Properties of aggregates- Physical properties, Chemical properties

Aggregate meaning

In the field of construction, the term "Aggregates" simply represent materials like sand, crushed stones, broken bricks, gravel, chips, etc. which are used in the manufacture of traditional cement concrete, asphalt concrete, or various other composite building materials.

Technically they are also called construction aggregates. These aggregates, simply are a collection of discrete materials of varying sizes, shapes, and other essentials attribute.

Aggregates can occupy up to 60%-75% volume of composite construction materials like concrete. Thus, their own properties have a significant impact on the overall properties of such composite materials. Now, let us discuss the Properties of aggregates.

A) Physical properties of aggregates

1) Shape and size

Properties of aggregates

Classification of aggregates on the basis of shape and size has already been discussed above. Here we will discuss the impact of shape and sizes of aggregates on concrete and its other applications.

The size of aggregate can have a significant impact on the strength and workability of the concrete in its fresh and hardened state. This is relatable to both fine and coarse aggregate. The maximum possible size of the coarse aggregate that can be used, should not exceed 1/4th of the minimum thickness of the structural member or should be 5mm less than the minimum clear spacing between reinforcements in RCC structure.

The use of the maximum possible size of the aggregates helps in reducing (binding material) cement content, reducing water requirements, and minimize shrinkage and creeping due to drying of fresh concrete.

In contrast, the use of a higher portion of larger aggregate may reduce the workability of concrete during application. For better soundness, compactness, band, and workability of concrete, a coarse aggregate of nominal size 20mm and sand as fine aggregate is recommended for normal concreting.

Similarly, the shape of aggregate grains can also affect the workability of the concrete in its fresh state and its durability, strength, and bonding in the hardened state. As mention in the above classification shape of aggregate can be classified into rounded, irregular, angular, flaky, elongated, and flaky elongated.

Each category of aggregate yields variable properties and can have different requirements. The shape of the aggregates is determined on the basis of visual inspection and various other parameters and indices like roundness index, sphericity, angularity number, flakiness index, elongation index, etc.

Rounded aggregates are found to require less cement content for constant W/C ratio due to their lower specific surface area and low angularity number. Specific surface area is defined as total surface area per unit weight of aggregate.

It is measured using the surface index of aggregate and gives an indirect measure of grading of aggregate.

In contrast to rounded aggregates, angular aggregates have high angularity numbers and higher specific surface area available for proper bonding between cement paste and aggregates along with better interlocking properties which makes them the most recommended shape for aggregates in the manufacture of concrete. But, an increase in such angularity number decreases the workability of the concrete.

Flaky and elongated aggregates also have larger specific surface areas but lack proper interlocking properties due to their shape. They also have a higher angularity number than angular aggregates due to which they have low workability.

Due to these reasons, they don’t make good concrete. Thus, flaky and elongated aggregates are generally discarded in concrete manufacturing.

2) Surface texture

The surface texture of an aggregate is a measure of degree up to which the surface of the particle of aggregate is polished or dull, smooth or rough. The surface texture of a crushed aggregate depends on the grain size, hardness, pore characteristics of the parent source rock. This can be determined through visual inspection.

As mentioned above it can be classified as Glassy, Smooth, Granular, Rough, Crystalline, and honeycomb. The surface texture of both fine and coarse aggregate can have a significant impact on the water requirement of the concrete mix and its workability in the fresh state.

Rough texture aggregates are found to form more strong bonds with cement paste than another textured aggregate due to the presence of voids and pores. On the other hand, glass, smooth aggregates absorb less water than rough aggregates which may influence the water requirement as mentioned above.

3) Specific gravity

Specific gravity is a dimensionless quantity that is defined as the ratio of the weight of oven-dried aggregates to the weight of a volume of pure water displaced by an equal volume of saturated surface dry aggregates.

An oven-dry condition of aggregate is obtained by drying the aggregates in the oven for 24 hours at 100°C -110°C. The above-mentioned ratio gives the apparent specific gravity of the aggregates as it includes the volume of impermeable pores (not capillary voids) present in the aggregates.

An absolute specific gravity includes only the solid material present in the aggregates i.e without including any voids and pores. Apparent specific gravity is more useful than absolute specific gravity.

The apparent specific gravity of fine aggregate is determined in the field and lab using a pycnometer which consists of a 1L jar with a water-tight metal conical screw top (lid) having a small hole at the apex of the cone. On the other hand, the apparent specific gravity of coarse aggregate is determined by using the wire basket method consist of a wire basket and a gas jar.

