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Gradation of Aggregates and its Effects on 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, aggregate 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 behaviour of coarse as well fine aggregate as properties of concrete.

Keywords: *Gradation, Well Graded, Uniform Graded, Gap Graded*

I. INTRODUCTION

Concrete, in the broadest sense, is any product or mass made by use of a cementing medium. This medium is a product of reaction between hydraulic cement and water. This medium cover a wide range of products: several types of cement containing pozzolona, fly ash, blast furnace slag, a 'regulated set' additive, sulphur, admixtures, fibers, and so on. The cementing medium, i.e. the products of hydration of cement, is the essential building material, with the aggregates fulfilling the role of a cheap, or cheaper, dilutant. Also the coarse aggregate is the mini-masonry which is joined together by mortar, i.e. a mixture of hydrated cement and the fine aggregate. Or as the approximation, concrete consists of two phases: hydrated cement paste and aggregate, as a result, the properties of the two phases and also the presence of interfaces between them govern the 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 and ensure a workable concrete. It is desirable to optimize the aggregate gradation in concrete using Portland cement, as it is the most expensive and high carbon footprint ingredient, 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 optimization of aggregate gradation also improves the rheological, mechanical and durability properties of concrete.

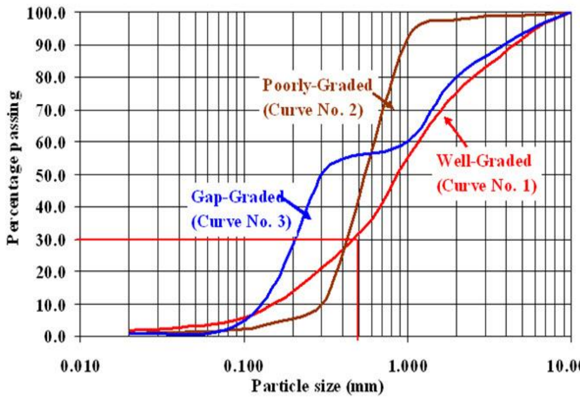
Proper aggregate gradation not only ensure a workable concrete mixture that can be compacted easily, but also reduces problems associated with plastic concrete such as potential for segregation, bleeding and loss of entrained air and plastic shrinkage cracking. Furthermore, most concrete that is used in construction of transportation infrastructure is often vibrated to achieve good compaction in concrete. Segregation in plastic state under vibration particularly is the most vulnerable problem in concrete containing aggregate with poor gradation. Cement paste filling the void space between the aggregate has a tendency to shrink when there is a progressive loss of moisture from concrete, either due to evaporation from surface of concrete or through internal consumption of moisture due to hydration reactions of cement. Aggregates in concrete, being much stiffer than the hardened cement paste, act to resist the shrinkage behaviour of concrete. Aggregate gradation, which determines the relative proportions of aggregate and cement paste in a concrete, therefore dictates the shrinkage behaviour of concrete and hence long-term durability of concrete.

A. 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 dense 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.

B. The Grading Curve

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.



C. Types Of Grade Of Aggregates

i. UNIFORM GRADED 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.

- Narrow range of sizes
- Grain-to-grain contact
- High void content
- High permeability
- Low stability
- Difficult to compact

ii. OPEN GRADED AGGREGATE

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.

iii. GAP GRADED AGGREGATE

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.

- Missing middle sizes
- No grain-to-grain contact
- Moderate void content
- Moderate permeability
- Low stability
- Easy to compact

iv. DENSE GRADED AGGREGATE

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.

- Wide range of sizes
- Grain-to-grain contact
- Low void content
- Low permeability
- High stability
- Difficult to compact

II. MATERIALS USED

CEMENT – Ordinary Portland cement, 53 grade was used.

Physical property	**IS: 8112-1989 specifications**
Fineness (retained on 90-µm sieve)	10mm
Normal Consistency	-
Vicat initial setting time (minutes)	30 min
Vicat final setting time (minutes)	600 max
Compressive strength 3-days (MPa)	22.0 min
Compressive strength 7-days (MPa)	33.0 min
Compressive strength 28days(MPa)	43.0 min
Specific Gravity	-

AGGREGATE - The maximum nominal size of aggregate is taken as 40 mm. Rounded aggregates are desirable and the sample should be of uniform quality. Fine aggregate can be natural or manufactured. The moisture content or absorption characteristics must be closely monitored. The percentage of each size of aggregate taken is mentioned in the given table as per the grade of aggregate desired.

<u>Well Graded Aggregate</u>

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

<u>Uniform Graded aggregate</u>

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

<u>Gap Graded Aggregate</u>

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

III. TESTING OF TRIAL MIXES

In all, 3 batches of concrete were made each of grade M20 with a constant W/C and cement content, by varying the proportions of the fine as well as coarse aggregate as per IS recommendations required (proportions are mentioned in the above tables). They are designated as follows:

SN	**Batch Designation**		**Grade of Concrete**	**Adopted Mix Proportions**
	Title	**Description**		
1	M1	Well Graded Aggregate	M20	1 : 1.5 : 3
2	M2	Uniform Graded Aggregate	M20	1 : 1.5 : 3
3	M3	Gap Graded Aggregate	M20	1 : 1.5 : 3

Note: Adopted a common W/C = 0.5 and cement for each batch is taken 5kg.

