gap Graded

IS Sieve Designation	Percentage of particular size present(%)	Weight of aggregate of size used (in kg)
40 mm	5	1.175
20 mm	13	3.055
10 mm	12	2.82
4.75 mm	-	-
2.36 mm	35	8.225
1.18 mm	18	4.23
600 microns	5	1.175
300 microns	4	0.94

For making M-20 Concrete Mix the weight of its ingredients were:
Cement = 5 kg
Fine aggregate = 7.9 kg
Coarse aggregate = 15.47 kg
The water content taken was 0.5%, i.e. water cement ratio was 0.5.

Note: The above values have been taken in according to prepare M-20 mix sufficient for preparing three cubes (size: 150mm*150mm*150mm) required to be tested for determining the properties of concrete. An additional 0.2% of cement as well as aggregates have been included in above weights regarding any loss.

III. TESTING OF TRIAL MIXES

In all, 3 batches of concrete were made of M20 grade with a constant W/C and Super Plasticizer content, by varying the type of grading of aggregates. To check the stability of the Batches, the following tests were conducted on the concrete:

- Slump Test
- Compaction Factor Test
- Compressive Strength Test
- Flexural Strength Test

IV. RESULTS & DISCUSSIONS

The value of Slump was unaffected by the grading of aggregates. In all the batches, zero slump was obtained. This leads us to believe that slump is just a basic term to define workability. In this case, Compaction Factor Test was needed to gather an accurate idea about the workability characteristics of the batches.

The value of Compaction Factor was most close to the ideal value of 0.9 in the case of batch with Gap Graded aggregates. This proves that contrary to the common belief, gap graded aggregates prove to be more efficient than well graded aggregates that are commonly used in construction.

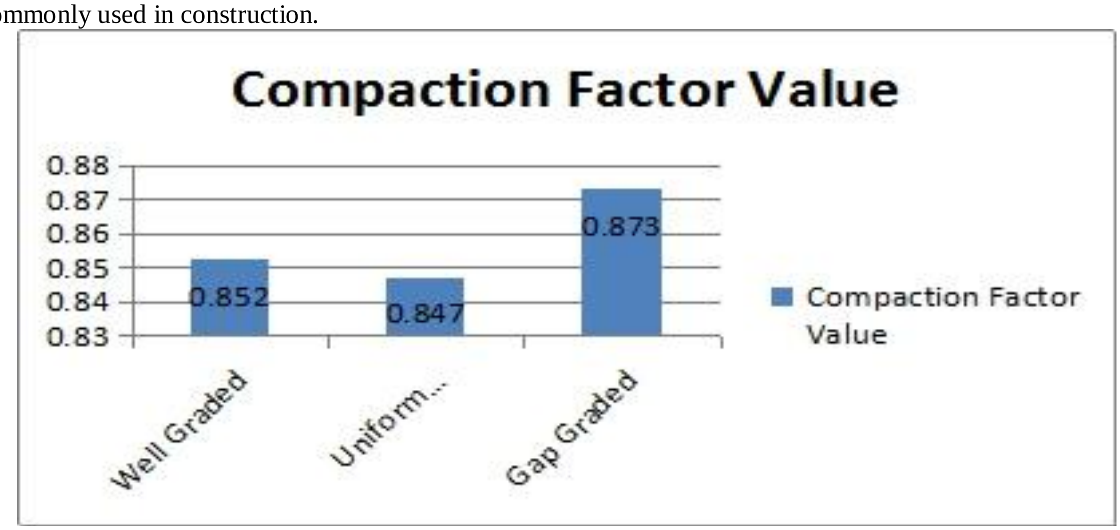

Fig. 3 - Results of Compaction Factor Test

The Characteristic Compressive Strength of concrete at 7 days and 28 days was found in N/mm-. The results showed a heavy decrease in the strength of batches with uniform graded aggregates. However, the batches with Gap Graded aggregates showed the most superior performance in case of initial strength and final strength both.