The specific gravity of most of the natural aggregates ranges from 2.6 – 2.9. It may be below this range in the case of lightweight aggregates. Specific gravity can be used to determine the suitability and quantity of the aggregates for the given volume of concrete.

Generally, aggregates with a higher value of specific gravity are compact, dense, strong, and have minimum pores and lower water absorption, thus they can be termed as useful aggregates. In contrast, aggregates with lower specific gravity can be porous, weak, and highly water absorptive.

4) Bulk density

Bulk density or also called unit weight or unit mass is the density of the aggregate at a certain degree of compaction. It is numerically equivalent to the specific gravity of the aggregate. It is measured in kg/m3 in the construction field. Bulk density can be used to convert weight batches to volume batches.

The bulk density of an aggregate sample is determined by filling a unit volume cylindrical container with aggregates at a specific degree of compaction. Thus it depends on the degree of compaction of aggregates during filling of the container and accordingly has been divided into categories of loose and compact bulk density.

In addition, the bulk density of the aggregate also depends on the particle size distribution and shape of particles. The particles or grain of similar size yields more voids thus have lower bulk density whereas aggregates with varying sizes of particles have a minimum void and higher bulk density.

The bulk density at saturated and surface dry conditions can be used to determine the void ratio at normal conditions. This void ratio affects the cement paste requirement of a concrete mix.

Similarly, elongated and flaky aggregates yield more void than angular and rounded ones. This increases cement content requirements. A maximum bulk density of aggregate is obtained when the mixture contains 35-40% fine aggregate by the total mass of the aggregate mix.

5) Porosity, water absorption and moisture content

The porosity, permeability, and absorption of the aggregate significantly impact the bond between aggregate and cement paste, durability, chemical stability of the concrete, resistance to abrasion, resistance to freezing and thawing, and a specific gravity of the concrete and aggregate itself.

Pores generally form during the formation of rocks or during some natural activities like decomposition and fossil formation. This pore may be of various sizes and shapes varying from rock to rock and may occur on the surface or enclosed inside the rock. It is found to vary from 0 -50% of the volume of aggregate.

Size, occurrence, and volume of such pores affect the amount and rate of penetration of water by the aggregates thus affecting the water absorptive properties of aggregate. The initial moisture content also affects the water requirement of concrete during mixing.

Dry porous aggregates require some water for themselves hence require more water than saturated or partially saturated aggregates whereas wet aggregate containing free water decreases the water requirement of the concrete during mixing.

Aggregates are found to absorb moisture from 0.5% to 25% by the weight of aggregate.

B) Thermal Properties of aggregates

The coefficient of thermal expansion, specific heat, and thermal conductivity of the aggregate are the major thermal properties that can affect the performance of the concrete.

It has been found that if the coefficient of thermal expansion of aggregates differs by more than 5.5*10^-6 per ° C from that of cement paste then the durability of the concrete may be affected significantly when exposed to a freezing and thawing environment.

The specific heat and thermal conductivity may affect the insulation property of the concrete structure.

- Deleterious materials

Deleterious materials are those harmful materials which may affect the strength and durability of the concrete when present in significant amount.

These consist of impurities which interfere with the hydration of cement during setting of concrete, coatings which prevent the formation of a proper bond between aggregate and cement paste, materials which alter the setting time and other material which are weak and unsound themselves.

The limit of deleterious materials that may be allowed in aggregate is not more than 5 % for a mix of fine and coarse aggregate. They can be broadly classified into the following:

- Organic matter

Organic matters are usually present in fine aggregates like sand. The presence of such matter interfere with the hydration of cement and thus resulting in weak and less durable concrete.

They can be checked with visual inspection like for vegetation or colorimetric test for non-observable impurities. They can be removed from manual picking or combustion.

- Clay and other fine materials

Clay material when present in the aggregate forms a certain coating around it which affects the bonding of aggregate with cement paste. They can be removed by washing the aggregates prior to use.

- Salt mineral

Sand retrieved from beaches and seashore generally consists of salts. When used without proper measures, the resulting concrete will become hydrophobic, absorbing moisture from atmosphere and causing efflorescence.

This can be prevented by washing the aggregates with fresh water.

Fineness Modulus of aggregate

Sieve Analysis and gradation curve: A sieve analysis is a process of dividing a sample of aggregate into fractions of aggregate having similar sized grains or within a certain range of grain sizes. It is one of the non-destructive tests conducted to determine the particle size distribution of aggregates.