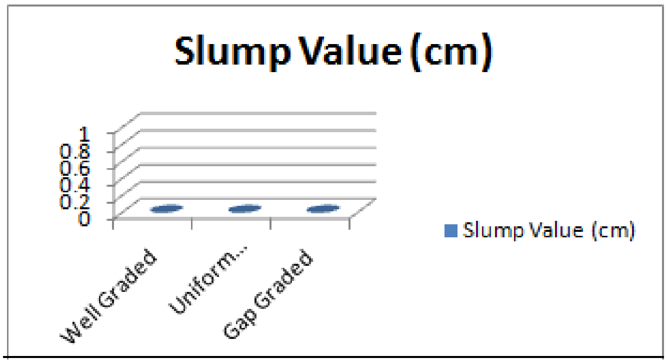
To check the stability of the Batches, the following tests were conducted on the concrete:

1. Slump Test
2. Compaction Factor Test
3. Compressive Strength Test

IV. OBSERVATIONS AND INTERPRETATION OF RESULTS

A. Slump Test

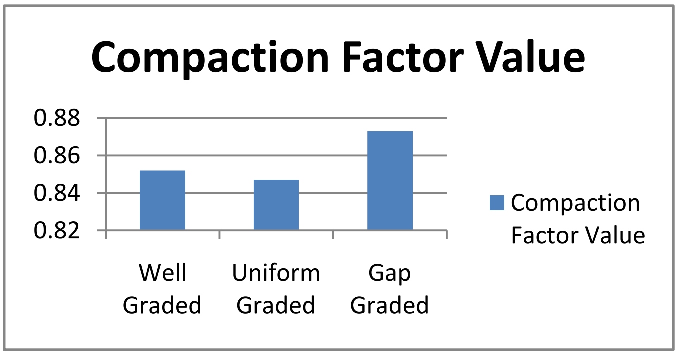
Grade of Concrete (M-20)	Value of Slump (in mm)
WELL GRADED	00
UNIFORM GRADED	00
GAP GRADED	00



B. Compaction Factor Test

Weight of empty cylinder = Wa = 8.601kg

Grade of Aggregate used	Weight of partially compacted Wb (kg)	Weight of fully compacted Wc (kg)	Wb -Wa (kg)	Wc-Wa (kg)	Compaction Factor
Well Graded	17.77	19.36	9.169	10.759	0.852
Uniform Graded	18.08	19.80	9.479	11.199	0.847
Gap Graded	17.627	18.947	9.026	10.346	0.873



C. Compressive Strength Test

WELL GRADED

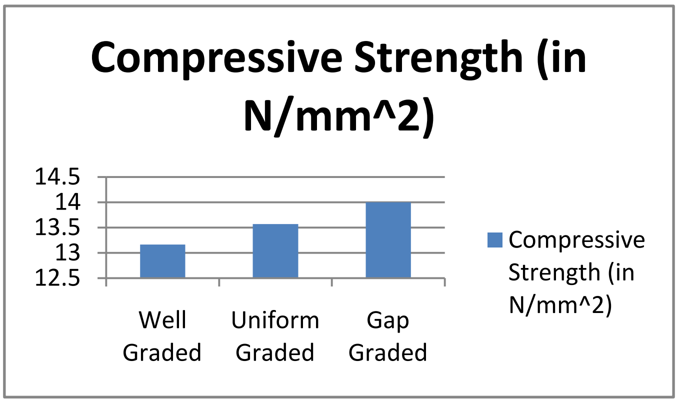
Sample No.	Load Of Failure (in KN)	Compressive Strength after 7 days curing (in N/mm^2)	Percentage of strength after 28 days curing (%)	Average Value fc (in N/mm^2)
Sample 01	305	13.56	67.8	
Sample 02	300	13.33	66.66	13.163
Sample 03	290	12.6	63.2	

UNIFORM GRADED

Sample No.	Load Of Failure (in KN)	Compressive Strength after 7 days curing (in N/mm^2)	Percentage of strength after 28 days curing (%)	Average Value fc (in N/mm^2)
Sample 01	280	12.5	62.2	
Sample 02	315	14	70	13.57
Sample 03	320	14.22	71.1	

GAP GRADED

Sample No.	Load Of Failure (in KN)	Compressive Strength after 7 days curing (in N/mm^2)	Percentage of strength after 28 days curing (%)	Average Value fc (in N/mm^2)
Sample 01	315	14	70	
Sample 02	320	14.22	71.1	14
Sample 03	310	13.78	68.9	



SUMMARY AND CONCLUSIONS

- 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.
- The fine aggregate gradation has more detrimental effect on concrete properties than coarse aggregate gradations.
- The study helps to understand that the gradation has no effect on the slump value of freshly prepared concrete**.**
- The Compaction factor test is more sensitive towards the gradation of aggregates and result shows that Gap Graded with compaction factor 0.872 has better workability among different grades.
- Though, well graded concrete has been preferred over gap graded but the results obtained by performing tests show that the compressive strength of latter is more than the former.

- The presence of more bigger sized aggregates causes a more homogeneity in concrete preventing the uniform distribution of the load when stressed.

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