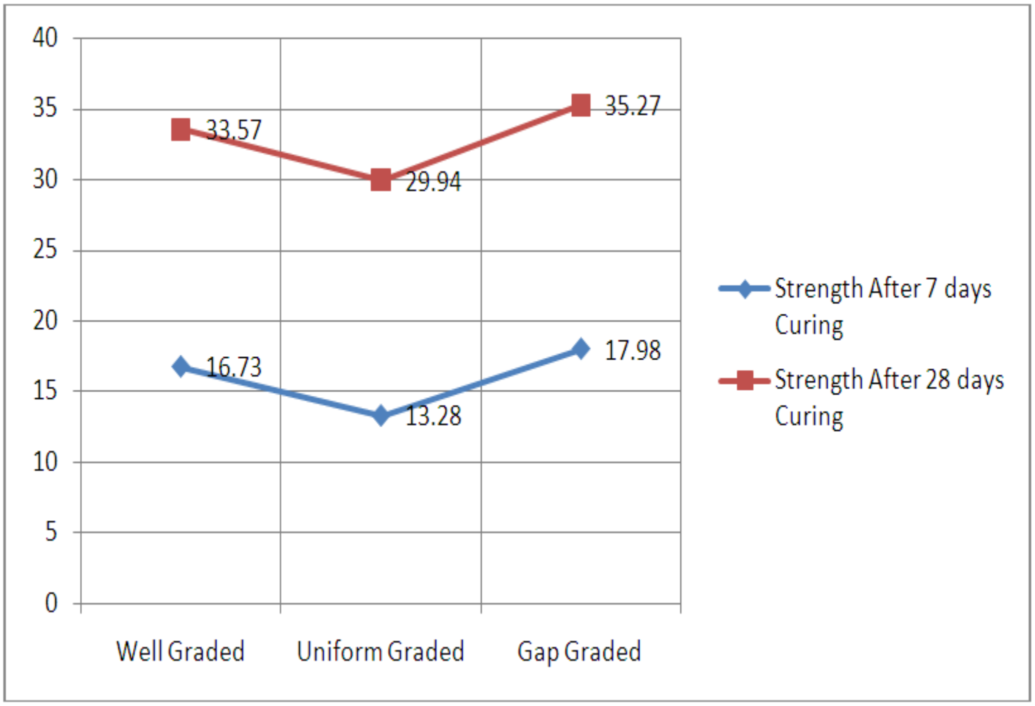

Fig. 4 - Results of Compressive Strength Test

The Flexural Strength of concrete was found in N/mm^2. Here also, the results followed a similar pattern as in the case of Compressive Strength. The batches with Gap Graded aggregates exhibited the best performance among all.

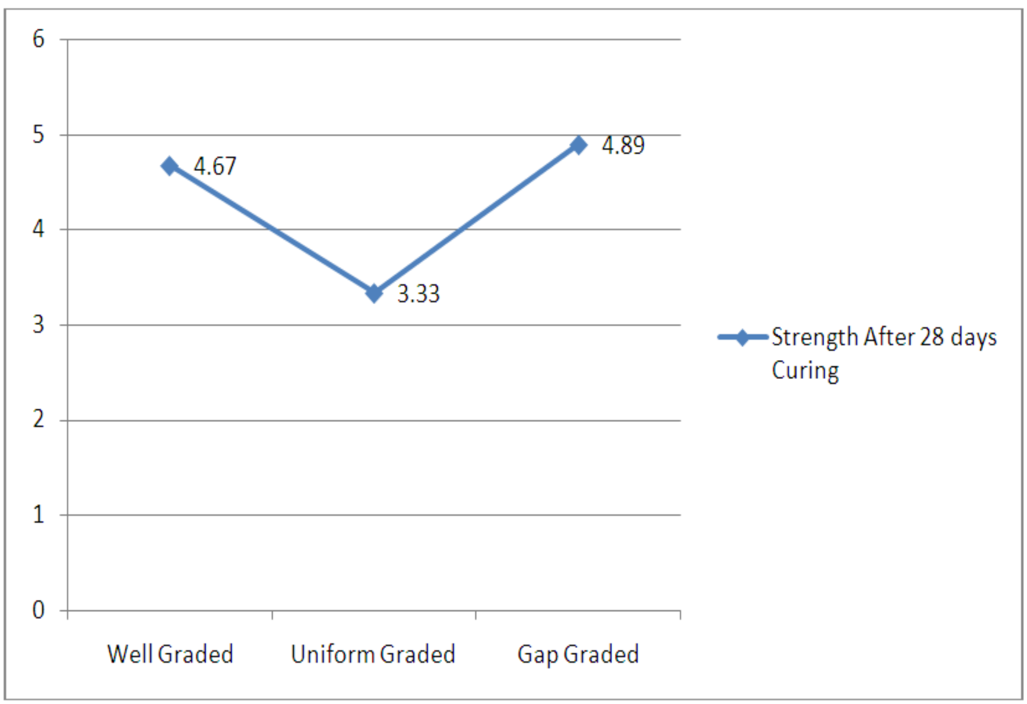

Fig. 5 - Results of Flexural Strength Test

Table 4 - Observations for Various Tests

Type of Sample	Slump (mm)	Compaction Factor	Compressive Strength (in N/mm²) After 7 days curing		Compressive Strength (in N/mm²) After 28 days curing		Flexural Strength after 28 days curing (in N/mm²)	
Well Graded	00	0.852	17.17	16.73	33.55	33.57	4.67	4.67
			16.38		34.16		4.89	
			16.64		33.00		4.43	
Uniform Graded	00	0.847	13.05	13.28	29.91	29.94	3.21	3.33
			13.23		30.13		3.63	
			13.57		29.78		3.16	
Gap Graded	00	0.873	17.78	17.98	35.14	35.27	5.12	4.89
			18.17		34.98		4.59	
			18.01		35.70		4.94	

V. SUMMARY & CONCLUSIONS

The following conclusions can be drawn from the above observations:

a) Though, well graded concrete has been preferred over gap graded but the results obtained by performing tests show that the performance of the later is even better.

b) The presence of more bigger sized aggregates causes a more homogeneity in concrete preventing the uniform distribution of the load when stressed. Presence of voids in case of batches with Uniform graded aggregates led to their poor performance.

c) There was no significant difference in the batches of Gap Graded aggregates in fresh state when compared to the others. However the strength obtained after hardening cleary show that all the batches exhibit different behaviors.

Study Outcomes -

a) The study gives a picture of the effects of aggregate type, size, and content on the compressive strength, workability, durability and other properties of fresh as well as hardened concrete.

b) The study helps to understand that the gradation has no effect on the slump value of freshly prepared concrete for lower grades of concrete (M20). However the Compaction factor test is more sensitive towards the gradation of aggregates.

c) It is evident that GAP GRADED AGGREGATES have shown better performance as compared to the traditional WELL GRADED AGGREGATES, thereby forcing Designers & Contractors to give serious thought to it.

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