A sieve analysis equipment consists of stacks of the sieve of varying aperture size arranged in descending order from top to bottom with a pan at the bottom-most and a lid at the top.

A sample of air-dried aggregates is graded by manually shaking or mechanically vibrating the sieve stack for a certain period of time. The fraction of aggregates retained in each stack of the sieve is coarse than that sieve aperture size.

This test can be conducted for both fine and coarse aggregate with a different set of sieve stacks. The percentage of a fraction of aggregate retained in each stack is measured by weightage.

A table representing sieve size, the weight of each aggregate fraction, percentage of a fraction of aggregate, percentage of a fraction of aggregate retained in each stack, percentage of the fraction of aggregate passing through each sieve stack, and cumulative percentage of a fraction of aggregates passing through each sieve stack is prepared.

Then a curve is plotted with cumulative percentage passing at ordinate and sieve in logarithmic scale at abscissa, which results in a curve know as gradation curve. According to this gradation curve, the aggregates can be classified into the following types.

- Uniform graded aggregate

Uniform graded aggregate consists of aggregates of the same or marginally similar sizes. This results in a maximum percentage of voids at any degree of compaction, yielding less interlocking and more cement paste requirements.

A degree of uniformity is determined using an index known as the coefficient of uniformity. It is defined as the ratio of the diameter of a particle with 60% cumulative passing percent to the diameter of a particle with 10% cumulative passing percent.

These data are obtained from the gradation curve.

Coefficient of Uniformity, Cu = (D60/D10)

Cu < 2, uniformly graded clay

Cu >= 6, uniformly graded sand

Cu >= 4 uniformly graded gravel or coarse aggregate

- Well graded aggregate

Well-graded aggregates have particles of all sizes so that they result in better compaction with minimum voids and yield less cement content requirement for bonding. It can be determined by an index known as the coefficient of curvature.

The coefficient of curvature can be defined as the ratio of the square of D30 particle size to the product of D60 and D10 particle size.

Coefficient of curvature = (D30^2)/(D60*D10)

D10 = particle size/diameter with 10% cumulative passing percentage

D60 = particle size/diameter with 60% cumulative passing percentage

D30 = particle size/diameter with 30% cumulative passing percentage

1<=Cc<=3, for well graded aggregates

- Gap graded aggregate

Gap graded aggregates are deprived of particles of certain intermediate sizes. These are generally used for aesthetic purposes. They have a larger surface area and have a greater tendency to segregate.

Similarly, another index that determines the average size of the particle is an aggregate which is known as the fineness modulus of aggregate. It is the ratio of summation of cumulative percentage retained on sieve stack of size ranging from 80mm to 150 microns to a constant 100.

Fineness modulus = Σ (Cumulative % retained) / 100

F.M = 2 -3.5, fine aggregate

FM = 5.5 – 8, Coarse aggregate

It helps to determine the coarseness and fineness of an aggregate sample.

B) Chemical properties of aggregate

- Chemical composition of aggregates

Natural aggregates are made out of various materials like silica mineral, feldspars, micaceous mineral, carbonate minerals, sulfate mineral, iron sulfide minerals, Zeolites, Iron oxide minerals, clay minerals.

All these mineral aggregates should possess all the properties of a good aggregate as mentioned above so that they can be used as aggregates for concreting or other purposes. All the materials which may deteriorate the durability and strength of concrete and make it unsound must be discarded.

- Alkali- aggregate reaction

Alkali aggregate reaction or AAR is a reaction that starts with the attack on reactive siliceous minerals or other minerals in aggregate by the alkaline hydroxides formed from alkaline oxides (K_2O, Na_2O) present in the cement, forming alkali silicate gel having unlimited swelling ability in presence of water.

This swelling of residue hampers the integrity of concrete, its strength, and durability. It can be prevented by adopting a lower W/C ratio, special low alkali cement, good surface sealant, and sound aggregate itself.

C) Mechanical properties of aggregates

1) Strength

Strength of the aggregates simply means compressive or crushing strength of the aggregate. It is represented by aggregate crushing value. ACV is the quantified resistance provided by aggregates to the progressively applied compressive/crushing loads.

This is generally determined for coarse aggregates. The procedure of determining aggregate crushing value can be found in "IS: 2386 (part IV) – 1963 Methods of test for aggregate for concrete Part IV Mechanical properties".

According to the IS code, the test is carried out with aggregate retained between sieve of size 12.5mm and 10mm which is then oven dried for 4 hours. Test equipment consists of two steel cylinder cups, a tamping rod, a compression testing machine, cylindrical metal measures, a balance, and an oven.

Firstly, the net weight of the oven-dried aggregate (only for 4 hours at 100°C) per a fixed volume (of the cylinder) is determined under standard compaction conditions. For this, a cylindrical cup of steel is filled with dry aggregates retained between sieve of size 12.5mm and 10mm in 3 layers- each layer compacted with 25 strokes from the round edge of the tamping rod.

The cylinder is filled up to the brim and leveled with a straight edge. The sample is then weighed using balance, say Wa. The sample is again filled in another cylindrical cup in a similar manner. A plunger is resting upon the level surface of aggregates inside the cup.

The whole assembly is then fixed firmly between the platens of the loading machine. The load is then applied at a uniform rate such that it reaches 40 tons in 10 minutes. The crushed sample is then removed from the cup and sieved on a 2.36mm sieve.

The fraction of the aggregate passing through the varied sieve is then weighed say Wb. Then the crushing value of an aggregate is given by (Wb/Wa)*100. A limiting value for ACV is equal to 30% for the wearing surface and 45% for other surfaces.

2) Toughness

The toughness of aggregate represents the resistance of an aggregate to suddenly applied load or impact load. It is indicated by aggregate impact value which is a measure of the resistance of an aggregate to impact load.

Aggregate impact value test can be conducted accordingly to IS:2386 (part IV). According to IS codes, the testing mechanism is similar to that of the aggregate crushing value test except for the load which is applied suddenly using the aggregate impact testing machine.

Similarly, prepared test sample assembly is fixed firmly on the base of the impact loading machine. A rammer of standard weight is dropped freely from a height of 380mm from the top of the cylindrical cup for 15times within an interval not less than 1 second between simultaneous drops.

After the load the crushed aggregate is sieved on a IS sieve of aperture size 2.36 mm and the material passing through the sieve is collect in a pan weighed. The percentage of the material passing through the sieve of 2.36mm to the total weight of the sample in the cup gives the aggregate impact value.

Limiting impact value 30% for wearing surface and 45% for other surfaces.

3) Hardness

The hardness of the aggregate signifies the resistance of the aggregate to wear, abrasion, and attrition. It is quantified using the abrasion value of aggregate which is the measure of the resistance of the aggregate to wear and abrasion.

It can be determined various tests like the Los Angeles abrasion test, Deval attrition test, and Dorry abrasion test. The most simple and commonly used one is the Los Angeles abrasion test which is conducted in a rotating drum consisting of metal balls.

According to IS 2368 (part IV), a Los Angeles test consists of rotating Los Angeles Drum, metal balls as abrasive charges, sieve, balance, and oven. Initially, test samples are oven-dried at a temperature of 100°C-110°C for four hours. The required weight of the test sample says (Wa) determine according to the grading of the aggregate as mentioned in Table below.

Then the test samples and metal balls (according to the grade of the sample) are placed inside a rotating drum. The drum is then rotated at a speed of 20 – 33 rev/ min for a certain number of revolutions according to the grading of the aggregate (500 revolutions for Grade A, B, C, D, and 1000 for grades E, F, G).

After the revolution commences the worn materials are taken out from the drum without significant loss. The worn materials are then sieved through an IS sieve of aperture 1.7mm. The fraction of worn aggregate retained on the sieve is washed and completely dried.

The dried materials are weighed using a balance say Wb. Now the aggregate abrasion value is given as the percentage of aggregate passing through the IS sieve of 1.7mm (Wa – Wb) to the total weight of sample Wa.

The limiting value for aggregate abrasion value is 30% for the wearing surface and 50% for other surfaces.

Table for determining weight of sample for Los Angeles test

Table for determining weight of sample for Los Angeles test

Sieve size		Weight of sample aggregates in gram for grade						
		A	B	C	D	E	F	G
Passing	Retained							
80	63					2500		
63	50					2500		
50	40					5000	5000	
40	25	1250					5000	5000
25	20	1250						5000
20	12.5	1250	2500					
12.5	10	1250	2500					
10	6.3			2500				
6.3	4.75			2500				
4.75	2.36				5000			

Table for number of charges for adjacent grading

Grading	Number of sphere	Weight of charges
A	12	5000 ± 25
B	11	4584 ± 25
C	8	3330 ± 20
D	6	2500 ± 15
E	12	5000 ± 25
F	12	5000 ± 25
G	12	5000 ± 25

4) Bond strength

The bond strength between the aggregates and the cement paste considerably influences the compressive and flexural strength and durability of the concrete. So a proper stronger bond between the aggregate and cement paste is required to form a durable and strong concrete structure.

Thus, various factors exist that significantly affect the bond between cement paste and aggregate. These include shape and surface texture of aggregate, presence of deleterious material, aggregate composition, etc. A rough aggregate provides better adhesion between the aggregates and cement paste.

Similarly, angular aggregates have a more specific area for greater bonding and better interlocking properties. The presence of deleterious material may make the surface of aggregate not suitable for forming bonds or directly affect the hydration of cement.

The tests for determining the quality of bonds is difficult and uneconomic. Thus it is estimated by observing the chunks of broken pieces of concrete after the crushing value test.

The product must consist of some broken aggregates in addition to the ones separated from the cement matrix. (in large number). This signifies a good bond.

Desirable properties of aggregates for road

Properties of aggregates

- Strength

Strength is the most important Properties of aggregates. Aggregates used in road construction especially in the surface course, are subjected to crushing, stresses, and wear and tear induced by stationary or moving traffic loads.

Thus the aggregates used in road constructions should have sufficient strength to withstand such induced stresses, crushing and wear, and tears. Aggregate crushing value for the bituminous wearing surface in the road is limited to 30%

- Toughness

Aggregates used in road construction whether, for the base, subbase, and especially inflexible or rigid surface course should be tough enough to withstand the impact load exerted by the traffic.

Aggregate impact values for bituminous wearing surfaces on roads are limited to 30%.

- Hardness

Aggregates used in road construction especially in the top surface course should be hard enough to withstand the abrasion and attrition due to moving vehicle load. Aggregate abrasion value for the bituminous wearing surface in the road is limited to 30%.

- Shape of aggregates

Rounded, angular, or cubical aggregates are more preferred in the construction of roads in subbase and top courses because of their higher strength value, durability, and superior interlocking and bonding properties so that they form a compact layer.

Angular and elongated aggregates can also be used but in a controlled amount as they have lower strength and durability along with higher bitumen or cement requirement. A combined shape index of not more than 30% is recommended for road aggregates.

- Water absorption and drainages

Aggregates that have a high affinity for water, may disrupt the bond between bitumen and aggregate. It makes bitumen strip off from the aggregate used in the surface course.

Similarly, when highly absorptive aggregates are used in the base or subbase courses it may affect the drainage properties of the courses and results in disruption of leveled top course due to alternate swelling and drying. Water absorption in percentage by weight of aggregate for road construction ranges from 0.1 to 2%.

- Durability and Soundness

The property of the aggregate to withstand the effects of adverse weather conditions is termed as the soundness of the aggregates. Such adverse condition consists of rain, freezing, and thawing, altering hot and cold weather, etc.

These may result in weathering of aggregates which affects the durability and integrity of aggregates used in pavements. Thus aggregates used in road construction should be sound enough to withstand the adverse effects of weather.

Soundness test for aggregate can be conducted by submerging the sample into the saturated solution of magnesium or sodium sulfates, in cycles of alternate wetting for 16-18 hours and drying in an oven at 100°C-110°C.

Then the loss of weight of aggregates is determined after 5 such cycles, which should not exceed 12% in sodium sulfate and 18% in magnesium sulfate. This method is an accelerated representation of weathering cycle.

- Adhesion with bitumen

Aggregates used in the construction of flexible bituminous pavement should have less affinity to water and more affinity to bitumen. This prevents stripping off of bitumen coating from the aggregate surface.

They also should be free from all the impurities like clay, dirt, salts, etc. which can affect the bond between the aggregates and bitumen. Thus road aggregate must be dry and clean when used for the manufacture of bitumen concrete.

The adhesion of bitumen to aggregates can be determined from the static immersion test. In this test, sample aggregates are first fully coated bitumen. The coated aggregates are then immersed in water maintained at 40°C for 24 hours.

After the elapse of 24 hours, the extent of stripping of bitumen is determined through visual inspection. The maximum value of stripping should not exceed 5% as recommended by IRC.

I hope this article on "Properties of aggregates" remains helpful for you.

Happy Learning – Civil Concept

Contributed by,

Civil Engineer – Ranjeet Sahani

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Effect of water cement ratio and Aggregate Size on Strength of Concrete

Grading of aggregates | Types of aggregate | Significance of grading

Sieve analysis of aggregates- Procedure and Sample Table for Calculation